Managing Water under Uncertainty and Risk

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THE UNITED NATIONS WORLD WATER DEVELOPMENT REPORT 4
VOLUME 1

UN WATER Report

United Nations Educational, Scientific and Cultural Organization

World Water Assessment Programme

UN WATER

UN WATER Reports

UN-Water is the United Nations inter-agency coordination mechanism for all freshwater related issues. Established in 2003, UN-Water fosters greater co-operation and information sharing among UN entities and relevant stakeholders.

UN-Water monitors and reports on the state, utilization and management of the world's freshwater resources and on the situation of sanitation through a series of inter-connected and complementary publications that, together, provide a comprehensive picture and, individually, provide a more in depth analysis of a specific issues or geographic areas.

PERIODIC REPORTS:

World Water Development Report (WWDR)

is coordinated by the World Water Assessment Programme (WWAP) on behalf of UN-Water and published every three years. It provides a global strategic outlook on the state of freshwater resources, trends in use of the resource base in the various sectors (inter alia, agriculture, industry, energy) and management options in different settings and situations (inter alia, in the context of urbanization, natural disasters, and impacts of global climate change). It also includes regional assessments.

- ✓ Strategic outlook
- ✓ State, uses and management of water resources
- ✓ Global
- ✓ Regional assessments
- ✓ Triennial (4th edition)

Global Analysis and Assessment of Sanitation and Drinking-Water (GLAAS)

is produced every two years by the World Health Organization (WHO) on behalf of UN-Water. It provides a global update on the policy frameworks, institutional arrangements, human resource base, and international and national finance streams in support of sanitation and drinking water. It is a substantive input into the activities of Sanitation and Water for All (SWA).

- ✓ Strategic outlook
- ✓ Water supply and sanitation
- ✓ Global
- ✓ Regional assessments
- ✓ Biennial (since 2008)

The progress report of the WHO/UNICEF Joint Monitoring Programme for Water Supply and Sanitation (JMP)

is produced every two years. The JMP Report is affiliated with UN-Water and presents the results of the global monitoring of progress towards MDG 7 target C: to halve, by 2015, the proportion of the population without sustainable access to safe drinking-water and basic sanitation. Monitoring draws on the findings of household surveys and censuses usually supported by national statistics bureaus in accordance with international criteria.

- ✓ Status and trends
- ✓ Water supply and sanitation
- ✓ Global
- ✓ Regional and national assessments
- ✓ Biennial (since 1990)

In the years 2012 – 2013 UN-Water also publishes:

2012 **UN-Water Report on Integrated Approaches in the Development, Management and Use of Water Resources** is produced by UN-Water for the Rio+20 Summit (UNCSD 2012). A similar status report was produced in 2008 for UNCSD. The report assesses the status and progress of the management of water resources in UN Member States and reports on the outcomes and impacts of improved water resources management.

2013 **UN-Water Country Briefs** pilot project. They provide a strategic outlook on the critical importance of investments in water for human and economic development at country level.

More information on UN-Water Reports at: www.unwater.org/documents.html

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VOLUME 1

Published in 2012 by the United Nations Educational, Scientific and Cultural Organization
7, place de Fontenoy, 75352 Paris 07 SP, France

ISBN 978-92-3-104235-5
e-book ISBN 978-92-3-001045-4

Original title: The United Nations World Water Development Report 4: *Managing Water under Uncertainty and Risk* (Vol. 1), *Knowledge Base* (Vol. 2) and *Facing the Challenges* (Vol. 3).

Published in 2012 by the United Nations Educational, Scientific and Cultural Organization

UNESCO Publishing: http://publishing.unesco.org/

Suggested citation:
WWAP (World Water Assessment Programme). 2012. *The United Nations World Water Development Report 4: Managing Water under Uncertainty and Risk*. Paris, UNESCO.

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The contents of Volume 2 were contributed by the UN-Water members and partners listed on the title pages of the chapters therein. UNESCO and the United Nations World Water Assessment Programme (WWAP) are not responsible for errors in the content provided or for discrepancies in data and content between contributed chapters.

WWAP provided the opportunity for individuals to be listed as authors and contributors or to be acknowledged in Volume 2. WWAP is not responsible for any omissions in this regard.

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Cover and interior design and typesetting by Phoenix Design Aid A/S, an ISO 14001 (environmental management) and a DS 49001 (corporate social responsibility) certified and approved carbon neutral company.

Printed by Imprimerie Centrale S. A. (Imprim'Vert certified) for UNESCO CLD, Paris.

This publication is printed with vegetable inks on FSC Mixed Sources paper, supporting responsible use of forest reserves. This is a carbon neutral print product. Imprimerie Centrale will contribute funds to a project replanting trees in Panama for this publication.

Printed in Luxembourg

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Paper from responsible sources
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WWDR4 has been published on behalf of the United Nations World Water Assessment Programme (WWAP) with the support of the following organizations:

United Nations Funds and Programmes
United Nations Children's Fund (UNICEF)
United Nations Conference on Trade and Development (UNCTAD)
United Nations Department of Economic and Social Affairs (UNDESA)
United Nations Development Programme (UNDP)
United Nations Environment Programme (UNEP)
United Nations High Commissioner for Refugees (UNHCR)
United Nations Human Settlements Programme (UN-HABITAT)
United Nations University (UNU)

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World Health Organization (WHO)
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United Nations Climate Change Secretariat (UNFCCC)

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FOREWORD

by Ban Ki-moon

Secretary-General of the United Nations

—

Water links the local to the regional, and brings together global questions of food security, public health, urbanization and energy. Addressing how we use and manage water resources is central to setting the world on a more sustainable and equitable path.

Universal access to safe drinking water and water resources is an imperative that cuts across all internationally agreed development objectives, including the Millennium Development Goals. Improving access to water improves health and education outcomes. It increases agricultural productivity. It is a force for gender equality and women's empowerment.

Yet pressures on freshwater are rising – from the expanding needs of agriculture, food production and energy consumption to pollution and the weaknesses of water management. Climate change is a real and growing threat. Without good planning and adaptation, hundreds of millions of people are at risk of hunger, disease, energy shortages and poverty.

This fourth edition of the *World Water Development Report* is the product of synergy within the United Nations system, in particular the United Nations World Water Assessment Programme hosted by UNESCO. It shines a spotlight on water use, analyses the question of managing water under uncertainty, and addresses gender issues throughout. The result is a call to action – to strengthen mechanisms of global coordination, to improve national institutions and to weave the two levels more tightly together.

This report is also intended to contribute to the Rio+20 United Nations Conference on Sustainable Development. If Rio+20 is to succeed, it must renew political commitment to integrated approaches to the sustainable management of the world's freshwater resources. Just as water is central to every aspect of life on earth, it must lie at the heart of the new vision we forge for sustainable development for the century ahead.

Ban Ki-moon

FOREWORD

by Irina Bokova

Director-General of UNESCO

—

What is the state of the world's freshwater today? What can we expect in the future? What must we do now to prepare better for tomorrow?

These questions concern the ability of women and men across the world to live in dignity. They touch upon the need to manage sustainably the earth's increasingly finite resources. They go to the heart of all efforts to reach internationally agreed development goals, including the Millennium Development Goals. Freshwater is a core issue for sustainable development – and it is slipping through the cracks.

We need new leadership on freshwater today. This leadership must bring together the multitude of actors involved in using and managing water. It must link different sectors and activities into a coherent whole. It must join the local with the national, and the regional to the global. We must manage freshwater more sustainably in order to make the most of it for the benefit of all. For this, we need a clear map of where we stand.

The fourth edition of the *World Water Development Report* provides this map. Hosted by UNESCO, the United Nations World Water Assessment Programme has brought together members and partners of UN-Water to draw a unique picture of the state, use and management of the world's freshwater resources. The report highlights different regions and examines the global pressures of uncertainty and risk. I am especially pleased that gender issues are mainstreamed throughout the analysis.

The conclusions are clear. Freshwater is a cross-cutting issue that is central to all development efforts. It faces rising challenges across the world – from urbanization and overconsumption, from underinvestment and lack of capacity, from poor management and waste, from the demands of agriculture, energy and food production. Freshwater is not being used sustainably according to needs and demands. Accurate information remains disparate, and management is fragmented. In this context, the future is increasingly uncertain, and risks are set to deepen.
If we fail today to make water an instrument of peace, it might become tomorrow a major source of conflict.

More than ever, we need Integrated Water Resources Management to provide coherent leadership. We need better information gathering and sharing on the state of freshwater, on the nature of demand and its use. We need better systems for measurement and control at the local, national and global levels. We must start early, by building water issues into education. We need also for governments, the private sector and civil society to work more closely together and to integrate water as an intrinsic part of their decision-making.

Our next step must be taken in Rio, by the United Nations Conference on Sustainable Development. Rio+20 must set a roadmap for the twenty-first century that includes a new direction for the sustainable use and management of the world's freshwater resources. Water is the condition for life; it is vital for sustainable development and for lasting peace. We must act today to protect it tomorrow. This means moving firmly in the direction charted by the *World Water Development Report*.

Irina Bokova

Irina Bokova

FOREWORD

by Michel Jarraud

UN-Water Chair and Secretary-General of WMO

—

It is an honour and a pleasure to have been invited to provide my brief remarks to the fourth edition of the United Nations *World Water Development Report*.

The report is the result of a broad collective teamwork of UN-Water agencies and partners, implemented through its World Water Assessment Programme, in particular to meet the challenges, risks and uncertainties blocking the road to sustainable development and the achievement of the UN Millennium Development Goals.

Today, water issues are positioned higher than ever on the international agenda, thanks in particular to the inspired leadership of the UN Secretary-General, who has expressed that *'Safe drinking water and basic sanitation are intrinsic to human survival, well-being and dignity'*.

The cross-cutting nature of water and the vital implications of international collaboration in this key area, spurred by the UN System acting *As One* through UN-Water, are intrinsic elements of the UN-Water mission statement and thereby essential for our actions to provide knowledge, tools and skills to various socio-economic sectors and to prop up high-level decision-making at global, regional and local scales.

This is especially significant at times of such crises as we encounter today when, for example, several consecutive seasons of drought in the Horn of Africa have left millions on the borderline of survival, thereby requiring emergency food assistance as well as sanitation, energy generation, and many other forms of support in disaster risk reduction.

I look forward to delivering the important messages of this key report in Rio in June 2012. However, since I have taken office very recently as UN-Water Chair, I wish to underscore that I make no claim of personal merit for this achievement which reflects the results of three years of collective UN-Water efforts.

Michel Jarraud

PREFACE

by Olcay Ünver

Coordinator, United Nations World Water Assessment Programme

—

Released every three years since March 2003, the United Nations *World Water Development Report* (WWDR), a flagship UN-Water report published by UNESCO, has become the voice of the United Nations system in terms of the state, use and management of the world's freshwater resources. The report is primarily targeted at national decision-makers and water resource managers, but is also aimed at educating and informing a broader audience, from governments to the private sector and civil society. It underlines the important roles water plays in all social, economic and environmental decisions, highlighting policy implications across various sectors, from local and municipal to regional and international levels.

Coordinated by the World Water Assessment Programme (WWAP), this fourth edition of the WWDR is the result of a concerted three-year effort by UN-Water agencies, in collaboration with dozens of scientists, professionals, NGOs and other UN-Water partners. The report addresses the most salient strategic and technical aspects relating to how and why we need to use, manage and allocate water to meet multiple, often competing goals, from all major policy directions – from poverty alleviation and human health to food and energy security and environmental stewardship. In describing how water underpins all aspects of development, the report provides a critical point of reference for linking water to global policy tracks, such as those for poverty eradication, including the Millennium Development Goals; sustainable development, the Rio+20 process; climate change, and the respective COP process.

While the report is factual, containing the most current information available concerning the state of knowledge about our water resources and covering the most recent developments that affect it, the report also provides decision-makers with concrete examples of approaches and potential responses for addressing water-related challenges from both a water management perspective and a broader political and sectoral scope, which covers development, financing, capacity-building and institutional reform.

The fourth edition of the WWDR builds upon the previous three editions. Similarly to the first two editions, it includes a comprehensive and up-to-date assessment of several key challenge areas, such as water for food, energy and human health, and governance challenges such as institutional reform, knowledge and capacity-building, and financing, each produced by individual UN agencies. And, as in the third edition, the report offers a holistic and integrated approach to examining the links between water and the drivers that create pressures on the resource, climate change, ecosystems and various aspects of human security as embodied under the Millennium Development Goals and other key global policy tracks. This fourth edition also continues to focus on how decisions made outside the 'water box' affect the resources and other users, linking water to a number of cross-cutting issues. Through this approach, the report illustrates how interactions between water and a multiplicity of externalities can be incorporated into analyses and decision-making processes in various sectors and domains. It is fortuitous that the release date for this report occurs a few months prior to the Rio+20 Earth Summit, thus providing a sound basis for discussions on the future of our planet in which the centrality of water can be clearly highlighted.

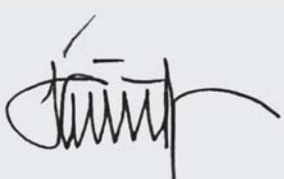
Several new elements have also been added to this fourth edition of the report. For the first time since the inception of the series, the WWDR4 has been developed under an overarching theme – 'Managing Water under Uncertainty and Risk' – which has served as a guide for the authors and collaborating agencies, allowing for the streamlining of the many different written contributions into a cohesive narrative. Second, the report has been enriched by the addition of five regional reports through the efforts of the five Regional UN Economic Commissions, which complement the challenge area reports by offering a more geographically focused examination of the issues and challenges related to water, including the identification of critical 'hotspots'. Third, this edition reports on the results of the first phase of the WWAP World Water Scenarios Project, which examines possible future developments in externalities that impinge upon water stress and sustainability. Finally, the entire report underwent a gender mainstreaming exercise to ensure that the important gender and social-equity issues were properly and systematically addressed, and a new chapter specifically focused on gender and water has been included in this edition.

In order to help countries improve their self-assessment capability by building on existing strengths and experiences, the report is once again accompanied by a set of case studies from countries around the world highlighting the state of water resources where different physical, climatic and socio-economic conditions prevail.

A series of collective and collaborative efforts has led to a highly comprehensive and integrated WWDR. Coordinating the fourteen challenge area reports, five regional reports and three special reports that make up the chapters in Volume 2, as well as the supplementary material and the multitude of comments from partners, reviewers and the general public over three years was a challenging process. The members of WWAP's Technical Advisory Committee were particularly generous in providing insight and expertise to the production team. Given such a broad scope of expertise over such a wide range of interests and sectors for which water is a vital component, a focused analysis was required to achieve a balanced structure to the report and to provide the most up-to-date knowledge and information in a consistent and harmonious manner.

It is hoped that this report, like its previous editions, will continue to be the main reference document about water and the central role it plays in all aspects of human development, that it will continue to be considered as essential reading for decision-makers, their advisors and anyone interested in – and concerned about – the state and the use of our planet's freshwater resources, and that this edition will reach an ever-widening audience that includes actors outside the 'water box' who make or influence broad socio-economic policies that affect water.

On behalf of the staff of WWAP and the authors, writers, editors and contributors of the fourth edition of the WWDR, I extend my sincerest appreciation to the members of UN-Water and its partners in producing this authoritative and critically important report that will serve as the knowledge base for understanding and solving water-related challenges around the world. A special word of thanks goes to Irina Bokova, Director-General of UNESCO, without whose crucial support this report would not be completed. Last but not the least, my undying gratitude goes to all members of the WWAP Secretariat, whose names are listed in Acknowledgements, for their professionalism and ceaseless efforts in completing the report.



Olcay Ünver

ACKNOWLEDGEMENTS

This report would not have been possible without financial support from the Italian Government and the contributions of many individuals and organizations from around the world.

The personal support of Ms Irina Bokova, Director-General of the United Nations Educational, Scientific and Cultural Organization (UNESCO) created a secure and enabling environment.

The excellent collaboration and timely contributions from the organizations that make up UN-Water and its partners were critical throughout the preparation of the report, from the initial conceptual discussions on to the final clearance stages, and through numerous exchanges and consultations in between.

We thank the management of the UNESCO Natural Sciences Sector and colleagues of the UNESCO International Hydrological Programme (IHP) for their support.

The contributions and counselling of Albert Wright, Josue Dione, Bai-Mass Taal, Stephen Maxwell Kwame Donkor and Members of UN Water/Africa were essential to the successful completion of the chapter on Africa and to various sections of the report focusing on the region.

A great deal of appreciation is extended to David Coates, Gerry Galloway, Jack Moss, Mike Muller and Uri Shamir for their extraordinary advice and special contributions to the report.

We also thank Aquafed, the Global Water Partnership (GWP) and the US Army Corps of Engineers (USACE) for their substantial and substantive support.

A special acknowledgement goes to all of the case study partners who volunteered their efforts, without which Volume 3 would not be possible. Special thanks to Laura Dubin and Mateo Gallego for assistance with this volume.

The rights to twenty beautiful photographs were graciously donated by Phillipe Bourseiller for use throughout the report and in accompanying material. Thanks also go to all other individuals who provided photographs (whose names are listed with the photographs).

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United Nations World Water Assessment Programme

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The Norwegian Ministry of Foreign Affairs financially contributed to the findings described in Chapter 9.

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Participants: Akif Altundas, Alice Aureli, Richard Connor, William J. Cosgrove, Gilberto Gallopin, Simone Grego, Engin Koncagül, Michela Miletto, Anil Mishra, Jack Moss, Mike Muller, Andras Szöllösi-Nagy, Stéfanie Néno, Daniel Perna, Walter Rast, Olcay Ünver, Samantha Wauchope and James Winpenny.

2nd Meeting of the Interim Core Group for the production of the WWDR4, 21–29 May 2009, Perugia, Italy.
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Workshop for the production of the WWDR4, 14 August 2009, Stockholm, Sweden. Participants: UN-Water Members and Partners, WWAP Secretariat.

Issues Workshop for the production of the WWDR4, 16–17 November 2009, Perugia, Italy. Participants: Yoganath Adik, Guy Alearts, Kodwo Andah, Kusum Athukorala, Reid Basher, Anders Berntell, Peter Koefoed Bjørnsen, Giorgio Cesari, Emmanuel Chinyamakobvu, Thomas Chiramba, Rudolph Cleveringa, Richard Connor, William J. Cosgrove, Andre Dzikus, Karen Frenken, Gilberto Gallopin, Joakim Harlin, Pierre Hubert, Angelo Izzo, Nancy Kgengwenyane, Spyros Kleitsas, Peter Kristensen, Henrik Larsen, Lifeng Li, Josefina Maestu, Anil Mishra, Jack Moss, Mike Muller, Johnson Oguntola, Walter Rast, David Tickner, Håkan Tropp, Lucio Ubertini, Konrad Vielhauer, Enrique Urrutia López de Viñaspre and James Winpenny.

Coordination Meeting on Substance, 16–17 March 2010, Perugia, Italy. Participants: Reid Basher, Peter Koefoed Bjørnsen, Claudio Caponi, Emmanuel Chinyamakobvu, Rudolph Cleveringa, Richard Connor, William J. Cosgrove, Rainer Enderlein, Karen Frenken, Matt Hare, Melvyn Kay, Eric Mimo, Anil Mishra, Diego Rodriguez, Kulwant Singh, Håkan Tropp and Pieter Van Der Zaag.

WWAP Core Group Meeting WWDR4, 14–15 March 2011, Paris, France. Participants: Anders Berntell, Richard Connor, William J. Cosgrove, Simone Grego, Engin Koncagül, Daniel P. Loucks, Michela Miletto, Jack Moss, Henk van Schaik, Uri Shamir, Olcay Ünver, James Winpenny and Albert Wright.

Consultations

We thank participants in the stakeholder consultations listed below (including consultation events and online consultations and surveys) as well as Anders Berntell, Bekithemba Gumbo, Howard Passel, Willi Struckmeier and Kristin Schumann for solicited feedback.

- Short survey on lessons learnt from the WWDR3 process, January–March 2009
- Consultation meetings at the 5th World Water Forum, March 2009
- WWDR3 Side Event at the 5th World Water Forum, March 2009
- WWDR3 Production Team meeting, March 2009
- Meeting of the WWAP Technical Advisory Committee, March 2009
- 1st UN-Water and stakeholders electronic surveys, June 2009
- UN-Water Delphi, July 2009
- Side Event at the Stockholm World Water Week, August 2009
- Public consultation on the table of contents, January 2010
- Expert survey on drivers, April 2010
- Side Event at the Stockholm World Water Week, August 2010
- Side Event at the 3rd Africa Water Week, November 2010
- Public consultation on Draft 1 of Parts 1 and 2, December 2010
- Policy survey for decision-makers, January 2011
- Side Event at the Stockholm World Water Week, August 2011

We apologize for any inadvertent errors or omissions of contributors to the report.

MAIN MESSAGES

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Compiled by William J. Cosgrove

Chapter 1. Recognizing the centrality of water and its global dimensions

Water is a critical natural resource upon which all social and economic activities and ecosystem functions depend. Managing water well requires appropriate governance arrangements that move considerations of water from the margins of government to the centre of society. On national and local scales, appropriately funded infrastructure and adequately funded robust governance mechanisms are required to protect water resources and ensure sustainable development and the equitable distribution of water-derived benefits.

The cross-cutting nature of the resource and its global dimensions underline the importance of addressing water issues in the context of all existing and developing international processes.

There are major uncertainties about the amount of water required to meet demand for food, energy and other human uses, and to sustain ecosystems. These uncertainties are compounded by the impact of climate change on available water resources.

Greater recognition is needed of the fact that water is not solely a local, national or regional issue that can be governed at any of those levels alone. On the contrary, global interdependencies are woven through water, and decisions relating to water use on a local, national, river basin or regional level often cannot be isolated from global drivers, trends and uncertainties.

Water demands and uses are often managed in silos with each focused on meeting specific developmental objectives, rather than as part of an overarching and strategic framework that balances different water uses in order to optimize and share its various benefits across society and the economy. This fragmentation increases risks to the sustainability of water resources as well as to the different development objectives that depend upon (and may be in competition for) limited supplies. Climate change exacerbates this problem still further.

The job of delivering adequate water for social, economic and environmental needs is often understood as the preserve of the 'water sector', which is expected to provide the appropriate infrastructure and channel water in the right direction. Yet in reality, water cuts across all social, economic and environmental activities. As such, it cannot be confined to one sector; its governance requires cooperation and coordination across diverse stakeholders and sectoral 'jurisdictions'. Furthermore, water availability must be understood within the context of the hydrological cycle, which is influenced by multiple factors, trends and uncertainties that extend beyond a narrow sectoral focus.

Climate change is a central external driver that affects both water and demands for all uses directly; mitigation measures are concentrated around the reduction of energy consumption and carbon emissions, while adaptation means planning and preparing for increasing hydrological variability and extreme weather events, including floods, droughts, and storms.

Addressing water challenges necessitates interventions across an entire economy, undertaken by strong institutions with the authority and leadership to take a proactive rather than a reactive role in water management, and to drive the productive use of water across sectors within the framework of environmental sustainability. Members of the water community have the duty to inform and provide guidance on decision-making and to regulatory authorities on how to use and managed the resource sustainably, so as to optimize and share its many benefits.

Efficiency and productivity gains alone cannot alter global patterns of unequal supply of resources and consumption or access to benefits. Addressing the

cross-sectoral and global dimensions of water will require that all countries take an interest and make specific commitments in the global forums designed to address and create solutions to impending resource challenges. The water community in general, and water managers in particular, have the responsibility of informing the process.

Implementing the outcomes from global policy agreements will remain a national imperative, and countries are responsible for setting international policy in the first place. Setting the framework requires a widening of the sectoral and spatial horizons of all those who have a stake in water management. However, many of the global policy agreements have been developed without proper local and national consultation processes and are, in many cases, general agreements that do not reflect the political economy and institutional capacities of the countries, thus compromising the overall effectiveness of said policies at national and subnational levels.

Part 1: Status, trends and challenges

Chapter 2. Water demand: What drives consumption?

Agriculture accounts for 70% of all water withdrawn by the agricultural, municipal and industrial (including energy) sectors. Responsible agricultural water management will make a major contribution to future global water security.

Predicting future water demand for agriculture is fraught with uncertainty. Future demand for water in this sector is in part influenced by demand for food, which depends in part on the number of people needing to be fed, and in part on what and how much they eat. This is complicated by, amongst other factors, uncertainties in seasonal climatic variations, efficiency of agriculture production processes, and crop types and yields.

The main challenge facing the agricultural sector is not as much growing 70% more food in 40 years, but making 70% more food available on the plate. Reducing losses in storage and along the value chain may go a long way towards offsetting the need for more production.

Innovative technologies will be needed to improve crop yields and drought tolerance; produce smarter ways of using fertilizer and water, new pesticides and non-chemical approaches to crop protection; reduce postharvest losses; and ensure more sustainable livestock and marine production. The industrialized countries are well placed to take advantage of these technologies, but they must also take responsibility to ensure that the least developed countries have opportunities to access them on equitable and non-discriminatory terms.

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Reducing vulnerability to drought will require investment in both constructed and 'green' infrastructure to improve water measurement and control and, where appropriate, increase surface water and groundwater storage in constructed reservoirs and in natural storage in wetlands and in the soil.

Most benefits are expected to come from applying existing water management technologies and adapting them to new situations.

Over 1 billion people lack access to electricity and other clean sources of energy today. When added to meeting these needs, external challenges, including demographic development from population increase and migration and increased economic activity, will create a surge of energy consumption, particularly in non-OECD countries.

Energy and water are intricately connected. There are different sources of energy and electricity, but all require water for various production processes, including extraction of raw materials, cooling in thermal processes, cleaning materials, cultivation of crops for biofuels and powering turbines. Conversely, energy is required to make water resources available for human use and consumption through pumping, transportation, treatment, desalination and irrigation.

Regions that are water scarce will face more water-for-energy stresses than others and will need to explore more water-efficient technologies to develop both primary energy and electric power.

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Water and energy policies, which are often made in different government departments or ministries, will need to be integrated, with policy-makers increasingly working in close coordination.

Effective operation of an industry requires a sustainable supply of water in the right quantity, of the right quality, at the right place, at the right time and at the right price.

Industry should play an important role in effectively addressing the unsustainable exploitation of freshwater resources around the world by addressing first its own priorities and values.

The urban population of the world is forecast to grow to 6.3 billion people in 2050, from 3.4 billion in 2009. Urban growth will be equal to all of the world population growth over this period plus some net moves from the current rural population. Problems of adequate water supply, sanitation and drainage will increase in the urban slum areas already faced with a backlog of unserved populations. Initiatives worldwide are emerging to address the need for improved and comprehensive urban water planning, technologies, investment and associated operations.

Water management in urban areas can benefit from more comprehensive urban planning and integrated urban water management (IUWM). IUWM involves managing freshwater, wastewater and stormwater as links within the resource management structure, using an urban area as the unit of management.

Ecosystems underpin the availability of water, including its extremes of drought and flood, and its quality.

Growing attention to resolving the increasing competition for water between ecosystems and socio-economic sectors signals progress towards better integrated water management and more sustainable development.

Chapter 3. The water resource: Variability, vulnerability and uncertainty

Freshwater supplies are erratically distributed in time and space. From one year to the next, there can be considerable variability between arid and humid climates and wet and dry seasons. Water resource management plans and policies need to take into account this variability and distribution of freshwater supplies.

The state of water resources is influenced by withdrawals to meet socio-economic demands. This in turn is affected by drivers such as population growth, economic development and dietary changes, as well as the need for control of water resources to protect settlements in flood plains and drought prone regions.

The global groundwater abstraction rate has at least tripled over the past 50 years. This has fundamentally changed the role of groundwater in human society, in particular in the irrigation sector, where it has triggered an 'agricultural groundwater revolution'.

Groundwater is crucial for the livelihoods and food security of 1.2 to 1.5 billion rural households in the poorer regions of Africa and Asia, and for domestic supplies of a large part of the population elsewhere in the world.

Withdrawals in many basins are exceeding the rate of recharge and are unsustainable.

In spite of valid concerns about unsustainable abstraction rates and pollution in many parts of the world, groundwater resources if carefully managed can make a significant contribution to meeting the demand for water in the future and to adapting to climate change. The shrinking of glaciers is, in the short term, adding water to streamflows over and above annual precipitation and thus increasing water supply; in the longer term (decades to centuries) as glaciers disappear those additional sources of water will diminish and the buffering effects of glaciers on streamflow regimes will lessen.

Sufficient water supply, of good quality, is a key ingredient in the health and well-being of humans and ecosystems and for socio-economic development. Though there have been some regional successes in improving water quality, there is no data to suggest that there has been an overall improvement in water quality on a global scale.

Water quality is just as important as water quantity for satisfying basic human and environmental needs, yet it has received far less investment, scientific support, and public attention in recent decades than water quantity.

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Poor water quality has many economic costs associated with it, including degradation of ecosystem services; health-related costs; impacts on economic activities such as agriculture, industrial production and tourism; increased water treatment costs; and reduced property values.

With freshwater projected to become an increasingly scarce resource in the coming years, the costs associated with addressing water quality problems can be expected to increase.

Chapter 4. Beyond demand: Water's social and environmental benefits

Improving water resource management, increasing access to safe drinking water and basic sanitation and promoting hygiene have the potential to improve the quality of life of billions of individuals and are critical for the achievement of the goals to reduce child mortality, improve maternal health and reduce the burden of waterborne disease.

A preventive and collaborative approach of Water Safety Planning has demonstrated benefits, including cost savings and sustainable improvements in water quality. Each risk management solution needs to be tailor-made to the water supply in question, and demands that key stakeholders become engaged and committed to a common goal. These include land users or householders who may discharge industrial, agricultural or domestic waste into a catchment area, policymakers from various ministries overseeing the implementation and enforcement of environmental regulations, practitioners delivering water and consumers at the tap.

Poor women shoulder the brunt of economic crises and women with less education tend to increase their work participation more in times of crisis in almost every region of the world.

Social and financial investment along with policy support to improve women's access and control over water resources will reduce vulnerability to poverty and enable women to secure sources of food and livelihoods, and to maintain the health of themselves and their families.

Ecosystems deliver multiple benefits (services) that are essential for sustainable development. Many of these key services are derived directly from water, and all are underpinned by it. Trends in ecosystem health, therefore, indicate trends in the delivery of these overall benefits and provide a key indicator of whether we are in or out of balance with water.

Trends in ecosystems, including the life they support, are telling us that things are out of balance. Policymakers and managers need to recognize that ecosystems do not consume water – they supply and recycle it – and water taken from ecosystems unsustainably reduces their ability to deliver the benefits we need ecosystems to provide.

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While we are getting better at saving lives, saving livelihoods and assets remains a key development challenge: water-related disasters are a major obstacle to poverty reduction efforts and to meeting development objectives, such as the Millennium Development Goals.

One of the major impacts of desertification, land degradation and drought (DLDD) associated water scarcity is felt through food insecurity and starvation among affected communities, particularly in developing countries in the drylands.

If dryland countries could reduce the impacts of DLDD on water resources and achieve water security, opportunities of achieving food security would be greatly enhanced.
Different developmental sectors are often in competition with each other for the finite water resources upon which they all depend. While they can be 'in competition' over water, it is clear that *all* the benefits of water are required for sustainable economic development. In countries and regions where water resources are limited, decisions made to generate benefits through water from one sector often produce negative consequences for other sectors. Uncertainties regarding future demands add to the complexity of the challenge.

Where water resources are limited, certain trade-offs may be required in order to allocate water towards different uses in order to maximize the various benefits water provides though different developmental sectors. This is a critical yet difficult and complex challenge. Decisions about water allocation are not merely social or ethical, but are also economic, such that investing in water infrastructure and management generates increasing returns though these various benefits.

Chapter 5. Water management, institutions and capacity development
Water is characterized by the fact that all benefit from it but few understand why and fewer actually manage it.
Water management requires a mix of structural and non-structural options. Adaptive Integrated Water Resources Management (IWRM) can provide the necessary integration of water management across sectors, policies and institutions in a continuous process

of adjustment that attempts to deal with the increasingly rapid changes in our societies, economies, climate and technologies.

Competing user groups (e.g. water utilities, farmers, industry and mining, communities, environmentalists) can influence strategies for water resource development and management, meaning that the process becomes more political and less purely technical as integration occurs and a potential basket of benefits emerges.

Water management now has to account for unforeseeable changes in the nature and timing of issues like population growth, migration, and globalization, changing consumption patterns, technological advances, and agricultural and industrial developments. The spectre of climate change has drawn attention to the importance of these and added a new dimension. The rules of the game for water are often dictated by actors other than water managers, and are not set with water as their central focus or with the recognition of its pivotal importance. Making coherent decisions, with the various trade-offs they imply, calls for some institutional machinery linking decision-makers in key sectors with those responsible for water management. A wider group of stakeholders needs to be involved in the 'rule-setting' process.

Water institutions are still largely technology and water supply driven. To improve the effectiveness of these institutions, the emphasis has to gradually change

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from technological solutions to management of processes and people, involving inclusive decision-making and bottom-up approaches.

At the national level, it is essential to establish sustainable frameworks for capturing, storing and disseminating data, information and knowledge to all stakeholders in the water sector, thus contributing to improved decision-making regarding water resource management.

At the community level, concrete steps towards sharing information and knowledge, contributing to improved decision-making and resource management can include creating dialogue platforms involving local stakeholders and their assisting service organisations; for example, government institutions, extension services, NGOs and other service providers.

Chapter 6. From raw data to informed decisions

Information about water supply and use is becoming increasingly important to national governments, who need reliable and objective information about the state of water resources, their use and management.

Farmers, urban planners, drinking water and wastewater utilities, the disaster management community, business and industry, and environmentalists all need to be informed.

The data required to populate the indicators are seldom systematically or reliably available at a global, national, regional or basin level. If actual data are not obtained, trends will not be tracked, even if they are substantial.

For the purposes of planning and design, engineers have typically assumed that the hydrological processes in a particular watershed or basin could be described by probability distributions that were not changing over time; that is, the historical statistical characteristics of those processes were assumed essentially constant over time, or stationary. The more these extreme events happen due to changes in the Earth's climate or from unpredictable human behaviour, the more challenging it is to plan and manage water. The question is how best to include these nonstationarity considerations of both water supply and demand in water planning and management.

Concerns about climate change, one of the factors that have led to the growing interest in water indicators, explicit recognition that the 'stationary hydrology' assumption can no longer be used as the basis for assessment of water availability. This has focused attention on the limited availability of global data on stream flows, on which estimates of water resource availability must be based. While there are a great deal of available data on precipitation, which can be measured by remote sensing, changes in runoff to rivers or recharge of groundwater are much harder to measure.

Because of the relatively low value and wide distribution of water, its use is often not measured directly. Because water resources are often 'shared' between a number of different political jurisdictions, there is often a disincentive for upstream communities to share information about resource availability and use with downstream jurisdictions, as the information may be used in disputes about the division of the resource.

To achieve a balanced allocation and protection of water resources, indicators should support policy instruments which are carefully chosen and designed. They may include regulation (e.g. technical standards, performance standards), quotas, access rules and allocation procedures, as well as economic instruments (especially pricing mechanisms and payments for ecosystem services).

Because water occurs in natural structures whose behaviour often varies from one season to the next, measuring simple parameters such as flow is often extremely expensive. There is a huge resource base from remote sensing, which has not yet been translated into significant flow of useful processed information about water and its use. However, using remote sensing data without ground truth may be risky; strengthening existing hydromet networks and services is a necessary condition for proper water resources management, planning, design and operation.

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The most effective driver of efforts to improve the flow of information about water will be a demand from policy-makers and decision-makers in the socio-economic sectors of activity.

From a government perspective, economic policy-makers have recognized that water resources have an important but largely unaccounted for influence on national economies. There are now significant opportunities for the global community of water practitioners, as well as water users and the much broader community that has a stake in water, to make substantial improvements in the availability and quality of information about the resource, its use, users, benefits derived from its use and how these benefits are allocated, and who bears the costs and negative impacts.

Chapter 7. Regional challenges, global impacts

Africa

Sub-Saharan Africa faces endemic poverty, food insecurity, very low coverage of both drinking water and sanitation, and pervasive underdevelopment, with almost all countries lacking the human, economic and institutional capacities to effectively develop and manage their water resources sustainably.

Overall, only one in four people in Africa has electricity. Hydropower supplies 32% of Africa's energy; only 3% of its renewable water resources are exploited for hydroelectricity. Yet the region has vast hydropower potential – enough to meet all the continent's electricity needs.

Drought in sub-Saharan Africa is the dominant climate risk; it destroys economic livelihoods and farmers' food sources and has a significant negative effect on GDP growth in one-third of the countries. Floods are also highly destructive – to infrastructure and transportation and to goods and service flows, and they can contaminate water supplies and cause waterborne disease epidemics.

Europe and North America

The relatively affluent lifestyles of most Europeans and North Americans make large demands on the region's water resources. North Americans, the highest per capita water users in the world, however, consume two and a half times the volume that Europeans use per capita: one reason is that water is relatively inexpensive compared to other industrialised countries.

Some 120 million people in the European region do not have access to safe drinking water. Even more lack access to sanitation, resulting in water-related diseases. Water quality remains a persistent problem in many parts of the region. Agrochemicals in particular have had a detrimental impact on water resources throughout the region as nitrogen, phosphorus and pesticides run into water courses.

The Water Framework Directive concluded in 2000, and including more recent directives on standards and groundwater, is the most important piece of EU water legislation and the only such supra-national water arrangement in the world. It has accelerated and deepened a historical process of transboundary water management.

Asia-Pacific

The Asia and Pacific region is extremely dynamic, undergoing rapid urbanisation, economic growth, industrialization, and extensive agricultural development. Although these trends are desirable in many ways, they also represent drivers that are affecting the region's capacity to meet its socioeconomic water development needs. They are accompanied by the intensive use of resources that exert considerable pressure on aquatic ecosystems, which continue to deteriorate.

Food security is an important issue since about two-thirds of the world's hungry people live in Asia.

The Asia-Pacific is the world's most vulnerable region with respect to natural disasters, which undermine economic development to varying degrees. Much economic growth is generated in coastal and flood-prone areas, for example, which are heavily populated and especially vulnerable to typhoons and rainstorms.

The Pacific's small island developing states (SIDS) are particularly vulnerable to environmental natural hazards, such as tropical cyclones, typhoons and earthquakes turning into disasters. Climate change will further exacerbate the vulnerability of SIDS with anticipated sea-level rise and the risk of storm surge and beach erosion. One tropical cyclone can negate years of development efforts.

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The region is shifting from predominantly short-term benefit planning and development of water infrastructure, to a more strategic and long-term benefit planning concept that also addresses ecological efficiency in economic development.

Latin America and the Caribbean

Latin America and the Caribbean (LAC) is basically a humid region although it contains some very arid areas. The pattern of water use in the region can be described as spatially sporadic and highly concentrated in relatively few areas.

With the exceptions of Mexico, Brazil and some of the small Central American countries, LAC economies depend on the export of natural resources. Global demand for these products, which include minerals, food and other agricultural products, timber, fish and tourism services, has increased notably in recent years. This has implications for competing water demands and the export of 'virtual' water from the region.

Although most LAC countries enjoy high levels of coverage of improved water and sanitation, there is a large variation in the quality of services and important differences between rural and urban areas and among countries. Almost 40 million people still lack access to improved water and nearly 120 million to proper sanitation facilities. The majority of those without access to services are poor and live in rural areas.

In general, poor governance in many LAC countries extends from the top to the bottom. It is not restricted to the management of the water resource, but rife in the management of most water-based services. With relatively weak water management capacities, the region's poorest countries in Central America, the Caribbean and the Andes will be at the highest risk from the impacts of climate change.

Arab and Western Asia region

Population growth and migration, growing consumption, regional conflicts and governance constraints in the Arab and Western Asia region have resulted in increasing risks associated with water quantity and quality, but are accompanied by the sustainable management of shared resources and their use, as well as the success of policies to promote rural development and food security.

Water scarcity leads to food insecurity concerns in the Arab region. Imported grain accounts for a large amount of 'virtual' water consumed in the Middle East and North Africa, which was importing 50 million tonnes of grain annually by the year 2000. This has fostered interest in agricultural investments outside the region to produce food, which in effect increases the importation of virtual water.

Cyclical conflict has been characteristic of the Arab region. Violent conflict has also destroyed water infrastructure at different times in Beirut, Kuwait and Lebanon, requiring rehabilitation instead of expansion of delivery. About 66% of the Arab region's available surface water originates from outside of the region. At times, this has led to conflict with upstream countries. Local-level water conflicts can also exist between administrative districts, communities and tribes.

Regional–global links: Impacts and challenges

Water-related natural disasters pose major impediments to achieving human security and sustainable socio-economic development. Droughts have significantly impacted agricultural production, which in turn have contributed to soaring food prices and shortages. These increases have other major socio-political impacts and can lead to far reaching consequences such as food riots and political instability.

Water shortages can cause conflicts of varying intensity and scale. Although conflicts may appear localized, they present challenges to the broader context of peace and security. Conflicts over water resources can also turn into or fuel ethnic conflicts – as ethnic conflict is most commonly fuelled by collective fears for the future, one can see how water scarcity could play into such fears.

There are useful reasons for incorporating the positive aspects of the market when considering water resources. For instance, one of the reasons for water resource depletion is that typically it has been undervalued as a resource. It is thus important to place a value on it. Whether earmarking it as a commodity is the best solution for placing value on it is subject to debate.

Whether through norms or values, water resources must be valued for their worth, else the trend of degradation will ensue.

Part 2: Managing water under uncertainty and risk

Introduction to Part 2

Political and social systems are changing in ways and with impacts not always predictable. Technology is evolving, living standards, consumption patterns and life expectancies are changing, and human populations are growing and increasingly moving to expanding urban areas. Consequently, land use and cover is changing, as is the climate. The rates at which these changes are occurring are often increasing and their long-term impacts are usually uncertain. Discontinuities are possible and tipping points can exist beyond which change is irreversible.

Adapting to change presents an opportunity. What has happened in the past cannot be changed, but the future can be influenced by the decisions being made now.

Water is a primary medium through which changes in human activity and the climate impact with the earth's surface, its ecosystems, and its people. It is through water and its quality that people will feel the impact of change most strongly.

Without proper adaptation or planning for change, hundreds of millions of people will be at greater risk

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of hunger, disease, energy shortages and poverty due to water scarcity, pollution or flooding. Adapting to changes in water quantity and quality, together with their risks and uncertainties, is a challenging area for water management.

The risks, or consequences of making decisions under uncertainty, can be qualified and even sometimes quantified. Robust decision-making is a tool that attempts to support different management actions under deep uncertainty.

Providing decision-makers with tools that show the broader water resource consequences of various decisions (actions, inaction) can substantially contribute to better overall resource management, and reduced threats and adverse impacts.

Chapter 8. Working under uncertainty and managing risk
Risk and uncertainty characterize much of what water managers and socio-economic policy-makers must deal with. The more they understand these uncertainties and risks, the more effectively they can plan, design and manage water systems to reduce these risks and uncertainties.

Today water planners and engineers are particularly concerned with uncertainties associated with extremes that have not yet been observed and are outside the envelope of variability defined by past events. The world is witnessing the occurrence of such extreme events today. Because of this water resources planners and managers must apply a significant amount of judgment in their analyses due to changes in land use, urbanization, and the impacts of a changing climate that influence future precipitation, evaporation, groundwater infiltration, surface runoff and channel flow.

No matter what design is chosen there is always a risk of failure. Questions that plague anyone making long-term decisions include what levels of risk are acceptable, and just how much more money, if any, should be spent on designs that reduce the costs of infrastructure expansion in the future, should future conditions warrant it.

When sufficient information is available to determine probabilities of decision outcomes and evaluate the consequences, decision-making can be based on risk analysis. Decision-making may be assisted by the use of a wide variety of analytical tools and techniques, varying from the simple to the sophisticated.

The decision process should encourage active participation from interested stakeholder groups. This will ensure that differences in the perception of risks and values are fully explored within the risk assessment and decision appraisal process. Interactive decision support models have been developed and successfully used to facilitate stakeholder participation.

In situations where it is difficult to assign probabilities to possible events or future outcomes, perhaps due to our limited understanding of human and ecological processes or due to the intrinsic indeterminism of complex dynamic systems, we can still create scenarios that force us to consider the possibility of such outcomes and whether or not we should make decisions that might lead to such outcomes. Water futures depend on human choices that are yet to be made.

Water management agencies with users and policy-makers need to participate in the development of alternate methodologies that take into account non-stationarity and make water resource projects more adaptable, sustainable and robust.

If humans are to live within the limits of their water resources (and there is no other choice), they must live within the limits of the natural systems that provide, treat and distribute those resources. Humans need to include natural ecosystems, along with built infrastructure and human activities that determine the allocation and use of water, in an integrated way, each affecting and benefiting the other and necessarily managed together within an integrated system of a river basin. Recognizing and managing the *interconnectedness* among living systems is a means of reducing both short and long-term risks.

Chapter 9. Understanding uncertainty and risks associated with key drivers

Projected pressures on water resources lie outside the control of water managers. These can significantly affect the balance between water demand and supply – sometimes in uncertain ways – and thus create new risks for water managers and users. Such increasing uncertainties and risks necessitate a different approach to water management strategies.

Drivers that directly impinge upon water stress and sustainability are the ecosystem, agriculture, infrastructure, technology and demographics. The ultimate drivers – governance, politics, ethics and society (values and equity) and climate change – exert their effect mostly through their impacts upon the proximate drivers.

In the absence of technological improvements or policy interventions, economic polarities will increase between water-rich and water-poor countries, as well as between sectors or regions within countries. This would mean higher numbers of people with higher needs competing for less water, of lesser quality. Because allocation will inevitably go to the highest paying sector or region, this may result in an increasingly significant portion of people not being able to satisfy their basic needs for food, energy, water and sanitation. This would not be mere stagnation, but would likely take the form of a distinctly regressive trend compared to current conditions.

Further technology developments applicable to urban water production and waste handling that are likely to increase due to sheer urban population growth are also expected to contribute to reducing absolute water withdrawals and waste. Rapid uptake of these technologies would be paired with the anticipated evolution of global consciousness regarding human impacts on environment, and in particular, an increased understanding of water scarcity.

A legally binding international agreement to combat climate change could be in place by 2040, along with significant financing for awareness-raising and adaptation in low-income countries. Because most climate change impacts are felt through water, this would have positive repercussions on the overall levels of financing for water. This could mean higher levels of investment in water infrastructure, leading to reductions in waste and increases in sustainable mobilization, as well as increased sanitation network coverage.

Central water authorities, supported by river-basin institutions and decentralized entities would be given increased power and resources to effectively manage water within countries. This would promote dynamic and climate-responsive re-allocation of water among users, facilitated by well-regulated pricing and, potentially, innovative water rights trading mechanisms. The development of water scenarios appears ever more necessary in the face of the risks and uncertainties involved in continuing with the business-as-usual modes of water management.

Chapter 10. Unvalued water leads to an uncertain future

Policies with profound effects on water are made by agents – politicians and officials in planning, economic, finance and water-using departments – that are heavily influenced by national economic and financial considerations. In addition, the case for investment in water, and for making the reforms to its development and management is also commonly framed in social, ethical, equity or public health terms.

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Water is increasingly becoming a critical factor in decisions for the location of economic activities such as industry, mining, power and tourism. Companies working or contemplating investment in water-stressed regions are becoming aware of their 'water footprint' and its impact on local communities, which could pose operational and reputational risk to their business.
Valuing the multiple socio-economic benefits of water is essential for improving decisions of governments, international organizations, the donor community, civil society and other stakeholders. Conversely, a failure to fully value all the benefits of water in its different uses is a root cause of the political neglect of water and its mismanagement.

The allocation of scarce water to competing uses lies at the heart of water management. In many parts in the world, increasing pressures on water resources are leading to a shortage of water to satisfy all needs. Stresses on water are mainly driven by four interrelated processes: population growth; economic growth; increased demand for food, feed and energy (of which biofuel is one source); and increased climate variability. Choices must be made about how to share, allocate and reallocate the increasingly scarce water within sectors, from one user group to another, or between sectors.

Chapter 11. Transforming water management institutions to deal with change

There are calls for a change in thinking away from separate ecosystems and social systems to socio-ecological systems instead. Rather than planning for one defined future, water management agencies increasingly need to improve their methods of assessment in order to respond to a range of possible future scenarios, all uncertain but presenting at varying degrees of probability.

Defining social risk tolerance and service reliability is part of a social contract to be determined through a continuing dialogue within each society, whether it be for new drugs, nuclear power plants or water infrastructure. IWRM is contextually shaped through this process to encompass the different dimensions of sustainability (ecological, biophysical, economic, social and institutional), but it is also often path dependent. Thus, effective IWRM is knowledge-intensive and simply needs to be adaptive if it is to continue to respond to exogenous changes over which it generally has little direct control. Adaptive management is a process that

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promotes flexible decision-making in the face of uncertainties as outcomes from management actions and other events become better understood.

In an inherently complex world, most of the important decisions impacting on water occur out of the water box. They are taken by leaders in governments, private sector and civil society. It is therefore important that new methods be developed for technical people to inform decision-makers in government, as well as those who are affected by these decisions. This requires a formal structuring of relationships between technical specialists, government decision-makers and society as a whole.

Looking beyond what is traditionally considered water management – going outside the water box – is inevitable. Interconnecting water management with land management and sectors like agriculture, mining and energy, at the institutional level, will enhance the probability of effective decision-making. Realising this is highly demanding on leadership. Overcoming the inertia of traditional approaches and resistance from various actors remains daunting. Decision-makers need support in putting these ideas into practice, as well as the courage to withstand criticism and to share power with other actors.

In order to make appropriate decisions to manage particular uncertainties and risks, they have to be clearly understood. It is therefore important to supply enough accurate information to provide the decision-maker(s) a certain amount of control when faced with uncertainty. Managing uncertainty can then become less stressful and result in more positive and realistic outcomes.

Chapter 12. Investment and financing in water for a more sustainable future

Water in all its facets needs financing – at a higher level than is currently happening – for both 'hard' infrastructure and the 'soft' but equally important items such as data collection, analysis and dissemination, human resources and technical capacities, regulation and other governance issues.

Investment in water infrastructure, in both its physical and natural assets, can be a driver of growth and the key to poverty reduction.

Adequately funded water governance is essential for reducing uncertainty and managing risks. Effective governance in areas such as environmental controls, groundwater monitoring and abstraction licensing, and monitoring and control of pollution can reduce the risk of overexploitation of water resources or of catastrophic surface water pollution and irreversible contamination of aquifers. Some of these governance functions can sometimes be self-financing through abstraction and pollution charges.

The neglect and decline of national observation systems cause loss of vital hydrological data. Investment in the technology needed to upgrade countries' water and water-related information bases can show good returns, and is being targeted for support by the international development community. Such information is of vital national concern, but is often a local, river basin, regional or international public good that is seriously underfunded and under-provided.

Adaptation and mitigation projects implemented by public agencies can draw on a range of development funds, including new adaptation funds created for this specific purpose. However, much of the adaptation/mitigation effort will fall to private companies, farmers and households, as well as subsovereign agencies that will have to rely on other sources of financing according to their particular situation.

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Increasing the use of technologies, such as desalination and reclaimed water can reduce and distribute risk, compared with relying on withdrawals of fresh surface and groundwater. Desalination plants and some projects for the use of reclaimed water (entailing sizeable investment in wastewater treatment plants) potentially lend themselves to stand-alone commercial ventures funded from equity and commercial finance.

Raising commercial finance for water has become more difficult due to the global financial situation since 2007. This, as well as the problems typical of certain regions, most notably Latin America,, have discouraged new private interest in water infrastructure projects, and has unsettled partners in existing private public partnership (PPP) ventures. The financial climate has affected both the supply of risk capital (e.g. equity) and loan capital to finance these concession deals, as liquidity has become scarce, and the problems of international banks have had repercussions on local banks. Many innovative deals, developed with technical assistance and risk-sharing from donor agencies, are at risk.

As a general principle, the risk of financial default can be managed by tailoring financial terms to the risk profile and expected cash flow of the project concerned. For large and complex projects it is becoming common to blend different types of finance (commercial loans, concessionary loans, grants, equity) to achieve an acceptable overall mix.

There is a feasible approach to financing in the face of unknowns and risks. It involves a mixture of efficiency measures, review of standards and technological options, improved rates of collection, better cost recovery from water users, more predictable government subsidies and ODA, and the intelligent use of such basic revenues to attract repayable funding sources using the array of risk-sharing devices now available.

Chapter 13. Responses to risk and uncertainty from a water management perspective

There are no responses to risk and uncertainty that can be universally applied. However, by examining approaches that have been tried by others it is possible to learn from one or more that have succeeded or failed elsewhere under different circumstances. These responses have usually involved the use of various tools to identify and evaluate alternative water resources plans, policies, infrastructure designs and operating rules applicable to different regions of the developed and developing world.

One of the most direct ways of reducing uncertainty is to generate new knowledge or understanding of conditions governing water availability and quality in the present and in the future. Data collection, analytical capacity and predictive ability are all required to reduce uncertainty and therefore to facilitate decision-making about allocations, uses, mobilization and treatment. While the risk to water is not reduced, it is better understood.

Adaptive management strategies allow changing course based on new insights, help establish and sustain institutional settings and technological systems that are flexible and error-tolerant, and offer a framework for transparent decision-making processes. Funding a diversity of water storage projects, from small-scale rainwater tanks and larger-scale dams to systems that artificially recharge groundwater aquifers, to improving the soil so it can hold more water, is one option to meeting the increased need for storage. Stored water in times of drought can lead to increased food security. Just as modern consumers diversify their financial holdings to reduce risk, smallholder farmers can use a wide array of 'water accounts' to provide a buffer against climate change impacts.

Limited water availability, growing and evolving demands, and competition among increasingly scarce financial and physical resources create difficult trade-offs for decision-makers who must plan effectively under considerable risk and uncertainty. Countries can take precautionary or status quo approaches towards addressing risk and uncertainty, and these reflect the trade-offs they are willing to make to address risk and uncertainty. Policy changes only occur when the costs of maintaining the status quo exceed the transaction costs of implementing change. However, not all trade-offs need be negative. There are indeed examples of win–win situations where addressing risks and uncertainties in and outside of the water realm have led to multiple multi-sectoral benefits and to benefits for water in the long term.

Chapter 14. Responses to risks and uncertainties from out of the water box

Many of the problems faced within the water sector are caused by decisions made in other sectors, while many of the solutions to water problems can also be found within these sectors. Most decisions, within or outside the water world, involve some form of risk management. Anticipation of future benefits or threats is an integral part of sectoral decisions and business decisions alike. These decisions do not always take water into consideration, but often have an impact on water – and an impact on the types of decisions and reactions that water managers have to choose from.

Beyond the provision of water for basic human needs, such as food, drinking and hygiene, many development efforts have an impact on water risks and uncertainties. In most cases, more development means more water use, and more water pollution arises from higher levels of economic growth.

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Choosing diverse economic growth pathways could help to address risks and uncertainties related to water availability; however, very few countries have the option to do so because the trade-offs and political costs are so high and immediately felt.

In some cases, green growth entails turning a development challenge – for example, lack of access to chemical fertilizer – into a sustainable development opportunity. Following this model, existing water scarcity could provide a basis for technological innovation to help countries leapfrog towards greener growth, while avoiding the common risks faced by other countries. Climate change represents one of the greatest uncertainties currently facing human society. At the global level, there may be a high degree of likelihood for certain types of impact such as temperature increases and sea level rise; however, impacts at the local level are far less predictable.

Most business decisions are based on an approach to risks and uncertainties. Decisions on investments and modes of production make presumptions about the future. Many decisions that are uniquely motivated by the financial bottom line can also provide effective means of reducing risks and uncertainties related to water.

Government policies such as taxation rates, or fiscal incentives for attracting investment and business in a given location, while legal frameworks can go a long way to reducing uncertainties by providing boundaries for the investment context.

Governments may choose to attract investments that provide the highest value for water units, although examples of such types of decision remain unfortunately rare.

Tools such as the proper pricing and valuation of water resources can drive business decisions, particularly when water is a key input in production. They can also help to highlight trade-offs, costs and benefits/co-benefits that would otherwise not be apparent to business owners.

Win–win benefits between water and health planning can be found as the world's concern over pandemics and rapidly transmissible animal and human diseases increases. Because water acts as a vector of transmission or as a determining factor in the prevalence of certain transmissible diseases, efforts to prevent (or prepare for) global pandemics could generate benefits for managing risks and uncertainties related to water.

A number of international organizations highlight the water–food–energy nexus as illustrating the most difficult choices, risks and uncertainties facing policy-makers today. Examples abound of the various intended or unintended consequences of favouring one pillar over the other (e.g. food security versus energy security). A key challenge is to incorporate the complex interconnections of risks into response strategies that are integrated and take into account the many relevant stakeholders.

Insurance is of one of the oldest risk mitigation mechanisms – one that is applicable to all sectors, but that also helps to reduce the impacts of water-related risks. Index-based (or parametric) insurance is also emerging as a potentially powerful tool for risk management in all sectors.

Water treaties or agreements regarding water allocation in shared transboundary basins are multiplying, and are often quoted as having side benefits for reducing other risks, through the establishment of trust-building mechanisms and a certain amount of predictability in stakeholder behaviours.

Agreements and treaties signed for purposes other than water may help reduce risks and uncertainties regarding water, particularly where they provide mutual assurance of the other party's behaviour regarding natural resource use.

INTRODUCTION

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No water users, anywhere in the world, can be guaranteed they will have uninterrupted access to the water supplies they need or want or to the water-derived benefits from key developmental sectors such as agriculture, energy and health. Examples from around the world warn us that disregard for the central importance of water will eventually lead to breakdowns in the socio-economic and environmental systems so vital to the prosperity of all countries and their citizens.

While it is true that all aspects of social and economic development – often referred to as the *food–energy–health–environment 'nexus'* – depend on water, that is only half of the truth; the relationship is one of interdependency. All of the activities that drive development also shape important political and economic decisions that influence how water resources are allocated and managed, all of which often has substantial impacts on the quantity and the quality of the water available, and thus on other developmental sectors. Indeed, all of the sectors of the nexus are interlinked through water.

The combination of growing populations, increasing demands for resources associated with improving standards of living, and various other external forces of change are increasing demand pressures on local and regional water supplies required for irrigation, energy production, industrial uses and domestic purposes. These forces are undergoing rapid, accelerating and often unpredictable change, creating new uncertainties for water managers and increasing risks to all developmental sectors of the nexus through water. At the same time, climate change is creating new uncertainties with regard to freshwater supplies and to the main water use sectors such as agriculture and energy, which will in turn exacerbate uncertainties regarding future demands for water. In summary, the determinants of change in water demand and supply are themselves undergoing unpredictable changes.

Water is a vital component in the production of all goods and commodities, particularly food, and is thus embedded in marketed goods. Globalization of trade means that all countries and companies (consciously or unconsciously) are involved in the 'import and export' of virtual water and therefore share some responsibility for the local and regional impacts associated with international trade (including increasing scarcity and pollution) and the foreign investment protection system. As water demand and availability become more uncertain, all societies become more vulnerable to a wide range of risks associated with inadequate water supply, including hunger and thirst, high rates of disease and death, lost productivity and economic crises, and degraded ecosystems. These impacts elevate water to a crisis of global concern.

This fourth edition of the *World Water Development Report* (WWDR4) drives home the point that *all water users are – for better or worse and knowingly or unknowingly – change agents* who affect and are affected by the water cycle. It presents the case that, in today's world, a 'business-as-usual' approach to water management is tantamount to blind neglect of the ecosystems that sustain life and well-being. Past attitudes – which in many cases were of an expectation of governments to manage water as a 'sector' while decision-makers in other true sectors (food, energy, health and others) paid little attention to how their actions affected the water cycle (and other users) – have created a disconnect between policies and actions, and the role of managing both their consequences. The lack of interaction between the diverse communities of users, decision-makers and isolated water managers has caused serious degradation of the water resource and increased the risks to all the other sectors that depend upon it.

Perhaps the most troubling aspect of this assessment is that the rate of change now seen across the water cycle leaves water experts somewhat perplexed; history is no longer a reliable means of predicting future water demand and availability. In admitting that current understanding of the various pressures being placed on the water cycle is akin to islands of knowledge in a vast sea of unknowns, the WWDR4 also sets a challenge for all water users and the full spectrum of leaders and decision-makers to invest in building and sharing knowledge about how their actions affect water quality, quantity, distribution and use. Only through such a collective effort can ways be found to reduce uncertainty and manage risk to balance and optimize the many fundamental benefits provided to society through water.

As discussed in the WWDR3, globalization processes have brought benefits to billions of people, but have in large part left the 'bottom billion', in which women and children are disproportionally represented, marginalized and most vulnerable to existing risks. Learning how to equitably balance the many benefits, from local to global, derived from water will be a necessary key for change. If measures taken to deal with water-related issues do not explicitly incorporate equity issues, the poorest and the most underprivileged people are likely to continue being excluded from benefiting from the outcomes of these measures.

There are success stories of multiple stakeholders working together to turn rapid change in the forces that influence the water cycle into new opportunities to improve water provision, use and management. Presented throughout the report (and especially in Chapters 13 and 14), these examples of progress highlight the interaction of knowledge-building, policy, technology and greater input by a wider range of water stakeholders. Yet they also highlight the complexity of each and every situation – overemphasis on one aspect can unbalance the effort.

What's new in the WWDR4

The first two editions of the WWDR provided comprehensive assessments of the issues, trends and developments affecting and related to water on the basis of different 'challenge areas'. Under the coordination of leading United Nations (UN) agencies, these challenge areas were presented as individual chapters that described the state of the resource and ecosystems; major use sectors (human health, food and agriculture, industry, energy, human settlements); and management challenges (managing risks, sharing water, valuing water, enhancing knowledge and capacity, governance).

The third WWDR took a different approach (and structure) by providing a holistic analysis of the water domain while recognizing the externalities and their role on the state, use and management of the earth's water resources. It introduced the concept of external forces, providing a general description of the main 'drivers' of change and how these ultimately affect demand for – and thus have impacts on – freshwater resources. The key message of the report was that most decisions about water are not made by water managers, but by decision-makers outside the 'water box'; that is, actors from the spheres of civil society, business and government leadership, whose decisions concerning policy formulation, resource allocation and other political and operational issues affect water directly (through allocation and demand) and indirectly (through various drivers of change).

This fourth report builds on different elements of the first three editions and incorporates some entirely new aspects.

First, it reintroduces the twelve challenge area reports that provided the foundation for the first two editions. These were again prepared under the coordination of leading UN agencies. However, unlike the earlier versions, which provided a comprehensive overview of the issues, the new challenge area reports are shorter, with a focus on key challenges, recent developments and emerging trends, and on the external drivers and the pressures they place on water systems and how these can lead to a better understanding of uncertainty, management of risk and identification of opportunities. This is the context in which approaches to water management and policy are illustrated through specific examples, ranging from adaptive design criteria for infrastructure or demand management to institutional capacity development and policies for different developmental sectors.

Second, in addition to these challenge area reports, four new reports have been introduced, covering issues that had not been specifically covered under previous WWDRs: Water Quality, Groundwater, Gender, and Desertification, Land Degradation and Drought.

Third, in recognition that the global challenges of water can vary considerably across countries and regions, a series of five regional reports have been included, providing for the first time a regional focus to the WWDR4. These 'regional reports', which follow the same overall structure as the challenge area reports, were coordinated by the UN regional economic commissions.

Fourth, WWDR4 delves into a deeper analysis of the drivers described in the third edition, and examines possibilities for their future evolution. This analysis emanates from the results of the first phase of the World Water Assessment Programme's (WWAP) Scenarios Project, which is also described in WWDR4.

Fifth, this fourth edition of the WWDR incorporates a theme, 'Managing water under uncertainty and risk', which serves as the overarching topic for the report. This does not mean that the WWDR4 is about uncertainty and risk; rather, the WWDR4 examines current challenges to water resources, their use and management through the lens of uncertainty and risk. The WWDR4 considers the uncertainties associated with different external drivers and looks at managing the risks emanating from within and outside the water box, thus further building on the holistic approach taken in the WWDR3.

In summary, building on the comprehensive approach taken in WWDRs 1 and 2, and the holistic view taken in WWDR3, this fourth edition gives an account of the critical issues facing water's challenge areas and different regions and incorporates a deeper analysis of the external forces (i.e. drivers) linked to water. In doing so, the WWDR4 seeks to inform readers and raise awareness of the new threats arising from accelerated change and of the interconnected forces that create uncertainty and risk – ultimately emphasizing that these forces can be managed effectively and can even generate vital opportunities and benefits through innovative approaches to allocation, use and management of water.

Structure and content

The WWDR4 is separated into four parts. Part 1, 'Status, trends and challenges', provides an overview of recent developments, emerging trends and key challenges, including the external forces driving these and the uncertainties and risks created by the drivers. Part 2, 'Managing water under uncertainty and risk', is the thematic part of the report in which decisions affecting water, from management and institutions to allocation and financing, are investigated through the lens of risk and uncertainty, with particular emphasis on climate change and other drivers of change. Part 3 (Volume 2), 'Knowledge base', contains each of the challenge area reports prepared by UN-Water agencies and the regional reports prepared by the UN regional economic commissions – from which much of the material in Parts 1 and 2 was extracted – as well as other supporting documents. Like the earlier editions, the WWDR4 also contains case studies, Part 4 (Volume 3). The 15 country-level case studies describe the progress made in meeting water-related objectives, as well as some obstacles leading to lingering and in many cases worsening problems, showing that there are lessons to be learned from success stories as well as from failures.

The WWDR4 opens with Chapter 1, which describes the global dimensions of water and underlines the need to move beyond the concept of water as a sector. It discusses water's central role and cross-cutting nature in achieving various developmental targets, a reality that is evolving in key international processes such as the United Nations Framework Convention on Climate Change (UNFCCC) negotiations and the preparatory work leading up to the Rio+20 Conference of the UN Commission for Sustainable Development (CSD), or being adequately implemented in national frameworks.

Part 1 begins with Chapter 2, which focuses on the key sectors of water demand: food and agriculture, energy, industry, and human settlements. In addition to reporting recent trends and developments, this chapter describes the pressures for the main drivers, the uncertainties and risks related to each sector, projections on future demands (where possible) and possible response measures. The chapter concludes with a section on ecosystems as a 'user' of water, arguing that water demand by ecosystems is to be determined by the water requirements to sustain or restore the benefits for people (services) that we want ecosystems to supply.

Chapter 3 looks at the supply-side aspects of the water resources equation. Focusing on information provided in previous WWDRs, the chapter examines the role of large-scale climate drivers in distributing the earth's water resources over time and space. Two very important storage-related issues, groundwater and glaciers, are addressed here in terms of their vulnerability and the long-terms risks that may evolve from over-exploitation (groundwater) and from climate change (glaciers). The chapter concludes with an examination of the most pressing water quality issues and the risks these can engender.

Chapter 4 focuses on the benefits received through water in terms of human health and ecosystems and the challenges faced from natural hazards and desertification. These are examined in terms of current trends and hotspots, with uncertainties and risks associated with the main external drivers, and response options. The chapter includes a section focusing on gender-related challenges and opportunities and concludes with an examination of the current global water balance, describing the role of water as the nexus for sectors related to development and poverty eradication.

Chapter 5 describes how different water management systems and institutions function, looks at the challenges they face, and examines the important role of developing knowledge and capacity in addressing increasing uncertainty and risk.

Chapter 6 explores the need for better data and information for improved decision-making. The chapter describes the value of focusing on a small set of specific data items from which myriad indicators of performance can be developed, and highlights several promising options that, if properly implemented, could begin providing highly valuable information for water managers, institutions and decision-makers inside and outside the water box alike.

Chapter 7 presents a summary of each of the five regional reports contained in Part 3/Volume 2: Africa; Europe and North America; Asia-Pacific; Latin America and the Caribbean; and the Arab and Western Asia region. Each region is examined in terms of the driving forces and pressures on water resources, the main challenges, risks and uncertainties associated with these, hotspots, examples from responses to the challenges, and potential response options. The chapter (and Part 1) closes with an examination of the interlinkages between different regions and global challenges, which describes how actions in one part of the world can create negative impacts, as well as opportunities, in other parts of the world.

Part 2 begins with Chapter 8, which introduces some of the basic concepts of uncertainty and risk, including thresholds, tipping points and nonstationarity and what they mean in terms of water management, decision-making and policy formulation. Different principles and approaches to dealing with uncertainty and risk are presented with examples of their strategic applications.

Chapter 9 builds on the analysis of the main external forces (i.e. drivers) that were first introduced in the WWDR3. It includes an examination of the possible evolution of ten key drivers and the uncertainties and risks associated with them. It also reports on the results from Phase I of WWAP's World Water Scenarios Project, demonstrating the complexity of the interlinkages between these drivers of change. The chapter concludes with short examples that illustrate the possible futures that could arise from a water-centred scenario development exercise.

Chapter 10 focuses on the values of water, its benefits and its allocation. It sets out the elements of an economic case for investment in water and for reforming its development and management, starting with the overall benefits of water to an economy, and proceeding to consider the value of water in the various parts of its cycle. It shows how these benefits and values can be used to inform policies for the allocation and use of water in situations of growing resource pressures, uncertainties and associated risks.

Chapter 11 describes a set of different tools for leaders in government, the private sector and civil society who make most of the important decisions impacting water. Important instruments to support decision-making include forecasts and scenarios, as combining a range of forecasts of possible futures allows for more robust decision-making. A key tool to initiating the much-needed adaptation, proactive adaptive integrated water resources management (IWRM), is also presented. The chapter closes with a focus on ways institutions can be reformed to better deal with uncertainty and manage risk.

Chapter 12 builds on the case made in Chapter 10, showing that water development is key to sustainable development and an integral part of a green economy, and explaining how increased financing is necessary for all facets of water development, ranging from 'hard' infrastructure to equally important 'soft' items such as capacity; management; data collection, analysis and dissemination; and regulation and other governance issues. It examines efforts to help reduce the funding gap through internal efficiency and other measures; improve the generation of revenues from users, government budgets and official development assistance (ODA); and use these flows to leverage repayable finance such as bonds, loans and equity.

Chapter 13 presents a set of responses to risk and uncertainty from a water management perspective. Examples of reducing uncertainty are provided in terms of monitoring, modelling and forecasting to reduce uncertainty and understand risk; adaptive planning; and proactive management. Examples of reducing exposure and minimizing risk are also presented in relation to investments in infrastructure and environmental engineering. Finally, examples of trade-offs in water decision-making are presented.

Part 2 concludes with Chapter 14, which focuses on responses to risks and uncertainties from outside the water box. Examples are provided of how water can be affected (positively or negatively) through actions and policies aimed at reducing poverty and promoting green growth, responding to climate change (in terms of adaptation and mitigation), informing business decisions and managing sectoral risks. The chapter closes with approaches to mitigating risks and uncertainties, with a look at the roles of insurance, treaties and multi-sectoral cooperation.

CHAPTER 1

Recognizing the centrality of water and its global dimensions

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Italy: Countryside around Siena, Tuscany (43°19' N, 11°19' E)

Water is an essential resource required for sustaining life and livelihoods: safe water is required for drinking, hygiene and providing food; and adequate water to produce energy and support economic activities such as industry and transportation. Water in the natural environment ensures the provision of a multitude of ecosystem services to meet basic human needs and support economic and cultural activities. For too long water has been an issue that is at once everywhere and nowhere: it is the lifeblood of our planet and of the human societies that flourish upon it, but is frequently taken for granted, with decisions at all levels and across all sectors made without full consideration of the potential impacts on water resources and other water users. The challenge for twenty-first century governance is to place water at the heart of decision-making at all levels – horizontally across departments and sectors, and vertically at local, national, regional and global scales. Two prerequisites are essential to this happening.

First, *it must be understood that water is a natural resource upon which all social and economic activities and ecosystem functions depend.* It cuts across and affects more aspects of life than can be easily listed or categorized. It is a basic amenity of life, as well as being indispensable for other necessities: as an input to agriculture for food, fibre, feed and biofuels, the production of energy, and for industrial and manufacturing processes for multitudes of products. Water also has tradable aspects – both directly, for example, through pipes and bottles, in tankers and vessels, and indirectly or 'virtually' through products. In many contexts it is understood as a commodity although with many characteristics of a public good. Understanding the multiple aspects and roles of water is crucial to governing it effectively.

Second, *greater recognition is needed of the fact that water is not solely a local, national or regional issue that can be governed at any of those levels alone.* On the contrary, global interdependencies are woven through water, and decisions relating to water use on a local, national or regional level often cannot be isolated from global drivers, trends and uncertainties. Impacts on water resources are driven by factors both outside the 'water box' and, importantly, outside the 'decision-making box' of local, national and regional actors. The recognition that water is an ubiquitous cycle, tapped into by development at all levels, has implications for the processes instituted for governing water at local, national and regional levels, for sharing expertise, and moving towards more robust water management in different locations.

Some global dynamics and drivers, such as climate change and patterns of global trade or foreign investment regimes, cannot be dealt with solely at local, national or regional levels. Recognition of these *global dimensions* at the country level may influence the kinds of institutional arrangements necessary at the international level to address water-related challenges that demand an international response. The United Nations Conference on Sustainable Development (UNCSD) in 2012 and its subsequent plan of action[1] offer an opportunity for countries to advance discussions in this area, as do the United Nations Framework Convention on Climate Change (UNFCCC) in its negotiations on climate change mitigation and adaptation and the post-2015 processes surrounding the Millennium Development Goals (MDGs). Other relevant processes include Ramsar and the conventions on biodiversity and desertification. Forums and groups of formal and semi-formal nature such as the G8, G20, the World Economic Forum, the World Water Forum, and the World Social Forum also have an impact on global thinking.

This chapter explores these observations – that water is a natural resource critical to socio-economic development, and that some dimensions of water management are global. These factors sometimes demand global responses in addition to local, national and regional governance. Population growth, technology, changing lifestyles and increasing consumption and climate change, among others, introduce uncertainty to water management at both local and global levels.

1.1 Beyond the concept of water as a sector

Water is a necessary component for all major socio-economic sectors, contributing to each in different ways. Agriculture requires large quantities of water for irrigation as well good quality water for various production processes. Energy requires water for powering turbines (hydroelectricity), cooling power plants (thermal and nuclear electricity) and growing biofuels. Access to safe water supplies and basic sanitation are necessary for maintaining public health, and water is needed to support healthy ecosystems, which in turn provide critical environmental goods and services. The benefits from each of these sectors are provided through water.

A core focus of the third edition of the *World Water Development Report* was the impact on water resources of decisions taken outside the 'water box'. Planning for public health, urbanization, industrialization, energy production and agricultural development – to name but a few areas – is all too often conducted in isolation from water ministries and water managers. Furthermore, water demands and uses are often managed in silos with each focused on meeting specific developmental objectives, rather than as part of an overarching and strategic framework that balances different water uses in order to optimize and share its various benefits across society and the economy. This fragmentation increases risks to the sustainability of water resources as well as to the different development objectives that depend upon (and may be in competition for) limited supplies. Climate change exacerbates this problem still further. Climate change impacts on water resources, as well as the 'drivers' of demand, stand to turn water from an intermittent problem to an acute one in many parts of the world (Steer, 2010), making the case for consultation with actors outside the water box even more compelling.

The job of delivering adequate water for social, economic and environmental needs is often understood as the preserve of the 'water sector', which is expected to provide the appropriate infrastructure and channel water in the right direction. Yet in reality, water cuts across all social, economic and environmental activities. As such, its governance requires cooperation and coordination across diverse stakeholders and sectoral 'jurisdictions'. Furthermore, water availability must be understood within the context of the hydrological cycle, which is influenced by multiple factors, trends and uncertainties that extend beyond a narrow sectoral focus. This principle has been captured to a great extent by the movement towards integrated water resources management (IWRM), a governance framework for water resources that seeks to manage water across competing uses and needs – including agriculture, energy and industry – as well as water for basic human needs and ecosystem functions (see Chapter 5). Yet progress towards such governance frameworks has been slow, as operationalizing the principle of IWRM necessitates institutions that facilitate discussion and decisions on the targets of society, and the allocation of water resources across sectors to meet them. In the absence of institutionalized IWRM (or a similar coordinating mechanism), growing recognition of the water-food-energy-health-environment *nexus* concept can help raise awareness among managers responsible for planning in different water-dependent sectors of the broader implications of their actions, including their water use, on the resource and other users.

It is true that water unites a community of experts, managers, officials and other stakeholders who are tasked with managing the resource effectively and responding to increasing demand. As such, its status as a sector cannot be completely denied. The crucial factor for water governance is therefore the recognition that water is not *only* a sector, but also a necessary element that provides benefits for all sectors, thus requiring active consultation with, and coordination among, the sectors and communities that depend upon it. In particular, members of the water community have the duty to inform and provide guidance to decision-making and to regulatory authorities on how to use and manage the resource sustainably, so as to optimize and share its many benefits and minimize conflicts. In short, addressing water challenges necessitates interventions across an entire economy, undertaken by strong institutions with the authority, capacity and leadership to take a proactive rather than a reactive role in water management, and to drive the productive use of water across sectors within the limits of social and environmental sustainability (Steer, 2010). The importance of political leadership in establishing, reviewing and maintaining the frameworks to manage these competing demands cannot be understated. Some of the areas where this is particularly critical are outlined in this section.

1.1.1 Food

Water for irrigation and food production constitutes one of the greatest pressures on freshwater resources. Agriculture accounts for around 70% of global freshwater withdrawals (reaching up to 90% in some fast-growing economies). Global population growth projections of 2 to 3 billion people over the next 40 years, combined with changing diets, result in a predicted increase in food demand of 70% by 2050 (see Section 2.1 and Chapter 18). However, as the largest user of water, food production also represents the largest unknown in terms of future global water demand, for several reasons.

First, it is difficult to predict how diets in different countries and regions will evolve over the next few decades, and therefore what type of food (with its varying demands for water) will be produced. The quantity of biofuel that will be needed is also unknown, or how this demand will affect food production through increased competition over land and water. The extent to which technological improvements in agricultural water productivity ('crop per drop') will affect future water demand is extremely difficult to predict. Finally, because of climate change, there are many uncertainties concerning how much water will be available where and when.

In the short-term, increased demands for food represent a significant economic opportunity for farmers and agricultural producers all over the world, especially in developing countries whose economies are often highly dependent upon agricultural production and export. There are plenty of sustainable ways of responding to increased food demand, such as drought resilient crops, incentives for more efficient irrigation and water usage, removal of subsidies encouraging inefficient water use, and regulatory frameworks to control water pollution from excess fertilizer use (WEF, 2011). Dialogue between water managers and agricultural planners is crucial to ensuring that the right combination of the above is identified and properly implemented, so as to reduce uncertainties and risks related to food and water security. This dialogue must include stakeholders who make a living from agriculture (including biofuels), at all levels, in order to inform the decision-making authorities about their current and future allocation needs.

1.1.2 Energy

The relationship between water and energy is reciprocal (see Section 2.2 and Chapter 19). Energy is required for humans to make use of water – to lift, move, process and treat it at every phase of its extraction, distribution and use (USAID, 2001). Out of all energy produced globally, 7% to 8% is used to lift groundwater and pump it through pipes, and to treat both groundwater and wastewater (Hoffman, 2011) – a figure that rises to around 40% in developed countries (WEF, 2011). Desalination, the process by which seawater is converted to freshwater, is especially energy intensive. The treatment of wastewater also requires significant amounts of energy, and demand for energy to do this is expected to increase globally by 44% between 2006 and 2030 (IEA, 2009), especially in non-OECD countries where wastewater currently receives little or no treatment (Corcoran et al., 2010).

> "The crucial factor for water governance is … the recognition that water is not *only* a sector."

Conversely, water is needed to produce and make use of energy. It is required for cooling in the generation of thermal and nuclear electricity, and is necessary for alternative or renewable forms of energy such as hydropower (as a direct input), as well as concentrated solar energy. Biofuels represent an additional demand on water resources, and also compete with food for limited water and land. In 2009, the number of people without access to electricity was 1.4 billion or 20% of the world's population. Global energy consumption is expected to increase by about 50% between 2007 and 2035 with non-OECD countries accounting for 84% of this increase (IEA, 2010*b*). The need to increase energy supplies to meet rising populations and living standards, as well as presently unmet demand, creates several unknowns: which energy mix will be used (and where), and how much more water will be needed to generate this additional energy? These unknowns add to the other major uncertainties regarding future demands for water. Climate change further complicates the issue because mitigation and adaptation imperatives have energy implications (see Section 1.2.1). As the pressure to invest in renewable energy intensifies in an effort to achieve mitigation objectives, there may be significant trade-offs in relation to water resources.

The relationship between water and energy illustrates the centrality of water in relation to other developmental sectors. For example, health problems induced by a lack of access to clean energy (e.g. cooking inside on wood burners) often go hand-in-hand with diseases caused by lack of access to safe drinking water (see Section 4.1 and Chapter 34). How can governments simultaneously deliver expanded energy access while also increasing access to water for both personal and productive uses? Enhancing efficiency in both energy production and the extraction, delivery and treatment of water will be critical, as will the choice of energy source according to context. Biofuels are an increasingly prominent component of the energy mix, as exemplified by the EU target for biofuels to constitute 10% of transport fuel by 2020 (EU, 2007). This target has been hotly debated as it acts as a driver for conversion of land from food to biofuel production, placing upward pressure on food prices, and in some cases leading to the conversion of forest ecosystems to land to 'grow' biofuels. Estimates vary, but even modest projections of biofuel production suggest that if by 2030 – as the IEA suggests – just 5% of road transport is powered by biofuels, this could amount to at least 20% of the water used for agriculture globally (Comprehensive Assessment of Water Management in Agriculture, 2007). Of course, should alternative technologies for biofuel (e.g. photobioreactors for algae) become available on a large scale, these projections could change dramatically, further illustrating the increasing uncertainties related to future water demands from different, often interconnected, demand sectors.

1.1.3 People

Beyond physiological hydration (roughly 60% of human body weight is water) water is necessary for meeting most of our basic physiological needs and provides us with myriad additional benefits (see Chapter 4). Access to drinking water supply and sanitation (WSS) services is key to meeting many of these needs. The importance of safe drinking water and sanitation for human health, well-being and socio-economic development is well established and is, quite understandably, a recurring issue in this report.

WSS is a 'service sector', which like electricity is supported by different institutional arrangements and financial mechanisms to provide people with a set of basic services. In fact, the WSS services sector is so important that it has led to a common and reoccurring misperception: that water and the WSS services sector are synonymous. This is not true. As is the case for agriculture, energy and other sectors, water is the resource upon which the sector is based – in this case, it is both the substance *and* the medium through which water supply and most urban sanitation services are provided. This can (and has been) the source of some confusion, even among those in the water community. But it is important to differentiate water (which is a fundamental natural resource that needs to be managed and protected) from WSS services, which are services that need to be *provided*.

Providing increased access to WSS services raises some interesting questions with respect to uncertainties. For example, will sanitation always be closely linked to water – or will it evolve to capturing urine and excreta for productive uses? Will there be more capture of rainwater or reuse of wastewater for gardens and urban green spaces? This would naturally make a major change in household water consumption.

Many of water's benefits to people are imparted through the services provided by the WSS services sector. Direct benefits to living standards include health and dignity. These also lead to indirect benefits such as increased access to higher levels of income and education, as well as the promotion of gender equality and empowerment of women. But there are also several benefits that are not necessarily related to WSS services. For example, water is indispensible for 'income sources for both smallholders and landless people, such as raising livestock. Trees and shrubs for fuel wood, timber, fruits and medicaments need water. Catching fish for family consumption can provide a major source of protein for poor households and provides incomes for small artisan fishermen and women. Water is also needed for various small industries and crafts, like brick-making, pottery, or beer-making.' (WWC, 2000, p. 15). Transportation and recreation are yet other examples of the benefits we receive through water.

Water can also help to shape our values and ethics, as individuals or as part of wider communities that can work together to manage the resource and share its benefits. Involving end users, particularly women, in water management contributes to optimizing benefits from water projects (see Section 4.2 and Chapter 35). It should also be remembered that, in Africa, women are the ones who produce 60% to 80% of the food for their families (FAO, n.d.). Water and energy are needed for this and it is imperative that women have access to water for irrigation from surface, ground and rainfed sources, generally at a small scale. This is sometimes a function of land and water rights, but also requires that local water managers recognize women's water needs outside of the household. Water managers can work with men and women who use WSS services to find out what they need and what the best solutions are. Urban and rural communities can make practical contributions regarding new approaches to urban planning and land use, and can identify the most suitable technical solutions, including technology, the location of various facilities, and the most appropriate sources of water, according to what they can afford. The community can support their water facility through resource mobilization and labour for construction, operation and maintenance.

1.1.4 Ecosystems

Ecosystems provide a multitude of benefits to humans (ecosystem services); for example, products such as food, timber, medicines and fibre, regulating climate and supporting nutrient cycling, and soil formation and deposition. Providing water, as a resource for direct use, is also an ecosystem service in terms of both its quality and its quantity. Ecosystems, in turn, also depend on water in order to function; when they are stressed the benefits are reduced or eliminated (see Sections 2.5 and 4.3 and Chapter 21).

The water cycle is a biophysical process. Without life on earth the water cycle would still exist, but be quite different. Ecosystems underpin the sustainable quantity and quality of water available: for example, the life in soils regulates water storage there and nutrient cycling, supporting all terrestrial life (including food production); forests (through plant transpiration) regulate local and regional humidity and precipitation; wetlands (and soils) regulate the extremes of drought and flood.

The role of ecosystems in the water cycle has two interrelated implications for water management. The first is that water must be allocated so as to allow ecosystems to continue to deliver the level of benefits we need (e.g. through maintaining environmental flows).[2] The second is that ecosystems can be proactively managed (other than by allocating water to them), through, for example, conservation or rehabilitation, in order to deliver what we need to meet water-related objectives. For example, forests are very good at delivering clean water, and wetlands at regulating floods and restoring soil functionality, a key mechanism to combat desertification.

The stability of ecosystems is under increasing threat from unsustainable patterns of human consumption, development, and climate change across the globe. The Millennium Ecosystem Assessment states that the 'primary indirect drivers of degradation and loss of inland and coastal wetlands have been population growth and increasing economic development' (MA, 2005). Examples of ecosystem damage largely coincide with areas of high water stress, such as in West Asia and the Indo-Gangetic Plain in South Asia, the North China Plain and the high plains in North America (Arthurton et al., 2007). Excessive withdrawal of both surface and groundwater over the past 50 years for agriculture, energy, industry and urban growth has led to a situation in many parts of the world where water abstraction exceeds the threshold of water renewability in the river basin, resulting in widespread damage to ecosystems (Molle and Vallée, 2009). The precise amount of water required to sustain a given ecosystem over a certain period is often unknown, and allocation decisions would also depend on the type of ecosystem services to be maintained. As this is a societal judgement that can also vary over time, it adds to the uncertainties in anticipating future water demands.

1.1.5 Water-related hazards

Many of the impacts of natural hazards on socio-economic development occur through water (see Section 4.4 and Chapter 27). Between 1990 and 2000, in several developing countries, natural disasters caused damage representing between 2% and 15% of their annual GDP (World Bank, 2004; WWAP, 2009). Water-related hazards account for 90% of all natural hazards, and their frequency and intensity is generally rising. Some 373 natural disasters killed over 296,800 people in 2010, affecting nearly 208 million others and costing nearly US$110 billion (UN, 2011).

The increase in natural disaster losses over the past few decades is largely attributable to the increase in the value of exposed assets (Bouwer, 2011). While there is currently no evidence that climate change is directly responsible for increased losses associated with water-related hazards (Bouwer, 2011), it is expected to bring about an increase in the frequency of certain natural hazards, including floods and droughts (IPCC, 2007).

Water management plays a central role in reducing the risks of natural disasters. Water storage (via reservoirs, aquifer recharge or other means) is vital to combating the effects of drought, providing a supply buffer that

"Managing water sustainably supports the overall objectives of a green economy or a green growth pathway, and also satisfies critical social imperatives."

can be made available for key beneficial uses during times of scarcity. Reservoirs can also serve to retain floodwaters, and are often an important component of physical flood defence systems, along with levees, weirs and dykes designed to prevent rivers from bursting their banks.

Such infrastructure forms part of a broader and integrated water management system (see Chapters 5, 11 and 12), which also include ecosystems and urban drainage systems, whose operation and maintenance (when available) reduce uncertainties and risks to water use sectors and development goals. Rising levels of uncertainty and risk associated with extreme events are indeed worrying, but must not become paralyzing. Quite the opposite: not knowing something implies opportunities to find out more and the notion of risk implies the existence of choices. It is possible to influence outcomes including minimizing risk or mitigating its impacts (see Chapter 8).

1.1.6 Water's role in greening economies and growth

Recognizing the centrality of water for sustainable development is crucial in the development of a green economy. In a green economy, the role of water in maintaining ecosystem services and water supply would be acknowledged, appreciated and paid for (UNEP, 2011). Direct benefits to society as a whole can be gained by increasing investment in water supply and sanitation, including investment in wastewater treatment, watershed protection and the conservation of ecosystems critical for water. New approaches, such as planning for adaptation to uncertain futures, the adoption of green technologies, improving the efficiency of water provision, and developing alternative water sources and forms of management (e.g. desalination, water recovery and reuse, payment for environmental services, ecosystem conservation, improved property rights) will play an essential role in enabling a cross-sectoral transition to a green economy. The consideration of full costs of service provision may also be an enabling factor, but this principle has often proven to be impractical in many situations as it can be difficult to implement in practice, especially in developing countries.

Managing water sustainably supports the overall objectives of a green economy or a green growth pathway, and also satisfies critical social imperatives of poverty alleviation, food and energy security, and health and dignity, through the provision of water and sanitation services. Investment in and protection and sustainable management of water resources, across society as a whole, allow significant steps to be made towards achieving a green economy that advances long-term human well-being within ecological limits (see Chapters 12 and 24). The way that water is managed and allocated has impacts across all areas of society and economy, and its governance must move 'from the pump room to the Boardroom' (Steer, 2010). Embedding water management as the central pillar of sustainable development requires institutions that facilitate discussion and decisions on society's targets and the allocation of water resources to optimize generation and equitable distribution of its many benefits. It is, then, the role of water managers to inform the process and do what is necessary to implement the decisions.

As conceptualized within a green economy, those benefitting from environmental services would be valued stakeholders, alongside other water users who would be recompensed to provide more equitably distributed benefits. The 'polluter pays principle' provides a basic model with which to achieve this, supported by robust and proactive regulation on a relevant river basin scale to identify polluters and enforce compensation for the restoration of environmental impacts. Furthermore, existing aspects of sound water policies related to poverty alleviation and gender equality are already supportive of the objectives of a green economy, whereby all water users have fair and equitable access to the benefits of maintaining a healthy environment. For example, the provision of water services to families in extreme poverty in Lima, Peru, within the framework of the Water for

All Programme, is estimated to have increased total disposable family income by 14% per month, resulting from lower water expenditures and reduced health care costs (Garrido-Lecca, 2010; see Box 1.1).

1.2 Beyond the basin: The international and global dimensions of water governance

The drivers of water use and availability (the impact of many of which is uncertain) are found not just outside the water box and beyond the sector, but also often in other nation states. Although water is distributed unevenly across the planet, it forms part of a global cycle – the hydrological or water cycle – which can be interrupted by actions and phenomena that take place beyond the nation state (e.g. regionally through upstream diversions and globally through the impacts of climate change). Other aspects of the global equation include the international distribution of certain water-related benefits (predominantly expressed through trade in agricultural products), the rising global demand for water, the limited availability of the resource at any one time or place, and the over-consumption of water and high-water content of goods and commodities in some developed countries. Building on these observations, this section addresses four prominent, interconnected factors that introduce a global dimension to water governance: climate change, transboundary basins, global trade and international investment protection, and equity.

BOX 1.1

Water for All Programme, Peru

In Peru, the Water for All Programme was designed not only as a mechanism for expanding the coverage of water supply and sanitation services, but also as a 'cost-based approach' to the alleviation of extreme poverty or indigence.

Once connected to the network, families living in extreme poverty, who previously bought water in drums, more than tripled their water consumption. However, their monthly spending on water decreased, resulting in a 10% increase in disposable income. The Programme also helped reduce gastrointestinal diseases caused by a lack of basic services and by inadequate sanitary conditions, with estimated additional monthly savings for families from lower health care costs – taking account only of the elimination of the episodes of acute diarrhoeal diseases – of about 4% per month (resulting in a total increase in disposable family income of 14% per month).

The aspiration of the Programme is that, by reducing unavoidable expenses, freeing up cash flow and increasing disposable income, it will ultimately generate a small amount of savings that will allow families to transition towards poverty levels that at least make inclusion in the formal market possible.

A potentially attractive feature of the Programme is that it has a once-off investment cost; the families themselves then pay for the service with only a small, pre-existing cross-subsidy that covers an initial consumption block. Therefore, in terms of sustainability and from a fiscal point of view, the Programme does not jeopardize its continuity or the beneficiaries' chances of escaping from extreme poverty.

Sources: Garrido-Lecca (2010, 2011).

1.2.1 Climate change

Climate change highlights the centrality of water in relation to a key global issue. First, because the worst climate impacts are delivered through a changing water cycle, and their avoidance requires global cooperation on a climate change agreement. Second, unavoidable climate change impacts through water in developing countries result in an obligation for developed countries to assist some in adapting to these impacts. Third, efforts to improve water governance arrangements are, in effect, the focus of climate change adaptation needs, and must be explicitly recognized as such in climate change funding. And last, climate change mitigation and adaptation responses are related because the carbon and water cycles are interdependent.

The Intergovernmental Panel on Climate Change (IPCC) states that 'water and its availability and quality will be the main pressures on, and issues for, societies and the environment under climate change' (Bates et al., 2008, p. 7). People will feel the impact of climate change most strongly through changes in the distribution of water around the world and its seasonal and annual variability (Stern, 2007). The poor, who are the most vulnerable, are also likely to be affected the most (Stern, 2007). Climate change also leads to new uncertainties concerning future water demand through different water-using sectors. For example, global warming suggests increased energy demands for air conditioning, and higher evapotranspiration rates could increase future demands for agriculture.

The precise impacts of climate change through water, in particular locations, remain uncertain and are notoriously difficult to predict, especially at the local

> "The carbon cycle (the realm of climate change mitigation) and the water cycle (the realm of adaptation) are interlinked: ecosystems require water to store carbon and by doing so impact water."

or river basin level. Under different IPCC scenarios, regions may become 'drier' or 'wetter', as there are a variety of possible ways in which climate change may impact the hydrological cycle in different areas and at different times. What is certain is that the uncertainties generated by climate change add a global dimension to the challenges of water resources management, as efforts to effectively manage water locally may be impeded by climate-induced hydrological impacts or increasing demands. Efforts to limit negative climate change impacts occurring through the water cycle require collective, global efforts to reduce carbon emissions, which 'go beyond the governance domain of water managers who operate at the local, national or river basin level' (Hoekstra, 2011, p. 24). Indeed, discussions on the respective responsibilities and capabilities of states to reduce greenhouse gas (GHG) emissions are rightly conducted through the UNFCCC.

Even if the most ambitious GHG reduction agreement were to be implemented now, it would likely not prevent the world from experiencing a certain level of climate change. The interconnected nature of our global economy means, for example, that climate-induced water shocks in an important food-producing region may potentially have significant impacts on food security in other parts of the world. But the capacity to adapt to climate change impacts through the water cycle is extremely low, particularly in a number of developing countries, which may be facing increasing water scarcity, and where the adaptive capacity of institutions is often restricted by deficient design, low operational capacity, and insufficient human and financial resources. For these countries, which have contributed the least amount of GHGs, adaptation represents an additional financial burden that many find difficult to support without assistance from the most prominent GHG-producing countries.

The cost of adapting to the impacts of a 2°C rise in global average temperature could range from US$70 to US$100 billion per year between 2020 and 2050 (World Bank, 2010). Of these costs, between US$13.7 billion (drier scenario) and US$19.2 billion (wetter scenario) will be related to the 'water sector', predominantly through water supply and flood management. However, these estimates do not take account of the benefits water provides through other 'sectors' (food, energy, health, etc.) and is thus under-representative of the full value of the benefits that would be obtained from a greater focus on adaptation through water. Water's central role in adaptation, and in socio-economic development in general, merits explicit recognition in the ongoing negotiations concerning Green Climate Fund (GCF)[3] and other financing mechanisms. Furthermore, infrastructure development, as well as the institutional reforms required to ensure the optimization of water's benefits across various socio-economic sectors, should be considered as key components of climate change adaptation.

In mitigation terms, the appropriateness of global interventions and mechanisms relating to land use, notably forestry and agriculture should be analysed in ways that include their potential impacts on water in each context.

In recognition of the role that deforestation plays in contributing to global GHG emissions (estimates suggest between 20% and 25% of total emissions), the UNFCCC has explored options through its initiative on Reducing Emissions from Deforestation and Forest Degradation (REDD) (UN, 2009). REDD basically ascribes a value to the carbon sequestration potential of forests and calls on developed countries to transfer funds to developing countries to preserve those forests to help mitigate climate change. However, the relationship between water and forests is complex. While it is true that forests rely on water availability for their long-term sustainability through groundwater, surface water and precipitation, it is also true that forests play a central role in improving water quality and, by maintaining or improving soil infiltration and soil water storage capacity, they influence the timing of water delivery (Hamilton, 2008). Forests also play an important self-regulating role in the regional cycling of water by re-intercepting atmospheric water locally generated by evaporation and redistributing it over different parts of the forest (Hamilton, 2008). The key point is that the carbon cycle (the realm of climate change mitigation) and the water cycle (the realm of adaptation) are interlinked: ecosystems require water to store carbon and by doing so impact water.

BOX 1.2

Climate change adaptation: The pivotal role of water

Water is the primary medium through which climate change influences Earth's ecosystem and thus the livelihood and well-being of societies. Higher temperatures and changes in extreme weather conditions are projected to affect availability and distribution of rainfall, snow melt, river flows and groundwater, and further deteriorate water quality. The poor, who are the most vulnerable, are likely to be adversely affected.

Adaptation to climate change is urgent. Water plays a pivotal role in it, but the political world has yet to recognize this notion. As a consequence, adaptation measures in water management are often underrepresented in national plans or in international investment portfolios. Therefore, significant investments and policy shifts are needed. These should be guided by the following principles:

- Mainstream adaptations within the broader development context
- Strengthen governance and improve water management
- Improve and share knowledge and information on climate and adaptation measures, and invest in data collection
- Build long-term resilience through stronger institutions, and invest in infrastructure and in well-functioning ecosystems
- Invest in cost-effective and adaptive water management as well as technology transfer
- Leverage additional funds through both increased national budgetary allocations and innovative funding mechanisms for adaptation in water management

Application of these principles would require joint efforts and local-to-global collaboration among sectoral, multi-sectoral as well as multidisciplinary institutions.

Source: An extract from the UN-Water policy brief Climate Change Adaptation: The Pivotal Role of Water, available at http://www.unwater.org/downloads/unw_ccpol_web.pdf (p. 1, Executive Summary).

Agriculture has in recent years also emerged as a potential area for carbon sequestration, and discussions have emerged as to whether sustainable agricultural practices that reduce 'business-as-usual' carbon emissions might be eligible for carbon credits. Yet water remains an under-recognized part of this equation. Farming practices that sequester more carbon usually do so by restoring soil functions and land cover, both of which require the conservation of soil water. The linkages between carbon, water and sustainable farming are therefore usually significant and mutually inclusive. A global market incentive for low-carbon farming, therefore, involves a significant water dimension. These examples serve to highlight the global and multi-disciplinary, interfaces of water governance in relation to climate change objectives.

A policy brief issued by UN-Water makes the case for water's role in adaptation to climate change (Box 1.2).

1.2.2 Transboundary basins

Water is not confined within political borders. An estimated 148 states have international basins within their territory (OSU, n.d., 2008 data), and 21 countries lie entirely within them (OSU, n.d., 2002 data). In addition, about 2 billion people worldwide depend on groundwater supplies, which include to date 273 transboundary aquifer systems (ISARM, 2009; Puri and Aureli, 2009).

There are numerous examples where transboundary waters have proved to be a source of cooperation rather than conflict. The Food and Agriculture Organization of the United Nations (FAO) has identified more than 3,600 treaties relating to international water resources (FAO, 1984). The earliest recorded water-related international treaty is usually considered to be the one which concluded the first and only water war (between Umma and Lagash city states). Nearly 450 agreements on international waters were signed between 1820 and 2007 (OSU, n.d., 2007 data).

There are numerous examples of existing bilateral and regional water agreements, including the Great Lakes Water Quality Agreement (1978), the Convention on Co-operation for the Protection and Sustainable Use of the River Danube (1994) and the Agreement on the

Cooperation for the Sustainable Development of the Mekong River Basin (1995). The Indus Water Treaty, signed between Pakistan and India in 1960, has survived three major conflicts and remains intact today. Benefit sharing, as opposed to the sharing of water resources, represents a key positive aspect in transboundary cooperation, as exemplified by the Nile Basin Initiative's Socio-economic and Benefits Sharing Project (2010) that builds a 'network of professionals from economic planning and research institutions, technical experts from both the public and private sectors, academics, sociologists, and representatives from civic groups and NGOs from across the basin to explore alternative Nile development scenarios and benefit-sharing schemes'.[4] However, multiple and increasing drivers of water use and the uncertainties associated with them are likely to put existing transboundary agreements under significant strain. The increasing demand for water for agriculture, industry, energy and urbanization is likely to put pressure on transboundary relations as states may seek to make more river diversions, store more water and further exploit aquifers. The need to meet a 60% increase in demand for energy over the next three decades, combined with the imperative to invest in clean energy to mitigate climate change, is already making hydropower and biofuels critical parts of the development equation (Steer, 2010). Only 5% of total hydropower potential has been exploited in Africa (IEA, 2010*a*), where many hydropower sites are situated on transboundary rivers, thus providing significant opportunities for increased cooperation on benefit-sharing among neighbouring states.

The increasing pressures on transboundary waters require significant investment in political capital (Steer, 2010) so as to either renegotiate existing but inadequate transboundary arrangements where needed, or establish new ones that as yet do not exist. Despite the proliferation of agreements on transboundary water management, there remain numerous river basins and aquifers without adequate legal frameworks for cooperation. According to a recent study, 60% of the world's 276 international river basins lack any type of cooperative management framework (De Stefano et al., 2010).

The role of global guidelines and normative legal principles is critical in this regard. The UN Convention on the Law of the Non-navigational Uses of International Watercourses was adopted in 1997 after 27 years of development. The Convention establishes the rights and obligations between states relating to the management, use and protection of international watercourses, which includes groundwater. To date, only 24 nations have ratified the Convention and a further 11 are required for it to enter into force. The principles enshrined within the Convention, including those widely recognized as part of customary law, can still be used as helpful guidelines irrespective of ratification. Nevertheless, entry into force represents a vital step in the process of further clarifying and, where necessary, developing and adapting the rules of the game to emerging challenges, so that the Convention can effectively fulfil its roles of governing and guiding interstate relations. In Europe, the 1992 United Nations Economic Commission for Europe (UNECE) Convention on the Protection and Use of Trans-boundary Watercourses and International Lakes has been used as the basis for adoption of many bilateral and multilateral agreements. The Convention was amended in 2003 to allow accession to countries outside the UNECE region. The amendment is expected to enter into force in 2012, thereby making this successful framework available to all UN Member States. There is also emerging recognition of the governance dimensions of transboundary aquifers. The International Shared Aquifer Resources Management (ISARM) Programme is a UNESCO-led worldwide effort involving multiple UN agencies, which strive to draw attention to the issue.[5] The UN General Assembly reaffirmed in its sixty-sixth session on 9 December 2011 the importance of transboundary aquifers and the related Draft Articles. It adopted a resolution in which States are encouraged to make proper arrangements for transboundary aquifer management and UNESCO-IHP to continue its related scientific and technical support to the States. In addition, the General Assembly decided to put 'The Law of Transboundary Aquifers' on the provisional agenda of its sixty-eight session, in order to examine – among others – the final form to be given to the Draft Articles.

The unavoidable reality that water resources do not respect political boundaries demonstrates the supranational dimensions of water, and represents a compelling case for international cooperation on water management. Multiple and mounting pressures on water resources globally urge caution against complacency. A strong focus on resource protection, sustainability and benefit sharing between states through robust and fair basin, aquifer, estuarine and inshore arrangements and institutions, supported by a strong and solid system of international water law, will be critical in an impending era of global water resource constraints.

1.2.3 Global trade

Water is a truly global issue through its trade as ‘virtual water’ (also known as embedded water). This refers to the volume of water used in the production of a good or service. Through this process, countries engage in water trading through products rather than through the physical transportation of water itself, which is a difficult and costly exercise. As a result, billions of tonnes of food and other products that require water to produce are traded globally. Some water-scarce countries, including a number in the Middle East, have become net importers of virtual water, relying on the importation of agricultural commodities to meet the food needs of their growing populations. As per capita water scarcity grows, more and more countries may be increasingly incapable of feeding themselves with the amount of water they have available, and will thus have to make trade-offs in their economic, agriculture and trade policies. Other countries, including a number of European nations, are also net importers of virtual water due to the consumer tastes and demands of their populations for particular foodstuffs and products via imports (Hoekstra, 2011).

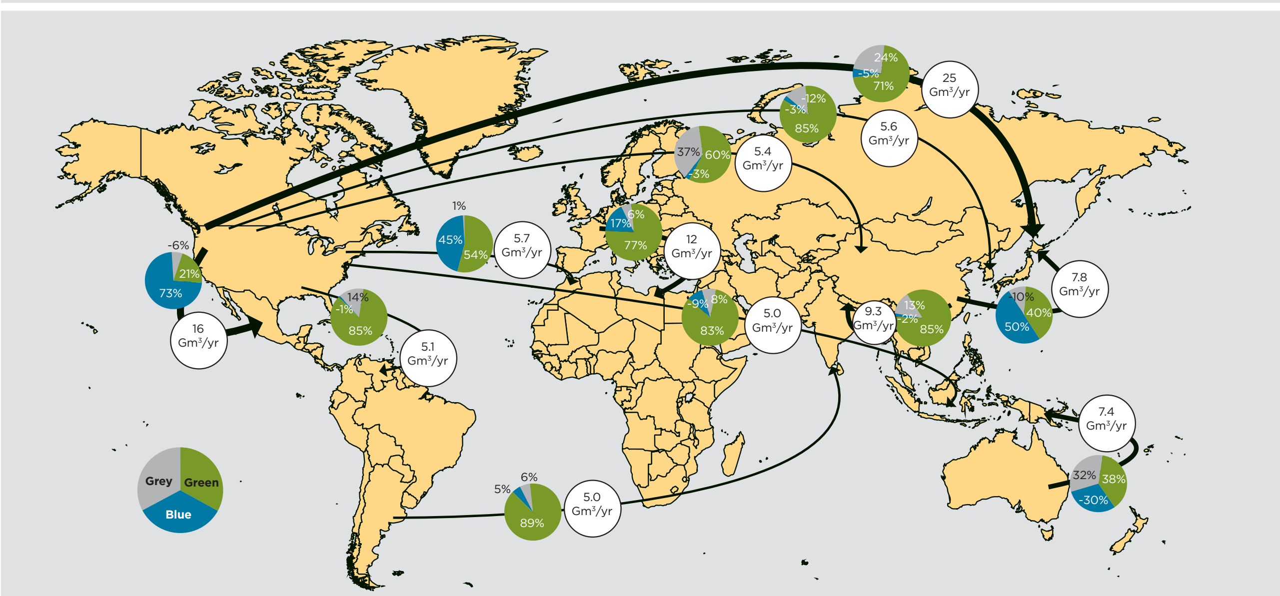
In many ways – at least at face value – virtual water trade is a process that represents a sensible and win–win realignment of the water needs of countries and their environmental and economic circumstances. Analyses show that, indeed, the trading of virtual water has in many cases led to certain efficiency savings. Figure 1.1 shows trade flows that save more than 5 Gm^3 per year. Export of agricultural products (mainly maize and soybean products) from the United States of America (USA) to Japan and Mexico represent the largest global water savings, accounting for over 11% of the total global water saving (Hoekstra and Mekonnen, 2011).

Although global water trade can lead to significant *national* water savings, through virtually transporting water from a place of relative abundance to a place of relative scarcity, trade alone cannot guarantee sustainable water management at the source. Indeed, as virtual water-exporting nations increasingly respond to global demand, the dimensions of responsibility for sustainable water management are subsequently elevated to a more complex and supranational relationship between consumer and producer.

One of the challenges to enhancing water efficiency and productivity is that there are no immediate, direct

FIGURE 1.1

Global water savings associated with international trade in agricultural products (1996–2005)



Note: Only the biggest water savings (> 5 Gm^3 per year) are shown.
Source: Mekonnen and Hoekstra (2011, p. 24).

“As is the case with most globalization processes, virtual water trade can lead to a further marginalization of the world’s poorest women and men.”

incentives to actually do this. The incentives that are available are in turn influenced by global trade imperatives which are clearly beyond regulatory reach of water managers. If water-intensive products were traded only within the nation state then market-based policies to incentivise sustainable water management practices could potentially be instituted relatively easily, including perhaps a ‘water scarcity rent’ or through an ‘internalization of externalities’; for example, incorporating into the cost of a product its negative impact on freshwater ecosystems and thereby incentivizing the producer to reduce or eliminate their environmental impact. But in a globalized economy it is a challenge to institute such policies on a national or a regional level as they may artificially increase costs of products from that area and make them uncompetitive.

The virtual water trade can provide opportunities for developing countries blessed with a relative abundance of renewable freshwater supplies to grow their economies by exporting increasing amounts of food, if they can afford the infrastructure to harness the water and there are no artificial barriers in international trade. Unfortunately, many countries still require some kind of financial support in order to develop this infrastructure and remain competitive within the global markets. Another troubling issue concerns developing countries that are water-scarce and whose people are too poor to buy imported food. As is the case with most globalization processes, virtual water trade can lead to a further marginalization of the world’s poorest women and men.

The growing trend towards large land acquisitions,[6] which in some cases can lead to significant advances in infrastructure development, also raises some concerns about equitable distribution of benefits to the host country and its people. Although water shortages are an important driver of large-scale land acquisitions by investors, water is typically not explicitly mentioned in disclosed land deals. In the few cases where water is referred to, the amount of water withdrawals to be permitted is not specified. The rural poor end up competing for scarcer water with actors that are more powerful and technically better equipped to take control of the water. Potential inter-state tensions and conflicts, especially in transboundary basins, are also a cause for concern.

A subject relevant to the governance of water resources and public services is the effect that international investment agreements may have on national capacities to manage water resources and to regulate public services (see Solanes and Jouravlev, 2007; Bohoslavsky, 2010; Bohoslavsky and Justo, 2011). As a consequence of globalization, many public services are provided and water rights held by companies within foreign investment protection systems or special conflict resolution regimes, which means that external jurisdictions can intervene in local matters. Agreements which over-ride national laws can restrict the power of governments to act in the best public interest and in that of local communities. Many countries have yet to assess the consequences that international investment agreements may have on the economic, social and environmental sustainability and efficiency of water resources utilization and provision of public services.

1.2.4 Equity

Discussions relating to pricing mechanisms and other incentives are predominantly motivated by the objective to enhance efficiency and encourage sustainable water usage at the source of production. Increased efficiency and productivity at a local and national level will be critical in meeting growing global aggregate demands, given mounting pressures on and demand for water resources globally (predominantly through food and agricultural products). Yet it will be important for enhancements in water efficiency and productivity to be accompanied by concomitant efforts to reduce demand. If society operates within ecological limits, and recognizes the limited availability of water resources globally at any one time, it will be unviable for all citizens globally to consume the same amount of water as the highest consuming individuals (and countries) do today. Therefore, efforts to tackle excessive demand in the developed world need to comprise part of a more equitable distribution of the benefits of water globally if increases in demand within emerging economies and developing countries are to be even partially satisfied without heavily depleting aquifers or irreversibly damaging freshwater ecosystems. Although the physical distribution of water across the earth, through the hydrological cycle, is by its nature uneven (see Section 3.1 and Chapter 15), the way in which the goods, products and benefits derived from that water are distributed can be influenced by policy interventions – including global governance frameworks and national water governance arrangements.

In addition to addressing inequities in global demand and consumption, it is also critical to address inequities at the local and national level in terms of the impacts of and benefits derived from the global trade in water resources. Many national or regional water resource management and allocation mechanisms are currently insufficient to sustainably protect resources and equitably distribute any water-derived benefits. The production and export of water-'thirsty' products, such as rice or cotton, in arid areas where water is already under pressure to meet local needs, can exacerbate local and national challenges – including food security. Furthermore, the benefits derived from such production and export are often not experienced by local communities (e.g. through either health care or infrastructure). The virtual water concept has been a useful tool in highlighting the global transport of water through trade; however, new tools will need to be devised to enable the development of sustainable governance mechanisms and policies that rebalance pressures on water resources and seek to equitably distribute any benefits derived from reducing local availability of this precious resource. In this regard, the fact that inequity discriminates against women and children, who make up the largest proportion of the bottom billion, must also be taken into account.

One tool that presents an opportunity to uphold the importance of the equitable distribution of water and its benefits on a national level is the consensus adoption by the United Nations Human Rights Council (HRC) in September 2010 of a resolution affirming that access to water and sanitation is a human right. Building on the July 2010 Resolution[7] by the United Nations General Assembly, recognizing access to safe water and sanitation as a human right, the HRC resolution states that 'the human right to safe drinking water and sanitation is derived from the right to an adequate standard of living and inextricably related to the right to the highest attainable standard of physical and mental health, as well as the right to life and human dignity.'[8] This bestows upon states a certain obligation to promote governance arrangements that secure drinking water supply and sanitation services, and it also provides a basis for further potential discussion and debate on and equitable distribution of social and economic benefits derived from water through agriculture, energy, health and other productive activities. However, these resolutions fail to provide guidance on how progress can be accurately monitored, or how to provide for capital costs – as well as operation and maintenance costs – of the infrastructure (new as well as expanded) required to operationalize them while maintaining affordable prices for the poor.

1.3 Recognizing water in global policy

Recognition of the centrality of water to socio-economic development comes at an opportune time. There are three processes underway to establish global policies that will benefit from this: the MDGs, the UNFCCC and the UNCSD (also referred to commonly as Rio+20).

These three particular processes have been highlighted because of their significant profile and the impact they have at an international level, and because together they cover a number of dimensions relating to global water governance: human health and development, environment and climate change, and broader sustainable development objectives. Importantly, all three processes operate under the auspices of the United Nations, which makes them particularly relevant to this publication. It should be noted, however, that other international forums such as the G8/G20, the World Economic Forum and the World Water Forum can also play an influential role in the recognition of water's central role in socio-economic development, as exemplified by the G8 Water Action Plan (Evian, 2003).

Although these processes can have a significant influence on national policy, their agendas and negotiations are in fact *driven* by the member states. It is therefore up to the different member states themselves to take leadership and ensure that water is put on the agenda of these processes.

1.3.1 Millennium Development Goals

It was appropriate at the turn of the millennium to shine a light on the alarming persistence of poverty in many parts of the world, and on the shameful inequality globally in people's access to basic services. The MDGs helped to emphasize the existence of a right to development, and that the international community has a responsibility to alleviate global suffering. Although many of the MDGs are unfortunately off track, there is no doubt that the framework of clear time-bound goals and targets has been a valuable tool in enabling civil society and the general public to hold governments to account, and that the existence of a relatively short-term 'end-date' has helped to accelerate action in a number of areas.

Yet the MDGs also have their limitations, not least in their failure to recognize the cross-cutting nature of water in relation to all MDGs. For example, it is well-established that improving access to water improves education outcomes (Goal 2) and gender equality and empowerment of women (Goal 3). Water is required to grow food (Goal 1) and improve all aspects of economies to eradicate poverty (Goal 1). These are just a few examples of the positive and cross-sectoral interactions between water and other diverse development imperatives outlined in the MDGs. Energy is another essential, cross-cutting – and water dependent – element of socio-economic development that was overlooked in the MDGs.

One of the targets of the seventh MDG (MDG7), the overall objective of which is to ensure environmental sustainability, is to halve, by 2015, the proportion of the world's population without access to safe drinking water and basic sanitation (Target 7c). However, as currently formulated, it fails to consider essential aspects of service provision, such as their quality, mode of provision or access, and affordability. The world is on track to meet the 'access to safe drinking water' target, although progress varies across regions and sub-Saharan Africa and the Arab Region lag behind. By contrast, the sanitation target (which is not necessarily linked to water, although hygiene is) currently appears out of reach, as half the population of developing regions continue to lack access to basic sanitation.[9]

In light of both progress and continued challenges, it is important that efforts are maintained and intensified to achieve MDG7c by 2015. This poses a real challenge for the international community, especially as the characteristics and criteria related to the requirements to comply with the right to water and sanitation, as recognized by the Human Rights Council, may render the criteria used to set the MDGs obsolete. To date, this community has had no better way to measure and monitor progress than to use the criteria of the MDGs as monitored by WHO/UNICEF's Joint Monitoring Program (JMP) and WHO/UN-Water's Global Analysis and Assessment of Sanitation and Drinking-Water

"It was appropriate at the turn of the millennium to shine a light on the alarming persistence of poverty in many parts of the world, and on the shameful inequality globally in people's access to basic services. The MDGs helped to emphasize the existence of a right to development, and that the international community has a responsibility to alleviate global suffering."

(GLAAS), which are based on the concepts of access to *improved* sanitation facilities and drinking water sources. However, new approaches to monitoring these goals are being produced to monitor the goals as now described.

Another limitation of the MDGs is that they neglect the 'centrality of water' to the other goals. While delivery of drinking water and sanitation services should remain a focus of human health and development, the importance of water resources and water governance in achieving the goals collectively needs explicit recognition. It is critical that the drinking water and sanitation issues do not divert attention from the need for efforts to enhance institutional arrangements for water, with water allocation frameworks that prioritize water for these and other basic human needs above all other uses, and which encourage efficiency and productivity in resource use and management. For example, subsidies for irrigation might well be employed to achieve MDG1 to eradicate poverty and hunger, but such policies often discourage efficient water usage and therefore lead to unnecessary levels of extraction, which may ultimately compromise the water source, and in turn the sustainability of both MDG7 and indeed a number of other water-dependent MDGs.

These observations are relevant to water on a number of levels, and the messages from this chapter do have relevance for the way that the MDGs are addressed beyond 2015. First, freshwater is a finite precious natural resource that is essential to all aspects of development. Second, water not only creates connections between the goals, but is also a potential source of conflict between them. In moving beyond 2015, it will be critical to word each of the new goals in such a way as to recognize the role(s) that water plays in achieving them.

1.3.2 The UN Framework Convention on Climate Change

In June 2008, the IPCC Working Group II released a technical paper on water and climate change, which stated that 'the relationship between climate change and freshwater resources is of primary concern to human society and also has implications for all living species' (Bates et al., 2008, p. vii).

Water resources are referred to in Article 4 of the Convention, while at the UNFCCC's 15th Conference of the Parties (COP15) in Copenhagen in 2009, the importance of water resources management for climate change adaptation was referred to in a footnote of the outcome document. Under the UNFCCC, Parties have provided information on freshwater-related impacts and vulnerabilities in their national communications[10] and national adaptation programmes of action (or NAPAs),[11] in which they also spell out adaptation and development priorities.

The newly created institutions in the Cancun Agreements, particularly the Cancun Adaptation Framework and the Adaptation Committee, will provide new and increased opportunities to address the issues around water. At the 16th session of the Conference of the Parties (COP16) in Cancun, 2010, Parties agreed to establish the Cancun Adaptation Framework,[12] with the objective of enhancing action on adaptation, including through international cooperation and coherent consideration of matters relating to adaptation under the Convention. The Cancun Agreement makes specific reference to water resources, freshwater, marine ecosystems and coastal zones when it refers to 'Planning, prioritizing and implementing adaptation actions, including projects and programmes'.[13]

As part of the Cancun Adaptation Framework, developing countries will have the opportunity to address water issues in their National Adaptation Plan, which will provide the opportunity to identify targeted actions. In addition, water and related extreme events like droughts and floods will be considered in the agreed activities under the loss and damage work programme.[14] It is urgent for the member states (i.e. 'Parties') to ensure that water be addressed as a key issue on the agenda for upcoming negotiations.

In a unique move water was tabled for discussion on provisional agenda for the Subsidiary Body for Scientific and Technological Advice (SBSTA) at its 34th session in June 2011, which requested the Secretariat prepare, before its 35th session, a technical paper on water and climate change impacts and adaptation strategies. It was eventually agreed that water would be addressed under the auspices of the Nairobi Work Programme on impacts, vulnerability and adaptation to climate change (the NWP), the work programme with an objective to assist all Parties, in particular developing countries, including the least developed countries (LDCs) and small island developing states (SIDS), to improve their understanding and assessment of impacts, vulnerability and adaptation to climate change, and to make informed decisions on practical adaptation actions and measures to respond to climate change on a sound scientific, technical and socio-economic basis, taking into account current and future climate change and variability. Although not developed to exclusively target specific vulnerable sectors, knowledge products, such as the adaptation practices interface[15] and the local coping strategies database,[16] provide information on adaptation planning and practices on vulnerable sectors at various levels of implementation.

Several partner organizations have pledged actions to undertake research and assessment; enhance technical and institutional capacities; promote awareness; and implement adaptive actions on the ground. These actions have contributed to the enhancement of understanding and assessment of vulnerabilities and adaptation practices related to water resources management. Relevant documents prepared under the NWP to date on water include a synthesis publication on climate change and freshwater resources UNFCCC, 2011) and a technical paper on water and climate change impacts and adaptation strategies.[17]

The mandate for the NWP represents an important building block in mainstreaming and integrating water more effectively in the decision-making of the Convention. Limiting a discussion on water under the UNFCCC to a programme on adaptation means that the cross-cutting and multifaceted nature of the resource will be hard to fully capture unless a congregate of Parties steps forward and assumes a leadership position in recognizing the need to address the multiple and cross-cutting elements of water more comprehensively.

It will also be important to address water in relation to other emerging and important entities of the Convention, including the Adaptation Committee and the Green Climate Fund (GCF). One of the functions of the Adaptation Committee is to provide technical support and guidance to the Parties. Such technical support and guidance should arguably include the provision of expertise in relation to water and adaptation.

The UNFCCC remains to this day one of the most significant global conventions addressing sustainable development. Despite the multitude of valuable multilateral environmental agreements (MEAs), the UNFCCC has captured the imagination and buy-in of international policy-makers and the general public alike more than any other process on environment or sustainable development in the past decade. In this context, ensuring a strong focus on water under the UNFCCC is likely to remain a high priority for the water community.

1.3.3 Beyond the UN Conference on Sustainable Development

The UNCSD 2012, or Rio+20, will take place in Rio de Janeiro 20 years after the first Rio Earth Summit in 1992. The Rio Summit succeeded in putting sustainable water management on the global agenda with Chapter 18 of Agenda 21 (the outcome document from the Summit) dedicated to the 'protection of the quality and supply of freshwater resources'. This chapter represented a significant milestone in the promotion of integrated approaches to water management; that is, managing water across its multiple users.[18] The World Summit on Sustainable Development (WSSD) in 2002 agreed on a specific target for integrated water resources management (IWRM), a concept that by then had become an established part of global water discourse. The target (Article 26) included a call, at all levels, 'to develop IWRM and water efficiency plans by 2005 with support to developing countries'. IWRM is a holistic water management framework that recognizes the multiple users of water – including ecosystems – and so the WSSD's call to plan for it represented a significant step in the right direction. Although its existence has led to a number of national-level initiatives and monitoring processes, progress is far short of the ambitions of the 2005 target and the principle it was trying to push forward. In countries where national plans have been developed, many are not being implemented. Moreover, these plans were meant to be adaptive – in other words, to be part of an ongoing process and thus adaptable to changing conditions and new uncertainties.

In 2006, a task force on water resources management was established under UN-Water, which in its review for the 13th session of the Commission on Sustainable Development in 2008 found that only 6 out of 27 developed countries surveyed had fully implemented IWRM plans, and that only 38% of the developing countries surveyed had plans completed or under implementation. At the request of the UN Commission on Sustainable Development, UN-Water conducted a similar global survey in 2011 to determine progress towards sustainable management of water resources using integrated approaches for the Rio+20 conference. Preliminary findings from the analysis of data from over 125 countries show that there has been widespread adoption of integrated approaches with significant impact on development and water management practices at the country level. The survey showed that 64% of countries have developed IWRM plans, as called for in the Johannesburg Plan of Implementation (JPoI), and 34% report an advanced stage of implementation. However, progress appears to have slowed in low and medium Human Development Index (HDI) countries since the survey in 2008.

Though debate and dialogue on the appropriateness of these and other such specific targets will continue beyond the Rio+20 Summit in June 2012, the consistent messages emerging on water will help to focus and mobilize the water community and hopefully other stakeholders and ensure that water emerges as a priority issue in the global discourse on sustainable development. However, defining and monitoring targets is a difficult exercise, especially given water's centrality, its cross-cutting nature and its wide range of roles and benefits. It may be appropriate for the water community to work with member states, NGOs, various UN agencies and other stakeholders to provide a set of principles recognizing water's central role in achieving various developmental goals. Furthermore, without institutional arrangements for the equitable optimization of water's many benefits in the face of increasing uncertainty, funding for water infrastructure (including operation and maintenance), improved capacity to manage water resources in an integrated and adaptive fashion, most development goals and the 'green economy' itself will continue to be significantly compromised.

UN-Water, following consultations with its members and partners, produced a statement, reflecting the collective opinion of its members on the green economy, as input into the Rio+20 Summit. The statement comprises UN-Water's recommendation to the participants of the Summit as well as a list of potential actions in support of green economic approaches. The main messages of the statement are in Box 1.3.

BOX 1.3

UN-Water's recommendation to UNCSD and potential actions in support of green economic approaches

1. Success of green economy depends on sustainable management of water resources and on safe and sustainable provisioning of water supply and adequate sanitation services. This approach must be underpinned by timely measurement of economic performance in terms of indicators of social and environmental sustainability.
2. The integrated approach to water resources management, as defined in Agenda 21, remains relevant and must be central in strategies towards a green economy.
3. The highest priority must be given to the 'bottom billion' people while addressing inequities in access to water, which are closely linked to energy security as well as food security.
4. Effective management of water variability, ecosystem changes and the resulting impacts on livelihoods in a changing climate scenario are central to a climate-resilient and robust green economy.
5. Universal coverage of water supply and sanitation services must be a central development goal in the post-2015 period. UN-Water urges national governments to set realistic intermediate targets and goals.
6. There must also be a commitment to build the foundation for a water resource efficient green economy.
7. There is a need for increased water resilience and sustainability of cities, keeping in view the global challenges and urbanization trends.
8. Water challenges are a global concern and international action and cooperation at all level are required to accommodate them within the green economy.
9. Green economies can only be achieved if they are supported by green societies.

Source: Water in a Green Economy: A Statement by UN-Water for the UN Conference on Sustainable Development (UNCSD) 2012 (Rio+20 Summit), November 2011.

Conclusion

This chapter has sought to explore the cross-sectoral and global dimensions of water – looking beyond the boundaries of traditional water governance. The mounting demand for water from a diverse range of social and economic sectors, and the potentially irreversible ecosystem impacts of unregulated demand, require strong water governance institutions that facilitate discussion and decisions on the targets of society and the allocation of water resources across sectors to meet them. Equally, water governance frameworks at local, national and regional levels must be complemented by global governance processes, frameworks and institutions that can appropriately address the global dimensions of the benefits of water resources beyond the basin. Water has long ceased to be solely a local issue. Not only do many river basins and aquifers transcend national boundaries, water has also been globalized through international trade in water-dependent products and international investment protection agreements, as well as through climate change impacts on the hydrological cycle, which stand to have potentially devastating affects in certain locations. In a world of increasing uncertainty regarding the demand for finite water resources, global water use will also have to be considered through the lens of equity. Efficiency and productivity gains alone cannot alter global patterns of unequal supply of resources and consumption or access to benefits. Addressing these cross-sectoral and global dimensions of water will require that all countries take an interest in the global forums designed to address and create solutions to impending resource challenges. The water community, and water managers in particular, have the responsibility of informing the process. Implementing the outcomes from global policy agreements will remain a national imperative, but setting the framework requires a widening of the sectoral and spatial horizons of all those who have a stake in water management. Global policy agreements made with local and national processes and reflecting the political economy and institutional capacities of the countries will assure the overall effectiveness of these policies at national and subnational levels.

Notes

1 At the time of preparing the final draft of the WWDR4, the specific post-UNCSD 2012 process was undetermined.

2 The concept of environmental flows recognizes that ecosystems, too, are water users, and that to function properly and provide the necessary services they must benefit from water allocation of sufficient quantity and quality (see eFlowNet, n.d.).

3 For information on the Green Climate Fund see http://unfccc.int/5869.php

4 For more information see http://www.nilebasin.org/newsite/

5 The ISARM2010 International Conference 'Transboundary Aquifers: Challenges and new directions', which took place in Paris, 6–8 December 2010. See http://www.isarm.net/publications/360

6 For the purposes of the WWDR4, 'land acquisition' is defined as the gaining of tenure rights to large areas of land through purchase, lease, concession or other means.

7 Resolution 64/292, 28 July 2010.

8 Human Rights Council, Promotion and protection of all human rights, civil political, economic, social and cultural rights including the right to development, p. 15. Human Rights and Access to Water and Sanitation, 24 September 2010.

9 For further analysis of progress see UN (2010, pp. 58–60).

10 For more information see http://unfccc.int/ 1095.php and http://unfccc.int/2716.php

11 For more information see http://unfccc.int/cooperation_support/least_developed_countries_portal/items/4751.php

12 FCCC/CP/2010/7/Add.1.

13 From page 5 of the report of the Conference of the Parties on its sixteenth session, held in Cancun from 29 November to 10 December 2010, available at http://unfccc.int/resource/docs/2010/cop16/eng/07a01.pdf

14 For more information see http://unfccc.int/ 6056.php

15 The adaptation practices interface is available at http://unfccc.int/4555.php

16 The local coping strategies database is available at http://maindb.unfccc.int/public/adaptation.

17 See http://unfccc.int/documentation/documents/advanced_search/items/3594.php?rec=j&priref=600006592#beg

18 The United Nations Conference on Environment and Development, Agenda 21, UN, 1992.

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PART 1

Status, trends and challenges

CHAPTER 2

Water demand: What drives consumption?

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Human demands for water are usually broken down into five major water use sectors:

- Food and agriculture, which accounts for the majority of water withdrawals globally;
- Energy, for which the quantities of water used (consumptively and non-consumptively) are rarely reported and thus are poorly known;
- Industry, which covers an exceptionally broad range of income-generating activities with equally broad impacts on both the quantity and the quality of local water resources and the environment;
- Human settlements, which includes water for drinking and household uses such as cooking, cleaning, hygiene and some aspects of sanitation;[1] and
- Ecosystems, whose water demands are determined by the water requirements to sustain or restore the benefits for people (services) that societies want ecosystems to supply.

Water managers and decision-makers concerned with meeting humans' basic water-related needs are faced with some important questions: How much water are we using now? How efficiently are we using it? How much will we need 30 years from now? Fifty years? Although these questions appear simple, getting the answers right is not as straightforward as it might seem.

Each of the water use sectors is driven by a number of external forces (such as demographic changes, technological developments, economic growth and prosperity, changing diets, and social and cultural values) which in turn dictate their current and future demands for water. Unfortunately, predicting how these drivers will evolve over the next few decades – and how they will ultimately affect water demand – is fraught with a multiplicity of uncertainties. Future water demands will depend not only on the amount of food, energy, industrial activity, and rural and urban water-related services we will need to meet the requirements of growing populations and changing socio-economic landscapes, but also on how efficiently we can use limited water supplies in meeting these needs.

This chapter draws principally from the Part 3/Volume 2 challenge area reports 'Managing water along the livestock value chain' (Chapter 18), 'The global nexus of energy and water' (Chapter 19), 'Freshwater for industry' (Chapter 20), 'Human settlements' (Chapter 17) and 'Ecosystems' (Chapter 21) to highlight the current challenges and trends specific to each sector, the main drivers and their related uncertainties and risks, and potential response options. With the exception of Section 2.1 (Food and Agriculture) for which all content has been extracted from the respective challenge area report. Sections of this chapter also include complementary material that is not part of the final Part 3 chapters, which were subject to strict length limitations.

2.1 Food and agriculture

The link between water and food is a simple one. Crops and livestock need water to grow, and lots of it. Agriculture accounts for 70% of all water withdrawn by the agricultural, municipal and industrial (including energy) sectors.

Water is the key to food security. Globally, there is enough water available for our future needs, but this world picture hides large areas of absolute water scarcity which affects billions of people, many of whom are poor and disadvantaged. Major changes in policy and management, across the entire agricultural production chain, are needed to ensure best use of available water resources in meeting growing demands for food and other agricultural products.

2.1.1 Water use in agriculture

The agricultural sector as a whole has a large water footprint when compared to other sectors, particularly during the production phase. The booming demand for livestock products in particular is increasing the demand for water, not just during production, but also at every stage along the livestock value chains. It is also affecting water quality, which in turn reduces availability.

The annual global agricultural water consumption includes crop water consumption for food, fibre and feed production (transpiration), plus evaporation losses from the soil and from open water associated with agriculture, such as rice fields, irrigation canals and reservoirs. Only about 20% of the total 7,130 km^3 of agriculture's annual water consumption is 'blue water' – that is, water from rivers, streams, lakes and groundwater for irrigation purposes. Although irrigation is only a modest part of agricultural water consumption, it plays a crucial role, accounting for more than 40% of the world's production on less than 20% of the cultivated land.

Concerns about food insecurity are growing across the globe, but people generally have little or no appreciation of the dependency of food production on water. There is little recognition that 70% of the world's freshwater withdrawals are already committed to irrigated agriculture (Figure 2.1) and that more water will be needed in order to meet increasing demands for food and energy (biofuels). Relatively speaking, withdrawals for agriculture tend to decrease with increasing levels of development.

However, in many countries, not just in the least developed countries (LDCs), water availability for agriculture is already limited and uncertain, and this is set to worsen. Agricultural water withdrawal accounts for 44% of total water withdrawal in OECD countries, but this rises to more than 60% within the eight OECD countries that rely heavily on irrigated agriculture. In the BRIC countries (Brazil, Russian Federation, India and China),[2] agriculture accounts for 74% of water withdrawals, but this ranges from a low 20% in the Russian Federation to 87% in India. In LDCs the figure is more than 90% (FAO, 2011*c*).

Globally, irrigated crop yields are about 2.7 times those of rainfed farming, hence irrigation will continue to play an important role in food production. The area equipped for irrigation increased from 170 million ha in 1970 to 304 million ha in 2008. There is still potential for expansion, particularly in sub-Saharan Africa and Southern America, in places where there is sufficient water available. Pathways to improve productivity and bridge the yield gap in irrigation include increasing the quantity, reliability and timing of water services; increasing the beneficial use of water withdrawn for irrigation; and increasing agronomic or economic productivity so that more output is obtained per unit of water consumed (FAO, 2011*a*).

Although there is still potential to increase the cropped area, some 5–7 million ha (0.6%) of farmland are lost annually because of accelerating land degradation (see Section 4.5 and Chapter 28), and urbanization (see Section 2.4 and Chapter 17), which takes agricultural land out of production and reduces the number of farms as more people move to the cities. Increasing population means that the amount of cultivated land per person is also declining sharply: from 0.4 ha in 1961 to 0.2 ha in 2005.

2.1.2 Expected growth in demand

The world population is predicted to grow from 6.9 billion in 2010 to 8.3 billion in 2030 and 9.1 billion in 2050 (UNDESA, 2009). By 2030, food demand is predicted to increase by 50% (70% by 2050) (Bruinsma, 2009), while energy demand from hydropower and other renewable energy resources will rise by 60% (WWAP, 2009) (see Section 2.2 and Chapter 19). These issues are interconnected – increasing agricultural output, for example, will substantially increase both water and energy consumption, leading to increased competition for water between the different water-using sectors.

Predicting future water demand for agriculture is fraught with uncertainty. It is partially influenced by demand for food, which in turn depends partly on the number of people needing to be fed, and partly on what and how much they eat. This is complicated by, among other factors, uncertainties in seasonal climatic variations, efficiency of agriculture production processes, crop types and yields.

Although projections vary considerably, based on different scenario assumptions and methodologies, future global agricultural water consumption (including both rainfed and irrigated agriculture) is estimated to increase by about 19% to 8,515 km^3 per year in 2050 (Comprehensive Assessment of Water Management in Agriculture, 2007). The Food and Agriculture Organization of the United Nations (FAO) estimates an 11% increase in irrigation water consumption from 2008 to 2050. This is expected to increase by about 5% the present water withdrawal for irrigation of 2,740 km^3. Although this seems a modest increase, much of it will occur in regions already suffering from water scarcity (FAO, 2011*a*).

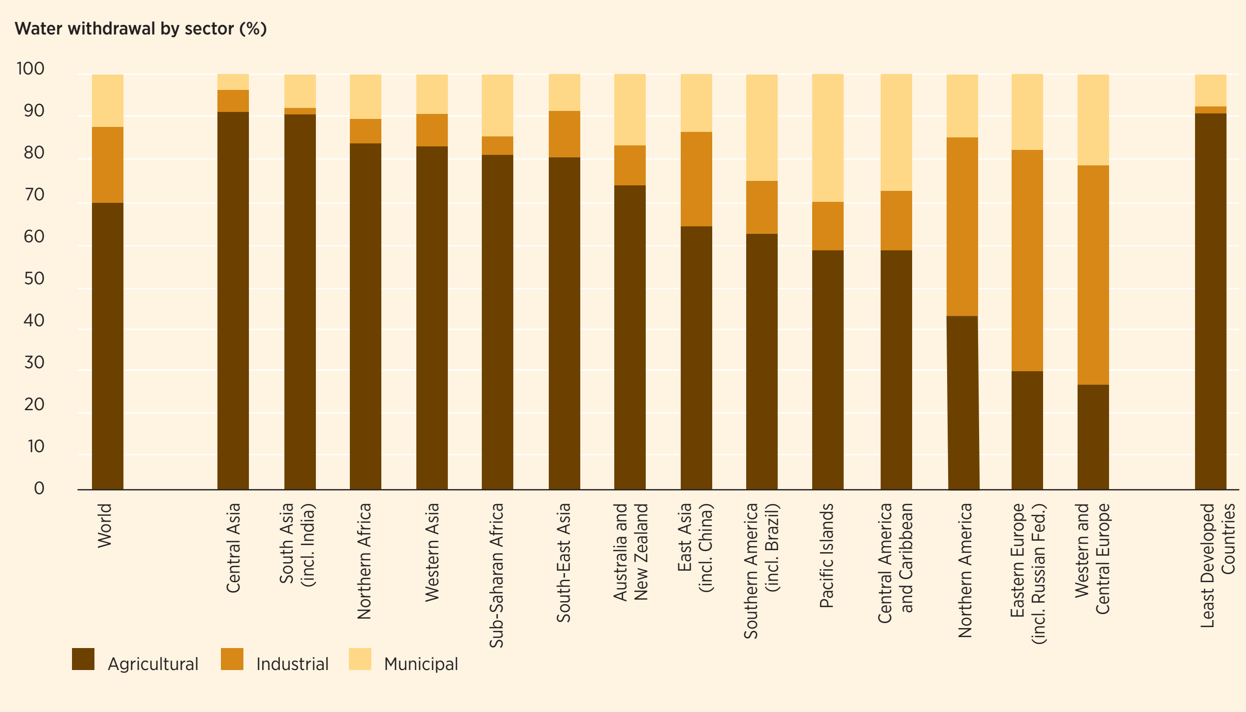
In essence, the main challenge facing the agricultural sector is not so much growing 70% more food in 40 years, but making 70% more food available on the plate. Reducing losses in storage and along the value chain may go a long way towards offsetting the need for more production.

2.1.3 Agriculture's impacts on water and ecosystems

The way that water is managed in agriculture has caused wide-scale changes in ecosystems and undermined the provision of a wide range of ecosystem services. Water management for agriculture has changed the physical and chemical characteristics of freshwater and coastal wetlands and the quality and quantity of water, as well as direct and indirect biological changes in terrestrial ecosystems. The external cost of the damage to people and ecosystems, and clean-up processes, from the agricultural sector is significant. In the United States of America (USA), for instance, the estimated cost is US$9–20 billion per year (cited in Galloway et al., 2007).

FIGURE 2.1

Water withdrawal by sector by region (2005)



Source: FAO AQUASTAT (http://www.fao.org/nr/water/aquastat/main/index.stm, accessed in 2011).

Land-use changes as a result of agriculture have produced a wide range of impacts on water quantity and quality (Scanlon et al., 2007). Wetlands in particular have been affected. Poor water quality originating from agricultural pollution is most severe in wetlands in Europe, Latin America and Asia (Figure 2.2). The status of species in freshwater and coastal wetlands has been deteriorating faster than those of other ecosystems (MA, 2005*a*).

Diffuse pollution from agricultural land continues to be of critical concern throughout many of the world's river basins (see Sections 3.3 and 4.3). Eutrophication from agricultural runoff ranks among the top pollution problems in Canada, the USA, and Asia and the Pacific. Australia, India, Pakistan and many parts of the arid Middle East face increasing salinization as a result of poor irrigation practices (MA, 2005).

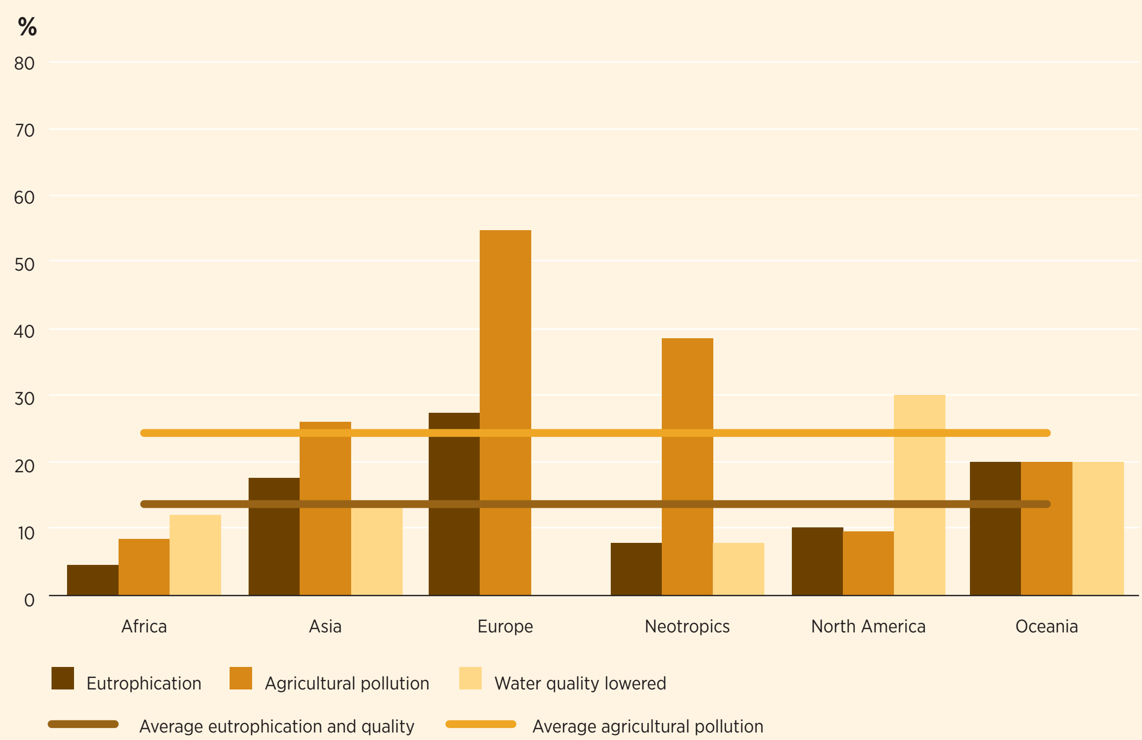
Nitrate is the most common chemical contaminant in the world's groundwater resources. According to available data in FAO AQUASTAT (2011*c*), the USA is currently the country consuming the largest amount of pesticides, followed by countries in Europe, especially those of Western Europe. In terms of use per unit area of cultivated area, Japan is the most intensive user of pesticides. Over-abstraction of renewable groundwater resources and abstraction of fossil groundwater reserves in arid North Africa and the Arabian Peninsula, driven primarily by the agricultural sector, are exerting irreconcilable pressures on water resources.

2.1.4 Pressures from population growth and changing diets

The growing population (9.1 billion by 2050, as per above) is increasing the pressures on land and water. At the same time, economic growth and individual wealth are shifting diets from predominantly starch-based to meat and dairy, which require more water. Producing 1 kg rice, for example, requires about 3,500 L water, 1 kg beef some 15,000 L, and a cup of coffee about 140 L (Hoekstra and Chapagain, 2008). This dietary shift is the greatest to impact on water consumption over the past 30 years, and is likely to continue well into the middle of the twenty-first century (FAO, 2006).

FIGURE 2.2

Wetlands water quality state changes by continent



Source: FAO (2008, p. 50).

Demand for livestock products is closely linked to economic growth

The world food economy is being increasingly driven by the shift in diets and food-consumption patterns towards livestock products (FAO, 2006). In 2008, 3,350 million ha were used as permanent meadows and for pasture – more than twice the area used for arable cropping and permanent crops. Livestock provides not just meat, but also dairy products, eggs, wool, hides and so on. The livestock sector is now changing at an unprecedented pace as demand for food derived from animals has boomed in the world's most rapidly growing economies (Steinfeld et al., 2006). Livestock already contributes 40% of the global value of agricultural output. It constitutes one of the most dynamic parts of the agricultural economy, driven by population growth, rising affluence and urbanization.

But the increasing demand for livestock products is being matched by concerns about its impacts on the environment. The expansion of land for livestock has led to deforestation in some countries (e.g. Brazil) and intensive livestock production (mainly in OECD countries) is already a major source of pollution. Livestock contributes less than 2% of global gross domestic product (GDP), yet produces some 18% of greenhouse gases (GHGs) (Steinfeld et al., 2006*b*). Hence critics argue that the dis-benefits from livestock far outweigh the benefits, but others argue that this seriously underestimates the economic and social importance of livestock, particularly in low-income countries. Regardless of the balance of these arguments, the increasing demand for livestock seems likely to continue (FAO, 2006). This means that resource-use efficiency in livestock production is now an urgent priority, and this includes the management of water.

Water pollution from livestock production and processing

During the production phase, livestock requires water for drinking, cooling and cleaning, but the amounts required differ according to the animal, the method of rearing and the location. Extensive livestock systems can increase water demand because of the additional effort required as animals search for feed. Intensive or industrialized systems, however, require additional service water for cooling and cleaning facilities. Globally, the annual drinking water requirement for livestock is about 16 km^3 and services require another 6.5 km^3 (Steinfeld et al., 2006).

The amount of water used to grow feed and fodder is much more significant in volume terms. This amount depends not just on the number and kinds of animals and amount of food they eat, but also where the food is grown. It is estimated that livestock consume about 2,000–3,000 km^3 of water annually – as much as 45% of the global water embedded in food products (Comprehensive Assessment of Water Management in Agriculture, 2007; Zimmer and Renault, n.d.) – although these estimates are quite imprecise. Rainfed grasslands and non-cultivated grazed fodder crops consume most of this water and this is generally thought to be of little environmental value. Indeed, if these lands were not used for grazing there would be very little water saving or potential for alternative use. Irrigation water volumes are much smaller, but play an important role in producing feed, fodder and grazing for livestock, and have a much greater opportunity cost than rainfed cropping.

During meat processing, the slaughterhouse is the second largest user of water in the meat-processing value chain (after the production phase), and a potentially significant point source of pollution to local ecosystems and communities. But the most serious aspect of food consumption is food wastage. This is particularly the case in industrialized countries where food is wasted because too much perishable food is produced and not sold, products deteriorate in storage, and food is bought and not consumed and hence thrown away. All this adds up to both a significant waste of food, and also a significant waste of the water used to produce it (Lundqvist, 2010).

2.1.5 Other pressures on water resources in the agriculture sector

Climate change

Agriculture contributes to climate change through its share of GHG emissions, which in turn affect the planet's water cycle, adding another layer of uncertainties and risks to food production. Climate change impacts are mainly experienced through the water regime, in the form of more severe and frequent droughts and floods, with anticipated effects on the availability of water resources through changes in rainfall distribution, soil moisture, glacier and ice/snow melt, and river and groundwater flows. These climate change-induced hydrological changes are likely to affect both the extent and productivity of irrigated and rainfed agriculture worldwide, hence adaptation strategies will focus on minimizing the overall production risk (FAO, 2011*b*).

> "Food security is threatened by the potential for waste as agricultural products move along extensive value chains and pass through many hands … from field to fork."

It is predicted that South Asia and Southern Africa are predicted will be the most vulnerable regions to climate change-related food shortages by 2030 (Lobell et al., 2008). Their populations are food-insecure because they are highly dependent on growing crops in ecosystems that display high vulnerability and consequences to climate change projections of temperature and precipitation changes.

Food, economy and the energy crisis

The food price crisis, followed shortly by the 2009 economic crisis, has had tragic consequences for world hunger. Food prices are significantly higher than they were in 2006. Although the factors which led to this increase in food prices were thought to be temporary – such as drought in wheat-producing regions, low food stocks and soaring oil barrel prices that drove up the price of fertilizers – food prices in 2010 had not yet returned to their pre-2006 levels. Poor women shoulder the brunt of economic crises and women with less education tend to increase their work participation more in times of crisis in almost every region of the world (FAO, 2009).

The demand for biofuels has also soared in recent years. Substantial amounts of maize in the USA, wheat and rapeseed in the European Union (EU), oil palm in parts of sub-Saharan Africa and South and South-East Asia, and sugar in Brazil, are being raised for ethanol and biodiesel production. In 2007, biofuel production was dominated by Brazil, the USA, and to a lesser extent, the EU. Biomass and waste represented 10% of the world's primary energy demand in 2005, more than nuclear (6%) and hydro (2%) combined (IEA, 2007).

If a projected bio-energy supply of 6,000–12,000 million tonnes of oil equivalent were to be reached in 2050,[3] this would require one-fifth of the world's agricultural land (IEA, 2006). Biofuels are also water intensive and can add to the strains on local hydrological systems and GHG emissions.

Land acquisitions and land-use changes

The relatively recent phenomenon of large-scale, international land acquisitions is leading to land-use changes, which in turn impacts water use. Since 2007–2008, sovereign funds and investment companies of some OECD and BRICS countries have bought or leased large tracts of farmland across Africa, Asia and Latin America in order to secure their fuel and food requirements. This was triggered in part by the fuel crisis and the demand for biofuels to replace petroleum-based products, as explained in greater detail in Chapter 7 (Box 7.14). The problem is that in most states where such contracts are being completed, water rights are often not codified in 'modern' law, but are based on local traditions, weak and outdated water legislation or non-existent in any formal legal terms (Mann and Smaller, 2010).

2.1.6 Waste in the food chain

When water is scarce it is no longer enough just to consider the amount of water needed to grow food (Lundqvist, Fraiture and Molden, 2008). The way water is used along the entire value chain must be examined, from production to consumption and beyond. This is particularly true for the more industrialized countries, and also to some extent in the towns and cities of BRICS countries, where food increasingly comes from many different sources, often over long distances, and in some cases from many different countries. Food security is threatened by the potential for waste as agricultural products move along extensive value chains and pass through many hands – farmers, transporters, store keepers, food processors, shopkeepers and consumers – as it travels from field to fork. Food can be wasted at every step along the value chain, which means that the water used to produce it is also wasted.

Water management has traditionally been the responsibility of governments, but major international food companies are beginning to realize the importance of water to their businesses, particularly where their value chains are situated in water-short countries. Although their concern may have more to do with customer perceptions and security of profits, using water with greater care can provide potential knock-on benefits for all. Initiatives to promote more efficient use of water along the value chain include, for example, the CEO Water Mandate and the Alliance for Water Stewardship.

2.1.7 'Water-smart' food production

The world is clearly entering a new era of water management characterized by increasing recognition of the links between water and other resources and the socio-economics of poor post-harvest management and food waste along the value chain.

The role of technology

In higher income countries, science and technology have long been major drivers of global prosperity. This will undoubtedly continue in the future. Food production will need to be much 'greener' and more sustainable to ensure that it does not add to the burden of climate change and ecosystem deterioration.

Innovative technologies will be needed that can improve crop yields and drought tolerance; produce smarter ways of using fertilizer and water; improve crop protection through new pesticides and non-chemical approaches; reduce post-harvest losses; and create more sustainable livestock and marine production. Industrialized countries are well placed to take advantage of these technologies, but also have the responsibility to ensure that LDCs have opportunities to access them on equitable or non-discriminatory terms.

Human capacities and institutions are assets

Agricultural development in LDCs lies mainly in the hands of smallholders, a large majority of whom are women. Water technologies appropriate to their needs will play a crucial role in meeting the food security challenge. However, in many LDCs women have only limited access to a wide range of physical assets and lack the skills to deploy them. Multiple water-use schemes can provide opportunities for women to extend their influence over water allocation and management.

Major changes in policy and management will be needed to make best possible use of available water resources. New institutional arrangements are needed that centralize the responsibility for water regulation, yet decentralize water management responsibility and increase user ownership and participation. New arrangements are required for safeguarding access to water for poor and disadvantaged groups, particularly women, and ensuring they have long-term land and water security.

A focus on the value chain

Improvements will be needed all along the agricultural value chains. Early gains include opportunities to reduce post-harvest crop losses in LDCs and food wastage in the higher income countries, hence saving the water embedded in them. In the medium term, innovations in climate-smart cropping are possible. In the longer term, energy-smart conversion of feed and fodder for livestock is also possible. Water recycling at all stages of the value chain can help secure environmental water requirements when reuse of treated water is not culturally acceptable for other uses.

Managing risk creatively

Reducing vulnerability to drought will require investment in both constructed and 'green' infrastructure to improve water measurement and control and, where appropriate, increase surface water and groundwater storage in constructed reservoirs and in natural storage both in wetlands and in the soil. Most benefit is expected to come from existing water management technologies through adaptation to new situations. 'Design for management', promoted in the 1980s to ensure infrastructure design took account of who would manage it and how it would be managed, remains highly relevant today and important for future water management.

Virtual water trade

Virtual water may play an increasing role as water-rich countries export water embedded in food to water-short countries that find it increasingly difficult to grow sufficient staple food crops. But the aqua-politics of exporting/importing food versus self-sufficiency will not be easy to resolve. Food-producing countries may not wish to export crops when food security is threatened; lower income and LDCs may need to continue over-exploiting water resources to feed their populations to avoid market-imposed high prices. Subsidies on food and other products can distort markets with possible negative implications on the use of the virtual water notion.

Implementing 'water smart' production

A twin-track approach is needed that makes best use of available water: demand-management options that

> "All forms of energy require water at some stage of their life cycle, which includes production, conversion, distribution and use."

increase productivity (more 'crop per drop') and supply management that makes more water available through water storage to cope with seasonality and increasingly unpredictable rainfall.

Major investment in agricultural water management will be needed and the present-day national priorities in some countries give cause for serious concern. In 2010, it was estimated that only US$10 billion was invested globally in irrigation systems, a surprisingly low figure given the importance of water for the agricultural sector (in comparison, the global market volume for bottled water in the same year was US$59 billion) (Wild et al., 2010). Surely it is time for the world to wake up to the fact that agriculture is a major, valid consumer of water, and that investment is essential for the future of food and water security. When water is scarce there is a global responsibility to use water wisely, efficiently and productively. Agriculture needs to be much more 'water-smart' and must be given the right signals and incentives to make this happen.

2.2 Energy

Energy and water are intricately connected. Although there exist different sources of energy and electricity, all require water for various production processes, including extraction of raw materials, cooling in thermal processes, cleaning materials, cultivation of crops for biofuels, and powering turbines. Conversely, energy is required to make water resources available for human use and consumption through pumping, transportation, treatment, desalination and irrigation. This double-sided interdependency of both resources has been coined the water-energy nexus, and introduces key cross-sectoral vulnerabilities.

The challenge of managing this nexus is increased by external drivers, whose impact can only be estimated but never wholly planned for. Climate change is a central external driver that affects both water and energy directly; mitigation measures are concentrated around the reduction of energy consumption and carbon emissions, while adaptation means planning for increasing hydrological variability and extreme weather events, including floods, droughts and storms. Further external pressures are created through demographic development, both from population increase and migration, as well as from increased economic activity and living standards, which will generate a surge of energy consumption, particularly in non-OECD countries. Lastly, policy choices by governments often exacerbate the strains by pursuing more water-intensive energy and more energy-intensive water.

2.2.1 Water for energy

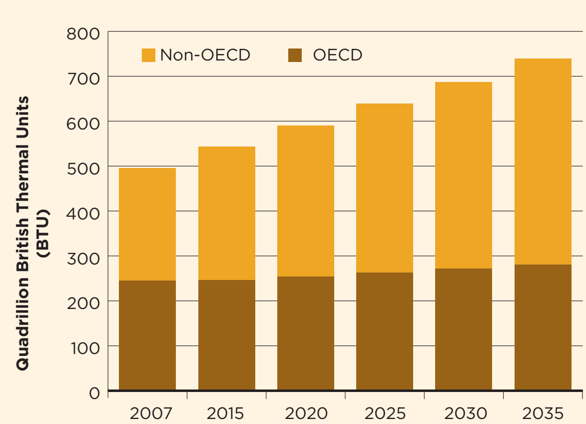
Trends and forecasts in the demand for different types of energy

EIA (2010) estimates that global energy consumption will increase by around 49% from 2007 to 2035 (Figure 2.3). This increase in energy consumption will be higher in non-OECD countries (84%) than in OECD countries (14%), with the primary driver being the expected growth in GDP and the associated increased economic activity.

Energy sources are often divided into primary and secondary energies. Primary energies are extracted, captured or cultivated, and include crude oil, natural

FIGURE 2.3

World marketed energy consumption, 2007–2035



Source: EIA (2010, p. 1).

gas, coal, biomass and geothermal heat. Secondary energies undergo a transformation process into petroleum products and electricity generated from thermal processes (coal, fossil fuels, geothermal, nuclear) and hydropower, solar/photovoltaic (PV) and wind (Øvergaard, 2008).

With regard to primary energy carriers, Figure 2.4 shows that fuel production is expected to increase until 2035. While the increase in crude oil production is expected to be small, significant increases are expected in the production of biofuels, coal and natural gas. In particular, the production of biofuels has significant water impacts because of the water requirements of crops for growth during photosynthesis, along with other water uses at the biorefinery.

Similarly, there are great disparities in the 2035 trends for electricity production. Figure 2.5 shows that no increases can be expected in electricity from liquid fossil fuels, and very little from nuclear production. Notably, the global nuclear policy consequences of the nuclear accident in Fukushima, Japan, in March 2011 might further inhibit future nuclear generation. The production of electricity from coal, renewable energy and natural gas, however, is expected to increase significantly. Electricity production from renewables is expected to more than double until 2035 (Figure 2.4), with hydropower growing in overall production, but less significantly in percentage than wind, solar and PV (EIA, 2010; WWF, 2011).

Water requirements for primary energy

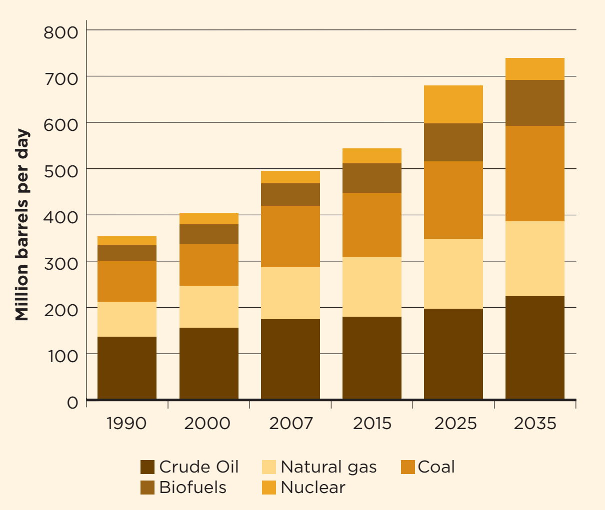
All forms of energy require water at some stage of their life cycle, which includes production, conversion, distribution and use. This chapter focuses on water quantity requirements, instead of water quality impacts. The water requirements for fuel production for coal, natural gas and uranium, while non-trivial, are much smaller than the water requirements at their use within power plants, and are therefore considered negligible by comparison. By contrast, the water requirements to produce coal, natural gas and petroleum for transportation applications are significant by comparison (because transport vehicles have no water requirements on-board.) Each fuel and technology has a slightly different set of requirements.

Crude oil

Crude oil is currently the largest primary energy source globally. Its production requires water at various stages, including drilling, pumping, refinement and treatment. The average water use is estimated to be 1.058 m^3 per GJ (Gerbens-Leenes, et al., 2008). Unconventional oil production, which is projected to increase in North,

FIGURE 2.4

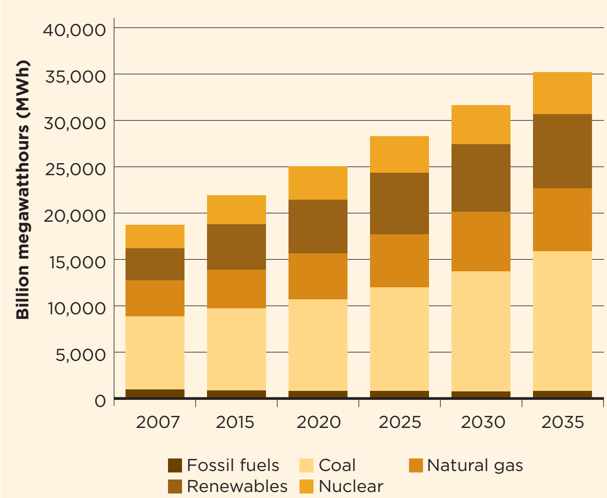
Historical world fuel production from 1990 to 2007 with projections to 2035



Source: Data from EIA (2010).

FIGURE 2.5

Projections for world net electricity generation, 2007–2035



Note: for this figure, fossil fuels refers to liquids such as petroleum and liquefied gases. Coal and natural gas are considered separately. Source: Data from EIA (2010).

Central and South America until 2035, consumes 2.5 to 4 times more water (WEC, 2010).

Coal

Coal is the second largest primary energy source globally, and its use is projected to increase by 2035 (Figure 2.4). Gerbens-Leenes et al. (2008) estimate that approximately 0.164 m^3 per GJ are used in the various processes, significantly more of which is used during underground mining operations than in open pit mining (Gleick, 1994).

Natural gas

Significant increases are expected in the production of natural gas by 2035 (Figure 2.4). Water requirements for the drilling, extraction and transportation of conventional gas sources are relatively modest, at an estimated 0.109 m^3 per GJ (Gerbens-Leenes et al., 2008). However, shale gas production, which is expected to increase in Asia, Australia and North America (Gascoyne and Aik, 2011), has slightly higher water-intensity than conventional gas, because its extraction method, hydraulic fracturing, injects millions of litres of water into each well.

Uranium

Uranium's share of global energy consumption is projected to increase from about 6% today to 9% by 2035 (Figure 2.4) (WEC, 2010). Gerbens-Leenes et al. (2008) estimate that water requirements for uranium mining and processing are modest at 0.086 m^3 per GJ.

Biomass and biofuel

Biomass, including wood, agro fuel, waste and municipal by-products, is an important source of fire and heating in many non-OECD country households (WEC, 2010). Furthermore, biofeedstocks are increasingly grown commercially to replace the use of fossil fuels in OECD countries – a trend that has raised concerns over the crop water requirements. However, the water intensity depends on the feedstock, where and how the crops are grown, and whether they are first or second-generation crops (Gerbens-Leenes et al., 2008; WEF, 2009). Due to this variety of production processes, it is impractical to attribute a singular value or even a representative range of water consumption to biofuel production.

Water requirements for the generation of electricity

Thermal electricity

Thermal power plants (coal, gas, oil, biomass, geothermal or uranium) generate electricity by heating water or gases and running them through steam or gas turbines to drive electrical generators. After passing through turbines, the water in the steam cycle is generally cooled (via water cooling loops) in a condenser and recycled. These processes currently account for 78% of world electricity production (EIA, 2010) and output is expected to grow, implying that even more water cooling will be needed.

Two types of water-cooling technologies as well as dry cooling are currently used (WEF, 2011). Once-through cooling withdraws relatively large quantities of water that are returned to the water body downstream after passing through the condenser. While some water is lost to evaporation (WEC, 2010), little water is actually consumed. However, significant downstream stresses on aquatic life can occur when the returned water has a significantly higher temperature than the environment, or if aquatic life is entrained into the cooling systems (DOE, 2006). Closed loop systems re-circulate the cooling water in the condenser and eject excess heat through cooling towers or ponds (WEF, 2011). These closed systems withdraw 95% less water than once-through technologies, but all of this water is lost to evaporation such that no water is returned directly to the natural system. Dry cooling systems do not require water for cooling, but have parasitic efficiency losses and have varying performance depending on the local temperature and humidity.

Values for the water consumption of thermal power plants vary due to the variety of existing technologies and fuel sources, as well as the climatic differences, which influence evaporation and the selection of the cooling process.

Hydropower

Hydropower presents the largest renewable source of electricity generation (15% of global production in 2007), and it is estimated that two-thirds of the world's economically feasible potential is still to be exploited (WEC, 2010). Hydropower uses water as its fuel by running it through turbines and discharging it to a water body further downstream. In this process, the water remains unpolluted and the hydropower production process is therefore by definition non-consumptive. However, in the case of storage reservoirs, additional evaporation might occur and has recently come to be considered by some observers as the water consumption of hydropower – even though evaporation losses are not usually factored into other reservoir-related uses. Estimation of water consumption for hydroelectricity is particularly difficult as it relies on modelling rather than measuring (WEF, 2009). Most of the latest research on this topic comes from the USA with findings presenting a range from 0.04 to 210 m^3 per MWh with an expected median of 2.6 to 5.4 m^3 per MWh (Gleick, 1994). Such estimates are meant to reflect losses through evaporation that would exceed what would have occurred if the basin had remained at its normal run-of-river surface area. It is important to note that these losses are not caused by hydropower generation itself, but by the surface area of reservoirs and site-specific climatic conditions, and could thus be applied to any water use that includes a reservoir, man-made or natural. Box 2.1 presents this and some of the complexities that are associated with the consideration of water use and consumption during hydropower production in comparison with other types of energy, and raises several points that are valid to measuring 'losses' attributable not exclusively to hydropower but to reservoirs for different, often multiple uses.

Wind, solar and photovoltaic

Wind and solar PV currently account for 3% of global electricity production. During operation, these technologies use virtually no water with the exception of that for washing of blades or solar cells (WEF, 2009). However, water requirements for washing of solar panels can be important to remove dust when operating in or near deserts. Also, in the case of large-scale deployment of concentrating solar power, the electricity is generated via the same steam cycle as thermal power plants and will therefore have cooling water

BOX 2.1

Complexities in comparing water use and consumption for hydropower production with that for other types of energy

Evaporation from hydroelectric power plants was initially researched in the early 1990s in the United States of America in an attempt to quantify the water usages of several energy resources. While few recent measurements exist, the US figures from the 1990s are frequently used to represent water requirements for hydropower at a global level (Figure 2.5). Pegasys (2011) notes that several points need to be considered when considering the impact of hydropower on the water resource:

- **Understanding water 'use', 'consumption' and 'loss'.** It is important to clarify the concepts and terminology associated with the 'non-consumptive use' of water for hydropower generation. While hydroelectric production does not 'consume' water, there are: (1) losses through evaporation that exceed what would have happened if the basin had remained at its run-of-river surface area, and (2) downstream impacts associated with altered flow regimes that need to be taken into account. Perhaps the most common complication arises with uses that rely on reservoir storage to allocate annual stream flow over time. For example, in many locations, as in Chile, hydroelectricity generation competes with other water uses because it shapes stream flows to meet power demand that are often out of phase with the seasonal requirements for other uses (Huffaker, Whittlesey and Wandschneider, 1993; Bauer, 1998).
- **Nature of generation capacity.** Understanding a generation technology and its footprint outside of the wider national or regional electricity system raises particular difficulties. Each generation facility has a prescribed performance and cost profile that determine its dispatch order and therefore water usage. This role can only be understood in the context of the other sources of power generation. For example hydropower has multiple uses in systems either as baseload capacity, peaking capacity or support. Furthermore, hydropower reservoirs potentially serve multiple purposes, including recreation, navigation, flood control and water storage, hence allocating its impacts across its myriad of services is difficult.
- **Energy supply chain.** Each generation technology has a different supply chain. A consideration of this supply chain from extraction of raw material to final product is critical in understanding the footprint of that technology. An omission of the supply chain obscures the water requirements for the technology and complicates comparisons between technologies.
- **Attribution of losses.** Hydropower in many instances is one of the functions in a multi-objective project, and the attribution of reservoir evapotranspiration to all of the uses is necessary when considering the footprint and usage of hydropower.
- **Structure of the hydropower system.** Each hydropower system is structured differently based on the nature and flow of the river system. Reservoir sizes, depth and shapes, as well as installed capacity, depend on the pre-existing geography, and determine the evaporation as well as generation value, highlighting the need to evaluate each project based on its specifics.
- **Climatic setting.** There is considerable debate around impact (or opportunity cost) of the footprint on the water resources of local basins. The meaning of the same footprint in a basin with excess water is different from that in a water-scarce basin.

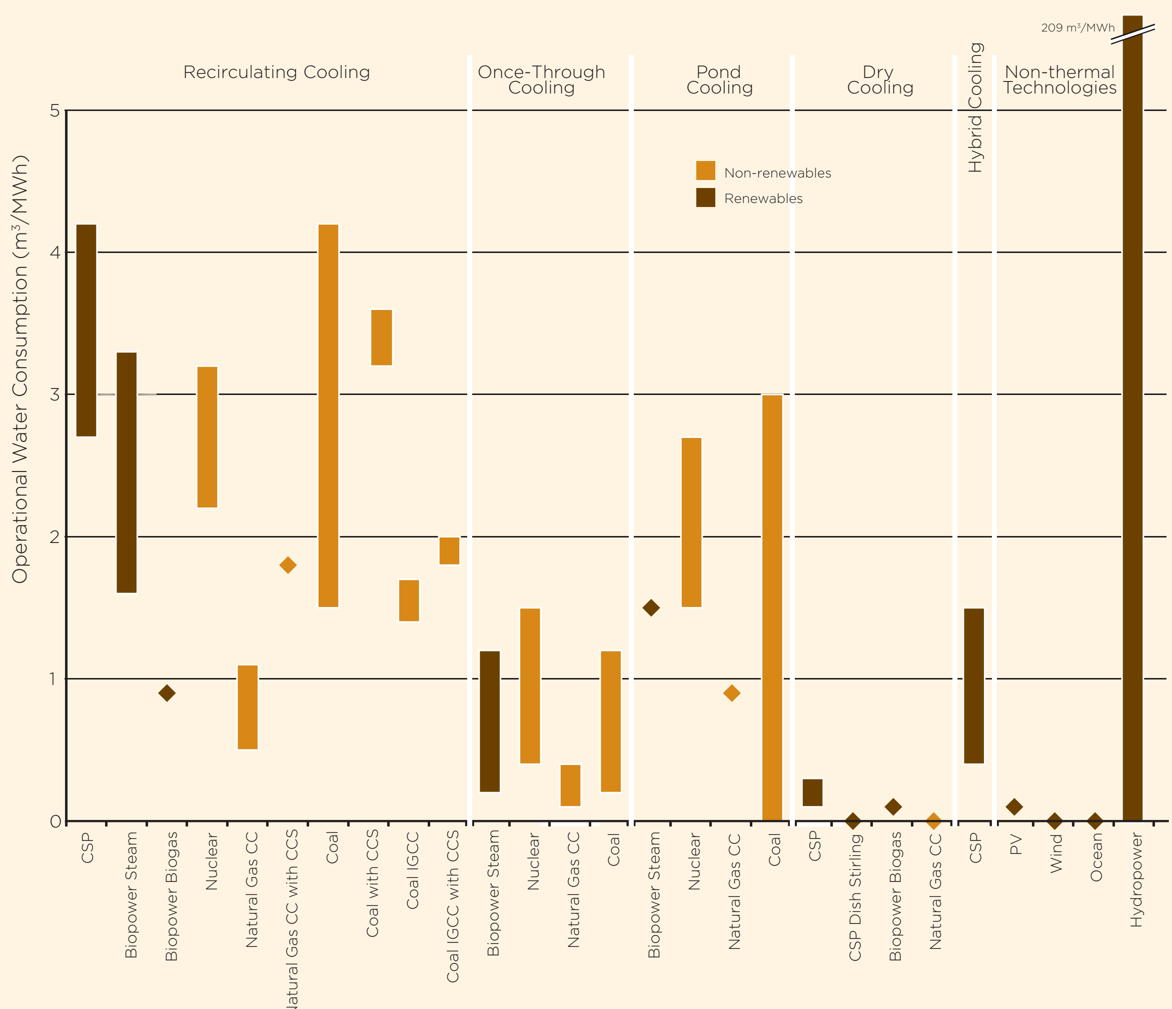
requirements, which can be a challenge in hot and dry regions (Carter and Campbell, 2009).

As a general trend, energy and electricity consumption are likely to increase over the next 25 years in all world regions, with the majority of this increase occurring in non-OECD countries. This trend will have direct implications for the water resources needed to supply this energy. Table 2.1 shows that the anticipated water requirements for energy production will increase by 11.2% by 2050 if current consumption modes are kept. Under a scenario that assumes increasing energy efficiency of consumption modes, WEC (2010) estimates that water requirements for energy production could decrease by 2.9% until 2050 (Table 2.2). Unfortunately, the water availability required for energy production is often not considered when new energy production facilities are planned. Similarly, energy needs for water systems are also often overlooked.

Water resources are not evenly distributed on the planet, and correspondingly some regions will face more severe water-for-energy stresses than others. WEC (2010) estimates that China, India and the Middle East, which already experience water stresses and are forecast to experience a five-fold increase in electricity production, will increasingly need to explore new technologies for processing primary energies and generating electricity. Other regions, although experiencing increasing water requirement for energy production,

FIGURE 2.6

Operational water consumption for the production of various types of energy



Source: IPCC (2011, fig. 9.14, p. 49). Trends in the demand of water for energy will most likely not suffer from water stress or scarcity, as they possess sufficient resources. WEC (2010) estimates that this scenario will be the case for most parts of North and South America and the Caribbean.

2.2.2 Energy for water

Energy is needed for extraction (surface water, groundwater), transformation (treatment to drinking water standards, desalination), water resource delivery (municipal, industrial and agricultural supply), reconditioning (wastewater treatment) and release. However, few countries currently research and report on energy requirements for water.

EPRI (2002) estimates that 2-4% of total US electricity consumption is used for water provision at water and wastewater treatment plants. Including end-uses, the national US energy consumption for water is approximately 10% (Twomey and Webber, 2011). Energy requirements for surface water pumping are generally 30% lower than for groundwater pumping (EPRI, 2002). It can be expected that groundwater will become increasingly energy intensive as water tables fall in several regions. In addition, where surface water is not abundant, importing water into the region might be more energy intensive than pumping available groundwater resources.

Water is commonly cleaned to meet drinking water standards by removing salts and chemical and biological contaminants. The energy requirements used for surface and groundwater treatment vary largely, based on water quality (WEF, 2011), technology used (Strokes and Horvath, 2009) and national drinking water standards. However, in international life-cycle analyses, it has been observed that desalination of locally available sources generally requires significantly more energy than importing water sources (Strokes and Horvath, 2009), and requires generally six times more energy than wastewater treatment (WEF, 2011). Electricity requirements for desalination are relatively well researched, and Strokes and Horvath (2009) found that international electricity use for conventional and membrane seawater desalination treatment averaged 0.38 kWh per year per m^3, while brackish groundwater desalination requires about 0.26 kWh per year per

TABLE 2.1

Population, energy consumption and water consumption for energy, 2005–2050

World	2005	2020	2035	2050
Population (million)	6290	7842.3	8601.1	9439.0
Energy consumption (EJ)	328.7	400.4	464.9	518.8
Energy consumption (GJ/capita)	52.3	51.1	54.1	55
Water for energy (billion m^3/year)	1815.6	1986.4	2087.8	2020.1
Water for energy (m^3/capita)	288.6	253.3	242.7	214.0

Source: Adapted from WEC (2010, table 1, p. 50, various data sources).

TABLE 2.2

Population, energy consumption and water consumption for energy, 2005–2050, with improved energy efficiency

World	2005	2020	2035	2050
Population (million)	6290	7842.3	8601.1	9439.0
Energy consumption (EJ)	328.7	364.7	386.4	435.0
Energy consumption (GJ/capita)	52.3	46.5	44.9	46.1
Water for energy (billion m^3/year)	1815.6	1868.5	1830.5	1763.6
Water for energy (m^3/capita)	288.6	238.3	212.8	186.8

Source: Adapted from WEC (2010, table 2, p. 51, various data sources).

m^3. The price of desalinated water is therefore closely linked to the energy price, which, despite fluctuations, has been steadily increasing over the past decade (EIA, 2010). However, while such global averages may be interesting in theory, drinking water is so important that local choices of water provision will in practice depend on availability of the resource. Furthermore, desalination produces highly concentrated waste brine streams that must be disposed of. Coastal desalination plants discharge that brine into neighbouring waters, with negative impacts on coastal marine ecology. Inland desalination plants face an equal challenge to find ecologically benign ways to dispose of the brine.

As Table 2.3 shows, wastewater treatment also requires large amounts of energy (WEF, 1997). High-income countries that have stricter discharge regulations install more energy-intensive treatment technologies. Trickling filter treatment, which uses a biologically active substrate for aerobic treatment, is a reasonably passive system, consuming over 250 kWh per ML on average (EPRI, 2002; Stillwell, 2011). Diffused air aeration, as part of activated sludge processing, is a more energy intensive form of wastewater treatment, requiring 340 kWh per ML due to blowers and gas transfer equipment (EPRI, 2002; Stillwell, 2011). More advanced wastewater treatment, utilizing filtration and the option of nitrification, requires 400–500 kWh per ML (EPRI, 2002; Stillwell et al., 2011). In fact, more advanced sludge treatment and processing can consume energy in the range 30–80% of total wastewater plant energy use (Center for Sustainable Systems, 2008).

Treating wastewater sludge through anaerobic digestion can also produce energy through the creation of methane-rich biogas, a renewable fuel that can be used to generate up to 50% of the treatment plant's electricity needs (Sieger and Whitlock, 2005; Stillwell, King and Webber, 2010).

Because wastewater treatment is generally more energy intensive than standard water treatment, the trend towards these higher treatment standards will likely increase the unit energy needs of wastewater treatment in the future for countries moving up in income (Applebaum, 2000). However, it is possible that the introduction of greater energy efficiency will offset the expected increases in energy intensity for stricter treatment standards, limiting the projected growth in electricity use at treatment plants. The higher per capita energy expenditures for wastewater treatment in order to achieve stricter environmental standards is a scenario likely to be repeated in analogous ways throughout all societies achieving affluence; that is, as nations get richer, they will demand more energy. Energy is also used for irrigation of crops. In OECD countries, energy for irrigation account for a small fraction of the total energy embedded in water (heating, treating and disposing of water requires much more energy). However, in non-OECD countries where treating and heating are less common, irrigation takes up a relatively larger share of energy for water.

Water requirements to support growing populations are increasing, and water scarcity will oblige nations to

TABLE 2.3

Average US figures for water production

	Source / treatment type	Energy use (kWh/million L)
Water	Surface water	60
	Groundwater	160
	Brackish groundwater	1 000-2 600
	Seawater	2 600-4 400
Wastewater	Trickling filter	250
	Activated sludge	340
	Advanced treatment without nitrification	400
	Advanced treatment with nitrification	500

Note: The table does not include energy used for distribution.
Sources: CEC (2005); EPRI (2002); Stillwell (2010); Stillwell et al. (2010, 2011).

progressively explore unconventional sources of water with larger electricity requirements. Thus, while technologies are steadily becoming more energy efficient (Strokes and Horvath, 2009), this gain in efficiency risks being offset by the increased energy requirements for delivering water from increasingly distant sources and sources disadvantageous due to their location, or treating water that is of lower quality.

2.2.3 Drivers, challenges and responses to the water-energy nexus

As stated earlier, global energy consumption is expected to increase dramatically over the next two decades. This trend is primarily a function of population and economic growth in developing countries. The main challenge with regard to water and energy will be the provision of water resources to ensure that the increased energy needs can be supplied. This need requires policy-makers to promote more efficient and integrated water uses for energy and vice versa. The first step toward such policies will be comprehensive assessments of water availability on a country level. Second, water and energy policies, which are often made in different government departments or ministries, will need to be integrated with policy-makers increasingly working in close coordination.

All the aforementioned trends suggest a potential movement towards water-production methods that are increasingly energy-intensive. Many high-income societies are moving towards more energy-intensive water because of a push by many water utilities for new supplies of water from sources that are farther away and lower quality, and which thereby require more energy to get them to the right quality and location. In addition to treating water to higher standards of cleanliness, societies are also going to greater lengths to transport freshwater from its sources to dense urban areas. These efforts include digging to ever-deeper underground reservoirs, or moving water via massive long-haul projects (Stillwell, King and Webber, 2010).

In politically stable regions, there is a strong possibility that the role of national decision-making frames will decline and that decisions on water and energy may increasingly be subjected to influences at the supranational level, with governments working together in basin organizations and power pools – assuming (as mentioned in Chapter 1) that such processes and related agreements reflect the political economy and institutional capacities of the countries involved. Conversely, there will also likely be an increase in localized measures to supply water and energy to remote locations in order to empower communities and promote sustainable livelihoods. Such measures include small and micro-hydropower and other small-scale renewables to provide electricity for communities (GVEP, 2011), as well as sand dams (Excellent, 2011) and energy-independent pumps for the provision of rural water sources.

There are also technical solutions to more efficient water use in the energy sector. For example, brackish water, mine pool water, or domestic wastewater and dry cooling have been used for cooling power plants (NETL, 2009). Research is also ongoing into the water efficiency of biofuels (Gerbens-Leenes et al., 2008), the energy-efficiency of desalination (AFF, 2002), and the reduction of evaporation from reservoirs.

The water–energy nexus will transcend water use and consumption in mere quantity considerations. Energy production also impacts water quality. Thermal, chemical, radioactive or biological pollution can have direct impacts on downstream ecosystems; where emissions are not sufficiently controlled, considerable amounts of agricultural land may be affected by acid rain. Similarly, where water scarcity obliges nations to use non-traditional sources of water (e.g. desalination, brackish water), choices will need to be sensitive to the water and environmental impacts of the required electricity.

2.3 Industry

2.3.1 Status and trends

Although industry uses relatively little water on a global scale, it nevertheless requires an accessible, reliable and environmentally sustainable supply. It is generally reported that approximately 20% of the world's freshwater withdrawals are used by industry, although this varies between regions and countries. Furthermore, as described in Section 2.2, water withdrawals for industry are most often reported in combination with those for energy. In addition, the water required for small-scale industry and commerce is often confused with domestic consumption. As a result, surprisingly little is known about how much water is actually withdrawn and consumed by industry for its purposed manufacturing, transformation and production needs.

The percentage of a country's industrial sector water demands is generally proportional to the average income level, representing only about 5% of water

> "Surprisingly little is known about how much water is actually withdrawn and consumed by industry for its purposed manufacturing, transformation and production needs."

withdrawals in low-income countries, compared to over 40% in some high-income countries (Figure 2.1). This observation suggests that the level of a country's or a region's economic development is an important driver of its industrial water use, and may ultimately have as much influence on water use as its population growth.

Water management in the industry sector is typically considered in terms of industrial withdrawals and consumption. Total industrial water withdrawals can be calculated as: Water Withdrawal = Water Consumption + Effluent Discharge (Grobicki, 2007).

Industry's total water withdrawal from surface water and groundwater is usually much greater than the quantity of water it actually consumes. Improved water management is generally reflected in overall decreased industrial water withdrawals or increased wastewater treatment, highlighting the connection between higher productivity and lower consumption and effluent discharges and reduced pollution.

The quality of water required by industry for specific needs can vary considerably. Water of lesser quality may be adequate for many industries, facilitating the use of recycled and reclaimed water. Conversely, some industries may have water quality requirements more demanding than those for drinking water; for example, food processing. Pharmaceutical and high technology industries can require very high-quality water, necessitating additional treatment of water from primary supplies. Other sectors, such as tourism, power generation and transportation, can also have differing water quality requirements.

The water quality of effluent discharges can have very significant environmental impacts, particularly on regional and local scales (UNEP, 2007). Small-scale industries such as agro-processors, textile dyeing, abattoirs and tanneries can cause the presence of toxic pollutants in local water resources. Not only do the pollutants make the water non-potable, but they also kill fish, which are a source of protein for many poor people. Certain toxic chemicals enter the food chain when polluted water or untreated wastewater from industries is used for agriculture. Industrial contamination tends to be more concentrated, more toxic, and often harder to treat than pollutants from other sectors or activities. The persistence of these contaminants, and their rate of movement though the environment and hydrological cycle, can often involve long periods of impaired water resources (UNEP, 2007).

In addition to considering water quantity and quality concerns, industry must also use water efficiently and wisely, even as it seeks to augment its economic output and profit. This concept of water productivity refers to the value that can be obtained from each unit of water used. The third edition of the *World Water Development Report* (Chapter 7) reported values ranging from well over US$100 to less than US$10 per m^3 of water used, depending on the country. As technology improves, industrial water productivity also typically rises. Thus, low productivity may indicate that the water is either under-priced or simply abundant, which results in cost becoming an insignificant factor. High productivity is linked to high water re-use, with reduced water withdrawals. Water productivity also can be of considerable interest to decision-makers concerned with water allocations.

In addition to water withdrawals, significant industrial interventions affecting the hydrological cycle include effluent discharges into surface water bodies, contaminant infiltration into groundwater, and atmospheric distribution and fallout of contaminants into water bodies. One approach to decreasing or avoiding environmental degradation from industrial activities, even as industry continues to develop, is through cleaner production and sustainability practices. Cleaner production has many facets, and one of its main objectives is to move toward zero effluent discharges, with industry working to convert wastewater streams into useful inputs for other processes, industries and industrial clusters.

2.3.2 External drivers

Industry is strongly influenced by external drivers that, indirectly, can add complexity and uncertainty to industry water needs. Economic growth and development are the overall main drivers of industrial water use, and that relationship is reciprocal: while economic forces affect water, the availability and state of water resources also influences economic activity. Ecosystem stress, societal values and security are also important drivers, but are typically more local in nature.

International trade – which a driver for industry and water – requires that exports from a source country meet environmental regulations in the destination country. A number of global Multilateral Environmental Agreements (MEAs), such as the Basel Convention,[4] have also resulted in global standards. Developing countries in particular can face trade hurdles in meeting the environmental requirements of developed countries, including ISO certifications, environmental management systems (EMS) and corporate social responsibility (CSR), which could be seen by some as non-tariff barriers to trade. Thus, industries in developing countries can be subjected to stricter, explicit and implicit international requirements, as well as some control, by the multinational companies to which they supply goods or services. However, these requirements can in turn lead to better product manufacturing standards, including energy efficiency and climate change (carbon footprint) considerations, with industry benefiting from better management (including water resources management) and resulting increased efficiency. Finally, the focus on 'green growth' and the 'green economy' (see Section 12.1) at the Rio+20 Summit in 2012 will likely lead to agreements among member states on the adoption of standards and/or protocols, which will in turn have significant implications for industry. The challenge and opportunity for business is to understand the concrete possibilities of a green economy, with its opportunities and risks for its many sectors and different national contexts. Governments will need to work collectively to ensure the prevention of pollution havens in countries with poor enforcement capacities.

The industrial utilization of water resources – including water supply quality and wastewater treatment – is greatly impacted by technological innovation, which can lead to cleaner production and sustainability. Assuming appropriate technologies are available to all (a situation not necessarily applicable to local industries in developing countries), water treatment constraints are primarily a function of cost rather than a lack of technical capability to achieve high-quality water. Although revolutionary technological breakthroughs for water treatment seem unlikely at present, there are nevertheless many incremental technological advances that often bring cost reductions, consistent with a primary industry goal of ensuring the most economic system for achieving required water quality.

In the past, water has been considered a relatively certain component of industrial processes. Indeed, it has been typically assumed that the needed water supply would be easy and relatively cheap to secure. Wastewater discharges have been more of a challenge, although effluent discharges were permissible provided water quality (or treatment) standards were achieved. The recent number of new external drivers on water and its management, however, has now made water use a much riskier proposition for industry (Figure 2.7). Effective operation of an industry requires a sustainable supply of water in the right quantity, of the right quality, at the right place, at the right time and at the right price (Payne, 2007). Industry will find itself increasingly competing for limited water resources as water demands and consumption increase in all sectors, particularly agriculture with its substantial water needs. Thus, all these factors are now subject to greater uncertainty.

Water scarcity is viewed as an increasing business risk, with industrial water supply security dependent on sufficient resources. This problem is compounded by geographic and seasonal variations, as well as water allocations and competing water needs in a given region (e.g. agriculture vs drinking water or residential supply vs industry), a situation that may be beyond the control of industry. This is especially true for transboundary water situations, where the needs of two or more countries may conflict or overwhelm water availability.

Water quality risks associated with both water supply and effluent discharges can affect industry, thereby restricting industrial expansion. In terms of water supply, it has been noted that many sectors require high-quality water, thereby necessitating additional water treatment. In cases of contaminated surface or groundwater supplies, industry faces increased costs associated with additional water treatment needs. Although this requirement may well prompt industry to more strongly consider using reclaimed or recycled water, it will most likely weigh on decisions regarding the location of a company's industrial activities.

In terms of industrial wastewater discharges, the vast majority in developing countries is discharged with little or no treatment (WWAP, 2009). Thus, there is considerable pressure on industry to clean its effluents. While compliance will doubtless become stricter and more onerous, the actual criteria and severity of standards vary by jurisdiction. An associated risk is investing in new treatment technology that may subsequently become obsolete within only a few years. Moreover, industrial accidents, such as uncontrolled discharges, may be the result of economic and other drivers that forced industrial expansion more quickly than was justifiable in a given situation, possibly utilizing unproven technology and/or in sensitive locations. Poor water quality, therefore, can restrict industrial expansion. Likewise, industrial expansion can place unsustainable strain on water resources.

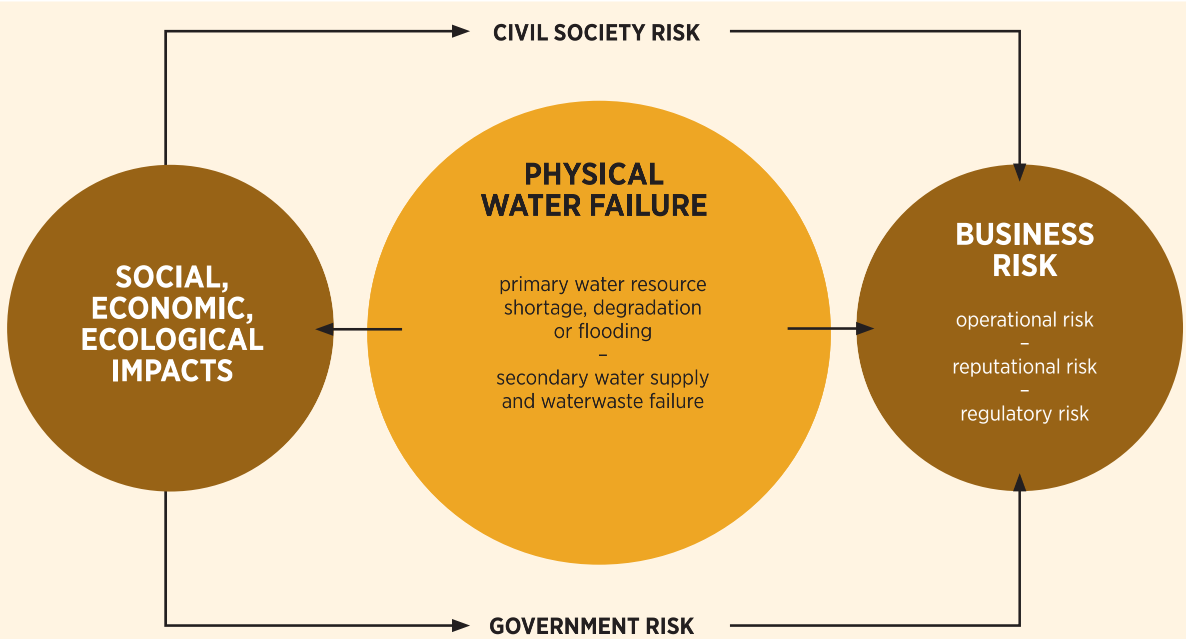
Government policies regarding water must often respond to multi-faceted agendas on the national to local level. Government priorities and policies inevitably change over time. These changes, particularly unpredictable ones, can make it difficult for industry, especially multi-national companies, to locate successfully in certain countries. For example, poor policy decisions can lead to over-use of water resources in some locations and under-use in others. Furthermore, governmental perceptions of water risks in a given case can be at odds with those of industry. Environmental concerns and pressures from the public, special interest groups and business can further influence government decisions regarding water.

2.3.3 Adaptations and options for solutions

Undoubtedly, business and industry can play a leading role in sustainable water practices. To successfully adapt to water scarcity – which can involve not only a lack of water but also poor water delivery infrastructure and/or poor water management – a business or industry must have accurate knowledge of its specific

FIGURE 2.7

Inter-relationship of water risks among business, government and society



Sources: SABMiller Plc and WWF-UK (2009, fig. 2, p. 5, refer to www.sabmiller.com/water).

water needs. For example, establishing water accounting techniques and measuring water impacts can allow an industry to more readily identify potential areas of increased water use efficiency; however, the accumulation of accurate data and a consistent approach to water measurements and monitoring are needed to achieve this end. Another approach to increasing water productivity involves 'doing more with less', ideally moving toward a goal of zero discharge (i.e. utilizing a closed-loop production system). This objective underpins the recent development of industrial ecology (eco-innovation) as a means of addressing the inter-relationship of industrial and economic systems to natural systems.

Industry is generally accustomed to having water available at a relatively inexpensive price. Increasing water scarcity, however, will result in higher charges, including additional charges for water treatment and discharge. There is an argument for developing a different price structure for industrial water use; that is, requiring industry to pay more per unit of water than the public, as well as increasing amounts per unit with increasing water use. The impacts of such practices on industry will naturally promote increased water use efficiency, since the economic realities of the cost of water will increase the price of the associated products. These effects could have an impact on the industrialization process in developing countries where water costs are usually low if not non-existent, and the concepts of water productivity and cleaner production are either unknown or sidelined in efforts to make goods and create jobs.

Against this background, the embracing challenge is for industry to play its appropriate role in effectively addressing unsustainable exploitation and contamination of freshwater resources around the world. This includes the impacts of industry on those supplies and the challenge of mitigating them for the benefit of all water users and the environment – a goal that must be approached within the context of corporate, social and environmental responsibility. Although there are ways to address the issues, risks and challenges of water productivity, they require effective implementation and oversight, including the application of environmental technologies to help conserve the natural environment and resources, as well as to curb the negative impacts of human activities. Moreover, information without action and public disclosure does not constitute real progress. Focusing on meeting this challenge will provide industry with an opportunity to increase productivity, efficiency and competitiveness in a sustainable way.

"Effective operation of an industry requires a sustainable supply of water in the right quantity, of the right quality, at the right place, at the right time and at the right price."

The problems surrounding water productivity in industry and broader global water concerns are interrelated. As such, they require integrated management, strategy, planning and actions to provide effective solutions. To meet these challenges, industry must first look to its management priorities and style, and its company values and culture, to encourage a positive response from within its own sphere. An integrated management approach, promoting proactive measures by industry, including consideration of the needs and interests of affected stakeholders and the environment, will not only anticipate the future, but actually help shape it (BSR and Pacific Institute, 2007). Innovation, investment and collaboration are key elements to addressing this goal, and achieving it will require a strategic approach, including the following points:

- A measure of industry's operational and supply-chain water use ('you can't manage what you don't measure').[5] An accurate water impact assessment considers a product's water content, and the less obvious inputs and uses of water in its production (virtual water). A further determination is where and when the water is used, and for what purpose. This determination requires accurate data and a consistent approach to measurement and monitoring.
- A measure of industry exposure to water risks involving a risk assessment that evaluates relevant hydrological, economic, social, political and environmental factors in different contexts.

- A corporate water policy that embraces strategies ranging from corporate values to communication, and which may include:
  - Promoting CSR
  - Encouraging cradle-to-cradle industrial operations[6]
  - Using the precautionary principle to promote action, develop options and assist decisions
  - Introducing EMS
  - Setting measurable goals and targets with regard to water efficiency, conservation and impacts, accompanied by public disclosure of relevant data
  - Decoupling material and energy consumption, and integrating energy needs and water requirements
  - Constant and effective communication with the public and local stakeholders regarding the economic and environmental costs and benefits of various industrial policies, strategies and measures
  - Collaboration with government agencies
  - Becoming involved with like-minded companies through such avenues as the CEO Water Mandate and the World Business Council for Sustainable Development, as a means of sharing and promoting successful actions, thereby assuming a proactive leadership role in sustainable practices
- An innovation implementation strategy involving both ongoing initiatives needing reinforcement and others that might be considered for the future, including:
  - Decreasing water use and increasing water productivity through water audits, zero discharge and water optimization techniques, water recycling and reuse, addressing water losses from aging infrastructure, and full and consistent monitoring activities
  - Introducing new technologies, including adapting new environmental technologies and incorporating natural water treatment systems, transferring environmentally sound technologies in conjunction with environmental management accounting (EMA)
  - Employing industrial ecology (eco-innovation), including employing environmental design into industrial design and planning, investing in environmental and ecological restoration, and using a life-cycle approach within the context of a closed-loop system

2.4 Human settlements

2.4.1 Urbanization and population trends

Between 2009 and 2050, the world population is expected to increase by 2.3 billion, from 6.8 to 9.1 billion (UNDESA, 2009). At the same time, urban populations are projected to increase by 2.9 billion, from 3.4 billion in 2009 to 6.3 billion total in 2050. Thus, the urban areas of the world are expected to absorb all of the population growth over the next four decades, while also drawing in some of the rural population. Furthermore, most of the population growth expected in urban areas will be concentrated in the cities and towns of less developed regions. Asia's population is projected to increase by 1.7 billion; Africa has a projected urban population gain of 0.8 billion; and Latin American and the Caribbean urban populations are projected to grow by 0.2 billion. In 1950, New York City and Tokyo were the only two cities with populations exceeding 10 million. By 2015, it is expected that there will be 23 such cities of which 19 will be in developing countries. Projections indicate a continuing increasing trend of urbanization in developing countries. By 2030, it is anticipated that the urban population in developing and developed countries will amount to 3.9 billion and 1 billion respectively. Population growth is therefore becoming largely an urban phenomenon concentrated in the developing world (UN-Habitat, 2006).

> Migration from rural to urban areas poses a major challenge for city planners; extending basic drinking water and sanitation services to peri-urban and slum areas to reach the poorest people is of the utmost importance to prevent outbreaks of cholera and other water-related diseases in these often overcrowded places. (WHO/UNICEF, 2006, p. iii)

Slums generally present a set of unique problems, including poor housing conditions, inadequate access to safe water and sanitation, overcrowding and insecure tenure; thus, the welfare of those living in these areas are seriously impacted (Sclar, Garau and Carolini, 2005). The relation between climate change and slum areas is cause for alarm in terms of disaster vulnerability resulting from meteorological phenomena. To complicate matters further, slums are usually built on dangerous land, unsuitable for human settlement. For example, shantytowns near Buenos Aires are built on flood-prone land, and residents are therefore forced to make a difficult choice between their safety and health and their need for shelter (Davis, 2006). In some cities, for example Mumbai, nearly half the urban population reside in slums and shantytowns (Stecko and Barber, 2007). As is evident from Figure 2.8, not only is the slum population rising, it is also highly concentrated in developing countries, especially in sub-Saharan Africa, Southern Central and Eastern Asia. In Latin America and the Caribbean, a significant reduction is observed in the proportion of the urban population living in marginal areas – from 37% (110 million people) in 1990 to 25% (106 million) in 2005 (United Nations, 2010).

Cities in developing countries face enormous backlogs in shelter, infrastructure and services, as well as insufficient water supply, deteriorating sanitation and environmental pollution. Population growth and rapid urbanization will create an even greater demand for water while decreasing the ability of ecosystems to provide more regular and cleaner supplies.

Climate change is posing an additional challenge to urban water supplies by changing water availability and exacerbating water-related disasters such as floods and droughts. For example, tropical storms were rare in Ho Chi Minh City, Viet Nam, until fairly recently. But over the past 60 years, 12 large tropical storms – including Vae (1952), Linda (1997) and Durian (2006) – have affected the city. Typically, these storms bring heavy rainfall, increased localized flooding and storm surges along the coastal areas, causing serious extensive flooding of 1.0 to 1.2 m. Of the Ho Chi Minh City's 322 communes and wards, 154 have a history of regular flooding. These floods cover close to 110,000 ha and affect some 971,000 people (12% of the population). It is predicted that by 2050, such regularly flooded areas will have increased to 177 (55% of the city's communes) covering 61% of the city area (ADB, 2010).

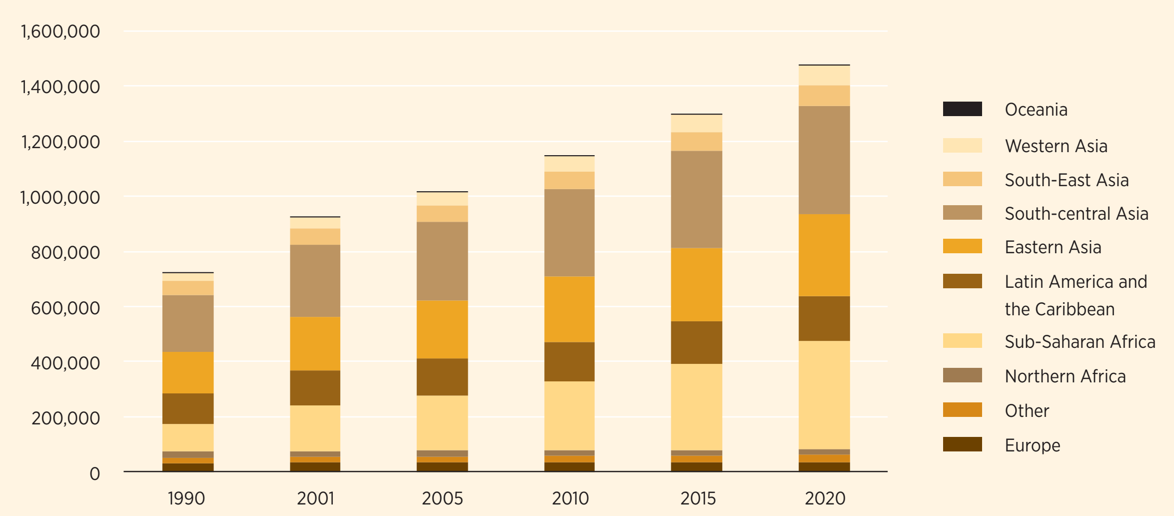
2.4.2 Water supply and sanitation coverage: Keeping up with urban growth

Worldwide, 87% of the population gets its drinking water from improved sources, and the corresponding figure for developing regions is also high at 84%. Access is far greater, however, in urban areas (at 94%), while only 76% of rural populations have access to improved sources (WHO/UNICEF, 2010). However, these estimates do not take into consideration service quality (e.g. intermittent supply, disinfection) or affordability. Also, given the lack of reliable data concerning human populations in marginalized communities (i.e. slums), governments and international agencies are likely to significantly underestimate the number of urban dwellers lacking adequate provision for drinking water. Furthermore, this number is actually increasing as rapid urbanization continues in many regions (UN-Habitat, 2003, 2010).

In 2010, a reported 2.6 billion people in the world did not use improved sanitation facilities (WHO/UNICEF, 2010). Of the approximately 1.3 billion people who gained access to improved sanitation during the period 1990–2008, 64% live in urban areas. However, urban areas, although better served than rural areas, are struggling to keep up with urban population growth

FIGURE 2.8

Slum population by region, 1990–2020 (thousands)



Source: Produced by UN-Habitat based on data available at http://ww2.unhabitat.org/programmes/guo/documents/Table4.pdf (published in State of the World's Cities Report 2001).

(WHO/UNICEF, 2010). Again, projected demographic growth in urban areas gives rise for concern: if efforts continue at the current rate, improvements in sanitation facility coverage will only increase by 2% – from 80% in 2004 to 82% in 2015 (an additional 81 million people) (WHO/UNICEF, 2006).

A comparison of the latest estimates from 2008 with those of 2000 indicates a deterioration in both water and sanitation coverage in urban areas. Over those eight years, in cities and towns of all sizes, the number of people without access to tap water at home or in the immediate vicinity increased by 114 million, and the number of people without access to private sanitary toilets (basic sanitation) increased by 134 million. In both cases, this means an increase of 20% in the number of individuals living in cities who lack access to basic facilities (AquaFed, 2010).

Keeping up with the population increase in cities and maintaining current water supply and sanitation (WSS) services coverage levels for 2015 requires serving 700 million urban dwellers over the coming decade (WHO/UNICEF, 2006). At present, the urban population is increasing faster than the speed of improvement in WSS services; however, current efforts to address this challenge are not insignificant (UNDESA, 2009). For example, the total percentage of individuals with access to improved WSS declined between 2000 and 2008, but the number of urban residents with access to tap water are estimated to have grown by 400 million (AquaFed, 2010).

Other improvements have been made, such as in Northern Africa, South-East Asia, Eastern Asia, and Latin America and the Caribbean, where access to improved water supply and sanitation has significantly increased (WHO/UNICEF, 2010). However, up to 50% of the urban population in Asia overall still lacks adequate provision of water, and up to 60% lacks adequate sanitation (UN-Habitat, 2010). In sub-Saharan Africa, the numbers of urban dwellers without access to tap water has increased by 43% in eight years.

2.4.3 Pressure from urban areas on water

Water withdrawals

Relative to other sectors, water withdrawal for urban use is low: industrial (including energy) use is around 20%, domestic use is about 10%, and abstraction for agriculture is as high as 70% globally (WWAP, 2009). Increasing water demands are leading to over-abstraction from groundwater, areas outside cities and upstream watershed areas, as well as from rural areas, depriving other users and challenging ecosystem functions.

In areas where surface water is not readily available, groundwater is the primary water source (UNEP/GRID-Arendal, 2008). Excessive groundwater abstraction is resulting in falling water tables, water quality degradation and land subsidence (see Section 3.2.1), as is the case in several cities in Asia – including Bangkok, Beijing, Chennai, Manila, Shanghai, Tianjin and Xian (Foster, Lawrence and Morris, 1998).

The supplying aquifer in Mexico City fell by 10 m as of 1992, resulting in land subsidence of up to 9 m. Over-abstraction in coastal areas results in saltwater intrusion: in Europe, 53 out of 126 groundwater areas show saltwater intrusion, mostly in aquifers that are used for public and industrial water supply (Chiramba, 2010). A growing number of large urban centre aquifers are also facing pollution from organic chemicals, pesticides, nitrates, heavy metals and water-borne pathogens (UNEP/GRID-Arendal, 2008).

Pollution and wastewater

Urban settlements are also the main source of point-source pollution. Urban wastewater is particularly threatening when combined with untreated industrial waste. In many fast-growing cities (small and medium-sized cities with populations of less than 500,000), wastewater infrastructure is non-existent, inadequate or outdated. For example, the city of Jakarta, with a population of 9 million, generates 1.3 million m^3 of sewage daily, of which less than 3% is treated. In contrast, Sydney, with a population of 4 million, treats nearly all of its wastewater (1.2 million m^3 per day) (Chiramba, 2010). Chile made impressive progress in urban wastewater treatment, increasing it from only 8% in 1989 to almost 87% in 2010 (SISS, 2011), with plans to treat all urban wastewater in 2012 (Pickering de la Fuente, 2011). Worldwide, it is estimated that over 80% of waste water worldwide is not collected or treated (Corcoran et al., 2010). As shown in Figure 2.9, the ratio of untreated to treated wastewater reaching water bodies for 10 regions in significantly higher in developing regions of the world.

Wastewater contributes to increase in eutrophication and dead zones in both oceans and freshwater. Dead zones affect about 245,000 km^2 of marine ecosystems, with consequent impacts on fisheries, livelihoods and the food chain. Discharge of untreated wastewater shifts problems to downstream areas. In coastal areas, seagrass ecosystems/habitats are damaged, and invasive species are increasing in estuarine ecosystems.

The economic recession of the 1990s combined with decline in highly polluting industries led to reduced discharge of wastewater and pollutants in Eastern Europe, relieving some of the pressure on river quality in many areas. It also resulted in the breakdown of water supply and wastewater treatment systems, and consequently heavy pollution of rivers and drinking water supplies in downstream cities in industrial and mining regions. Major losses of seagrass habitats occurred in Australia, Florida Bay (USA) and the Mediterranean, while increases occurred in the Caribbean and Southeast Asia (Chiramba, 2010).

Illegal and unreported releases of untreated wastewater continue to be an issue all over the world. Recently, for example, the city of Revere, Massachusetts has agreed to spend approximately US$50 million to reduce illegal discharges of raw sewage overflows into the environment from its wastewater collection system and separate storm sewer system, and to pay a penalty of US$130,000 for the Clean Water Act violation (CTBR, 2011) Corcoran et al. (2010) report that up to 90% of wastewater in developing countries flows untreated into rivers, lakes and highly productive coastal zones, threatening health, food security and access to safe drinking and bathing water.

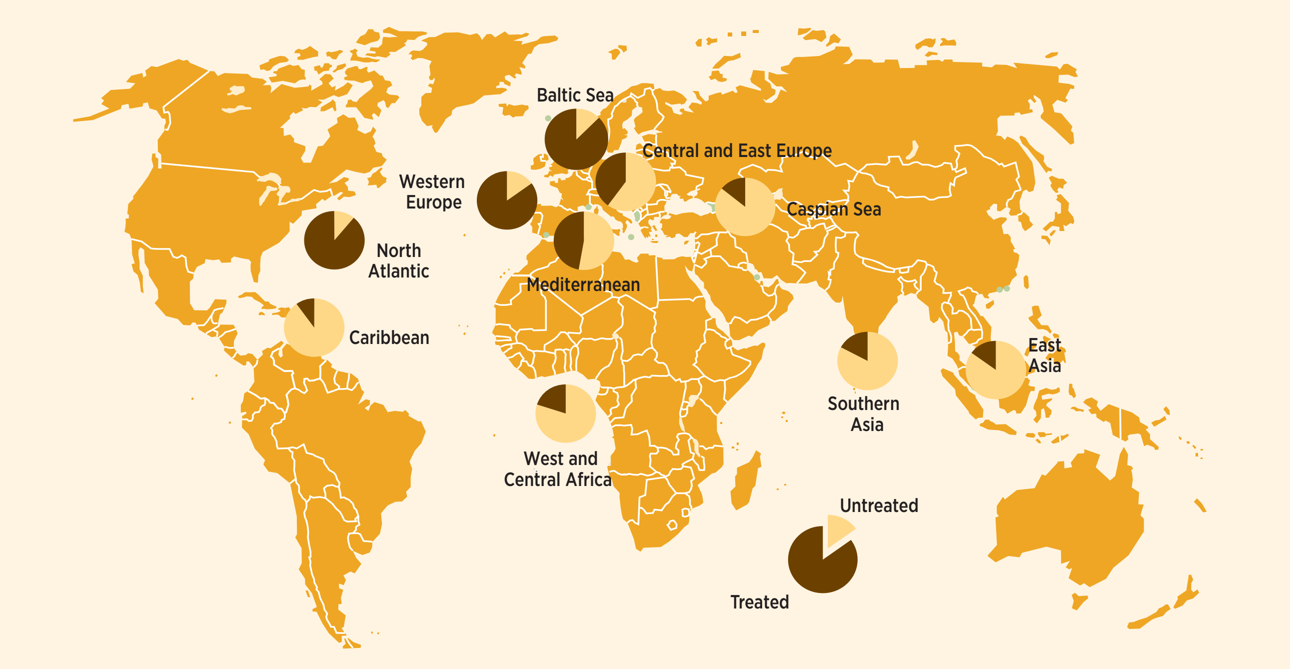
2.4.4 Water management in urban areas

Integrated urban water management

Water management in urban areas can benefit from more comprehensive urban planning and integrated urban water management (IUWM). IUWM involves managing freshwater, wastewater and stormwater as links within the resource management structure, using an urban area as the unit of management. The objective of such an approach is to facilitate the multi-functional nature of urban water services in order to optimize the outcomes of the system as a whole. The approach encompasses various aspects of water management, including environmental, economic, technical and political, as well as social impacts and implications. Issues, options and examples for arid, semi-arid and humid regions can be found in Tucci et al. (2010) and Mays (2009).

FIGURE 2.9

Ratio of treated to untreated wastewater discharged into water bodies



Note: Ratio of wastewater treatment (March 2010).
Source: UNEP/GRID-Arendal (http://maps.grida.no/go/graphic/ratio-of-wastewater-treatment1, adapted from a map by H. Alhenius with sources UNEP-GPA [2004]).

Urban agriculture

Urban and peri-urban agriculture (UPA) is the safe production of agriculture and cattle products in and around cities. UPA is estimated to involve 800 million urban residents worldwide (Smit et al., 1996) and contributes to solving several urbanization problems by enhancing food availability, particularly of fresh produce; providing employment and increasing income, food security and nutrition of urban dwellers; and greening cities and also recycling wastes. However, these areas can use water of lesser quality that contains nutrients beneficial to agriculture while preventing pollution downstream. UNEP estimates that sewage water irrigates about half the gardens, roadside verges and small fields where food is grown in the world's urban and peri-urban areas. A new look is being taken at how to use this traditional resource safely (Corcoran et al., 2010).

Urban food security projects are being undertaken in large cities of the Middle East and Africa with local partners, including women's farmers groups. For example, in Istanbul, an urban agriculture project supports and trains unemployed, poor women of Gürpinar to develop urban agricultural activities (e.g. composting, processing, marketing and organization) to help sustain them in the future (ETC Urban Agriculture, 2011). A study by Hovorka et al. (2009) provides evidence for the important role women play in household food production, growing vegetables in gardens and vacant urban spaces, raising animals, and trading in fresh and cooked foods.

Infrastructure and maintenance

> Protecting [and financing] the infrastructure used to treat and transport water (including sources, treatment plants and distribution systems) is an important step in ensuring safety in public health and the environment. However, in most cities worldwide, there has been years of neglected maintenance to water storage, treatment and distribution systems. A large proportion of this infrastructure is over 100 years old, placing it at increased risk for leaks, blockages and malfunctions due to deterioration (Vahala, 2004). Higher rates of water leakage mean greater water losses and higher chances of infiltration and ex-filtration of water. This will create higher chances of drinking water contamination and outbreak of water-borne diseases. (Vairavamoorthy, 2008, p. 5)

The cost of rehabilitation of water infrastructure is increasing substantially due to their deterioration over the world. In the USA, for example, the American Society of Civil Engineers forecasts a funding gap of US$108.6 billion over five years for drinking water and wastewater infrastructure system improvements and operations (ASCE, 2009). An earlier study (Olson, 2003) of urban water supply networks in 19 US cities revealed that 'pollution and deteriorating, out-of-date plumbing are sometimes delivering drinking water that might pose health risks to some residents' (NRDC, n.d.).

The deterioration process is more severe for developing countries, due to poor construction practices, little or no maintenance and rehabilitation activities, lack of records, and operation at higher capacities than design. The water supply services sector in sub-Saharan Africa, for example, has long suffered from poor performance of its public water utilities. Apart from service coverage of less than 60% (WHO/UNICEF, 2006), other problems that plague water utilities include high unaccounted-for water (UfW), which often averages between 40% and 60%, and overstaffing (Mwanza, 2005). Moreover, service providers are often confronted with financial problems due to a combination of low tariffs, poor consumer records and inefficient billing and collection practices (Foster, 1996; Mwanza, 2005; International Bank for Reconstruction and Development/World Bank, 1994).

In addition, the informal sector often supplies water to households and is unregulated and difficult to monitor. The poorest families in urban areas, often living in informal settlements lacking public services, often end up paying the most for drinking water that may be unsafe (Briscoe, 1993; Jouravlev, 2004; Garrido-Lecca, 2010). The highest risk for health occurs where there is a lack of basic access to safe drinking water (Howard and Bartram, 2003). The same families that purchase inexpensive drinking water from street vendors may also have poorer hygiene. A study in Jakarta, for example, showed that 55% of drinking water samples taken from households in the slums of east Jakarta had faecal contamination (Vollaard et al., 2004).

Cities of the future

Initiatives are emerging worldwide to address the need for improved and comprehensive urban water planning, technologies, investment and associated operations. The International Water Association

(IWA), for example, has launched the 'Cities of the Future' programme, which focuses on water security for the world's cities, and how the design of cities – including the water management, treatment and delivery systems that serve them – could be harmonized and re-engineered to minimize the use of scarce natural resources, and increase the coverage of water and sanitation in lower and middle-income countries. The Istanbul Water Consensus for Local and Regional Authorities, endorsed in 2009 during the fifth World Water Forum in Istanbul, is a local and regional government declaration that asks signatory cities to commit to developing water management strategies suitable to work towards the Millennium Development Goals (MDGs); and to address urbanization, climate change and other global pressures at local level. At the national level an example comes from a highly urbanized nation, Australia, where the government has recently re-evaluated the urban water sector within the framework of the National Water Initiative, and has identified reforms and changes in policy and institutional settings (National Water Commission, 2011).

Water management together with land-use planning for urban areas will need to become more efficient to meet current and growing demand through technology, investment, and comprehensive and integrated planning for multiple users. Water education can play a very important role in this regard by changing behaviour and attitudes in wider society. The Human Values-Based Approach to Water, Sanitation and Hygiene Education promoted by UN-Habitat is a proven approach that can be incorporated into current educational curricula without imposing a heavy burden on teachers and learners.

Investing in drinking water supply and sanitation systems, promoting efficiency in service provision, providing subsidies for the poor and protecting water resources from pollution and over-extraction are imperative to ensuring access to safe water for all, particularly poor urban populations who are too often left behind.

2.5 Ecosystems

Ecosystems underpin the availability of water, including its extremes of drought and flood, and its quality. Water management often involves trade-offs – and often the transfer of risks – between ecosystem services. Water demand by ecosystems is determined by the water requirements to sustain or restore the benefits for people (services) that we want ecosystems to supply. Better-integrated water management and more sustainable development require the focusing of greater attention on ways to resolve the increasing competition for water between ecosystems and socio-economic sectors.

Human versus 'environment' or 'ecosystem' demands for water have been the subject of debate for decades. A root cause of early disagreement has been the perception that these are somehow different subjects, thereby promoting conflicts between development and environment or nature conservation interests. Over recent years, there has been better convergence of interest through improved recognition that the water used to maintain the environment, or ecosystem integrity, is in fact also a means to support human needs through sustaining the benefits to people that a healthy ecosystem delivers. Such benefits are termed 'ecosystem services' (Box 2.2).

Ecosystems – including, for example, forests, wetlands and grassland components – lie at the heart of the global water cycle. All freshwater ultimately depends on the continued healthy functioning of ecosystems, and recognizing the water cycle as a biophysical process is essential to achieving sustainable water management (Figure 2.10).

Historically, some have regarded ecosystems as an unproductive 'user' of water. This is fundamentally incorrect as ecosystems do not use water – they recycle it. But perceptions are shifting towards managing human interactions with ecosystems ('the environment') in order to support water-related development goals.
All terrestrial ecosystem services, such as food production, climate regulation, soil fertility and functions, carbon storage and nutrient recycling, are underpinned by water, as are, of course, all aquatic ecosystem services. Water availability and quality, in terms of direct use by humans, are also ecosystem services, as are the benefits ecosystems offer to mitigate the extremes of drought and flood. Most ecosystem services are interrelated, and particularly so through water. Decisions that favour increasing one service over, or at the expense of, another therefore inevitably involve trade-offs. Importantly, this trading between ecosystem services can also carry with it the transfer of risks through associated ecosystem changes. Some examples of such trade-offs are provided in Section 8.3.

Biodiversity is also sometimes regarded as an ecosystem service as it does have direct value (i.e. cultural/aesthetic/recreational benefit, existence value); however, it is more widely regarded as underpinning the functioning of ecosystems and therefore their ability to continue to sustain service delivery (Box 2.3).

BOX 2.2

Water and ecosystem services

Ecosystem services (benefits for people) can be grouped in various ways. The Millennium Ecosystem Assessment has provided the most comprehensive assessment of the state of the global environment to date, and has classified ecosystem services as follows:

Supporting services: The services necessary for the production of all other ecosystem services. Supporting services include soil formation, photosynthesis, primary production, nutrient cycling and water cycling.

Provisioning services: The products obtained from ecosystems, including food, fibre, fuel, genetic resources, biochemicals, natural medicines, pharmaceuticals, ornamental resources and freshwater.

Regulating services: The benefits obtained from the regulation of ecosystem processes, including air quality regulation, climate regulation, water regulation, erosion regulation, water purification, disease regulation, pest regulation, pollination and natural hazard regulation (including extremes in water availability).

Cultural services: The non-material benefits people obtain from ecosystems through spiritual enrichment, cognitive development, reflection, recreation and aesthetic experiences, thereby taking account of landscape (including waterscape) values.

Water is multi-dimensional in the context of ecosystem services. Its availability and quality are products (services) provided by ecosystems. But water also influences how ecosystems can function and therefore underpins ***all*** other ecosystem services. This gives water paramount importance in managing ecosystems so as to deliver benefits to people.

The Millennium Ecosystem Assessment concluded that human development had tended to promote certain services (especially provisioning services) at the expense of others. This has led to an imbalance in services and indicates a path towards decreasing sustainability.

Source: Adapted from Ecosystem Services (2011, Crown Copyright).

The subject of 'water demand' by ecosystems therefore involves identifying ecosystem 'deliverables' and managing water accordingly. The valuation of these services is central to this, and the advances made over the past 20 years provide a range of techniques that can be used in practice. Even for many terrestrial ecosystems (such as forests), values related to water services outstrip more conspicuous benefits (such as timber products and carbon storage). For example, the water-related services provided by tropical forests include regulation of water flows, waste treatment/water purification and erosion prevention. These collectively account for a value of up to US$7,236 per ha per year – more than 44% of the total value of forests, exceeding the combined value of carbon storage, food, raw materials (timber), and recreation and tourism services (TEEB, 2009).

Comprehensive valuation of ecosystem services is not yet a precise science, but the process illuminates the potential stakes and provides good comparative indications of where priorities should lie (see Chapters 21 and 23 for further information on valuing ecosystem services). While some services are difficult to value, others are easier because information on how much their losses cost is available. A very large proportion of the capital investment and operational cost of physical water infrastructure is in effect expenditure that compensates for the loss of an ecosystem service, which can therefore

BOX 2.3

Biodiversity increases ecosystem efficiency

Controlling nutrient levels in watersheds is a primary objective of most water management policies. Much research has shown that ecosystems with more species are more efficient at removing nutrients from soil and water than ecosystems with fewer species. Recent experiments have demonstrated, for example, that different forms of algae dominate each unique habitat in a stream, and the more diverse communities achieved a higher biomass and greater nitrogen uptake. When habitat diversity was experimentally removed, these biofilms collapsed to a single dominant species and nutrient cycling efficiency decreased. Maintaining both the physical (habitat) and biological diversity of streams therefore helps to buffer ecosystems against nutrient pollution, demonstrating that the conservation of biodiversity is a useful tool for managing nutrient uptake and storage.

Source: Cardinale (2011).

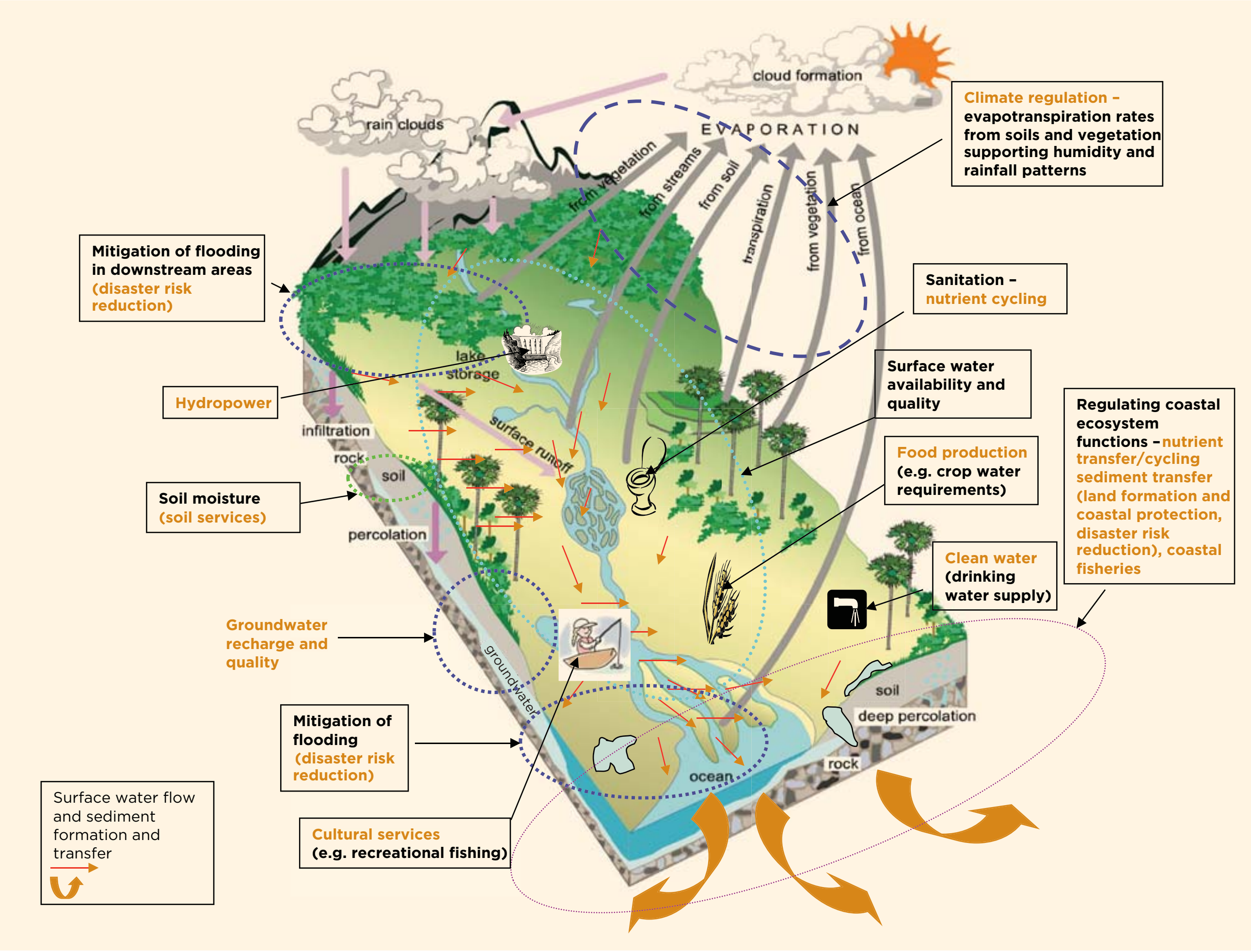
be used to indicate the value of that service. The classic example is water quality whereby, with very few exceptions, healthy ecosystems deliver clean water and any subsequent investment in treating a human-induced water quality problem can be attributed to the loss of this ecosystem service originally provided for free.

Water ‘demand’ by ecosystems, to a large extent, can therefore be assessed based on socio-economic criteria, as for any other use. Indeed, allowing water to underpin ecosystem health and therefore service delivery can result in net economic gains, or cost savings, very visible on financial balance sheets (Box 2.4).

An increasingly useful hydro-ecological expression for the quantity of water needed for healthy ecosystem functioning is ‘environmental or minimum flow’. The approach originates from the consideration of flows required to maintain the life cycles of biodiversity in rivers, as used most frequently in relation to water allocation and the design and operation of water infrastructure such as large dams. But in the past decade or so, the concept of environmental flow, and the science underpinning it, has shifted towards including socio-economic considerations by assessing requirements to maintain or restore the desired levels of ecosystem services in a given area (Box 2.5). The approach is therefore becoming a more powerful decision support tool. Its full application would consider not only surface water flows, but broader ecosystem flows (e.g. considering managing evapotranspiration, soil moisture and groundwater, as per Figure 2.10), and as a

FIGURE 2.10

A simplified conceptual framework illustrating the role of ecosystems in the water cycle



Note: The figure lists in blue some of the water-related ecosystem services provided and underpinned. In reality the various services illustrated, and others, are more dispersed, interconnected and impacted by land and water-use activities (not shown in full).
Source: Adapted from MRC (2003).

quantitative tool to assist more holistic approaches within integrated water resources management (IWRM).

One of the biggest historical failings of water management has been to base allocations on demand as driven by 'sectors', and a worse failing, in many cases, has been to disregard the sustainable supply. Unsurprisingly, this has led to conflict, crisis, overuse and environmental degradation. But approaches are evolving, and the role of the ecosystem in sustaining water supply is becoming increasingly recognized. Furthermore, as described further in Section 8.3, a new paradigm is emerging, which shifts understanding of the 'ecosystem' (environment) as an unfortunate but necessary cost of development to an integral part of development solutions.

Ecosystems are increasingly seen as solutions to water problems, not just as a casualty. The change in perception of ecosystems as just another 'demand' sector is the result of increasing recognition of the services they deliver, their value and an increasing willingness, if not necessity, to sustain them. In practice, this has inevitably led to ever increasing 'competition' between, and debate about, the needs of sectors and 'the ecosystem'. But this is a welcome and positive trend as it also reflects improvement in dialogue and a step towards better-integrated water resources management, and therefore more sustainable development.

BOX 2.4

Rethinking ecosystem water 'demand' using an ecosystem services framework: Disaster risk transfer and mitigation in the Mississippi Delta, USA

River deltas are dynamic and complex ecosystems driven largely by hydrology, including the regular transfer of sediments and nutrients from the catchment into lowlands and the estuary. Their functioning underpins numerous ecosystem services, in particular land regulation and formation. This in turn delivers benefits through the maintenance of coastal stability and erosion regulation, thereby, for example, reducing disaster vulnerability. The Mississippi River Delta, in common with many rivers, has been highly modified: its hydrology has been changed through water abstraction, principally for agriculture, while reservoir construction, also for hydropower, has interrupted sediment transfer. The resulting degradation of associated wetlands services is becoming regarded by some as a major contributing factor to the scale of economic and human losses resulting from hurricanes. If treated as an economic asset, the delta's minimum asset value would be US$330 billion to US$1.3 trillion (at 2007 values) in terms of hurricane and flood protection, water supply, water quality, recreation and fisheries. Rehabilitation and restoration of this natural infrastructure would have an estimated net benefit of US$62 billion annually. This includes reduced disaster risk vulnerability and savings in capital and operational costs for physical infrastructure-based solutions (factoring in the economic costs on existing users of reallocating water use).

Agriculture has been a key driver of water allocation policy. Yet the value of food, fibre and feed produced by agriculture represents only a fraction of the multitude of other services provided by the ecosystem, particularly wetlands. Historically, water development policy for the Mississippi has effectively traded increased agricultural production for other ecosystem services in the delta, and with significant net overall economic loss when viewed holistically. In the context of uncertainty and risk, history shows that the reduction of risks to agriculture (i.e. more stable crop water supply) resulted in the transfer and amplification of risks downstream, amply demonstrated by the impact of hurricane Katrina on New Orleans in 2005.

Source: Batker et al. (2010).

BOX 2.5

The Mekong River Basin, South-East Asia

The Mekong River Agreement, signed in 1995 between Cambodia, Lao PDR, Thailand and Viet Nam, established the Mekong River Commission, and specifically requires minimum stream flows 'of not less than the acceptable minimum monthly natural flow during each month of the dry season' (Mekong River Agreement 1995, Article 6, point A). An Integrated Basin Flow Management Programme has been undertaken since 2004 to support discussions between the governments on sustainable development and reasonable and equitable transboundary sharing of beneficial uses. The process essentially involves assessment of ecosystem services and the relationships between them as illuminated by environmental flows, consideration of water 'demand' as required to achieve agreed multiple uses, and recognition and agreement on relevant trade-offs.

Note: For further information, see MRC (2011). For further information about environmental flows, including 22 different case studies, see Le Quesne et al. (2010).
The text cited in the box is drawn from the Mekong River Agreement, signed by the four countries in 1995. The agreement can be found here: http://www.mrcmekong.org/assets/Publications/agreements/agreement-Apr95.pdf

Notes

1 For detailed reports concerning the coverage of water supply and sanitation services and progress towards the Millennium Development Goal (MDG) relating to drinking water and sanitation (MDG 7, Target 7c), see the latest reports from the Joint Monitoring Programme (JMP) for Water Supply and Sanitation (WHO/UNICEF) at http://www.wssinfo.org and the Global Analysis and Assessment of Sanitation and Drinking-Water (GLAAS) (UN-Water/WHO) at http://www.who.int/water_sanitation_health/glaas.

2 South Africa has now been added to this list and the present abbreviation is BRICS (not BRIC). However, the earlier designation is used in this passage because the statistical information here does not include South Africa.

3 IEA (2006) states that, taking into account very rapid technological progress, the higher figure could be 26,200 million tonnes of oil equivalent instead of 12,000. However, IEA also indicates that a more realistic assessment based on slower yield improvements would be 6,000–12,000. A mid-range estimate of around 9,500 would require about one-fifth of the world's agricultural land to be dedicated to biomass production.

4 The Basel Convention on the Control of Transboundary Movements of Hazardous Wastes and their Disposal is the most comprehensive global environmental agreement on hazardous and other wastes. The Convention has 175 Parties and aims to protect human health and the environment against the adverse effects resulting from the generation, management, transboundary movements and disposal of hazardous and other wastes. The Basel Convention came into force in 1992.

5 The ecological or social impact of a water footprint obviously depends not only on the volume of water use, but also on where and when the water is used.

6 The cradle-to-cradle approach is based on a life-cycle or ecosystem view that aims not just to reduce the negative impacts of industry and growth, but to create equal or positive environmental and social footprints. Cradle-to-cradle products are designed to be completely waste-free, using renewable sources of energy in their production and ensuring water and energy efficiency in their use.

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CHAPTER 3

The water resource: Variability, vulnerability and uncertainty

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Past editions of the *World Water Development Report* (WWDR) have addressed the state of the world's water resources in different but complementary ways. WWDR1 reported on long-term averages and general patterns of water availability through different elements of the hydrological cycle at the global scale. WWDR2 added a greater focus to the dimension of 'variability' in the distribution of water resources over space and through time, also describing some of the main human impacts in terms of the quantity and quality of the resource. WWDR3 explored the relationship between the water cycle and other global biogeochemical cycles, observational evidence of the impacts of climate change on the water cycle, and the need for increased observation and monitoring.

This chapter builds on the information provided in previous WWDR editions, focusing now on specific elements that had not received detailed coverage in the series. In an effort to better understand variability in the resource and the origins of the related uncertainties, this chapter opens with a description of the external stressors on water resources as sources of uncertainty in the hydrological cycle, including the complex, inter-related ensemble of dynamic natural processes, such as the El Niño-Southern Oscillation, which scientists refer to as 'climate forcings'. The chapter then focuses on long-term natural storage via two specific but often overlooked or misunderstood elements of the hydrological cycle – groundwater and glaciers – in terms of their benefits and vulnerabilities. The chapter concludes with a section describing how water quality and quantity are inextricably linked key elements of water availability, adding yet another layer of uncertainty and complexity to understanding and addressing water supply and availability issues.

With the exception of the subsection on glaciers, which is original to Part 1, the material in this chapter has been condensed from the challenge area reports (Part 3/Volume 2) 'State of the resource: Quantity' (Chapter 15) and 'State of the resource: Quality' (Chapter 16) as well as the special report on Groundwater (Chapter 36).

3.1 The hydrological cycle, external stressors on water resources, and sources of uncertainty

Precipitation delivers water unevenly over the planet from one year to the next. There can be considerable variability between arid and humid climates and wet and dry seasons. As a result, distribution of freshwater supplies can be erratic with different countries and regions receiving different quantities of water over any given year.

The average total annual renewable water resources (TARWR) available to each country (Figure 3.1) provides an overview of this geographical variability. Clearly, some countries have more water than others. However, such a measure is imprecise since a country's size can significantly influence much of the variation between different countries. It is often therefore more useful to consider the total water available per person (Figure 3.2), which can provide a more appropriate indication of water availability for social or economic purposes.[1] It should be noted, however, that tropical countries in Asia and Africa with the highest populations have low availability of freshwater. This poses a serious challenge to future water resources development and management (see Chapter 4, Section 4.6.1).

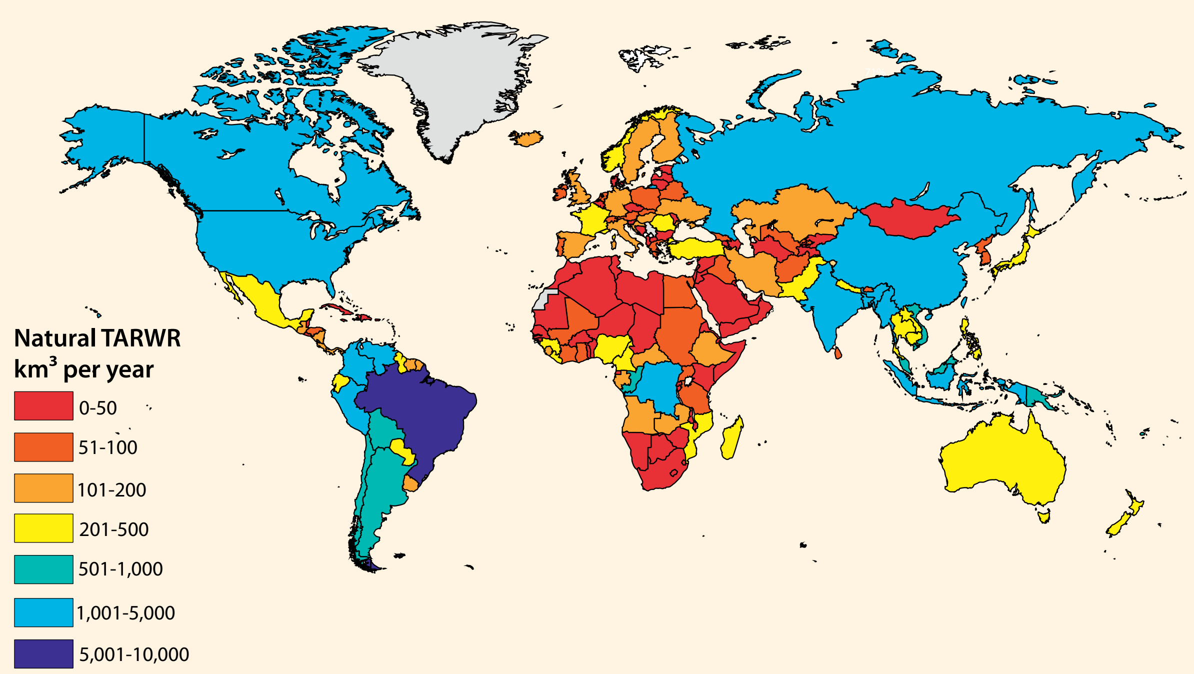
Understanding the spatial and temporal distribution and movement of water is crucial for efficient water resources management. Water resource management plans and policies must take into account this variability and distribution of freshwater supplies.

The hydrological cycle is driven by a complex, interrelated ensemble of dynamic natural processes, which scientists refer to as 'climate forcings'. The Earth's tilt and rotation around the Sun are among the primary drivers of seasonal variations in precipitation and water availability. Atmospheric and oceanic circulation patterns and their interactions are equally important drivers of weather, climate and the hydrological cycle. A better understanding of these phenomena (e.g. the El Niño-Southern Oscillation) and the 'teleconnections'[2] among different drivers can enhance predictive capability in many regions.

Humans are in the process of altering the earth's climate and by inference the global patterns in the circulation of moisture. Significant control over this part of

FIGURE 3.1

Total annual renewable water resources (TARWR) by country – most recent estimates (1985–2010)



Source: FAO AQUASTAT database (http://www.fao.org/nr/aquastat, accessed in 2011).

the hydrological cycle is not possible, but humans do have a significant impact on other components of the cycle. Some interventions are deliberate, such as modifying runoff through storage and inter-basin transfers. The former impacts floods and droughts to ensure water is available *when* needed and damage is averted or minimized when there is an excess; the latter brings water to *where* it is needed. Other interventions such as changing land surfaces for urban settlements or agriculture can severely alter the hydrological cycle through changes in infiltration, runoff and evapotranspiration rates.

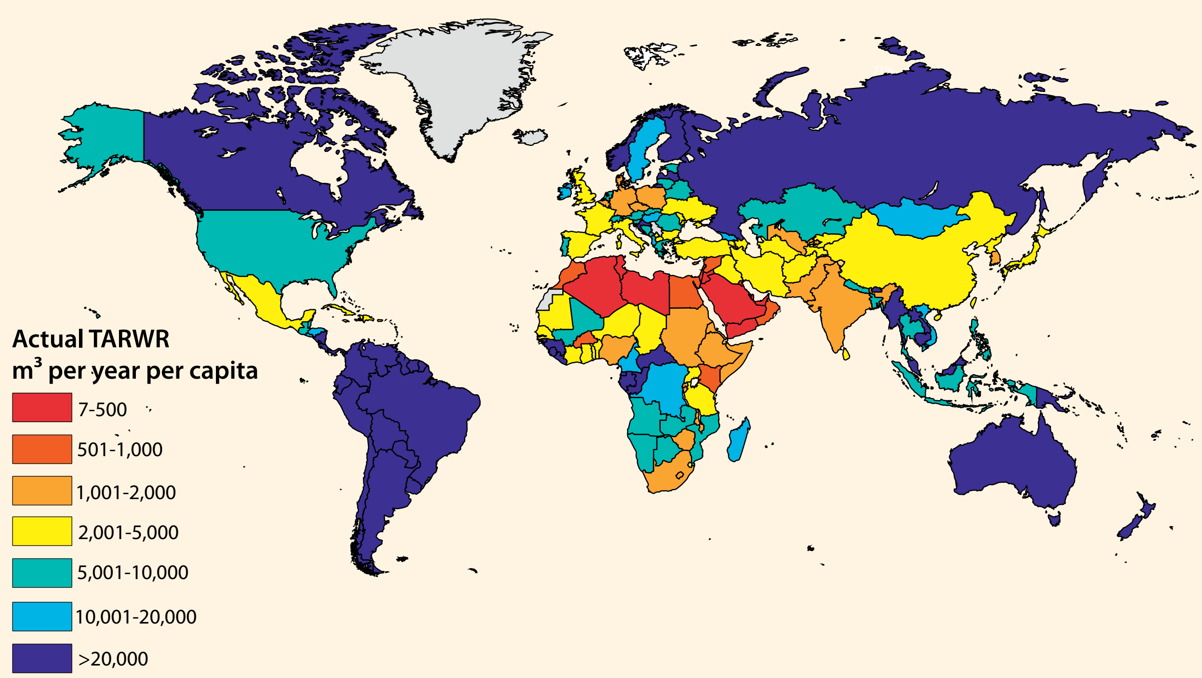
The state of water resources is one of constant change, resulting from the natural variability of the earth's climate system and the anthropogenic alteration of that system and the land surface through which the hydrological cycle is modulated. Specific changes to water resources and the hydrological cycle include:

- Changes in mean surface flows due to natural climate variability at interannual and multidecadal time scales and climate change
- Increased flood potential due to climate change
- Increased losses due to temperature increase
- Changes in the seasonality (or timing) of flows, especially in snow melt basins
- Changes in flows from glaciers due to their retreat
- Decreasing snow and permafrost
- Groundwater depletion – losing the buffer against rainfall variability
- Changes in soil moisture

The state of water resources is also influenced by withdrawals to meet socio-economic demands. These are in turn influenced by population growth, economic development and dietary changes, as well as by control measures exerted to protect settlements in flood plains and drought-prone regions. These change forces and possible developments are described in Chapter 9. These sources of change and the interactions between them create a new level of uncertainty associated with the use and availability of water resources – in addition to existing uncertainties related to the earth's climate system and hydrological cycle. As a result, it is no longer possible to assume that the future hydrological record will follow the course of the historical record.

FIGURE 3.2

Per capita total annual renewable water resources (TARWR) by country – population data from 2009



Source: FAO AQUASTAT database (http://www.fao.org/nr/aquastat, accessed in 2011).

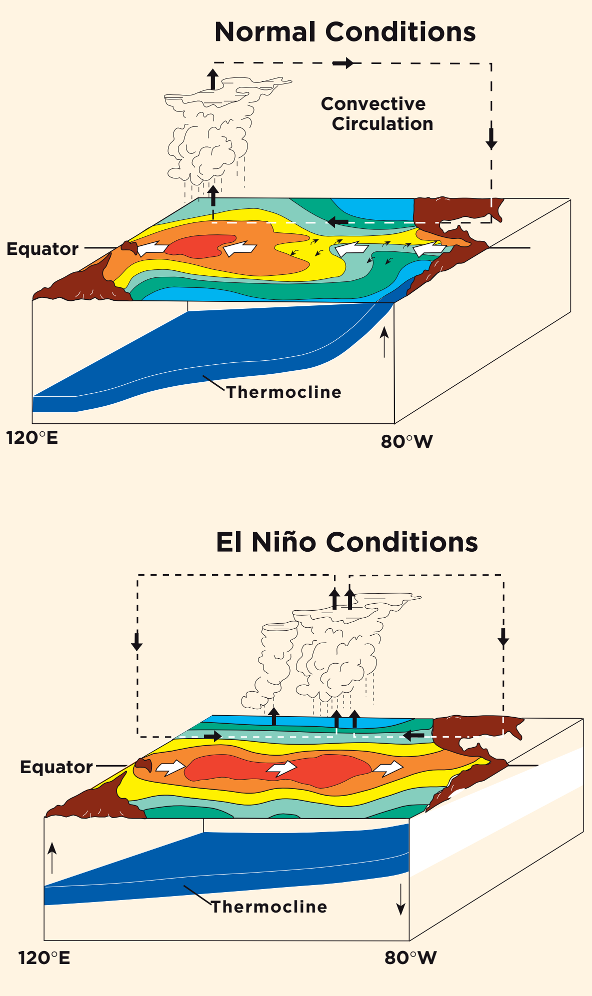
3.1.1 Drivers of global climate and hydrological variability

Water movement on spatial and temporal scales over the globe plays a crucial role in creating areas of abundance and scarcity. It is increasingly evident that a few large-scale climate drivers orchestrate this movement: the El Niño-Southern Oscillation (ENSO), the Pacific Decadal Oscillation (PDO), the North Atlantic Oscillation (NAO) and the Atlantic Multidecadal Oscillation (AMO). Increased understanding of these drivers has led to their use in interannual predictions of hydrology and climate and efficient resource planning. The following sections briefly describe ENSO, PDO and NAO.

> "It is no longer possible to assume that the future hydrological record will follow the course of the historical record."

FIGURE 3.3

Schematic of normal and El Niño conditions in the tropical Pacific Ocean



Source: NOAA/PMEL/TAO (n.d.).

ENSO

The El Niño-Southern Oscillation is a coupled ocean-atmospheric phenomenon in the tropical Pacific Ocean and the dominant driver of global climate at seasonal to interannual time scales. Warm waters in the equatorial western Pacific Ocean shift to the central and eastern region periodically over a three to eight-year time scale (Figure 3.3). As an immediate consequence, tropical western Pacific regions and Northern Australian regions see a reduction in rainfall and tropical eastern parts of South America see an increase in rainfall. These convection changes in the tropical Pacific trigger teleconnection responses to other parts of the world (Figure 3.4), especially South and South-East Asia and Africa. These changes also impact the location and strength of the mid-latitude jet stream and consequently the weather over North America. There has been extensive documentation of ENSO impacts on precipitation, temperature, hurricanes and tropical cyclones, ecosystems, agriculture, water resources and public health around the world, especially from the tropical countries where most of the world's population reside. Figures 3.4, 3.5 and 3.6 show the ENSO schematic, global teleconnections and mid-latitude jet stream shifts.

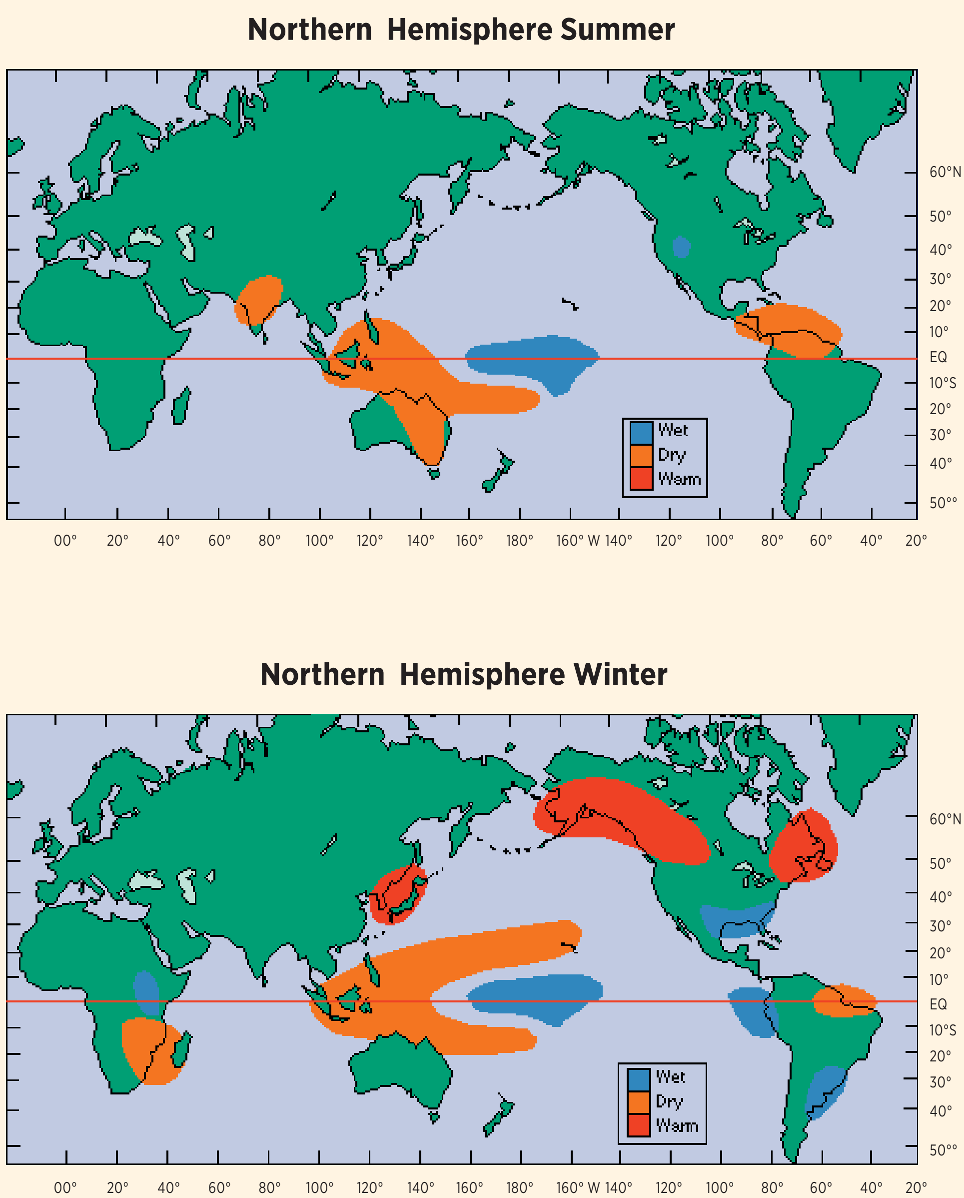
Understanding the ENSO teleconnections alone can provide significant predictive capability in many places. These efforts have received a significant boost since the mid-1990s with ongoing observation of the tropical Pacific Ocean, which has led to skilful long-lead ENSO predictions of immense value to society. The National Oceanic and Atmospheric Administration (NOAA) has created a dedicated site on El Niño[3] that provides information on ENSO monitoring and prediction efforts, and compiles links on impacts as well as numerous references.

PDO

The Pacific Decadal Oscillation is manifested in the large-scale sea surface temperature pattern predominant in the Northern Pacific region, but also includes participation from the tropical Pacific. The pattern resembles that of ENSO, but is slightly broader; furthermore, its index demonstrates a distinct variability over a decadal timescale. PDO has been shown to impact fisheries in the north-western United States of America (USA), and there is a growing body of literature that identifies its impacts on hydrology and extreme events such as droughts, focusing in particular on the same region. Figure 3.4 shows the spatial

FIGURE 3.4

Impacts of El Niño on global climate during northern hemisphere summer and winter seasons



Note: The La Niña impacts are quite symmetric. Notice that ENSO impacts rainfall and temperature especially in the developing countries in the tropics.
Source: NOAA/PMEL/TAO (n.d.).

pattern and time series of this phenomena. The Joint Institute for the Study of the Atmosphere and Ocean (JISAO) has a site that provides substantial details on PDO: data, impacts and bibliography.[4]

NAO

The North Atlantic Oscillation is a climate driver in the North Atlantic region and functions as an atmospheric feature mainly in the winter season. It is characterized by the location and strength of subtropical high-pressure and subpolar low-pressure centres in the North Atlantic (Figure 3.5). The location and strength of these pressure centres steer the jet stream and the storm tracks and consequently the regional climate and hydrology. The role of NAO in modulating European and North American climate has long been known, but the physical mechanism and its role in modulating sea surface temperatures are the subject of intense study. Recent studies have also identified NAO to be part of a hemispherical wide series of pressure centres named the Arctic Oscillation (AO). This has a decadal timescale of variability.[5]

Other drivers

Other climate drivers that that drive the global climate and hydrology at multi-decadal timescales are being studied. These include the Atlantic Multi Decadal Oscillation (AMO) and the Atlantic Meridional Overturning Circulation (AMOC) linked with the thermohaline circulation of which the Gulf Stream is an integral component.[6]

3.2 The vulnerability of natural long-term storage: Groundwater and glaciers

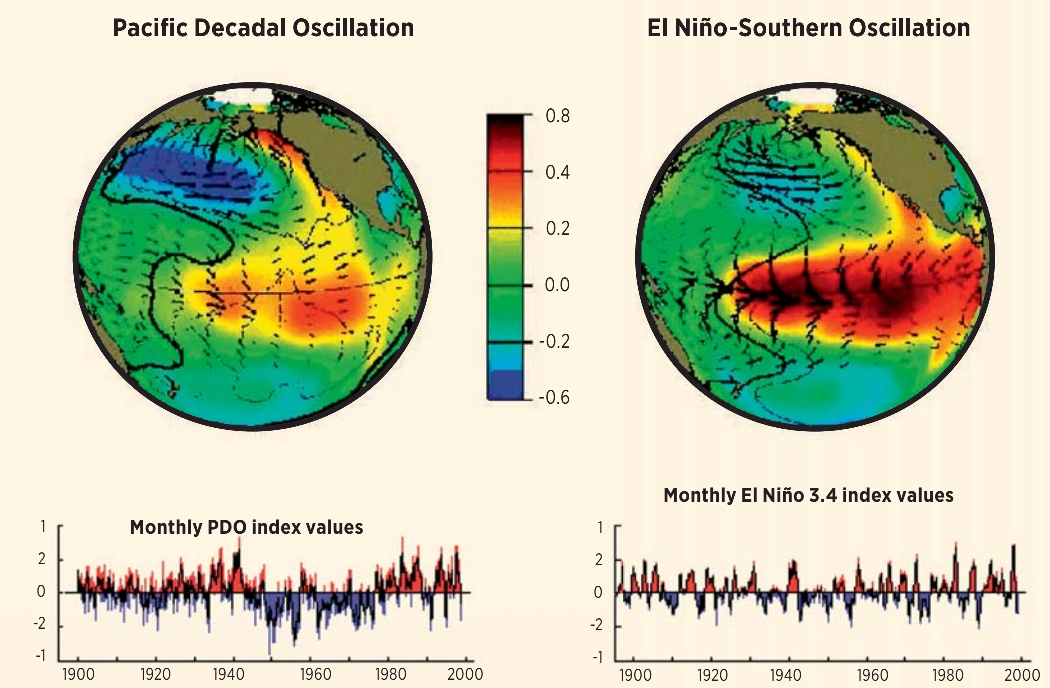
3.2.1 Groundwater: A resilient resource in transition

The changing role of groundwater in the world

Unlike surface water, which has been intensively developed in many parts of the world for thousands of years, groundwater has remained until less than a century ago a rather sparsely developed resource. However, during the twentieth century, an unprecedented 'silent revolution' (Llamas and Martínez-Santos, 2005) in groundwater abstraction took place across the globe. This boom was driven by population growth

FIGURE 3.5

Spatial pattern and time index of PDO and El Niño



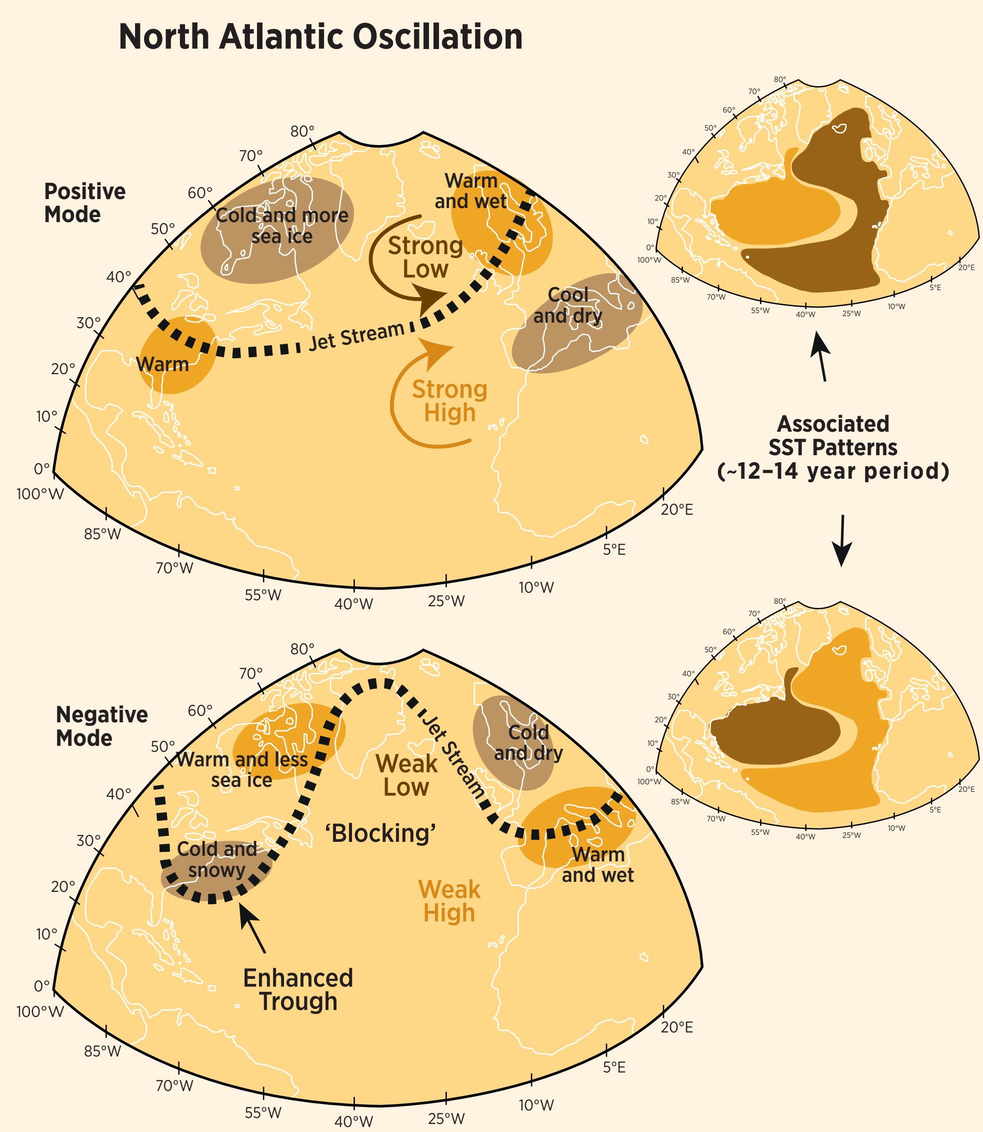
Source: JISAO (2000).

and the associated increasing demand for water, food and income, and facilitated by knowledge, technology and access to funding. Intensive groundwater abstraction began in the first half of the twentieth century in a limited number of countries including Italy, Mexico, Spain and the USA, and then expanded worldwide since the 1960s (Comprehensive Assessment of Water Management in Agriculture, 2007). This fundamentally changed the role of groundwater in human society, in particular in the irrigation sector where it triggered an 'agricultural groundwater revolution' (Giordano and Villholth, 2007), significantly boosting food production and rural development. The use of groundwater has also considerably modified local and global water cycles, environmental conditions and ecosystems.

As of 2010 the world's aggregated groundwater abstraction is estimated at approximately 1,000 km^3 per year – about 67% of which is used for irrigation, 22% for domestic purposes, and 11% for industrial purposes (AQUASTAT, 2011; EUROSTAT, 2011; IGRAC, 2010; Margat, 2008; Siebert et al., 2010).[7] Figure 3.7 shows

FIGURE 3.6

NAO spatial pattern and its impact on the mid-latitude jet stream and its impacts on climate over North America and Western Europe



Source: AIRMAP (n.d., fig.4) (J. Bradbury and C. Wake).

the global distribution of groundwater abstraction by the year 2000. Two-thirds of the total amount is abstracted in Asia with India, China, Pakistan, Iran and Bangladesh as major consumers (Tables 3.1 and 3.2). The global groundwater abstraction rate has at least tripled over the past 50 years and continues to increase at an annual rate of 1 to 2%. In a number of countries, however, abstraction rates have peaked and are now stable or even decreasing (Comprehensive Assessment of Water Management in Agriculture, 2007), as illustrated in Figure 3.8. These estimates may not be precise, but they suggest that the abstraction of groundwater accounts for approximately 26% of total global water withdrawal and equals around 8% of mean global groundwater recharge.

Groundwater is now a significant source of water for human consumption, supplying nearly half of all drinking water in the world (WWAP, 2009) and around 43% of all water effectively consumed in irrigation[8] (Siebert et al., 2010). Yet the relevance and socio-economic impacts of groundwater development are higher than these percentages may suggest. Due to the relatively large volumes of water stored underground, most aquifers have a considerable buffer capacity, which keeps their water available for withdrawal even during very long periods without rainfall. This enables people to have reliable access to water in regions that would otherwise be too dry if their water supply depended only on precipitation or surface water. The most striking example of this buffer capacity is formed by non-renewable groundwater resources: various large aquifer systems on earth still

TABLE 3.1

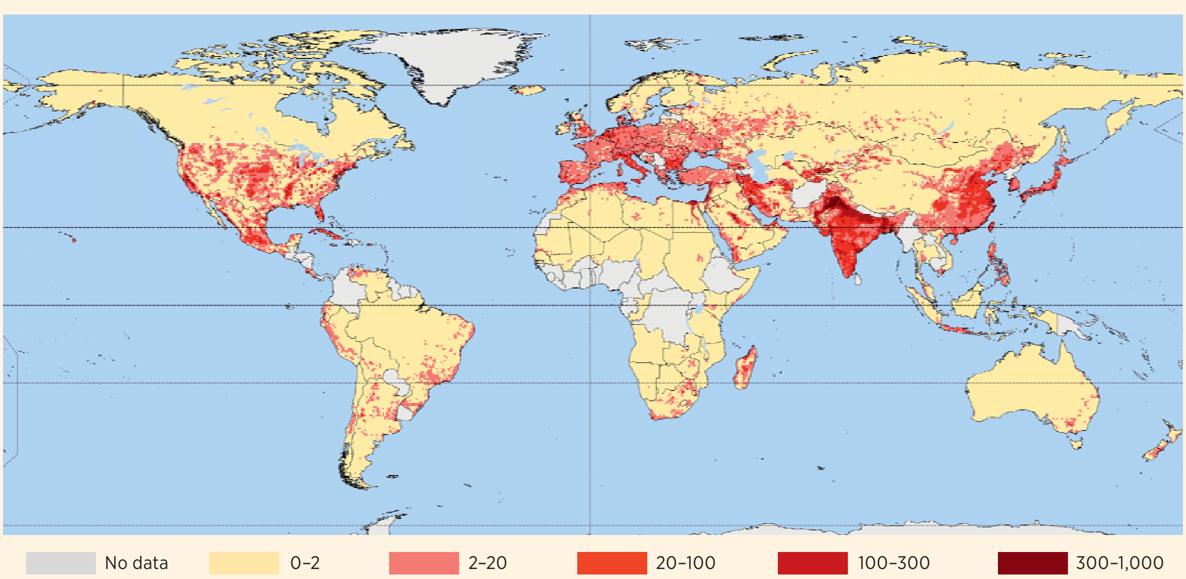
Top 10 groundwater-abstracting countries as of 2010

Country	Abstraction (km^3/year)
1. India	251
2. China	112
3. United States of America	112
4. Pakistan	64
5. Iran	60
6. Bangladesh	35
7. Mexico	29
8. Saudi Arabia	23
9. Indonesia	14
10. Italy	14

Note: About 72% of the global groundwater abstraction takes place in these ten countries.
Source: Data from IGRAC (2010), AQUASTAT (2011) and EUROSTAT (2011).

FIGURE 3.7

Intensity of groundwater abstraction by the year 2000 (in mm per year), as allocated to 0.5° x 0.5° grid cells by the PCR-GLOBWB model



Source: Wada et al. (2010, p. 2, © American Geophysical Union, reproduced by permission).

contain very large volumes of groundwater in spite of not having received significant replenishment during recent millennia (Foster and Loucks, 2006). However, no matter how large the volumes of water contained in these aquifers may be, the fact that they are non-renewable means they can eventually be mined to exhaustion if their use is not managed properly. And there are hotspots where the availability of non-renewable groundwater resources has reached critical limits (see below).

Groundwater is crucial for the livelihoods and food security of 1.2 to 1.5 billion rural households in the poorer regions of Africa and Asia (Comprehensive Assessment of Water Management in Agriculture, 2007), but also for domestic supplies of a large part of the population elsewhere in the world. Furthermore, groundwater-fed irrigation is usually considerably less susceptible to water shortage risks than irrigation supplied by surface water. This is likely to result in higher economic returns per unit of water used, as demonstrated by studies in Spain (Llamas and Garrido, 2007) and India (Shah, 2007). Consequently, the share of groundwater in the overall socio-economic benefit from abstracted water tends to be higher than its volumetric share in the total water abstraction.

Significant changes in the state of groundwater systems

Inflows and outflows, the volume of water stored and related groundwater levels, and water quality, are key characteristics of the state of any groundwater system. Steadily increasing rates of groundwater abstraction and other human interactions with groundwater, such as those produced by changing land use and emission of polluting substances, all affect the state of groundwater systems. Climate change and water resources management measures also have an impact on the state of groundwater systems. As a result, the majority of the world's groundwater systems are no longer in dynamic equilibrium, but do show significant trends. In particular, reduction of natural outflows, decreasing stored volumes, declining water levels and water quality degradation are widely observed, along with changes in the mean rate of groundwater renewal.

The groundwater resources world map produced by WHYMAP (2008) provides a visual impression of the global geographic distribution of favourable versus less favourable groundwater zones in terms of hydraulic continuity, stored volume and rate of groundwater renewal (recharge). A large proportion of the earth's groundwater (probably 80 to 90%) is stored in the zones mapped as 'major groundwater basins', covering only around 35%

TABLE 3.2

Key estimates on global groundwater abstraction (reference year 2010)

Continent	Groundwater abstraction[1]					Compared to total water abstraction	
	Irrigation	Domestic	Industrial	Total		Total water abstraction[2]	Share of groundwater
	km^3/year	km^3/year	km^3/year	km^3/year	%	km^3/year	%
North America	99	26	18	143	15	524	27
Central America and the Caribbean	5	7	2	14	1	149	9
South America	12	8	6	26	3	182	14
Europe (including Russian Federation)	23	37	16	76	8	497	15
Africa	27	15	2	44	4	196	23
Asia	497	116	63	676	68	2257	30
Oceania	4	2	1	7	1	26	25
World	666	212	108	986	100	3831	26

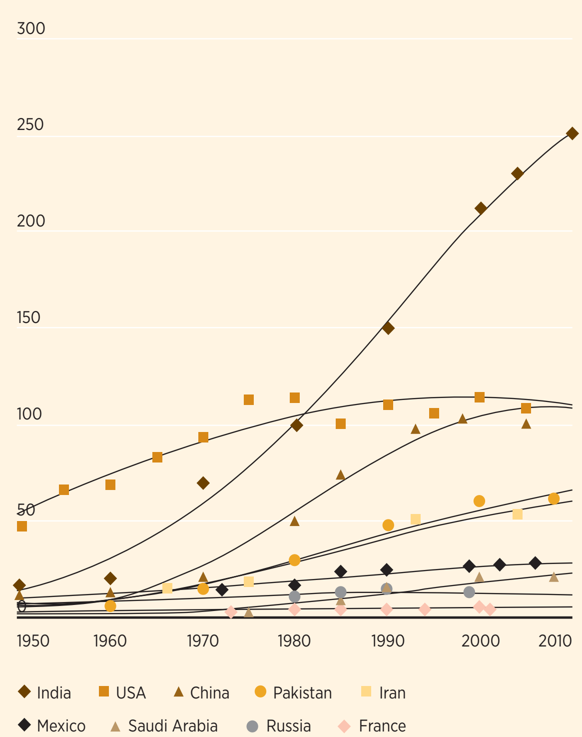
1 Estimated on the basis of IGRAC (2010), AQUASTAT (2011), EUROSTAT (2011), Margat (2008) and Siebert et al. (2010).
2 Average of the 1995 and 2025 'business as usual scenario' estimates presented by Alcamo et al. (2003).

of land surface. The global volume of stored groundwater is poorly known; estimates range from 15.3 to 60 million km^3, including 8 to 10 million km^3 of freshwater, while the remainder – brackish and saline groundwater – is predominant at great depth (Margat, 2008).

Recent model studies have produced global patterns of mean annual groundwater recharge (Döll and Fiedler, 2008; Wada et al., 2010), showing a strong correlation with global mean annual rainfall maps. The mean global groundwater recharge estimated by these models – $12.7 \cdot 10^3$ km^3 per year (Döll and Fiedler, 2008) and $15.2 \cdot 10^3$ km^3 per year (Wada et al., 2010), respectively – is at least three orders of magnitude smaller than the estimated total groundwater storage. What these estimates do not take into account is the possible impact of climate change. However, a recent study by Döll (2009) simulates climate change impacts on the basis of four Intergovernmental Panel on Climate Change (IPCC) scenarios, comparing the model outcomes with those of the reference period 1961–1990. The study concludes that groundwater recharge is likely to increase in the northern latitudes by the 2050s, but strongly decrease (by 30 to 70% or more) in certain currently semi-arid zones, including the Mediterranean, North-Eastern Brazil and South-Western Africa. The numerous narrow and shallow alluvial aquifers (strip aquifers) in dry climatic zones are among the world's most vulnerable with respect to climate change (van der Gun, 2009).

FIGURE 3.8

Groundwater abstraction trends in selected countries (in km^3 per year)



Source: Adapted from Margat (2008, fig. 4.6, p. 107).

Groundwater abstraction causes depletion of groundwater storage until a new dynamic equilibrium is established, under conditions of reduced natural outflow and/or induced recharge. In the world's arid and semi-arid zones, numerous groundwater systems are not resilient enough to accommodatestorage depletion under intensive groundwater development.[9] Evidently, this is true for non-renewable groundwater (Foster and Loucks, 2006), but it applies as well to many aquifers currently being recharged. The result is a progressive depletion of groundwater, accompanied by steadily declining groundwater levels. Konikow and Kendy (2005) estimate that about 700 to 800 km^3 of groundwater has been depleted from aquifers in the USA during the twentieth century. Recently, the Gravity Recovery and Climate Experiment (GRACE) produced estimates of the current rate of groundwater depletion in a number of very large aquifers (Rodell et al., 2009; Famiglietti et al., 2009) and a global simulation model produced estimates for the entire planet (Wada et al., 2010). Results so far show that significant groundwater storage depletion is taking place in many areas of intensive groundwater withdrawal.[10] Physical exhaustion of groundwater storage is a threat in very shallow aquifers only. More commonly, the more important impacts of groundwater depletion are side-effects of the associated declining water levels, and include increasing cost of groundwater (due to larger pumping lifts), induced salinity and other water quality changes, land subsidence, degraded springs and reduced baseflows.

While the bulk of global groundwater resources at shallow and intermediate depths have adequate quality for most uses, gradual changes in local groundwater quality have been observed in zones scattered around the world. The most ubiquitous changes are caused by pollutants produced by humans such as liquid and solid waste, chemicals used in agriculture, manure from livestock, irrigation return flows, mining residues and polluted air. A second category results from the migration of poor quality water into aquifer zones, such as saltwater intrusion in coastal areas or upward migration of deep saline groundwater as a result of groundwater abstraction. Climate change and associated sea level rise are expected to constitute another threat to groundwater quality in coastal areas.

Impacts on other components of the physical environment

The most visible impact of groundwater abstraction and associated changes in the groundwater regime relates to the reduction of natural groundwater outflows. The decrease or disappearance of the baseflow of streams, spring discharge and groundwater-related ecosystems has significantly changed the physical environment in many parts of the world, especially in arid and semi-arid zones.

Figure 3.9 shows a striking example of baseflow reduction due to groundwater storage depletion. In flat areas, the hydraulic setting may be such that part of the direct flow of streams (i.e. the more rapid and often more voluminous flow component) may be lost to adjacent aquifers.

Groundwater abstraction has caused land subsidence in numerous areas around the world where water-saturated compressible formations at relatively shallow depths are in hydraulic connection with intensively exploited aquifers. In flat areas with shallow water tables, land subsidence may generate the need for more intensive drainage, which in turn accelerates land subsidence (Oude Essink et al., 2010).

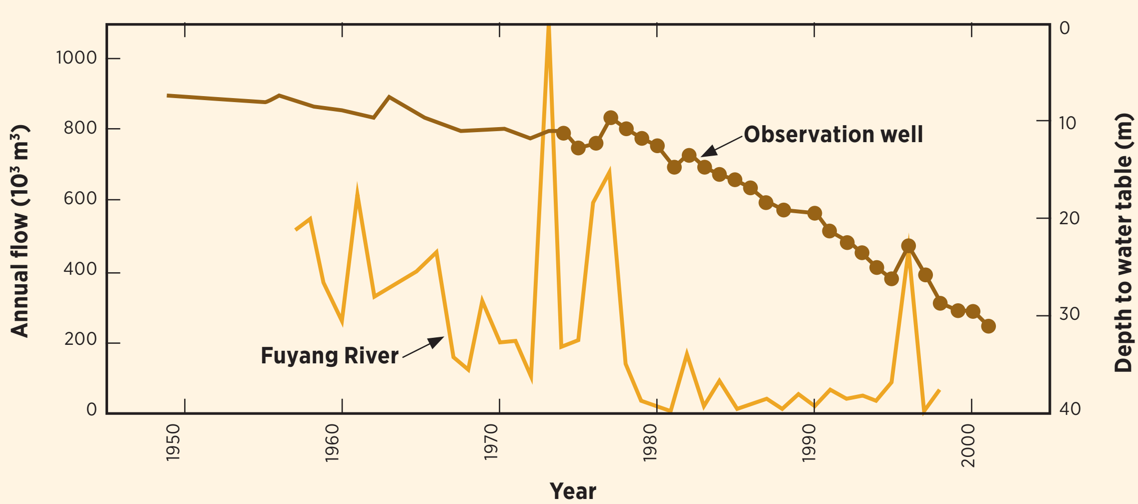
Of particular note is the impact of groundwater depletion on sea level rise. Konikow (2009), Konikow and Kendy (2005) and Wada et al. (2010) argue that the ultimate sink for most of the groundwater removed from aquifers by depletion is the oceans. Although their estimates are not yet precise, they make a plausible argument for groundwater depletion contributing significantly to sea level rise, implying that the current rise in sea level is due in part to influences other than climate change.[11]

Groundwater: Cause for concern or opportunity?

Groundwater constitutes a significant part of the water resource with profound impact on human welfare. Groundwater systems around the world are coming under increasing stress from various anthropogenic and natural factors. In many areas, this threatens the future availability of good-quality groundwater at affordable cost or in situ environmental functions of groundwater. Sound water resources management based on scientific knowledge and paying due attention to groundwater is therefore crucial. It should strive for a balance between present and future benefits

FIGURE 3.9

Stream and well hydrographs from the North China Plain, showing evidence of reduced stream flow caused by groundwater depletion



Source: Konikow and Kendy (2005, fig. 1, p. 318, with kind permission of Springer Science+Business Media).

from groundwater, pay attention to deterioration of groundwater quality, control environmental impacts of groundwater abstraction, and mitigate such impacts in cases where reduced groundwater availability cannot be prevented.

In spite of real concerns about unsustainable abstraction rates and pollution in many parts of the world, groundwater presents many opportunities and will continue to do so in the future if carefully managed. Groundwater's omnipresence and unique buffer capacity have enabled people to settle and survive in dry areas where rainfall and runoff are scarce or unpredictable. Groundwater is a reliable source of domestic water to many rural and urban areas around the world, and subsequent to the silent revolution has contributed and still contributes to significant socio-economic development and poverty alleviation. Groundwater is also likely to play a crucial role in the context of climate change and adaptation. In many water-scarce regions, climate change is expected to result in reduced and more erratic surface water and 'green water' availability. Groundwater recharge will decrease there as well, but the groundwater storage buffer will in most cases ensure uninterrupted water availability, thus triggering a shift in withdrawals from surface water to groundwater. This will reduce overall water supply risks and suggests that groundwater in such regions will provide the key to coping with water scarcity problems imposed or aggravated by climate change during the twenty-first century.

3.2.2 Glaciers

The role of glaciers within mountain hydrology

Mountains are the 'water towers' of the world, receiving much more precipitation than the surrounding lowlands. Their contribution to water supply is of particular significance where the lowlands are arid (Viviroli et al., 2003).

Mountain stream flow is composed of three major elements: rainfall, snow melt and water from glacier melt. The relative importance of these elements, varying through time and with elevation, is largely controlled by temperature and seasonality of precipitation. In many mid-latitude situations there is, on average, no marked seasonality in precipitation; winters are characterized by snowfall and summers by rainfall. In spring, snow melt may dominate the hydrograph, while glacier melt becomes more important in late summer. During years of low snowfall, glacier ice will begin to contribute melt-water to the streams earlier in the season and will be more dominant in late summer; thus, glaciers act as buffers with waters being released from permanent storage in years of low snowfall and as retaining waters (in the form of ice) in years of heavy snowfall.

"The global groundwater abstraction rate has at least tripled over the past 50 years and continues to increase at an annual rate of 1 to 2%."

The differences between winter and summer become more pronounced moving pole-wards from mid-latitudes, and are reduced moving towards the equator. Precipitation also varies with the type of climate: in Mediterranean climates winter precipitation predominates, while in monsoon climates summer precipitation is more pronounced.

Rising global temperatures have a particular effect on the relative importance of rainfall and snowfall, and on the rates at which glaciers are melting. In general, mountain glaciers are shrinking worldwide – with some notable exceptions, for example, in the Karakoram (Hewitt, 2005). In the short term, the shrinking of glaciers is adding water to stream flow over and above annual precipitation, thus increasing water supply. In the long term (decades to centuries), those additional sources of water will diminish as glaciers disappear, and the buffering effects of glaciers on stream flow regimes will lessen. Overall changes in glacier mass balance are well summarized by Dyurgerov (2010) and the Global Land Ice Measurements from Space (GLIMS) database.

Glacier-related floods are also important in many mountain regions, as illustrated in the examples below.

Regions of the world affected by glacier melt-waters

The global distribution of glaciers and ice sheets is illustrated in Figure 3.10. Most large ice masses are found in regions with sparse human habitation. However, glaciers of the Alps, the Andes, Central Asia, the Caucasus, Norway, New Zealand and Western Canada are important for water supply. In most of these regions glaciers are shrinking with impacts on stream flow as described above.

Populations are growing in all of these regions, and the subsequent demands for water are increasing. In several regions alternative sources of water are being depleted, in particular, groundwater. In most regions, supply is being outstripped by demand. It is arguable that changes in demand are often more significant than changes in supply; thus, care must be taken to consider both sides of the supply/demand equation in assessing water resources.

Examples from the Himalayan region

The basins of the Brahmaputra, Ganges and Indus, encompassing the Himalaya and Karakoram (illustrated in Figure 3.11) demonstrate the importance of glaciers on stream flow. Within these basins live some 0.8 billion people dependent on stream flow for water supply and at risk from glacier-related floods.

This region is characterized by great climatic, glaciological and hydrological diversity. The eastern Himalaya is dominated by the summer monsoon. Westward, the intensity of the monsoon diminishes, while in the Karakoram, intensive summer precipitation occurs only in exceptional years. Local precipitation varies greatly from less than 5,000 mm per year on the southern flanks of the eastern Himalaya to less than 250 mm per year on the northern slopes (Young, 2009).

Figure 3.12 illustrates glacier extent in the region. Most of the glaciers in the Himalaya are relatively small; they are found predominantly at high elevations and respond relatively quickly to global warming. Large glaciers dominate the Karakoram with areal extents of greater than 500 km^2. Such glaciers, many of which are surge-type, extend to elevations below 3,000 m and respond very slowly to changes in climate. Many are currently growing in areal extent and probably also in mass.

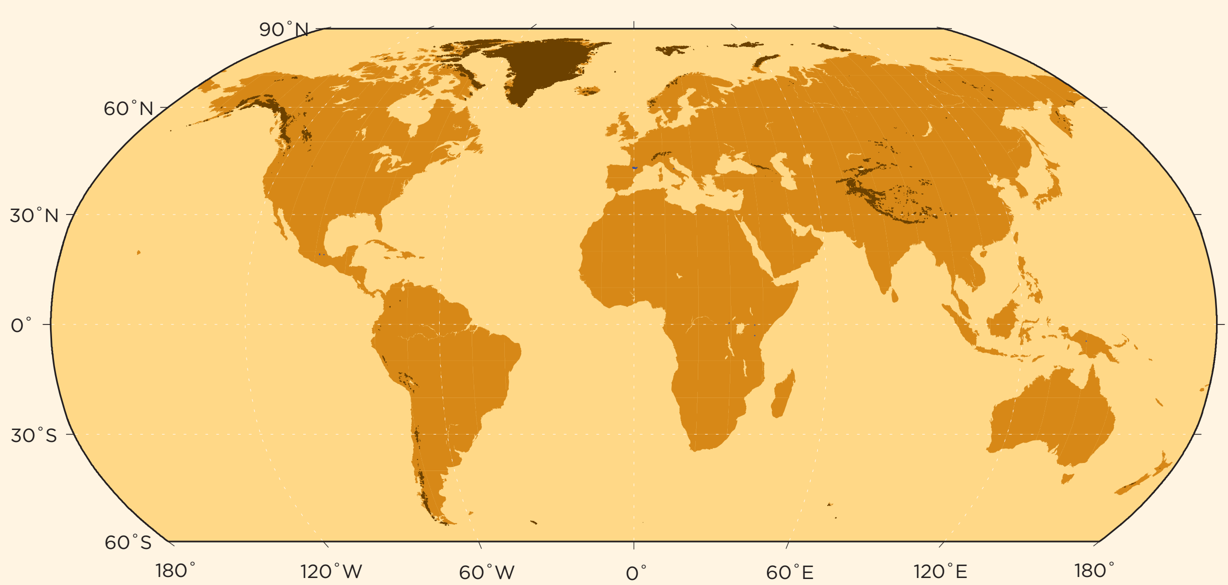
Glacier melt contribution to stream flow

The significance of glacier melt contribution to stream flow may be divided into two components:

- *The melting of glacier ice in the ablation zone,* that is, the part of the glacier with an annual net loss of mass. Such melting varies in importance within the Himalayan region. In the eastern Himalaya glacier,

FIGURE 3.10

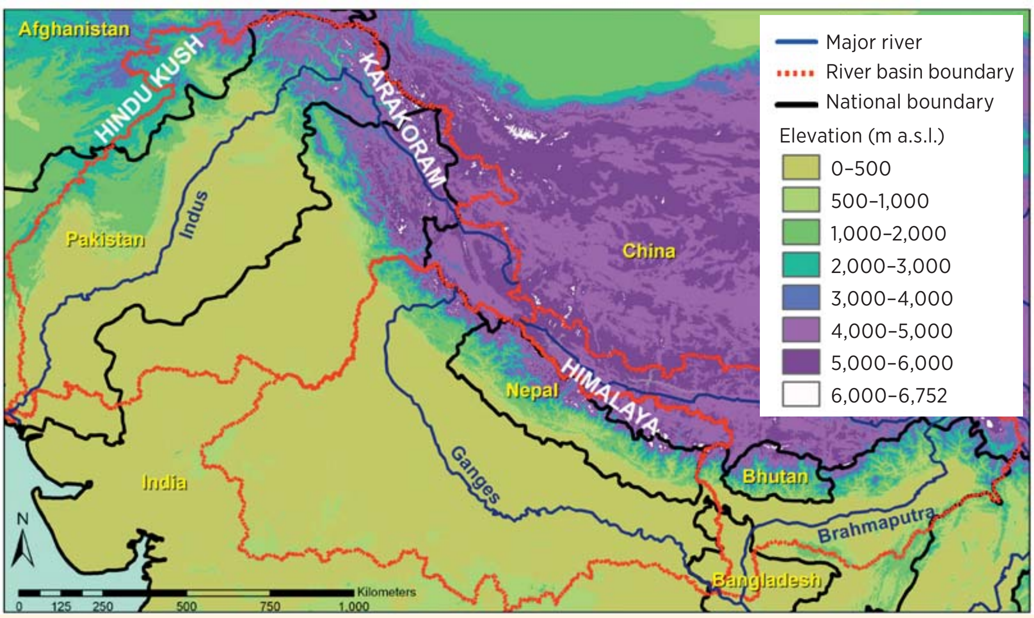
Global distribution of glaciers and ice sheets (Antarctica excluded)



Source: Armstrong et al. (2005, courtesy B. H. Kaup, National Snow and Ice Data Center, GLIMS).

FIGURE 3.11

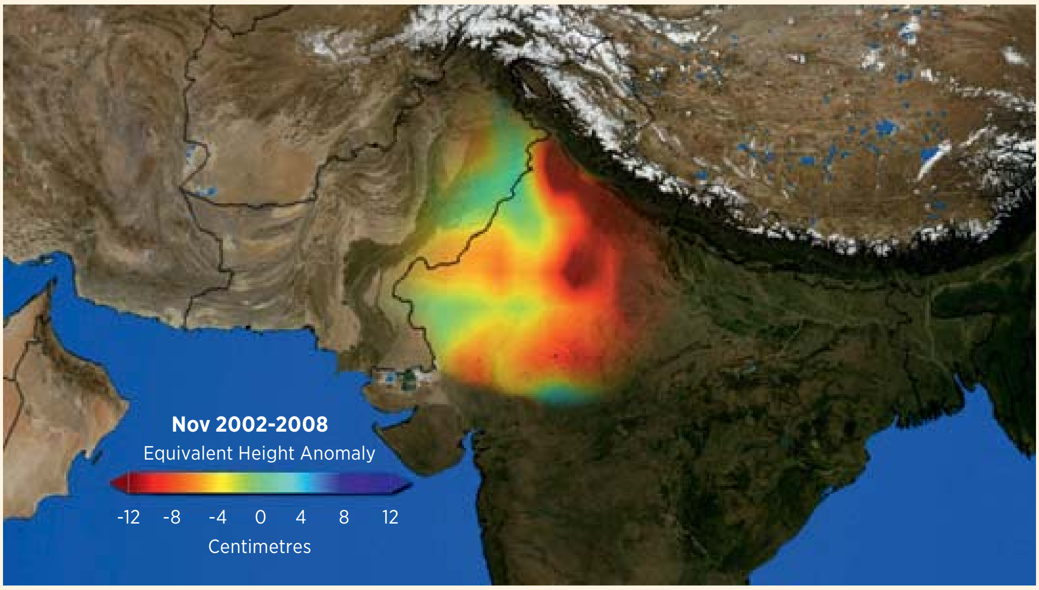
Delineation of the basins of the Brahmaputra, Ganges and Indus



Source: Miller et al. (2011 [in press], fig. 1, p.7, using US Geological Survey ESRI data).

FIGURE 3.12

GRACE satellite image showing the extent of glacier cover in the Himalaya – Karakoram and estimation of groundwater depletion in north-west India



Note: The loss of 109 km³ over a six-year period is significant.
Source: NASA GRACE Satellite image (http://www.nasa.gov/topics/earth/features/india_water.html), T. Schindler and M. Rodell.

ice melt is completely overshadowed by monsoon rainfall and snow melt, with the ice melt contributing less than 3% of annual stream flow. In the Karakoram, the glacier melt contribution is much more significant, reaching more than 20% of annual flow in some years during late summer.

- *The contribution derived from shrinkage of the glacier mass due to global warming,* that is, water being released from permanent storage and adding to stream flow derived from annual precipitation. While there is good evidence that most glaciers in the Himalaya are, very slowly, losing mass, many glaciers in the Karakoram are gaining mass (Hewitt, 2005). It has been clearly demonstrated that glaciers in different parts of the region are shrinking (or in some instances gaining) mass at very different rates (Scherler et al., 2011.) Those that are shrinking are doing so very slowly, probably contributing much less than 1% to annual stream flows. It is likely that very large glaciers will contribute melt-water to stream flow at much the same rate for many decades and possibly centuries; however, some glaciers will recede or even disappear (as in Peru [Oblitas de Ruiz, 2010]), with the resulting decrease in water supply for various uses, as in some areas of Argentina, Chile and Peru (ECLAC, 2009).

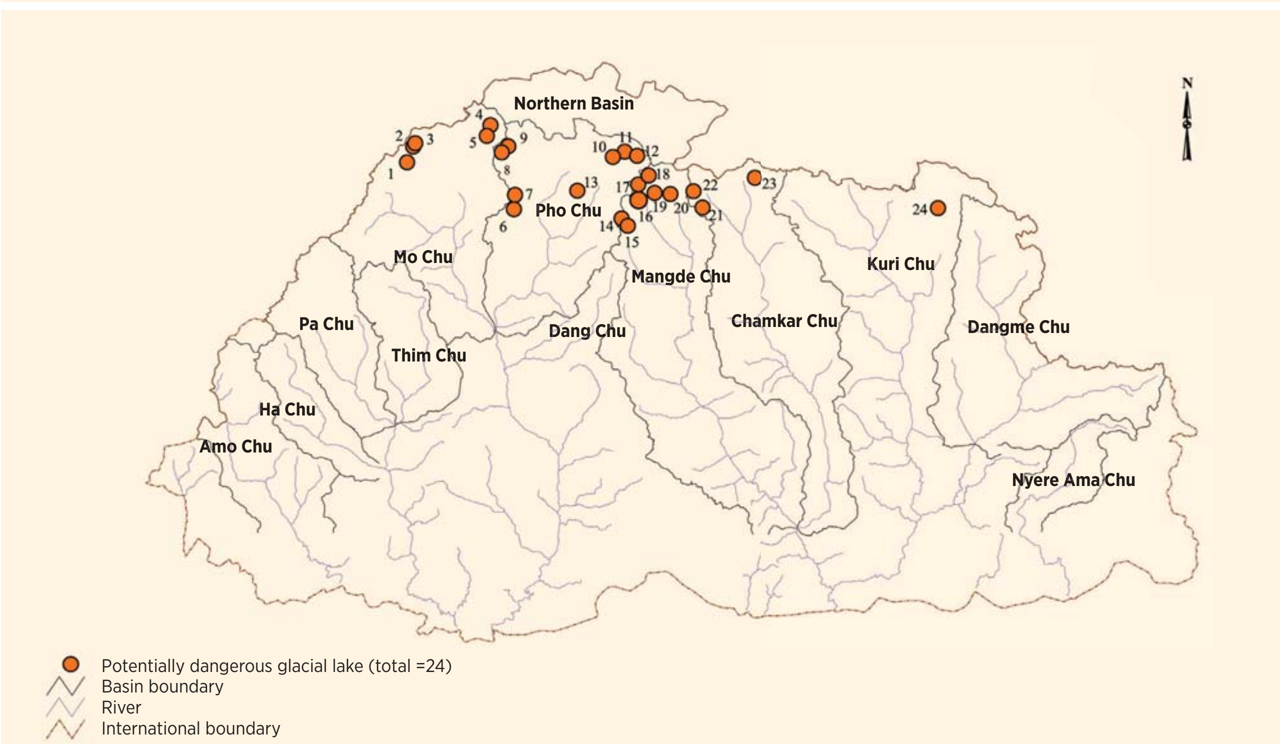
FIGURE 3.14

Lugge Tsho Glacial lake, Bhutan

Source: Mool et al. (2001b, plate 9.13, p. 93).

FIGURE 3.13

Dangerous glacier dammed lakes within Bhutan



Source: Mool et al. (2001a, p. 109).

Glacier-related floods

There are two types of glacier-related floods in the region: glacier lake outburst floods (GLOFs) and outbursts of glacier-dammed lakes (jökulhlaups).

GLOFs result from small pro-glacial lakes – that is lakes impounded by terminal and lateral moraines in front of the glacier termini – emptying very rapidly, producing floods of high intensity and short duration. With glaciers retreating due to global warming, such lakes are becoming larger. Sudden releases can result from the collapse of the retaining moraine or as a result of landslides into the lake with sudden displacement of the waters. The risks from such floods are increasing. There are many thousand such glacier lakes in the region. GLOFs can cause extensive damage downstream, with loss of life and economic damage from destruction of bridges, hydro plants and other infrastructure (Ives et al., 2010). In Bhutan, there are over 2,400 such lakes, 24 of which have been identified as potentially catastrophic (Figures 3.13 and 3.14).

Jökulhlaups result from the sudden release of water from lakes impounded by glaciers that have dammed valleys. Sudden release of lake waters can be truly catastrophic for the Karakoram (Hewitt, 1982), as illustrated in Figure 3.15. In the 1920s, successive floods initiated on the Shyok River resulted in an 18 m increase in the water level at Attock 1,400 km downstream, with catastrophic results in the plains of the Punjab.

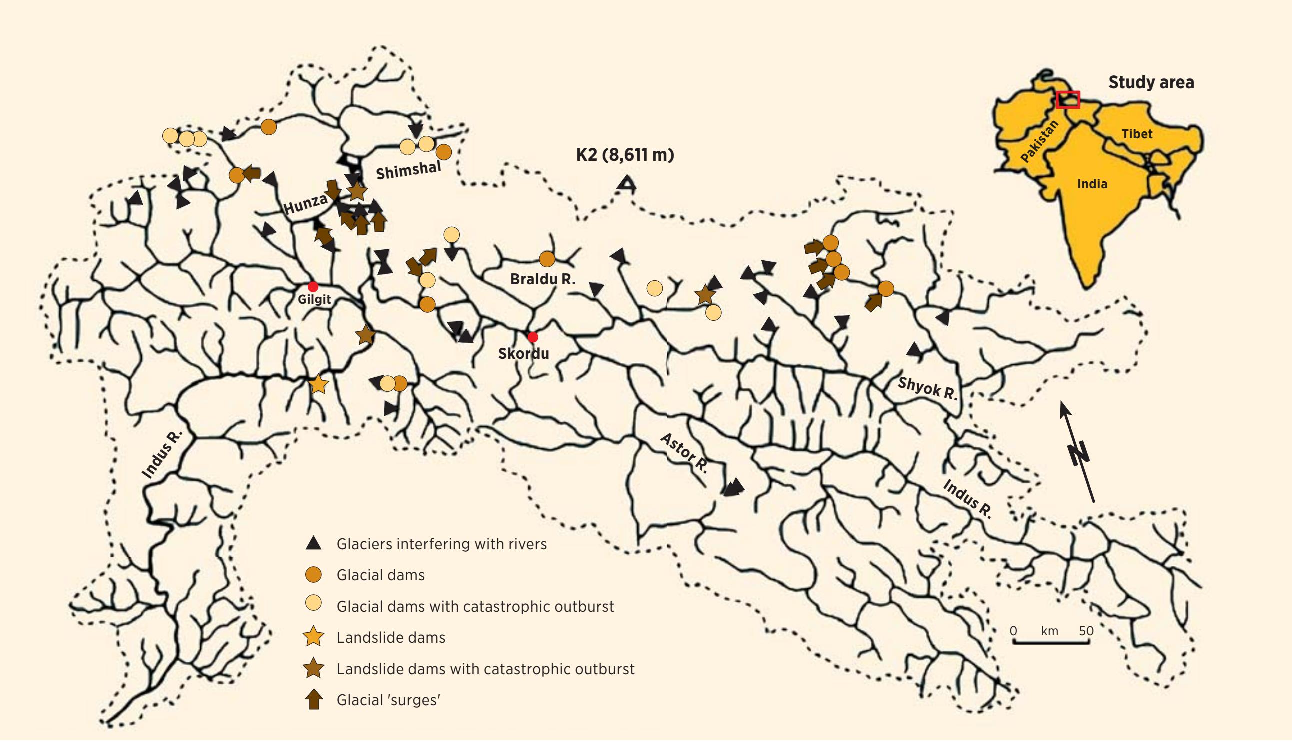
Policy options to deal with uncertainty and risk related to glaciers in the Himalayan region

The transboundary nature of all three of the river systems concerned – with headwaters in China, mid-sections in Nepal/Bhutan and/or India, and lower sections in Pakistan or Bangladesh – means that policy options for water resources management need to be considered within a broad political and economic context. The sharing of water resources between these countries is a challenge.

Demands for water supply are growing with dramatic population increases, a situation further complicated by the migration of people from rural to urban settings. In addition, economic development and higher standards of living are increasing demands for water. All of these issues pose challenges for water managers.

FIGURE 3.15

Indus River: Glacier dams and related events



Source: Hewitt (1982, p. 260, by permission IAHS).

> “Wastewater management solutions also need to be combined with public education efforts, such as those related to personal hygiene and environmental education.”

Alternative water supplies, particularly groundwater resources in north-west India vital to human life and livelihoods, are being depleted unsustainably (Figure 3.12). This has important implications for overall water supply.

A summary of how the countries in the region are adapting to the effects of climate change is provided in ICIMOD (2009). However, there is a general perception within most government circles that glacier melt and shrinkage will be highly detrimental to water supply. This perception is almost certainly misplaced. Most glaciers will continue to shrink very slowly, adding water to the streams over and above annual precipitation, but only in very small quantities relative to precipitation.

An example of how Bhutan is addressing flood risk issues is given within the UNDP Adaptation Learning Mechanism. The objective of the project is to reduce climate change-induced GLOF risks. Through the project, the Government of Bhutan will integrate long-term climate change-induced risks into the existing disaster risk management framework. It will demonstrate practical measures to reduce GLOF risks, such as installing pumps to reduce lake levels and introducing early warning systems to alert downstream populations.

3.3 Water quality

The ‘quality’ of water is a relative term. The notion of ‘good’ or ‘bad’ water quality is not only a function of its state and what it contains, but also depends on what it is used for. ‘Pure’ water does not exist in nature but only in the laboratory, and all substances may be pollutants depending on their concentration in water. This is one of the reasons health professionals often prefer to use the term ‘safe’ water rather than ‘clean’ water.

Sufficient water supply of appropriate quality is a key ingredient in the health and well-being of humans and ecosystems, and for social and economic development. Water quality is becoming a global concern of increasing significance, as risks of degradation translate directly into social economic impacts. Although there have been some regional successes in improving water quality, there are no data to suggest that there has been an overall improvement in water quality on a global scale.

Water quality is inextricably linked with water quantity as both are key determinants of supply. Compared to water quality, water quantity has received far more investment, scientific support and public attention in recent decades. However, water quality is just as important as water quantity for satisfying basic human and environmental needs. Moreover, the two are inextricably linked, with poor water quality impacting water quantity in a number of ways. For example, polluted water that cannot be used for drinking, bathing, industry or agriculture may effectively reduce the amount of water available for use in a given area (UNEP, 2010). The more polluted the water is, the greater the incremental cost of treatment required to return it to a useable standard (UNEP, 2010).

According to Stellar (2010), ‘The link between quality and quantity can take different forms in the cases of ground water and surface water. Where subterranean aquifers are concerned, there is an explicit connection between over-use and quality degradation’. Excessive pumping of groundwater over time can diminish water quality in two ways. First, quality can be affected through increased concentrations of naturally occurring compounds that become dangerously high as the amount of water dwindles, as in the case of India where fluorosis potentially threatens or directly affects millions of people. Second, quality can be affected by increasing salinity levels as a result of saltwater intrusion into coastal aquifers, as in the case of Cyprus and the Gaza Strip (Stellar, 2010). The most immediate problem that saltwater intrusion typically causes is a reduction in the amount of water available for human consumption, but it also directly impacts other uses including those relating to agriculture and industry.

Overuse of surface water, such as rivers and lakes, can lead to increased concentrations of harmful substances present in the water due to pollution or mineral leaching. 'A marked example of this is seen in the case of the Rio Grande River, where decreased flows in summer months coincide with large declines in water quality. During the dry season, pathogen concentrations increase by almost 100 times' (Stellar, 2010).

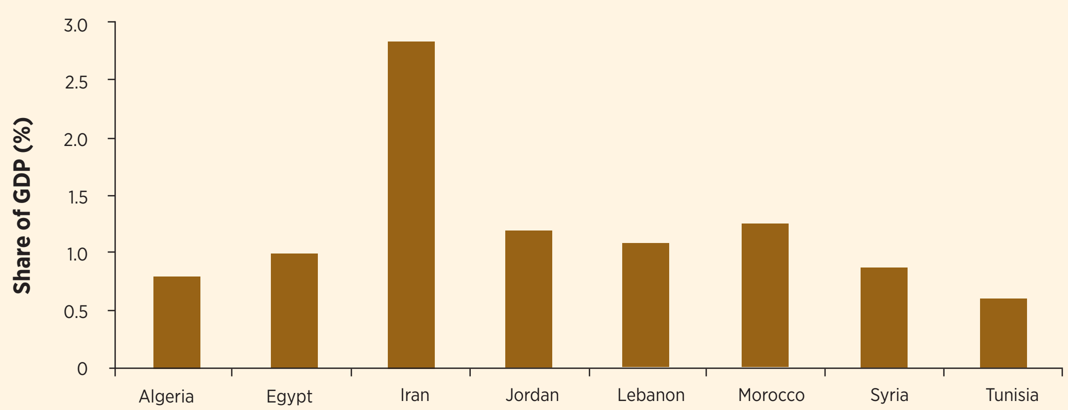
Policy-makers must make a concerted effort to better integrate the issues of water quantity and water quality in their responses. In turn, they need the support of the research community who can help to better quantify the problems, as well as the development of remedial solutions. Without an appropriate level of intervention, the major social, economic and environment-related risks, uncertainties and impacts related to water quality are expected to increase.

Socio-economic development is dependent on water quality. Risks to human and ecosystem health are linked to poor water quality, which in turn threatens socio-economic development. Ecosystem health has historically been a concern of the richer, more developed countries and their environmental movements. However, increasing recognition of the multitude of benefits of ecosystem goods and services, including wastewater treatment, has gradually made ecosystem health an important socio-economic issue, even in the poorest countries. Water polluted with toxic substances, such as inorganic compounds and untreated sewage, degrades the function of aquatic ecosystems by reducing the multifaceted goods and services they are able to provide. As many of the world's poorest people depend directly upon these goods and services for their existence, this situation further complicates efforts to alleviate poverty (MA, 2005*a*,*b*).

In terms of responses, there is a need for cost-effective options for collection, treatment and disposal of human wastes. It is estimated that over 80% of used water worldwide is not collected or treated (Corcoran et al., 2010). Wastewater management solutions also need to be combined with public education efforts, such as those related to personal hygiene and environmental education. Studies have shown that the provision of improved sanitation and safe drinking water could reduce diarrhoeal diseases by nearly 90% (WHO, 2008*b*). There is also a need to direct efforts toward industries using or producing toxic substances. Development of clean technology and substitution processes, combined with cost-efficient treatment options, is a priority component. The control of non-point sources of pollution, particularly nutrients leading to eutrophication, is an increasing global challenge. Regulations and efficient regulatory enforcement are essential – alongside institutional efforts to strengthen emergency responses, in particular when the safety of drinking water supplies is compromised during natural disasters. This issue

FIGURE 3.16

Annual cost of the environmental degradation of water



Source: World Bank (2007, fig. 4.4, p. 109, from data sources cited therein).

will increase in importance with the emerging threats brought about by climate change impacts.

Water quality is linked to human health. Human health risks are without doubt the major and most widespread concern linked to water quality. Approximately 3.5 million deaths related to inadequate water supply, sanitation and hygiene occur each year, predominantly in developing countries (WHO, 2008*a*) (see Section 4.1 and Chapter 34). Diarrhoeal diseases, often related to contaminated drinking water, are estimated to cause the death of more than 1.5 million children under the age of five per year (Black et al., 2010). The MDGs state that waterborne diseases related to unsafe drinking water supplies represent one of the major threats to the world's vulnerable poor.

Toxic water contamination is less widespread, but remains an important issue in many regions, particularly emerging economies. The release of toxic wastes from waste dumps and industrial enterprises is also a major threat and expense to the provision of safe water in the developing world. An important share of the total burden of disease worldwide – around 10% – could be prevented by improvements related to drinking water, sanitation, hygiene, and use of environmental management and health impact assessments (see Section 4.1).

TABLE 3.3

Key water quality risks

Risk	Waterborne diseases	Toxic contamination	Oxygen deficit and eutrophication	Poisoning	Ecosystem modification
Severity					
	Millions of cases Increasing trends	Thousands of cases of serious impacts in hot spots Lack of reliable documentation	Thousands of km^2 Decline in coastal fisheries Decrease in recreational value	Hundreds of km^2 Destruction of fisheries	Increase in invasive species Increase in invasive pests Increase in turbidity
Main drivers					
Natural Processes	Increasing flooding incidents	Saltwater intrusion	Heat waves		Seawater intrusion Heating Erosion after forest fires
Social	Urban migration Poverty	Waste disposal attitudes Poverty	Poor application of fertilizers	Waste disposal attitudes Poverty	Poverty
Economic	Inadequate investment in wastewater treatment	Industrial waste and spills	Intensive agriculture Mining Urban wastewater Industrial wastewater	Agriculture Urban wastewater Industrial wastewater Mining	Agriculture Forestry Urban wastewater Industrial wastewater Hydropower
Response options					
Interventions	Urban wastewater treatment	Industrial waste treatment Clean technology Warning systems	Sustainable agricultural practices Nutrient removal in wastewater	Industrial waste treatment Clean technology Integrated pest management	Sustainable agricultural practices Sustainable forestry Nutrient removal in wastewater

Poor quality water is expensive. Poor water quality incurs many economic costs: degradation of ecosystem services; health-related costs; impacts on economic activities such as agriculture, industrial production and tourism; increased water treatment costs; and reduced property values among others. In some regions these costs can be significant (UNEP, 2010). Figure 3.16 shows the estimated annual cost of poor water quality in countries in the Middle East and North Africa as a share of GDP (World Bank, 2007). Projections for these and other regions show increasing scarcity of freshwater in forthcoming years. The costs associated with addressing water quality problems can therefore be expected to increase.

Conversely, taking action to improve or ensure the maintenance of water quality can save lives and achieve significant savings. Examples include a reduction in industrial production costs and the use of natural waste treatment services provided by freshwater ecosystems. Although more research is needed to better understand and quantify the economic costs and benefits of industry and ecosystem services, most evidence suggests that many social and economic benefits derived from addressing water quality issues today will increasingly outweigh the future costs of inaction or delayed responses.

A global water quality assessment framework is necessary. While there are many possible ways to address

TABLE 3.4

Summary of possible water quality interventions by scale

Scale	Education and capacity-building	Policy/law/ governance	Financial/ economic	Technology/ infrastructure	Data/ monitoring
International/national	Initiate training and awareness building	Institute integrated approaches Institute pollution prevention	Institute polluter/ beneficiary pays system	Promote best practice and support capacity building	Develop monitoring framework
Watershed	Strategic level for raising awareness of the impacts of individuals on water quality Establish training for practitioners and develop best practice	Create watershed-based planning units. Develop water quality goals	Institute pricing systems Institute cost recovery Create incentives for efficiency	Invest in infrastructure and appropriate technologies	Build regional capacity to collect and process water quality data
Community/ household	Connect individual/ community behaviour to water quality impacts. Build capacity to make improvements in sanitation/ wastewater treatment	Amend codes to allow innovative storm water treatment options. Promote access to information	Encourage investments	Consider decentralized treatment technologies	Carry out and analyse household/ community surveys

Source: Adapted from UNEP (2010, p. 73).

water quality issues from the international to the household level, there is an urgent lack of water quality data to support decision-making and management processes. A global water quality assessment framework is needed to draw on existing national, regional and key basin-level data sources. Such a framework would go well beyond the current Global Environment Monitoring System (GEMS)[12] mandate to include a host of other international, regional and national programmes. According to Alcamo (2011) this type of framework could value freshwater goods and services, provide an assessment of water quality and data push, support the development and application of international water quality guidelines, develop international governance and institutions to support water quality protection, and include an assessment of ecologically based technologies for restoring water quality.

Such a framework would also help to increase understanding of the state of water quality, its causes and recent trends; identify hot spots; test and validate policy and management options; provide a foundation for scenarios used to understand and plan for appropriate future actions; and provide much-needed monitoring bench markers (Alcamo, 2011). As described in Chapter 6, there is growing interest from multiple stakeholders in improved data, information and accounting, all of which needs to be translated into improved data availability. Technological advancements are also making it easier to monitor and report on various dimensions of water resources. The main constraints to fulfilling these important needs are institutional structures and mandates, as well as political will, even though the benefits of improved water quality monitoring are likely to outweigh the costs, especially in areas with dense human populations or intense agricultural activity.

3.3.1 Water quality risks and potential interventions

The multitude of water quality parameters, uncertainties and impacts makes water resources management a complex and multidimensional issue, particularly with respect to human activities. Improved management of vulnerability and risks is essential to cope with as-yet unknown and unexpected factors in an era of accelerated changes and new uncertainties. Table 3.3 provides a summary of water quality risks describing the severity of each, the main drivers involved and the potential response options.

In addition to the response options provided in Table 3.3, some broad response options are provided in Table 3.4.

Notes

1 This measure is not necessarily a robust indicator of a country's potential for water-related challenges. Canada and Brazil, for example, both have a very high level of available water per capita, yet are still subject to various water-related problems.

2 Teleconnections are climate anomalies that are related but often widely spaced in distance and/or time. The relationship between two climate patterns is not necessarily one of cause and effect. Often unusual climate phenomena are caused by some third factor, such as when El Niño events increase the chance of above average precipitation in the south-west USA from January through March and increase the chance of drought in Indonesia from June through August. For more information see http://earthobservatory.nasa.gov/Features/HighWater/high_water1a.php

3 For more information see http://www.pmel.noaa.gov/tao/elnino/nino-home.html

4 For more information see: http://jisao.washington.edu/pdo/

5 For a good resource on NAO, its climate impacts and other information, readers are referred to http://www.ldeo.columbia.edu/res/pi/NAO/

6 See the website of the Atlantic Meridional Overturning Circulation Program for more details: http://www.atlanticmoc.org/

7 Almost all values mentioned in this paragraph are globally aggregated or averaged, and thus cannot be used to draw conclusions on conditions at a local or regional scale.

8 Siebert et al. (2010) estimate global consumptive irrigation water use at 1,277 km^3 per year, or 48% of global agricultural water withdrawals. Their estimate for groundwater use is 545 km^3 per year, which is fairly consistent with the estimated global groundwater abstraction for irrigation, taking into account irrigation water losses.

9 Examples of large aquifers in this category are the Highland Plains and Central Valley aquifers in the USA, the north-west India plains aquifers, the North China Plain aquifer and the Australian Great Artesian Basin.

10 For more details see Chapter 36.

11 For more details see Chapter 36.

12 The United Nations GEMS/Water Programme provides scientifically sound data and information on the state and trends of global inland water quality required as a basis for the sustainable management of the world's freshwater to support global environmental assessments and decision-making processes (see http://www.gemswater.org/).

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CHAPTER 4

Beyond demand: Water's social and environmental benefits

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Red-eyed tree frog

The many benefits humans derive through water are by no means limited to the five major use sectors described in Chapter 2. Water also provides a range of benefits through its impacts on human health. Healthy ecosystems provide an even broader array of benefits and services to individuals and societies. In addition to these benefits, water can also create serious risks when there is too much of it, as in the case of floods, or too little of it, as during periods of drought, especially in areas already subject to the processes of desertification and land degradation. Unfortunately, in many parts of the world, access to water's benefits are not equitably balanced, nor are vulnerabilities to water-related hazards, which disproportionally affect the poorest populations, and women and children in particular. This chapter examines water in relation to each of these important issues.

The first section, on water and human health, focuses on water-related diseases in the context of public health interventions, water management, drinking water supply and sanitation, and hygiene, identifying trends and hotspots, key external drivers and related uncertainties, and provides insights on actions for combating the major water-related disease burdens at different levels. The following section describes how gender differences in access to and control over water resources are key ingredients of many water-related challenges worldwide. The third section explores how healthy ecosystems offer solutions to achieving water-related objectives and help reduce uncertainty and risk as they deliver multiple benefits (or services) that are essential for sustainable development – many of these vital services are derived directly from water, and all are underpinned by it. The fourth section, on water-related hazards, reports on recent trends and examines the increased risks disasters create with respect to property, lives and livelihoods. The fifth section describes how the processes of desertification, land degradation and drought (DLDD) are increasing pressure on water resources, adding a new layer of uncertainty and risk in regions already facing water scarcity, and presents different measures that are being applied worldwide to reduce the impacts of DLDD.

The chapter closes with a discussion of the current balance between limited and often variable water supplies (Chapter 3), growing demands from the major user groups (Chapter 2), and the need to maintain benefits and reduce risks (this chapter). This section addresses concepts such as water stress and water scarcity, making the case that balancing the benefits and maximizing the returns from water and its multiple uses is essential for sustainable development and poverty eradication.

With the exception of Section 4.6, the material in this chapter has been condensed from the challenge area reports (Part 3/Volume 2) 'Water and health' (Chapter 34), 'Ecosystems' (Chapter 21), 'Water-related disasters' (Chapter 27) and 'Desertification, land degradation and drought and their impacts on water resources in the drylands' (Chapter 28) as well as the special report 'Water and gender' (Chapter 35).

4.1 Water and human health

Improving water resource management, increasing access to safe drinking water and basic sanitation, and promoting hygiene (WaSH) have the potential to improve the quality of life of billions of individuals. The global importance of water, sanitation and hygiene for improving health is reflected in the United Nations Millennium Development Goals (MDGs), explicitly, Goal 7, Target c, which aims to reduce by half the proportion of people without sustainable access to safe drinking water and basic sanitation by 2015). Yet water management, drinking water supply and sanitation, and hygiene are also critical for the achievement of MDGs 4, 5 and 6, and for sustaining the achievements thus far to reduce child mortality, improve maternal health and reduce the burden of malaria.

As public health interventions, water management, drinking water supply and sanitation, and hygiene can form the primary basis for prevention against a significant majority of the global burden of water-related disease. This includes diarrhoeal diseases, arsenic and fluoride poisoning, intestinal nematode infections, malnutrition, trachoma, schistosomiasis, malaria, onchocerciasis, dracunculiasis, Japanese encephalitis, lymphatic filariasis and dengue. However, efforts to implement successful WaSH public health interventions to combat these diseases are complicated by the fact that each is associated with a variety of economic, societal and environmental driving forces. Responsibilities within governments are fragmented over a number of entities at different levels, and coordination among these and across sectors continues to be a challenge. Moreover, large knowledge gaps currently prevent adequate prediction of trends and regional hotspots. Nevertheless, illustrative examples reveal how these interventions can contribute to reducing or preventing disease.

4.1.1 Trends and hotspots

Identifying trends and hotspots around the interface of water and health is extremely difficult, due to challenges in monitoring and reporting, a lack of information on environmental health determinants, and the interplay of non-environmental determinants on health. Nevertheless, available insights do provide a basis for effective action. Despite a lack of localized disease prevalence estimates, some diseases are clearly on the rise (such as cholera, see Box 4.1), and select reasons for these increases can be addressed. Three examples are provided below that illustrate the complex nature of disease risk, and highlight the ways in which strategies are already being investigated and implemented to combat these risks.

4.1.2 Drivers

The global drivers predicted to have the greatest effect on human health via the water environment include demography, agriculture, infrastructure and climate change.

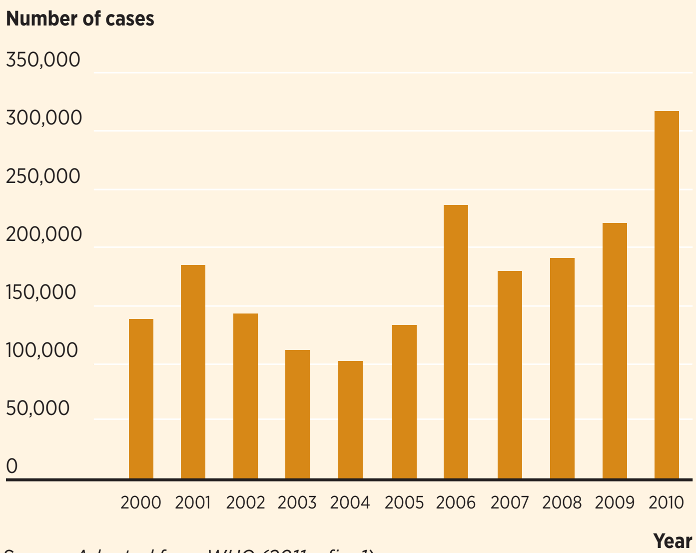
Population growth and urbanization can significantly impact human health through increasing water demands and increasing water pollution. Rising demand for water resources may contribute to water scarcity, with potential implications for reliability of drinking water access, water quality and hygiene. There will be a tendency for increased incidence of diseases transmitted in the absence of sufficient safe water for washing and personal hygiene, or when there is contact with contaminated water. These include diarrhoeal diseases, intestinal nematode infections and trachoma. Rapid population growth in urban or peri-urban areas that lack services for reliable provision of safe water, basic sanitation services or solid waste management can lead to increases in small-scale water storage (Bradley and Bos, 2010), water pollution and growing proportions of the population exposed to pathogens (WHO, 2007). Such situations amplify the risk for diseases such as diarrhoea, intestinal nematode infections, trachoma, schistosomiasis, dengue and lymphatic filariasis.

The accelerating process of global urbanization translates into increased exposure to poorly designed or managed water systems and poor access to hygiene and sanitation facilities in **public settings** (e.g. healthcare centres, schools, public offices). This results in an increased risk of disease outbreaks. Action to reduce this risk in public settings is a public health priority. The morbidity and mortality associated with healthcare-associated infections represents a loss of health-sector and household resources worldwide. Schools, particularly in rural and peri-urban areas, often lack drinking water, sanitation and hand-washing facilities. The resulting transmission of disease manifests as significant absenteeism. Public settings provide an opportunity to educate visitors about minimizing disease transmission with targeted messages and a 'model' safe environment, which can be emulated at home. National policies, standards, guidelines on safe practices, training and promotion can aim to reduce the

BOX 4.1

Cholera

Number of cholera cases reported to the World Health Organization between 2000 and 2010

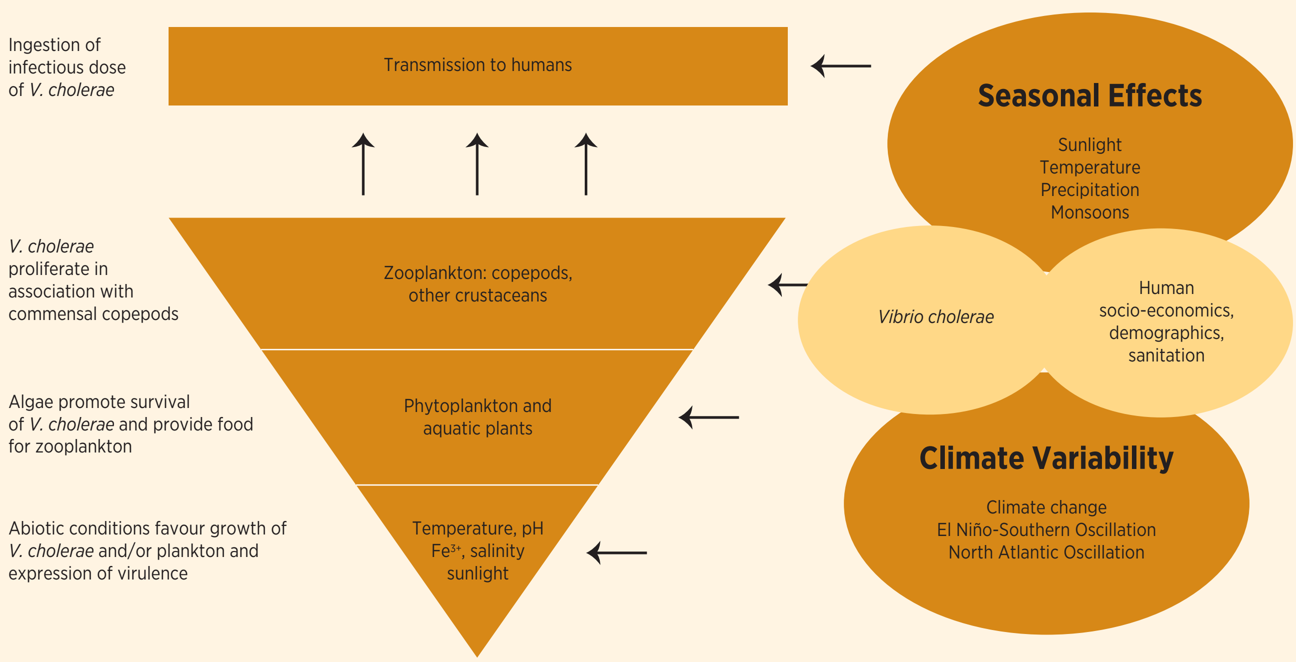


Source: Adapted from WHO (2011a, fig. 1).

Cholera is an acute diarrhoeal disease caused by the ingestion of food or water contaminated with the bacterium *Vibrio cholerae*. Every year, there are an estimated 3–5 million cholera cases and 100,000–120,000 deaths due to cholera. (WHO estimates that only 5–10% of cases are officially reported.) Moreover, the number of cholera cases continues to rise (see figure to the left): the number of cases reported to the World Health Organization (WHO) increased by 16% from 2008 to 2009, 43% from 2009 to 2010, and the overall increase for the decade 2000–2010 was 130% (WHO, 2010*a*). The massive increase in 2010 is largely due to the outbreak that began in Haiti in October 2010, following an earthquake in January 2010.

Cholera is endemic in regions with poor socio-economic conditions, rudimentary sanitary systems, absence of wastewater treatment and where public hygiene and safe drinking water is lacking (Huq et al., 1996). Specifically, cholera is endemic

Hierarchical model for environmental cholera transmission



Source: Lipp et al. (2002, fig. 1, p. 763, reproduced with permission from The American Society for Microbiology).

Up to 80% of cholera cases can be *treated* simply and successfully through administration of oral rehydration salts. *Prevention* of cholera, however, relies on the availability and use of safe water, improved sanitation, including wastewater treatment, and hygiene. Prevention strategies are also critical in averting or mitigating cholera outbreaks. In the case of the outbreak in Haiti, the country's public health response strategy, led by the Ministry of Public in many parts of Africa and Asia, and has more recently become endemic in the Americas. Risk factors in endemic regions can include proximity to surface waters, high population densities and low educational levels (Ali et al., 2002), while factors affecting *V. cholerae* include temperature, salinity, sunlight, pH, iron, and phytoplankton and zooplankton growth (Lipp et al., 2002). The figure below describes a hierarchical model for environmental cholera transmission. The risk of cholera outbreaks intensifies during humanitarian crises, such as conflicts and floods, and displacement of large populations. Typical at-risk areas include peri-urban slums without basic water and sanitation infrastructure, and refugee camps, where minimum requirements of safe water and sanitation are not met. In fact, the re-emergence of cholera has coincided with the increase in populations living in unsanitary conditions (Barrett et al., 1998). For example, the onset and spread of the cholera epidemic of 1991 in Peru are closely related to the deterioration in the drinking water supply, sanitation and health services brought by the economic crisis of the 1980s (Brandling-Bennett, Libel and Migliónico, 1994).

Health and Population and supported by WHO and other partners, has incorporated multiple health solutions to reduce the levels of morbidity and mortality due to cholera: delivery of soap for hand washing; delivery of chlorine and other products or devices for household water treatment; construction of latrines; improved hygiene in public places (such as markets, schools, healthcare facilities and prisons); and implementation of health education campaigns through various media including community mobilizers (WHO, 2010*b*). In fact, the availability of safe water supplies may prove to be more important for combating cholera than antibiotics or vaccines. A recent study showed that the provision of safe water might have averted 105,000 cholera cases (95% Confidence Interval 88,000–116,000) and 1,500 deaths (95% Confidence Interval 1,100–2,300) in Haiti between March and November of 2011 – more than the estimated individual effects of antibiotics or vaccines (Andrews and Basu, 2011). With increasing populations living in peri-urban slums and refugee camps, as well as increasing numbers of people exposed to the impacts of humanitarian crises, the risk from cholera will likely increase worldwide, reinforcing the need for safe drinking water, adequate sanitation and improved hygiene behaviour under these conditions.

number of infections associated with these settings (WHO, 2011*c*; WHO/UNICEF, 2009).

Agriculture is essential to food security and adequate nutrition; yet certain practices can adversely impact human health by increasing water withdrawals for irrigation, changing water regimes in agro-ecosystems, and increasing water pollution. Growth in agriculture and industry is currently reported to be the main cause of surface water and groundwater quality deterioration (WWAP, 2006). Poor agricultural practices can lead to pollution of surface water and groundwater with pesticides, pollutants, nutrients and sediments. Impacts also include increased breeding grounds for disease vectors and contamination of water supplies with pathogens from animal manure. Diseases that are likely to increase with agricultural expansion and intensification include diarrhoeal diseases, trachoma, schistosomiasis, lymphatic filariasis and malaria (Jiang et al., 1997; Nygard et al., 2004; Prüss and Mariotti, 2000; Rejmankova et al., 2006). Contaminated waters can also facilitate transmission of diarrhoeal diseases when wastewater (sewage) and excreta are used to irrigate or fertilize crops. This practice is employed increasingly in many peri-urban areas of the world, especially those in arid and semi-arid zones characterized by intense competition for water between agriculture and urban uses, and, combined with the changing nutritional habits of urban populations, poses a real health threat (Drechsel et al., 2010). Expansion of agriculture may also lead to deforestation, as regions seek to enlarge the areas available for agricultural practices. Deforestation can impact human health by removing the forest buffers that contribute to controlling non-point source pollutants from entering watercourses, increasing the concentration of pollutants downstream. Non-point source pollutants include nutrients, chemicals, sediments and pathogens, such as those that cause diarrhoeal disease. In addition to increasing water pollution, deforestation also affects disease rates by changing vector and host ecology and behaviour, potentially increasing the rates of malaria and onchocerciasis (Adjami et al., 2004; Walsh et al., 1993; Wilson et al., 2002).

The construction of **infrastructure**, including dams and irrigation projects, plays an important part in meeting demands for water. Yet while they contribute to food and energy and help manage the extremes of water, water resources infrastructure can also adversely impact human health. Dams and irrigation projects can, if not appropriately designed and managed, create breeding grounds for the black flies that spread onchocerciasis and the mosquitoes that spread malaria, lymphatic filariasis and Japanese encephalitis (Erlanger et al., 2005; Keiser et al., 2005*a*; Keiser et al., 2005*b*). These projects may also create habitats that encourage growth of the host snail of schistosomes (Molyneux et al., 2008).

BOX 4.2

Harmful algal blooms

Harmful algal blooms (HABs) are algae harmful to humans, plants or animals, as opposed to most algal species, which are nontoxic and constitute natural parts of marine and freshwater ecosystems. While HABs do not represent a dominant global disease burden, there is a trend of increasing bloom detection, which likely indicates a real increase in incidence as well as increased surveillance. The reasons for this growth are varied, and include natural mechanisms of species dispersal and anthropogenic causes, such as pollution, climate change and transport via ballast water (Granéli and Turner, 2006). Approximately 60,000 individual cases and clusters of human intoxication occur annually around the world (Van Dolah et al., 2001). Although the mechanisms by which HABs affect human health are not fully understood, government authorities are conducting monitoring for HABs and developing guidelines for public health action in order to mitigate their impact. For example, the US Environmental Protection Agency (EPA) has added specific HAB-related algae to its Drinking Water Contaminant Candidate List, which identifies organisms and toxins believed to be priorities for investigation. Direct control of HABs is much more difficult and controversial than mitigation, and strategies include mechanical, biological, chemical, genetic and environmental control. Conversely, prevention of HABs is currently hampered by a lack of understanding of the causes of HAB formation in many areas, as well as an inability to modify or control known determining factors. For example, increased inputs of nutrients from agricultural, domestic and industrial sources are a known cause for many HABs. Yet much of the nutrient input comes from non-point sources (Anderson et al., 2002), which are often difficult to control. The most effective strategies include controlling land use, maintaining landscape integrity, and implementing structural and non-structural practices for reducing nonpoint source pollution (e.g. stormwater detention ponds and improved infrastructure design) (Piehler, 2008). As the world's population continues to grow, its demands on coastal resources will most certainly increase, reinforcing the need to understand HAB phenomena and develop sound policies and practices.

Global climate change is expected to exacerbate current stresses on water resources from population growth and land use, and also to increase the frequency and severity of extreme weather and hydrological events (e.g. inland flooding). Higher water temperatures, increased precipitation intensity and longer periods of low flows are projected to exacerbate many forms of water pollution and increase pressure on diseases such as malaria, schistosomiasis and diarrhoea (Bates et al., 2008; Koelle et al., 2005; Zhou et al., 2008). For example, climate has been found to influence cholera dynamics in Bangladesh (Bouma and Pascual, 2001; Colwell, 1996; Koelle et al., 2005; Pascual et al., 2000; Rodo et al., 2002;), Peru (Colwell, 1996; Speelmon et al., 2000) and five countries in Africa (Constantin de Magny et al., 2007). More frequent heavy rainfalls will also likely overload the capacity of sewer systems, resulting in untreated

BOX 4.3

Dengue

In 2004, approximately 9 million people contracted the febrile illness dengue (WHO, 2008). Global incidence continues to rise with approximately 2.5 billion people now at risk. There is no drug or vaccine for the virus; therefore, safe drinking water and sanitation are key interventions for this disease. Dengue is transmitted by two mosquito species, *Aedes aegypti* and *Aedes albopictus*, which breed in temporary water-storage containers in the domestic environment. Thus, safe storage of household water supplies is a critical component of dengue prevention, especially in areas that practice rainwater harvesting and use large household water storage vessels (Mariappan et al., 2008). Household water containers can be fitted with screens or proper lids to exclude mosquitoes, but their scrupulous maintenance and consistent use is hard to achieve. Covers treated with insecticide can further reduce densities of dengue vectors and potentially impact dengue transmission (Kroeger et al., 2006; Seng et al., 2008). Water containers can also be eliminated entirely with piped water supplies. However, the extension of piped water supplies to villages has expanded the range of dengue from urban to rural environments, where the unreliability of piped water supplies has forced people to store water in their homes for longer periods of time when previously they relied on well water (e.g. Nguyen et al., 2011). In effect, an integrated approach, combining household water treatment and safe storage, is necessary for the reduction of diarrhoeal as well as other water-associated diseases (e.g. dengue and malaria) in the households and communities of developing and developed countries.

sewage, with its associated pathogens, flowing into water bodies, with a tendency towards increases in diarrhoeal diseases, including outbreaks.

The Vision 2030 study (WHO/DFID, 2009) advocates the need to integrate resilience of water and sanitation infrastructure into the planning, policy-making and management of drinking water and sanitation, to adapt and cope effectively with the potential adverse impacts of climate variability. A major paradigm shift from the 'business-as-usual' approaches in drinking water and sanitation systems and services is essential in order to adapt to climate change and transform threats into opportunities. Optimizing resilience of water and sanitation infrastructure will maximize health benefits of future investments, and ensure that drinking water and sanitation infrastructure remain functional in the face of climate change-induced extreme weather events.

There is an urgent need to improve our understanding of the dynamics relating to the ways in which each of these drivers affect human health: the complex set of factors that generate them, the characteristics of populations that increase their vulnerability, and the identification of populations most at risk for each of these threats (Myers and Patz, 2009). Such improved understanding would also provide a basis for measures aimed at reducing health risks from water-related diseases, and would thereby aid resource managers and policy-makers in determining the health impacts associated with their decisions, and allow aid organizations to target their resources more effectively.

4.1.3 Options and consequences

Key messages

1. The global drivers predicted to have the greatest effect on disease rates via the water environment are *population growth and urbanization, agriculture, infrastructure and global climate change*. Trends in these drivers directly and indirectly impact the global burden of disease, largely adversely, and increase the overall uncertainty in future human health.
2. There are numerous non-water-related environmental determinants of health, as well as non-environmental determinants of health that confound the attribution of health trends and hotspots to water.
3. By outlining the environment-health nexus for each of the major water-related disease groups, five key solutions were identified: *access to safe drinking water, access to basic sanitation, improved hygiene, environmental management,* and the *use of health impact assessments.* Implementation of these actions serves to reduce the burden of multiple diseases and improve the quality of life of billions of individuals.
4. In-depth studies targeting the future impacts of powerful underlying drivers, such as those identified in this report, are required to more accurately identify the risks and opportunities related to water and health. These studies would evaluate the complex interactions around population, development and urbanization, similar to The 2030 Vision Study, which determined the major risks, uncertainties and opportunities related to the resilience of water supply and sanitation in the face of climate change.
5. Protection of human health requires collaboration among multiple sectors, including actors and stakeholders in non-water and non-health sectors.

Determining how past and present (and indeed projected future) driving forces contribute to the burden of disease provides a basis for the development of the aforementioned primary prevention strategies. Outlining this pathway for each of the major water-associated diseases leads to the formulation of five key actions for combating the burdens they cause: access to safe drinking water, access to basic sanitation, improved hygiene, environmental management and the use of health impact assessments. Implementation of these actions would contribute to reducing the burdens of diverse diseases and improve the quality of life for billions of individuals.

This fact was reaffirmed in May 2011, when the 64th World Health Assembly unanimously adopted resolutions on 'drinking-water, sanitation and health' (WHA, 2011b) and 'cholera: mechanism for prevention and control' (WHA, 2011*a*). These resolutions established the policy framework for WHO, its sister UN agencies – in particular UNICEF, and the ministries of health of its 193 Member States –to take determined action to promote access to safe and clean drinking water, and basic sanitation and hygiene practices. Member States were urged to re-affirm a strong role for drinking water, sanitation and hygiene considerations in their national public health strategies.

Actions for combating the major water-related disease burdens can be pursued at a variety of different levels:

- The formulation of national policies and the creation of institutional frameworks: efforts in these areas can result in an enabling environment for universal and efficient provision of safe drinking water and sanitation services.
- Networking: bringing together professionals to share information and experiences can play a key role in combating the water-related disease burden. Examples of such networks include WHO-hosted international networks (e.g. the Drinking-water Regulators Network and the Small Community Water Supplies Management Network), the WHO/UNICEF Network on Household Water Treatment and Safe Storage, and the WHO/IWA Network on Operation and Maintenance.
- Normative capacities: efforts to strengthen normative capacities can bolster disease prevention, for example, the fourth edition of the *WHO Drinking Water Quality Guidelines* (WHO, 2011*b*) and subsequent water safety planning approach for implementation (WHO/IWA, 2009).
- Monitoring and surveillance: global monitoring by the WHO/UNICEF Joint Monitoring Programme on Water Supply and Sanitation (JMP) and by the UN-Water/WHO Global Analysis and Assessment of Sanitation and Drinking-water (GLAAS) guides policies, resource allocation and actions to achieve the MDG target, and provides a platform for the development of indicators and targets for post-2015 monitoring, linked to criteria for the human right to water and sanitation (WHO/UNICEF, 2011).

Health impact assessments (HIAs) can be used to objectively evaluate the potential health effects of a water policy or project before it is implemented or constructed, and provide recommendations to increase positive health outcomes and minimize adverse health outcomes as part of a public health management plan. The HIA framework is used to comprehensively address public health issues in the decision-making process for development planning that fall outside of traditional public health arenas: transportation, agriculture, land use, energy and infrastructure. Taking public health consequences into consideration 'upstream' as part of the early planning process creates a window of opportunity for design and management interventions that cannot be deployed once the project is operational. It also fosters an intersectoral approach to reduced pathogen transmission and prevents the subsequent transfer of 'hidden costs' to the health sector.

Determining how past, present and predicted future driving forces contribute to the water-related disease burden has also led to the identification of major risks, uncertainties and opportunities. These include the risk of increasing failures of aging water infrastructure and, conversely, the opportunity to increase the overall impact of water resources and water supply and sanitation infrastructure through improved management. The impact of such actions improves use of limited financial resources, thereby enhancing both access to water and sanitation, and associated service quality, and leads indirectly to improvements in wider health indicators such as malnutrition.

Additional in-depth studies are required to more accurately identify the risks and opportunities related to water and health. The 2030 Vision Study, commissioned by the United Kingdom Department for International Development (DFID) and WHO, performed such an analysis of the major risks, uncertainties and opportunities related to the resilience of water supply and sanitation in the face of climate change (WHO/DFID, 2009). The study brought together evidence from projections on climate change, trends in technology application, and developing knowledge about drinking water and sanitation adaptability and resilience, to identify key policy, planning and operational changes required to adapt to climate change, particularly in low and middle-income countries where access to water supply and sanitation services are more limited. Five key conclusions resulted from this study:

1. Climate change is widely perceived as a threat rather than an opportunity. There may be significant overall benefits to health and development in adapting to climate change.
2. Major changes in policy and planning are needed if ongoing and future investments are not to be wasted.
3. Potential adaptive capacity is high but rarely achieved. Resilience needs to be integrated into drinking water and sanitation management to cope with present climate variability. It will be critical in controlling adverse impacts of future variability.
4. Although some of the climate trends at regional levels are uncertain, there is sufficient knowledge to inform urgent and prudent changes in policy and planning in most regions.
5. There are important gaps in our knowledge that already or soon will impede effective action. Targeted research is urgently needed to fill gaps in

technology and basic information, to develop simple tools, and to provide regional information on climate change. (WHO/DFID, 2009, p. 3)

The relationship between the drivers of water-related diseases and human health is complex. Thus, protection of human health requires collaboration among multiple sectors. Policies and projects in non-water or non-health sectors should reflect the links between water management and health in decision-making processes in order to avoid unintended adverse public health consequences, as well as to increase overall benefits. To do so requires the engagement of health professionals and institutions.

In the case of drinking water quality management, there is increasing recognition that addressing the complex root causes of water contamination is a more effective and sustainable approach then reacting to problems after they occur. The fourth edition of the *Guidelines for Drinking Water Quality* (WHO, 2011*b*) emphasizes the need for collaboration between all stakeholders, including land users or householders who may discharge industrial, agricultural or domestic waste into a catchment area; policy-makers from various ministries overseeing the implementation and enforcement of environmental regulations; practitioners delivering water; and consumers at the tap. This preventive and collaborative water-safety planning approach has demonstrated benefits, including cost-savings and sustainable improvements in water quality. Experience also shows, most recently in South and East Asia, that while progress is being made, implementing such a 'no short-cut' approach remains a challenge. Each risk management solution needs to be tailor-made to the water supply in question, and demands that key stakeholders become engaged and committed to a common goal.

4.2 Water and gender

Among the many water-related challenges worldwide, the crisis of scarcity, deteriorating water quality, the linkages between water and food security, and the need for improved governance are the most significant in the context of gender differences in access to and control over water resources. These challenges are expected to become more intense in the future, due to the growing uncertainty and risk associated with the availability and quality of freshwater resources, arising from increasing demand for various uses, climate variability and natural disasters.

"In the case of drinking water quality management, there is increasing recognition that addressing the complex root causes of water contamination is a more effective and sustainable approach then reacting to problems after they occur."

Water is used for a wide range of socio-economic activities including public health, agriculture, energy and industry. Unsustainable and short-term decisions taken in the context of these activities have an impact on water resources, with different social and economic consequences for men and women in the community. Over the longer term, scarcity created at the local level as a result of this crisis is likely to increase inequity within local communities with regard to access and control over local water resources, affecting poor women the most.

Decisions related to water sharing, water allocation and water distribution between different uses and across regions are most often made at higher levels where economic and political considerations generally play a more important role than social concerns. These decisions impact the water resources locally available to communities, who are likely to lose access to the very resources that sustain their livelihoods and fulfil their needs. Rural women often rely upon common water resources such as small water bodies, ponds and streams to meet their water needs, but in many regions these sources have been eroded or have disappeared due to changes in land use, or have been appropriated by the state or industry for development needs or to supply water to urban areas.

Water has different values for different uses and purposes, and the same source of water can be used for social as well as economic purposes. Social and environmental valuation is more prevalent at the local level, where water sources may be designated for different uses such as drinking, common uses such as bathing and washing depending on the quality of water, or regarded as sacred for religious purposes. Water that has been valued as an economic good, such as irrigation water supplied through an irrigation scheme, also has a social value for local communities, especially for women, who may use the same irrigation water source for both domestic and farming purposes. Opportunities for improving access to water for women and improving their water security can be found by analysing water values through a gender lens.

Water policies based on broad, generalized perspectives are more likely to omit local knowledge, and social and gender dimensions and their implications. Recognizing the various purposes for which these local water resources are used by different groups of men and women in the community would help to successfully integrate gender considerations, not only in water resource management, but also in sectors such as urban water supply, agriculture, industry and energy that depend upon water resources, and which often conflict over water allocations and their demand for freshwater resources. By working together in partnership with these sectors, decision-makers in government bodies, private sector and civil society can understand and address the potential synergies and trade-offs that occur when providing access to different groups of men and women in local communities. This approach would help to anticipate risks and uncertainties and plan for safeguards to protect the most vulnerable groups in the community.

There is enough evidence to show that integrating a gender-sensitive approach to development can have a positive impact on the effectiveness and sustainability of water interventions and on the conservation of water resources. Involving both men and women in the design and implementation of interventions leads to effective new solutions to water problems; helps governments to avoid poor investments and expensive mistakes; makes projects more sustainable; ensures that infrastructure development yields the maximum social and economic returns; and furthers development goals, such as reducing hunger, child mortality and improving gender equality (Oxfam, 2005, 2007).

Although it is true that many socially constructed barriers need to be overcome in order to facilitate the involvement of both men and women in decision-making and management of water resources, it is also true that traditional gender roles have often been challenged successfully by developing women's capacities to manage water interventions, and providing them with opportunities to play leadership roles and improve their economic conditions. However, these successes are often limited to the local context, as the larger issues, such as providing water rights to women, are governed by external factors, which are not only outside the purview of these interventions, but involve traditional, cultural and political realities that are difficult to change in the short term, and require long-term commitment from policy-makers, governments, politicians and advocacy groups.

Over many decades, the United Nations has made significant progress in advancing gender equality, including through landmark agreements such as the Beijing Declaration and Platform for Action, and the Convention on the Elimination of All Forms of Discrimination against Women (CEDAW), and the setting up of UN Women to accelerate progress in achieving gender equality and women's empowerment. Water and Gender is listed as one of UN-Water's Thematic Priority Areas in its 2010–2011 Work Programme, while the promotion of gender equality is one of UNESCO's two global priorities for 2008–2013.

4.3 Ecosystem health

Trends in ecosystems and the benefits they deliver indicate the presence of a serious ecological imbalance. This instability and degradation in ecosystems increases uncertainty and amplifies risk. Tipping points in ecosystems, beyond which damage accelerates and becomes irreversible, are being rapidly approached, and involve high risk and potentially major socio-economic impacts. There is some good news: the current situation has resulted in increasing attention to ecosystems, some successful responses, and a narrowing divide between water, ecosystems, environment, biodiversity and human development interests. Ecosystems offer solutions to achieving water-related objectives and reducing uncertainty and risk; the task is to mainstream and upscale them.

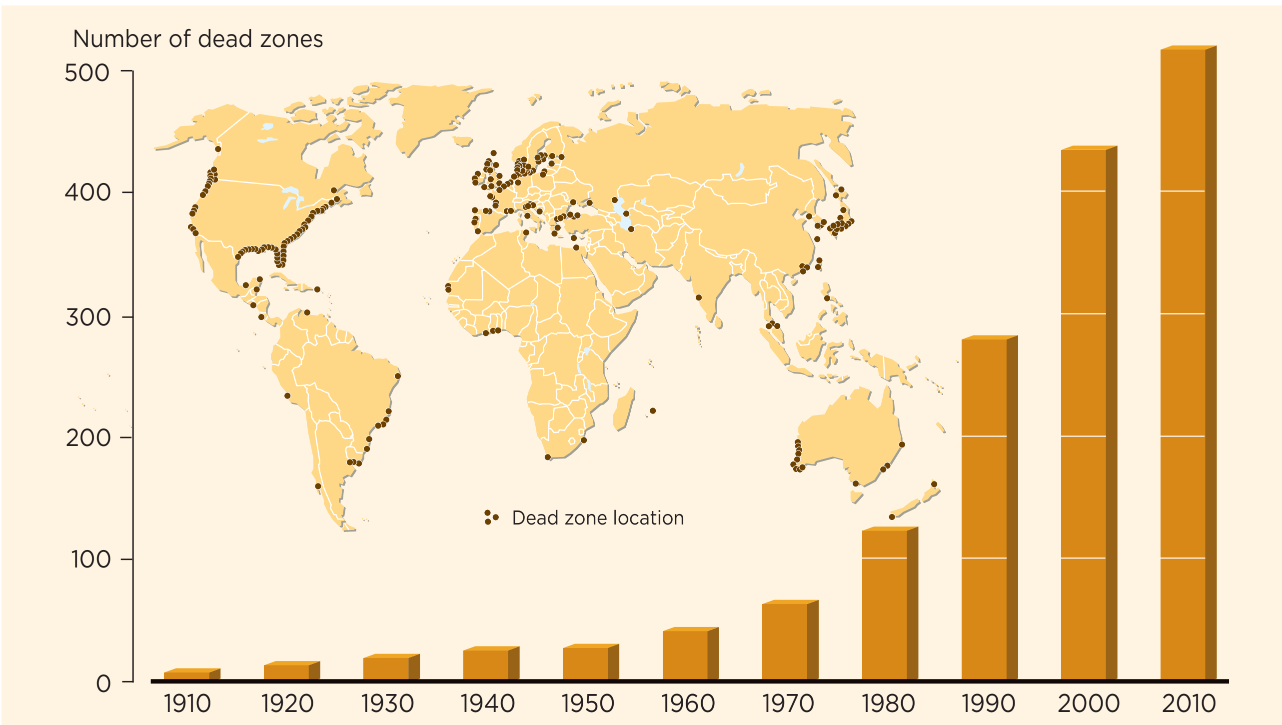
Ecosystems deliver multiple benefits (or services) that are essential for sustainable development. Many of these key services are derived directly from water, and all are underpinned by it. Trends in ecosystem health, therefore, indicate trends in the delivery of these overall benefits and provide a key indicator of whether human society is in or out of balance with water. And the trends in ecosystems, including the life they support, are indicating clearly and unambiguously that things are out of balance.

WWDR2 (WWAP, 2006) and WWDR3 (WWAP, 2009) reviewed the principal pressures and impacts on freshwater ecosystems. The key direct water-related drivers involved are ecosystem conversion (e.g. drainage and conversion of wetlands); fragmentation (e.g. dams and reservoirs); and degradation (principally, water availability/flow and water quality/pollution). The indirect drivers responsible for these arise from the social (including demographic) and economic changes associated with development, and the fact that most human needs and activities directly or indirectly impact limited water resources. At global and regional scales, the nature of these drivers remains largely unchanged. Although there are some shifts in their relative weight, most drivers show increasing negative trends overall.

Considering the trends in these drivers, the recent overall picture of ecosystem health is unsurprisingly one of escalating degradation. The increasing negative trend presented in WWDR2 and WWDR3, and comprehensively outlined by the Millennium Ecosystem Assessment (MA, 2005*a*), is maintained based on several recent detailed assessments; these include *Global Environment Outlook 4* (UNEP, 2007), *Global Biodiversity Outlook 3* (CBD, 2010*a*), and regional assessments such as those undertaken for Africa (UNEP, 2008). A review of progress towards the 2010 biodiversity target for inland waters concluded that the 2010 target and subtargets for inland waters biodiversity have not been achieved; the drivers of biodiversity loss remain unchanged and are all escalating; excessive nutrient loading has emerged as an important direct driver of ecosystem change in inland (and coastal) waters (Figure 4.1), and groundwater pollution remains a major concern; the surface water and groundwater portions of the water cycle have been subjected to massive changes by direct human use on local,

FIGURE 4.1

Nutrient loading in inland and coastal waters



Note: The number of observed 'dead zones', coastal sea areas where water oxygen levels have dropped too low to support most marine life, has roughly doubled each decade since the 1960s. Many are concentrated near the estuaries of major rivers, and result from the buildup of nutrients, largely carried from inland agricultural areas where fertilizers are washed into watercourses. The nutrients promote the growth of algae that die and decompose on the seabed, depleting the water of oxygen and threatening fisheries, livelihoods and tourism.
Source: CBD (2010a, fig. 15, p. 60).

regional and continental scales; and ecological sustainability of water available for abstraction is giving alarm signs (Box 4.4). Although progress has been made in policy and practical responses (e.g. designation of protected areas), the rate of increase is slowing, and most other indicators show continuing or often accelerating declines (Butchart et al., 2010). While protected wetland areas are increasing, most wetland sites are degrading (CBD, 2010*b*).

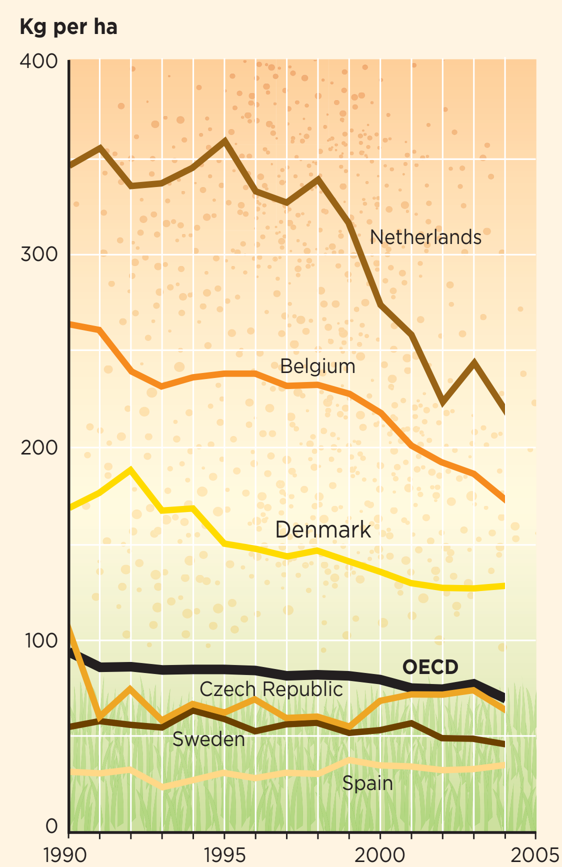
Some positive trends in developed regions – for example, improvements in managing nutrient loads (Figure 4.2), wetlands restoration, or a slowing or reversal of biodiversity loss – are offset by accelerated degradation in developing countries. An underlying problem is that rich nations are tending to maintain or increase their consumption of natural resources (WWF, 2010), but are exporting their footprints to producer, and typically, poorer, nations. For example, 62% of the United Kingdom's water footprint is virtual water embedded in agricultural commodities and products imported from other countries – 38% originates from domestic water resources – (Chapagain and Orr, 2008). In addition, much of the progress in pollution control in rich countries is attributable to the shift of industrial production elsewhere, for example, to China. This is particularly the case for water-related impacts, including through trade in virtual water. Notably, this also transfers uncertainty and risk to developing nations less prepared to deal with these impacts. Until richer consumers recognize and take responsibility for their global footprint, society shall continue to address the symptoms of the problem as a distraction from tackling its root cause.

There is ample evidence that humans are over-consuming natural resources overall at an unsustainable rate. Various estimates indicate that, based on business as usual, approximately 3.5 planet Earths would be needed to sustain a global population achieving the current lifestyle of the average European or North American. Importantly, the sustainability of water resources is a key subset of this dilemma. Recent studies suggest that the planetary limits of sustainable water may have already been reached or exceeded (Box 4.4). 'Hotspots' for ecosystem service degradation have not been systematically mapped, as such, but they correlate closely with areas of water stress (see Section 4.6) and high pollution loads (Figure 4.1). Rapid development, high population density and growth, industrialization, and to some extent limited water availability characterize the locations of the most impacted ecosystems.

'There is often an assumption that useable water in nature can be readily accessed and moved around at will. For example, many governments have ambitious plans to move massive volumes of water from water-rich to water-poor river basins' (Molden, 2009, p. 116). The consequences of these inter-basin water transfers on ecosystem health remain unclear, but they are likely to be immense. Water management also often focuses on surface water and groundwater to the detriment of ecosystems and their role in the water cycle. There needs to be broader recognition of the

FIGURE 4.2

Nitrogen balance in Europe



Note: The average nitrogen balance per ha of agricultural land (the amount of nitrogen added to land as fertilizers, compared with the amount used up by crops and pasture) for selected European countries. The reduction over time in some countries implies improved efficiency in the use of fertilizers, and therefore a reduced risk of damage to biodiversity through nutrient runoff.
Source: CBD (2010a, fig. 16, p. 61).

importance of conserving and restoring soil moisture, underpinned by soil ecosystem health, and the relationship between ground vegetation cover and local and regional humidity. Policy-makers and managers need to understand that ecosystems do not consume water – they supply and recycle it – and water taken from ecosystems unsustainably reduces their ability to deliver the benefits that society needs.

TEEB (2009) states that ecosystem loss and degradation does not always result in an immediately detectable or proportional response in terms of lost ecosystem services. Instead, a 'tipping point' may be reached, at which rapid and catastrophic collapse occurs following a period of apparent stability (e.g. Lenton et al., 2008). This potentially reverses sustainability and progress towards human welfare. The poor usually face

BOX 4.4

Have the global limits of water sustainability already been reached?

Based on an assessment of what the planet's ecosystem can sustainably supply, Rockström et al. (2009*a*) suggest that safe and sustainable consumption of 'blue water' sources (evaporation and transpiration from rivers, lakes, groundwater reservoirs and irrigation) should not exceed 4,000 km^3 per year. At present, blue water consumption is estimated at 2,600 km^3 per year. But Molden (2009) notes that, based on a wider review of studies on the global supply and demand of water, the 4,000 km^3 limit may be too high. These studies suggest that society is close to approaching the global limit of sustainable availability of water.

But distribution and consumption of water are uneven. The limits to sustainable water abstraction are already surpassed in many regions. For example, there is little or no additional stream flow or groundwater for further development in the Murray–Darling River in Australia, the Yellow River in China, the Indus in Pakistan and India, the Amu and Syr Darya in Central Asia, the Nile River, the Colorado River in the United States of America and Mexico, and in most of the Middle East. Many of these are important food-producing areas. The stress is reflected in ecosystem health, where all of these basins suffer from excessive pollution, river desiccation, competition for supplies and other ecosystem degradation (Molden, 2009). Globally, a strikingly small fraction of the world's rivers remain unaffected by humans, with the majority of river basins now exhibiting similar signs of stress (Vörösmarty et al., 2010).

BOX 4.5

Ecosystem tipping points: Theory or reality?

Deforestation can be seen as a mechanism that leads to decreasing regional rainfall through the loss of cloud-forming evapotranspiration from the forest. Local climate then becomes drier, thereby accelerating ecosystem change. In the Amazon, for example, an apparently moderate deforestation of 20% could mean that a tipping point is reached, beyond which forest ecosystems would collapse across the entire basin (World Bank, 2010*a*). This would have devastating impacts on water security and other ecosystem services that would reach far beyond the Amazon basin itself, including impacts on regional agriculture and global carbon storage.[1] Unfortunately, Amazon deforestation is already at approximately 18%.

Intact tropical forests of South America shifted from buffering the increase in atmospheric carbon dioxide to accelerating it during recent drought events; this was not compensated by recovery in non-drought years. If drought events continue, whether through climate change, deforestation or direct water use, the era of intact Amazon forests buffering the increase in atmospheric carbon dioxide may have passed (Lewis et al., 2011).

Nkem et al. (2009) provide evidence that these tipping points are being reached or surpassed in reality, as evidenced through some national reports to the UNFCCC, particularly for Central America. These suggest that the impacts of deforestation are already affecting water supply, to the extent of undermining, for example, sustainable hydropower. The countries surveyed also very clearly see the climate change-water-forest nexus as one of managing uncertainty and risk.

Tipping points triggered by multiple stressors go beyond just water and carbon. Rockstrom et al. (2009*b*) identify nine planetary boundaries beyond which ecosystems should not pass: climate change (greenhouse gas levels); ocean acidification; stratospheric ozone; nitrogen and phosphorus loads (cycling); global freshwater use; land-system change; the rate of loss of biodiversity, for which quantified limits are identified; and chemical pollution and atmospheric aerosol loading (which await metrics). They estimate that humanity has already transgressed three planetary boundaries: climate change, rate of biodiversity loss and the global nitrogen cycle (and note earlier that freshwater use is near or may have also exceeded the limits). 'The social impacts of transgressing boundaries will be a function of the social–ecological resilience of the affected societies. ... The proposed concept of "planetary boundaries" lays the groundwork for shifting our approach to governance and management, away from the essentially sectoral analyses of limits to growth aimed at minimizing negative externalities, toward the estimation [and management] of the safe space for human development' (Rockström et al., 2009*b*).

the earliest and most severe impacts of such changes, but ultimately all societies and communities would suffer as a result (CBD, 2010*a*) (Box 4.5).

One useful development is growing attention to the need to integrate available knowledge and datasets to better explain and illuminate the interdependency of water, ecosystems and humans. The aforementioned reviews of trends in environment, ecosystems and biodiversity continue a shift in this direction, but largely through interpretation of trends in numerous subject areas independently. The most significant advances are now likely to emerge from approaches that better integrate different datasets and knowledge sources. For example, Vörösmarty et al. (2010) used data depicting 23 stressors (drivers), grouped into four major themes representing environmental impacts (catchment disturbance, pollution, water resource development and biotic factors), to assess a 'cumulative threat framework'. The results show that nearly 80% of the world's population is exposed to high levels of threat to water security, based on figures for the year 2000, implying a much greater level of risk than previous assessments.

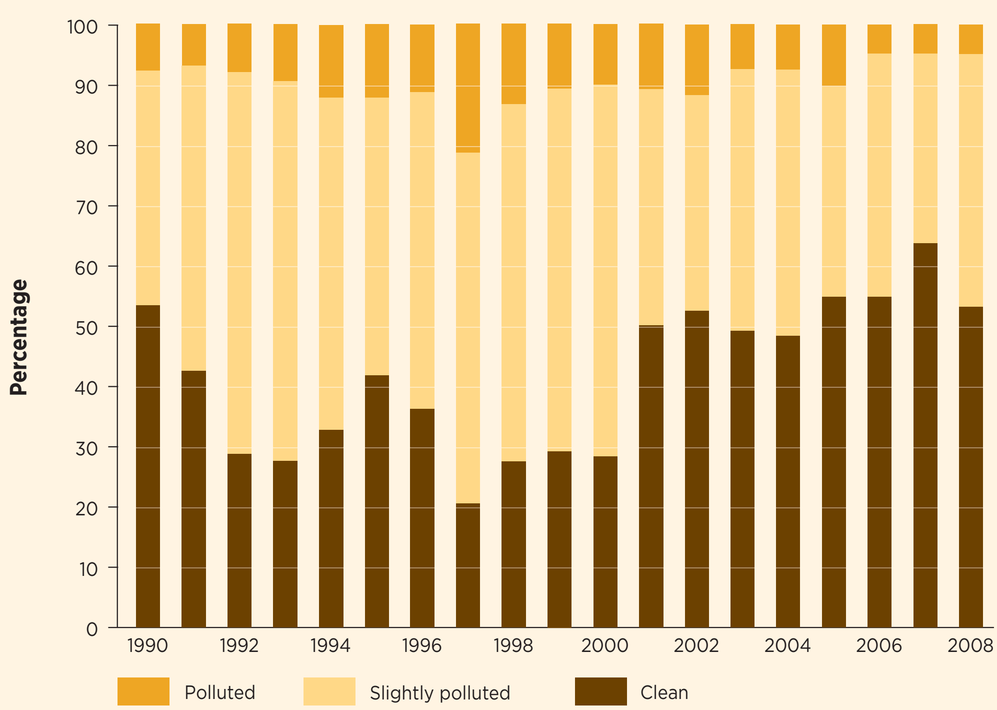
BOX 4.6

Trends in wetlands in China: Reversing losses to restore benefits

There is evidence of wholesale shifts in the right direction. For example, China's remarkable economic growth has unsurprisingly resulted in serious environmental problems, in particular rapid wetland degradation and loss, serious water shortages in the north, and wastewater pollution across the country. One report states that over 30% of natural wetland area may have been lost in only 10 years from 1990 to 2000 (Cyranoski, 2009). This is one of the highest rates of natural habitat loss recorded, outstripping trends in global forest loss, but is notably typical of the impacts of development. Where data exist they show even more extensive wetlands loss in OECD countries; for example, over 90% for New Zealand (Ausseil et al., 2008). However, wetland policies have changed in China, including shifts towards major rehabilitation efforts. A recent review suggests that in the five years post 2000, the wetland area in China has stabilized, possibly even increasing slightly (Xu et al., 2009). The driving force for this shift in policy has been recognition of the value of water-related wetland ecosystem services and the need to restore these as cost-effective solutions to water management problems.

FIGURE 4.3

Since 1997, the proportion of river basins in Malaysia classified as clean has been increasing



Source: CBD (2010a, fig. 11, p. 43).

Assessments of global or regional trends disguise good progress made at local and national scales. While water quality overall continues to deteriorate, there are signs of several pollutants coming under control through effective management measures (Figure 4.3), although non-point source pollution, particularly from agriculture, remains challenging in almost all areas. One positive trend is the emergence of more widespread attention to, and practical examples of, ecosystem-based approaches to achieving water management objectives. These approaches have yet to be upscaled and mainstreamed to attain the necessary impact on achieving global benefits, but there are promising signs (Box 4.6).

4.4 Water-related hazard risk

Water-related hazards form a subset of natural hazards; the most significant ones include floods, mudslides, storms and related ocean storm surge, heat waves, cold spells, droughts and waterborne diseases. Most disasters are caused by a combination of hazards, some related to water and other of geological and biological origin. Such events include those triggered by earthquakes, such as tsunamis, landslides that dam rivers, breakage of levees and dams, as well as glacier lake outbursts, coastal flooding associated with abnormal or rising sea levels, and epidemics and pest outbreaks associated with too little or too much water.

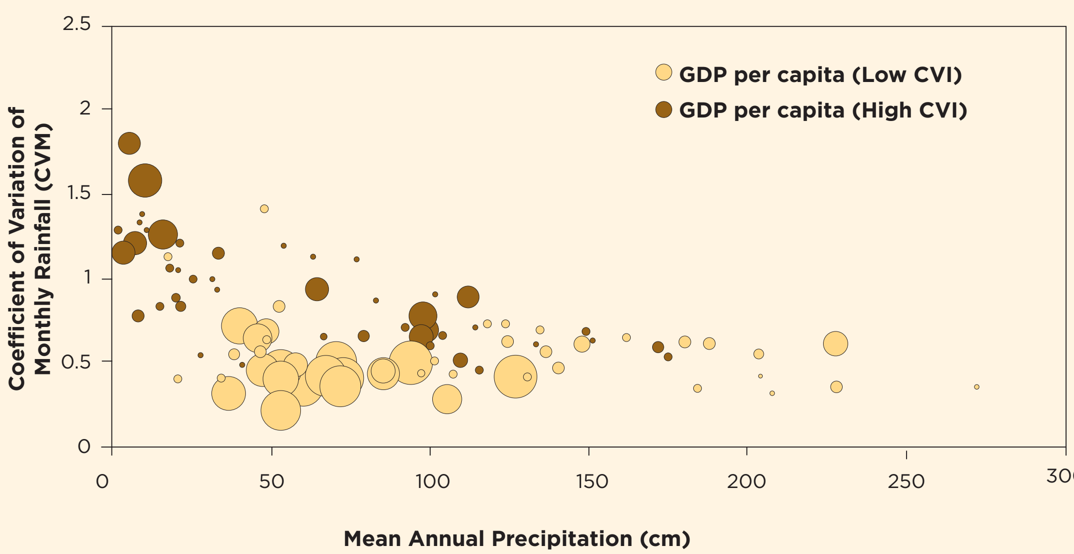
Water-related hazards account for 90% of all natural hazards, and their frequency and intensity is generally rising. 'Some 373 natural disasters killed over 296,800 people in 2010, affecting nearly 208 million others and costing nearly US$110 billion' (UN, 2011).

One water-related hazard that seldom makes it into the impacts statistics is drought. According to the United Nations *Global Assessment Report*, since 1900 more than 11 million people have died as a consequence of drought and more than 2 billion have been affected by drought, more than any other physical hazard (UNISDR, 2011). However, these figures are probably lower than the real total as few countries systematically report and record drought losses and impacts. According to same report, countries that do, such as the United States of America (USA), only report insured losses.

Disasters caused by water-related hazards have taken a toll not just on individual lives and livelihoods, but also on national development. Climate variability, which shows a strong correlation to the occurrence of

FIGURE 4.4

Climate variability has an impact on GDP



Note: This graph indicates that countries with a higher climate variability index (CVI) (dark brown dots) generally have lower GDP per capita (reflected in the size of the dots). The large dark brown dots here indicate the oil-producing states Kuwait, Oman and the United Arab Emirates
Source: Brown and Lall (2006, p. 310).

water-related hazards, has always existed and impacted development; in fact, countries with higher climate variability have generally been shown to have lower GDP per capita (Brown and Lall, 2006) (Figure 4.4). Between 1990 and 2000, natural disasters in several developing countries had caused damage representing between 2% and 15% of their annual GDP (World Bank, 2004; WWAP, 2009).

Due to climate change, it is expected that the frequency of certain natural hazards will increase (IPCC, 2007). While there is currently no evidence that climate change is directly responsible for increased losses associated with water-related hazards (Bouwer, 2011), given the increasing exposure and extremes, many countries are looking to reduce their risk to disasters as part of climate change adaptation (UNISDR, 2011).

A World Bank study released in 2010 examined the costs and benefits of specific prevention measures. The report examines government expenditures on prevention and finds that it to be generally lower than relief spending, which rises after a disaster and remains high for several subsequent years. But effective prevention depends not just on the amount, but on what funds are spent on. For example, Bangladesh reduced deaths from cyclones by spending modest sums on shelters, developing accurate weather forecasts, issuing warnings that people heeded, and arranging for their evacuation. All this cost less than building large-scale embankments that would have been less effective (World Bank, 2010*b*).

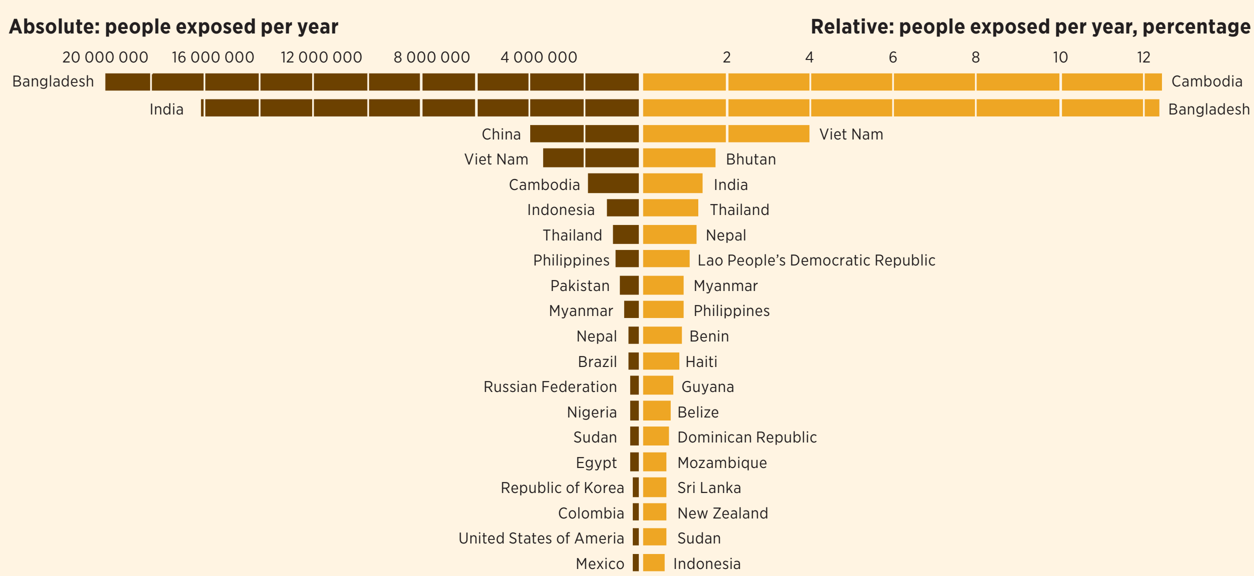
The increasing economic cost and toll of disasters should be a significant incentive for governments and humanitarian organizations to focus more attention on preparedness, prevention and addressing the root causes of vulnerability. In fact, increased donor interest in disaster prevention and risk reduction has not been matched by substantive amounts of new funding or new projects (Martin et al., 2006).

4.4.1 Trends in water-related hazard impacts and risk

Water-related disasters pose both direct impacts (e.g. damage to buildings, crops and infrastructure, and loss of life and property) and indirect impacts (e.g. losses in productivity and livelihoods, increased investment risk, indebtedness and human health impacts). The impacts of hurricanes, typhoons and cyclones depend on wind speed (category 1–5), where a storm strikes, how much flooding it causes, and the population density and quality of buildings and infrastructure in the affected area. Such storms cause impacts through high winds, tornadoes, storm surges (around 80–160 km wide across the coastline), storm

FIGURE 4.5

People exposed to floods



Source: UNISDR (2009, fig. 2.14, p. 36).

tides (tidally enhanced storm surges), and flooding associated with torrential rain. Along immediate coastlines, storm surges are the greatest threat to life and property. These types of storms can cause tremendous damage and loss of life in a matter of seconds.

Floods are one of the most frequent natural hazards, and they occur in almost every country. The severity of flash floods, river floods and urban floods depends on rainfall intensity, spatial distribution of rainfall, topography and surface conditions. Climate change is expected to increase the severity and frequency of flooding (IPCC, 2007). Drought affects more people globally than any other natural hazard (UNISDR, 2011). It does not destroy infrastructure or directly lead to human mortality, although famines may be triggered by drought (ultimately, however, mortality is due to a complex set of interactions surrounding food security). The 2011 famine in the Horn of Africa, which threatened the livelihood of more than 13.3 million people (UNOCHA, 2011), highlights the complex interaction between (and potential catastrophic consequences of) the climatic phenomenon resulting in low rainfall, the vulnerable pastoralist population with limited capacity to cope, and a political context of conflict.

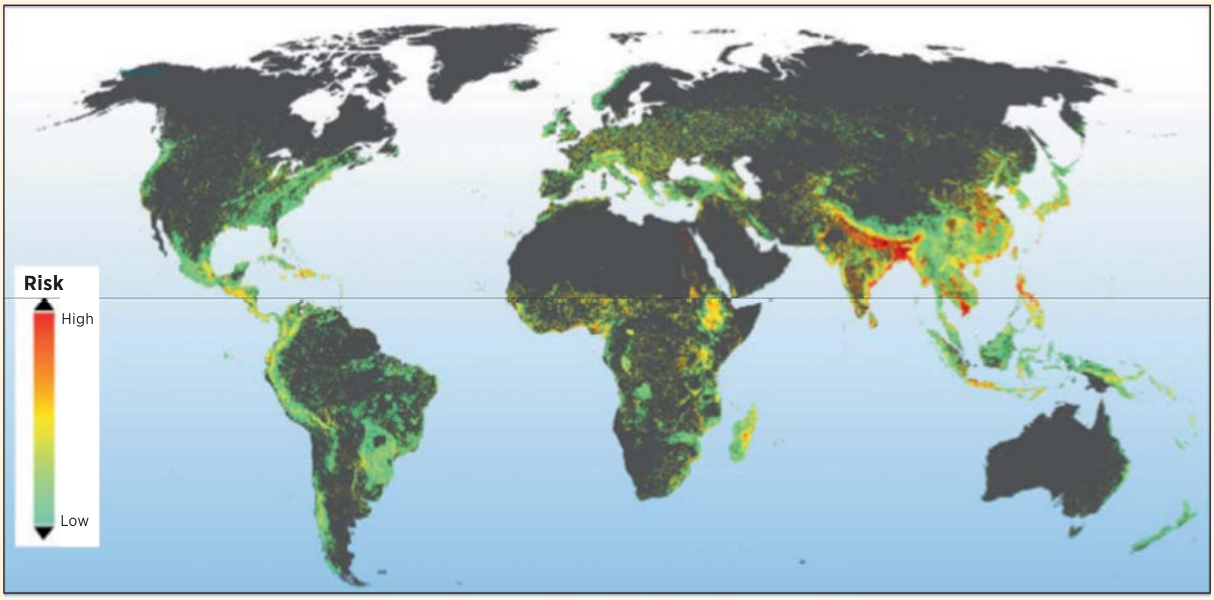
An observation of flood and drought 'risk patterns and trends at the global level allows a visualization of the major concentrations of risk and an identification of the geographic distribution of disaster risk across countries, trends over time and the major drivers of these patterns and trends' (UNISDR, 2011).
Between 1970 and 2010 the world's population increased by 87% (from 3.7 billion to 6.9 billion) (UNISDR, 2011). During the same period, the annual average population exposed to flood increased by 112% (from 33.3 to 70.4 million per year) (UNISDR, 2011) (Figure 4.5).

'Countries in all regions have strengthened their capacities to reduce mortality risks associated with major weather-related hazards such as tropical cyclones and floods' (UNISDR, 2011, p. 18). Figure 4.6 shows an updated global distribution of mortality risk for three weather-related hazards (tropical cyclones, floods and landslides provoked by rains). The areas of highest risk visible in these maps correspond to areas where concentrations of vulnerable people are exposed to severe and frequent major hazards.

In contrast, countries have had a far more difficult time successfully addressing other risks. Economic loss risk

FIGURE 4.6

Hazard mortality risk (floods, tropical cyclones and precipitation-triggered landslides)



Source: Developed by the GAR team at UNISDR.

> “Despite improvements in preventive efforts, disasters will still occur and preparedness and response capacity is essential.”

to tropical cyclones and floods is trending up because the rapidly increasing exposure of economic assets is outstripping reductions in vulnerability (IPCC, 2007). Flood mortality risk is highest in rural areas with a dense and rapidly growing population and in countries with weak governance. Across all water-related hazards, countries with low GDP and weak governance tend to have drastically higher mortality risk than wealthier countries with strong governance (UNISDR, 2011).

Human health is both directly and indirectly impacted by water-related hazards. Outbreaks of waterborne diseases, such as cholera, can occur after disasters as a result of contaminated or inadequate water supplies, sometimes affecting thousands of people and causing many deaths. Outbreaks of vector-borne disease can also occur. For example, malaria epidemics have been shown to occur more frequently (in epidemic-prone areas) following dry periods associated with El Niño-Southern Oscillation – as documented in Colombia, Sri Lanka and Venezuela (PAHO, 2000).

In complex disasters where malnutrition, overcrowding and lack of the most basic sanitation are common, catastrophic outbreaks of gastroenteritis (caused by cholera or other diseases) have occurred (PAHO, 2000*a*). In Haiti in 2010, figures released by the government after the earthquake cite over 200,000 deaths, leaving a large and highly susceptible displaced population to confront hurricane season and potential disease outbreaks. In the aftermath of the earthquake disaster and flooding, the cholera outbreak resulted in the hospitalization of nearly 150,000 people, and left nearly 5,000 dead (USAID, 2011).

4.4.2 Behind the trends: Drivers of change

Understanding the underlying factors of risk for water-related hazards is the cornerstone of any effort to reduce risk and future impacts. The factors that have led to increased water-related disasters include natural pressures such as climate variability; management pressures such as lack of appropriate organizational systems and inappropriate land and water management; and social pressures such as population growth, assets and settlements in high-risk areas (Adikari and Yoshitani, 2009).

The increase in natural disaster losses over the past few decades is largely attributable to the increase in value of exposed assets, while anthropogenic climate change has not had a discernable impact on losses (Bouwer, 2011). By 2050, rising populations in flood-prone lands, climate change, deforestation, loss of wetlands and rising sea levels are expected to increase the number of people vulnerable to flood disaster to 2 billion (UNU, 2004).

4.4.3 Meeting the challenges ahead

Meeting the challenges associated with disasters caused by water-related hazards requires investment in and implementation of good disaster risk-reduction (DRR) practice. Despite improvements in preventive efforts, disasters will still occur and preparedness and response capacity is essential. Examples of best practices led by humanitarians, governments, water resources managers, the private sector and development agencies abound, although scaling these up to meet real needs remains a central challenge.

Disaster preparedness is improving; investments enabling earlier early warnings and actions are being undertaken (IFRC, 2009). For example, real investments in capacity and tools that incorporate weather and climate information into contingency planning and preparedness action are improving preparedness and response-saving resources, livelihoods and lives (Hellmuth et al., 2011). Investments in the capacity of communities and early warning systems in flood-prone areas, such as Mozambique, have resulted in better preparedness and response during flood events (GIZ, 2007). In Botswana, seasonal forecasts can provide useful indications of the likelihood of a malaria epidemic several months in advance (Hellmuth et al., 2009; Thomson et al., 2006).

To deal with escalating costs, governments are increasingly using insurance mechanisms and weather indexes to help them manage risk more effectively. These offer payouts when extreme weather events occur, offering the key advantage of speeding injections of cash, allowing for more timely responses. Another advantage is the ability to make concrete plans even before disaster strikes, knowing that funds will be available when needed. The Caribbean, Ethiopia, India, Malawi and Mexico provide examples of index insurance for disaster relief (Hellmuth et al., 2009).

Investment in DRR targets the root causes of vulnerability, which often stem from a combination of political, economic and social forces, as well as the impacts of highly variable rainfall. For example, in chronic food insecurity regions, programmes that complement food aid and build resilience and productivity are necessary to lift people out of poverty traps (Trench et al., 2007). Households, for example, may employ mitigation strategies to reduce vulnerability or the impact of risk by pooling risks through informal or formal insurance mechanisms.

With regard to extreme events, a recent study of 141 countries found that more women than men die from natural hazards, and that this disparity is linked most strongly to women's unequal socio-economic status. 'Where the socio-economic status of women is high, men and women will die in roughly equal numbers during and after natural hazards, whereas more women than men die (or die at a younger age) where the socio-economic status of women is low' (Neumayer and Plumper, 2007, p. 5). Mainstreaming gender into DRR offers an opportunity for improving disaster resilience and enhancing gender equality and sustainable development. However, introducing a gender perspective to DRR requires a change in attitude for policy-makers and implementers. Every citizen has a role to play in reducing disaster risk, but governments can create an enabling environment for women and men to participate in the effort. This would include communications and warning systems that can be accessed by women, and tapping into their knowledge and skills, which are crucial when managing and addressing risks (UNISDR et al., 2009; see Box 4.7).

Although investment in DRR, including water resources infrastructure, continues to lag, awareness is being raised and quantified evidence is being produced regarding its relative cost-effectiveness. Humanitarians have changed their approach over the past few decades, shifting from response and recovery to a more balanced approach that includes risk reduction: However, complementary capacity-building and financing mechanisms are sorely needed to fill the gap. Given that the cost and frequency of flood disasters is on the rise, investments in preparedness activities and associated infrastructure, flood plain policy development, effective watershed land use planning, flood forecasting and warning systems, and response mechanisms are essential to reducing risks and impacts (UNISDR, 2011). Comprehensive assessments of risks from water-related hazards are necessary, not only for improved understanding of changing risks, but also for better decision-making, planning and implementation of sustainable solutions.

Finally, because of rapid change and sometimes discontinuity in the combination of political, economic and social forces, future risks are unknown. Reflecting on scenarios describing possible futures can help decision-makers to take a longer-term view.

4.5 Impact of desertification on water resources

Poor and unsustainable land utilization and management practices are leading to desertification and land degradation around the world, increasing pressure on

BOX 4.7

Women in times of disaster

Women are usually responsible for children and the elderly; therefore the demands on them immediately prior to and during a disaster are very different from those of men. Such different demands are especially important to consider in the case of rapid onset disasters, when the time between receiving a warning and responding can be very limited. A report on *Mainstreaming Gender into Disaster Recovery and Reconstruction* (Dimitríjevics, 2007) provides some examples of disaster managers setting up childcare facilities on-site so that female staff who are impacted by a disaster can still work to assist others. This type of on-the-spot decision illustrates how routine contingency planning to provide childcare to women involved in early warning and emergency response could help more people. The example above also illustrates that knowledge, acceptance and respect for gender differences and strong social norms, can improve response as well as the planning and administration of relief items (UNISDR et al., 2009).

water resources and leading to water scarcity. Recent estimates indicate that nearly 2 billion ha of land worldwide – an area twice the size of China – are already seriously degraded, some irreversibly (FAO, 2008). Land degradation is increasing, with almost one-quarter of the global land area being degraded between 1981 and 2003. The emphasis on land degradation has focused on dryland areas, but humid areas are also experiencing a surprising level of global land degradation, more than initially thought (Bai et al., 2008).

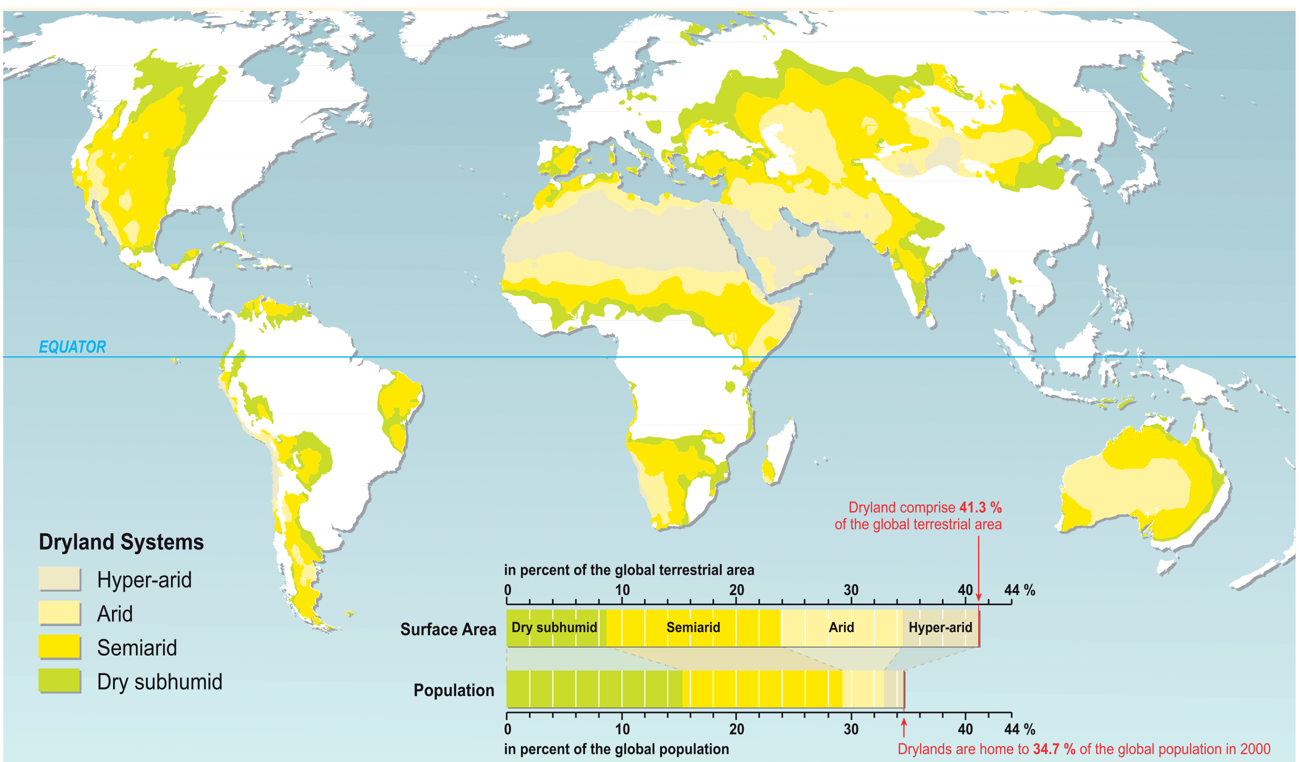
4.5.1 Recognizing desertification, land degradation and drought imperatives

Desertification, land degradation and drought (DLDD) constitute a ubiquitous challenge in the dryland regions of the world (Figure 4.7; Box 4.8), but are occurring in all agro-ecological zones and are increasingly considered a global problem with their extent and impacts affecting environmental and social vulnerability. Throughout the world DLDD affects arable lands, turning them into desolate wastes, affecting human livelihoods and well-being, exacerbating poverty and forced human migration, as well as inflicting destitution on the populations of vast areas and threatening them with food scarcity, malnutrition and famine.

Globally, DLDD affects 1.5 billion people who depend on degrading areas, and it is closely associated with poverty, with 42% of the very poor living in degraded areas, compared with 32% of the moderately poor and 15% of the non-poor (Nachtergaele et al. 2010). According to estimates, 24 billion tons of fertile soils are disappearing annually, and over the past 20 years the surface area lost is equal to all of the farmland of the USA. In the face of DLDD, it is estimated that a substantial proportion of the earth's natural forests have already been destroyed, and over 60% of ecosystem services are already degraded. This negative trend is set to continue at an accelerating pace over the next half century. For example, up to 90% of West Africa's coastal rain forests have disappeared since 1900 (MA, 2005*b*).

FIGURE 4.7

The extent of dryland systems worldwide (2000)



Notes: Drylands include all terrestrial regions where the production of crops, forage, wood and other ecosystem services are limited by water. Formally, the definition encompasses all lands where the climate is classified as dry subhumid, semiarid, arid or hyper arid. This classification is based on Aridity Index (AI) values. The AI is the long-term mean of the ratio of an area's mean annual precipitation to its mean annual potential evapotranspiration.
Source: MA (2005c, appendix A, p. 23, from data sources cited therein).

Those affected include the world's poorest, most marginalized and politically weak citizens. India alone accounts for 26% of this population, China 17% and sub-Saharan Africa 24%. The remaining part of the Asia-Pacific accounts for 18.3%. The other parts of the world are not far behind, with Latin America and the Caribbean accounting for 6.2% and North-East and North Africa 4.6% (ICRISAT, 2008). While DLDD affects all regions of the world, it has its greatest impact in Africa where two-thirds of the continent is desert or drylands.

Given desertification and land degradation, a number of countries in the drylands face increasing water scarcity. Most drylands have hyper-arid, arid, semi-arid and subhumid climatic conditions with limited water resources, which almost entirely depend on rainfall for replenishment. Rainfall is highly variable with considerable regional variations. Two, three or more consecutive dry years are experienced during some severe drought periods. Consequently, many people in the drylands suffer from a lack of access to water where it is very unevenly distributed.

BOX 4.8

Key facts on desertification

- Desertification occurs through land degradation in arid, semi-arid and dry subhumid areas resulting from various factors, including climatic variations and human activities.
- Desertification is not, as commonly thought, the actual expansion of existing deserts.
- Desertification affects nearly 1 billion people, or one-sixth of the world's population.
- Desertification is occurring in 70% of all drylands, or one-quarter of the total land area of the earth.
- Desertification is responsible for the degradation of 73% of the world's rangeland.
- Desertification is especially severe in Africa, where two-thirds of the continent is desert or drylands, and where 73% of its agricultural drylands are already seriously or moderately degraded.
- Asia contains the largest amount of land affected by desertification of any continent-just under 1400 million ha.
- Nearly two-thirds of Latin America's drylands are moderately to severely desertified.
- Desertification is estimated to cost the world more than US$40 billion a year in lost productivity.

Source: Reproduced from Rogers (1995).

Such is the case in sub-Saharan Africa, where 800 million people live, with a population growth rate of more than 2.5% (Carles, 2009). Statistical analysis of rainfall patterns in some of the drylands regions reveals a stepped drop in the early 1970s, which has persisted. An analysis of the situation indicates a reduction of approximately 20% in precipitation levels, which results in a 40% reduction in surface runoff (EU, 2007).

4.5.2 The impacts of DLDD on water resources

A variety of human activities modify the landscape, such as deforestation, veldt fires and inappropriate farming and animal husbandry practices. These result in the degradation and desertification of watersheds and catchment areas, and reduce the amount of usable safe water available downstream. Often, such landscape modifications tend to exacerbate soil erosion and reduce the soil water-holding capacity, and decrease the recharge of groundwater and existing surface water storage capacity, through siltation and sedimentation of rivers and reservoirs that subsequently result in water scarcity over time. Furthermore, the draining of wetlands reduces water availability to recharge groundwater, resulting in water scarcity in the long term as the groundwater table recedes. In addition, the diversion of rivers for agricultural (irrigation) or industrial purposes deprives rivers and lakes of their usual flow, contributing to water scarcity in their hinterland.

Desertification is a major culprit in inducing water scarcity through direct reduction of freshwater reserves. It directly impacts river flow rates by increasing river water turbidity, which in turn enhances siltation and sedimentation in surface water reservoirs and estuaries. Desertification also negatively impacts groundwater tables by reducing a soil's capacity to allow water to percolate in the event of rainfall. In the face of desertification and the resultant water scarcity, accelerated and often rampant exploitation of underground water reserves frequently occurs to meet socio-economic needs, leading to gradual depletion of groundwater and increased water scarcity.

Rich dryland nations like Australia are not immune to water scarcity either. Drought is causing acute water shortages in large parts of Australia, Africa, Asia and the USA (Morrison et al., 2009). Regardless, an urban Australian on the average consumes 300 L water daily and a European 200 L, while in sub-Saharan Africa an individual makes do with less than 20 L per day (Natarajan, 2007). Besides droughts, river flows

> “In the drylands, the timing of drought and the lack of suitable technological options often limit the flexibility of poor households to make tactical adjustments in drought management practices to reduce losses.”

and water supplies are being reduced by shrinking snow caps across China, India and Pakistan – countries where more than 1 billion people already lack access to safe drinking water and adequate sanitation (Morrison et al., 2009).

Often absent in these affected areas are efficient and reliable early warning systems to alert the populations of impending DLDD-related disasters. In the drylands, the timing of drought and the lack of suitable technological options often limit the flexibility of poor households to make tactical adjustments in drought management practices to reduce losses (Pandey et al., 2007). Where rains are late, farmers mostly delay planting or replant when suitable opportunities arise, and may reduce fertilizer use. When droughts and water scarcity are late, the opportunities for crop management adjustments to reduce losses are often no longer available.

One of the major impacts of DLDD-associated water scarcity is felt through food insecurity and starvation among affected communities, particularly in developing countries in the drylands. DLDD-related water scarcity brings about uncertainties that inevitably make communities vulnerable. The major issue is the inevitable failure of agriculture, because it is the largest water-consuming sector of poor economies (Carles, 2009). Thus, if dryland countries could reduce the impacts of DLDD on water resources and achieve water security, opportunities of achieving food security would be greatly enhanced. It is therefore essential for countries to take appropriate measures to address DLDD imperatives in the quest for greater water and food security.

In response to DLDD, some governments and water authorities resort to investing in supply-side measures that increase the extraction of countries' water resources, such as river diversions, construction of water reservoirs and groundwater pumping. Other investments that can be made include water-efficient processes, water-saving irrigation schemes and water recycling and reuse. Some of these measures, while they enhance water availability and accessibility and improve the prospects for water security, bring environmental and further financial costs, reduce downstream water security and aggravate water stress.

The Aral Sea and Lake Chad, for example, are disappearing because of upstream infrastructure developments. Lake Chad has lost 95% of its size since the 1960s. River diversion can also cause conflicts where a basin is shared by a number of riparian countries. For example, a number of river basins in Africa are shared by more than five riparian states, including the Congo (13), the Niger (11), the Nile (10), the Zambezi (9) Lake Chad (8) and the Volta (6) (Carles, 2009). The monitoring and management of such transboundary water resources is more complex and can pose greater risks in terms of DLDD if improperly managed, particularly for downstream users.

4.5.3 Combating DLDD imperatives to mitigate the challenges of water scarcity

Desertification should not be considered as an isolated process and neither should its mitigation processes. It constitutes an integral part of socio-economic development involving sustainable management of the land and water resources. Thus, combating desertification is complex and difficult, and usually impossible without alteration of the very land management practices that led to its occurrence.

A variety of different measures are being applied worldwide to reduce land degradation and avert desertification and water scarcity. In rice paddies throughout the mountainous regions of Asia, terracing is employed to restrain water erosion. On less steeply sloping land, contour strip-farming works well. Conservation agriculture, which includes both no-till and minimum tillage, is an additional tool in soil conservation. Conservation agriculture is widely used in Argentina, Australia, Brazil, Canada and the USA, as well as in some parts of Africa, Asia and Europe, (Brown, 2006).

The promotion of soil, water and vegetation conservation, combined with measures to rehabilitate, conserve and protect the natural environment, are prerequisites for sustainable land management (SLM). Practising SLM is one of the few options for sustaining livelihoods and generating income without destroying the quality of the land and the water resources, which are needed for agricultural production, food security, protection of biological diversity, as well as preventing and mitigating DLDD imperatives.

Decisions on how best to combat DLDD must also be based on solid scientific and economic analysis, recognizing the importance of local knowledge in cross-sectoral land and water resources management, and shifting focus from human uses of freshwater as a technical issue to the role of freshwater in catchments for the generation of ecosystem and societal services. Any policies adopted should enable participation of key stakeholder and incorporation of their ecological knowledge into institutional structures in a multi-level governance system. Consequently, the development of solutions must necessarily be inclusive and multi-sectoral (Climate Institute, 2009).

Finally, successful policies recognize that freshwater systems are complex and adaptive and can be degraded irreversibly (SIWI, 2009). The effects of DLDD can be felt globally, but the solutions are most often of a local, national or regional nature. An integrated and coordinated approach to combat DLDD, at local, national and transboundary levels, and policies that are highly integrated, are required to mitigate the various problems associated with water scarcity.

4.6 In or out of balance?

4.6.1 Balancing uses and supplies: Notions of water stress and water scarcity

As described throughout Chapter 2, the global demand for water is expected to grow significantly for all major sectors using water.

Although predicting future water demands for agriculture – the greatest user of water by far – is fraught with uncertainty, global agricultural water consumption is estimated to increase by about 20% by 2050. This increase could be even higher if substantial improvement in productivity of rainfed and irrigated agriculture are not set in place to meet the increasing demand for food from population growth and changing diets.

The growing demand for energy will also create increasing pressure on water resources, especially in sub-Saharan Africa and in the least developed countries of South Asia, which account for 80% of the 1.5 billion people lacking access to electricity globally. Growing demand for biofuels and other water-intensive energy sources, such as bituminous sands and shale gas, will only add to the energy sector's growing water footprint.

Proportionally, water use by the industry sector tends to increase with rising levels of national development, as growing economies shift from agriculture-based to more diversified economies. Demand should therefore be expected to see the highest rate of growth in countries with the fastest growing economies.

Like energy and industry, demand for water supply and sanitation services will also increase particularly in developing countries. Although the MDGs have helped to elevate the importance of these services onto national and international policy agendas, much remains to be done. Furthermore, national and local governments, which are ultimately responsible for meeting the growth in domestic demand, will still need to compete with other sectors for often-limited water supplies.

Ecosystems are both users (Chapter 2) and suppliers (Section 4.2) of water. Some water is required for the protection and maintenance of healthy ecosystems, which in turn provide important services related to water quality and protection against extreme events, as well as maintaining livelihoods among other benefits.

Human health (Section 4.1) will also vitally benefit from healthy ecosystems, safe water resources, and water supply and sanitation services. Maintaining human health through water translates into productivity gains from income earned from those saved from premature death from diarrhoea, gains in health care services in treating fewer patients, and the direct costs to patients of medication and transportation, as well as the time-saving benefits for people currently with inadequate services who gain access to nearby water and sanitation facilities.

As described in the previous section of this chapter, the increasing number and cost of water-related disasters create negative consequences that directly affect human livelihoods and impact national development.

While per capita consumption of water is decreasing in most of the industrialized world, overall demand for water is increasing throughout all major use sectors, driven primarily by the growing demands for food and energy in the developing world and emerging economies. This will invariably increase pressure on the earth's limited water resources, which in many regions are already experiencing varying levels of water stress. The world is transitioning to a new era where finite water constraints are starting to limit future economic growth and development, and it is becoming clear that even renewable water resources cannot supply enough water if not managed carefully (Patterson, 2009).

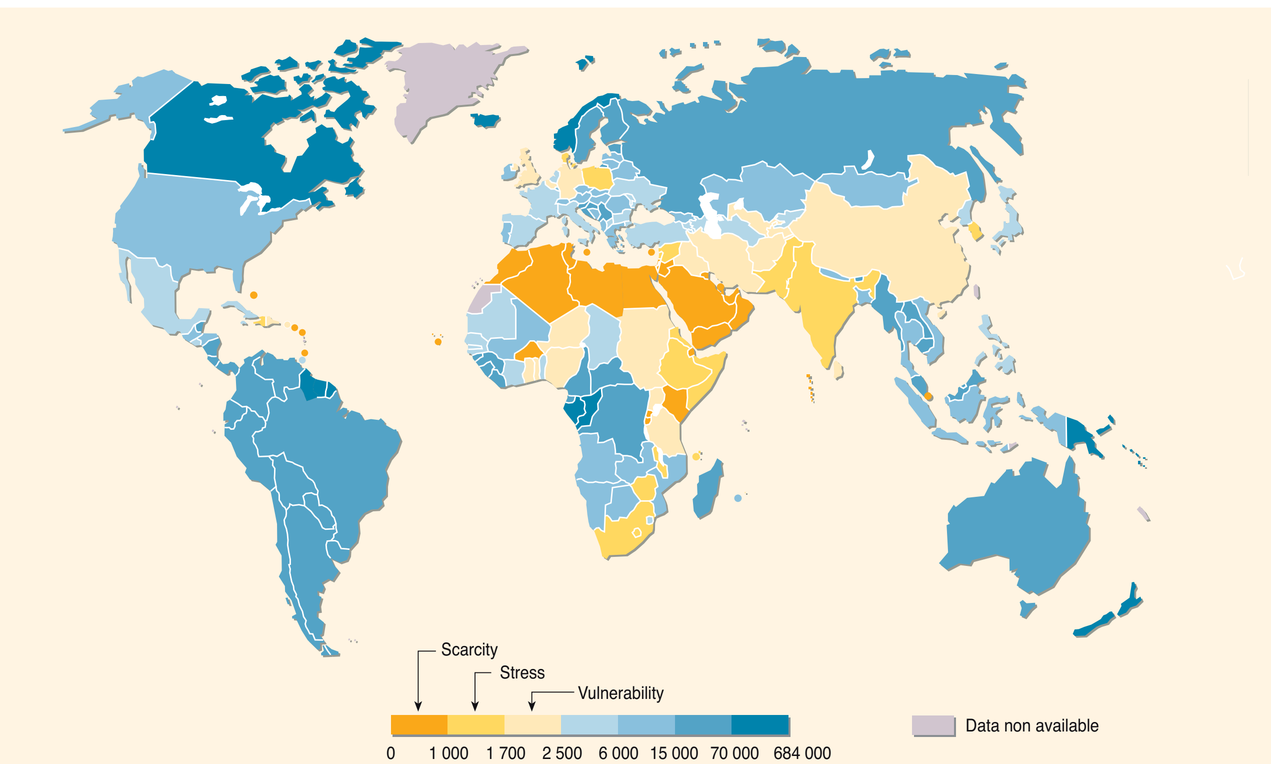
Water stress and water scarcity

'Hydrologists typically assess scarcity by looking at the population-water equation. An area is experiencing water stress when annual water supplies drop below 1,700 m^3 per person. When annual water supplies drop below 1,000 m^3 per person, the population faces water scarcity, and below 500 m^3 "absolute scarcity"' (UN-Water, n.d.) (Figure 4.8).

The notions of water stress and water scarcity might appear synonymous, but this is not always the case, and different definitions have been used to describe these terms, sometimes leading to confusion. For example, the term *water stress* is generally used to describe the ratio of water use (i.e. the amount of water withdrawn from the natural hydrological system) over the total amount of renewable water available. Thus, the higher the use as a fraction of available water, the higher the stress on the supply system.

FIGURE 4.8

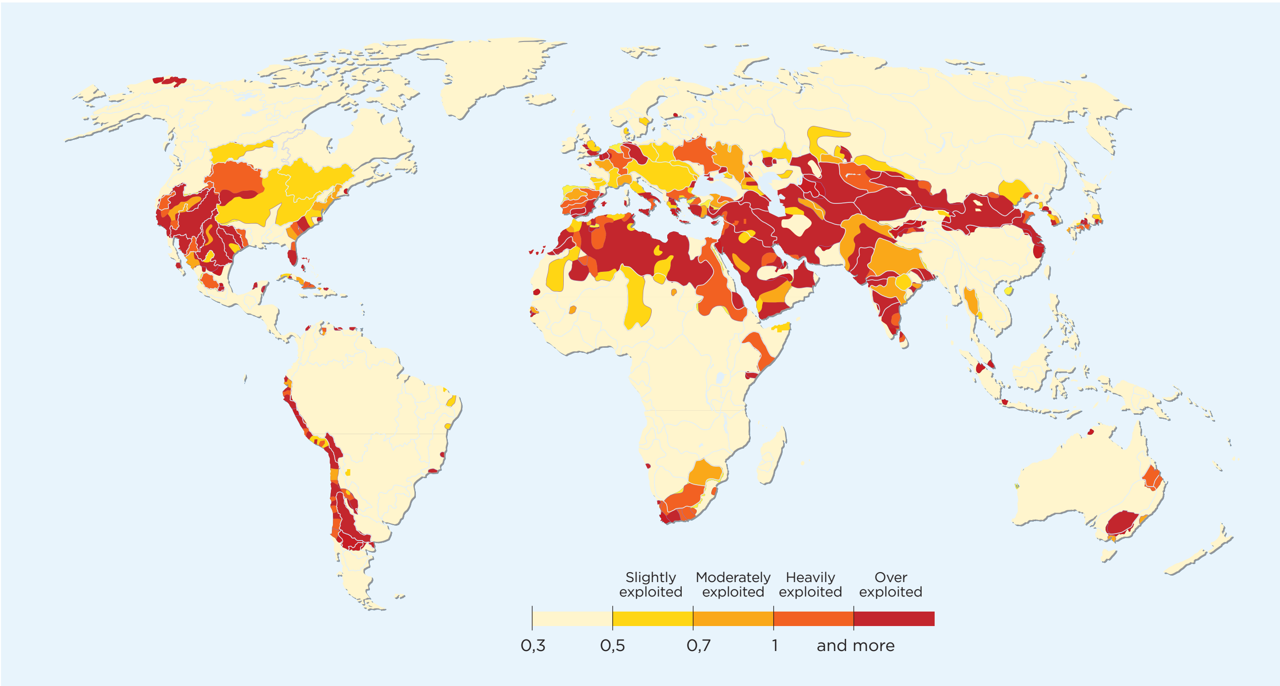
Freshwater availability (m^3 per person per year, 2007)



Source: UNEP/GRID-Arendal (2008) (http://maps.grida.no/go/graphic/global-waterstress-and-scarcity, P. Rekacewicz [cartographer] (Le Monde diplomatique), with sources FAO and WRI).

FIGURE 4.9

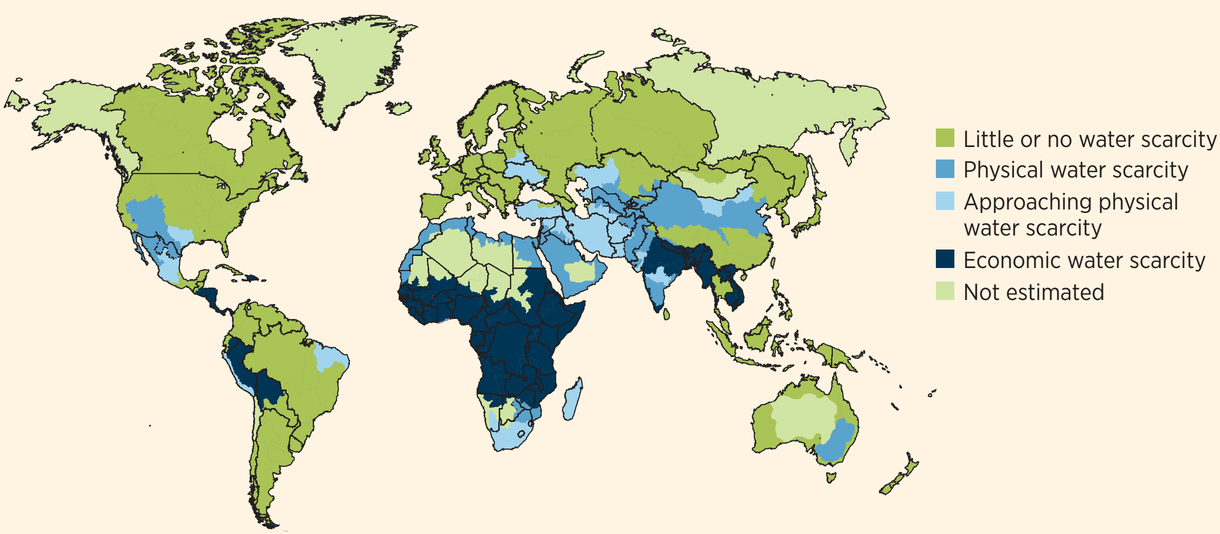
Global Water Stress Indicator (WSI) in major basins



Source: UNEP/GRID-Arendal (2008) (http://maps.grida.no/go/graphic/water-scarcity-index, P. Rekacewicz [cartographer], with sources Smakhtin, Revenga and Döll [2004]).

FIGURE 4.10

Global physical and economic water scarcity



Definitions and indicators

- Little or no water scarcity. Abundant water resources relative to use, with less than 25% of water from rivers withdrawn for human purposes.
- Physical water scarcity (water resources development is approaching or has exceeded sustainable limits). More than 75% of river flows are withdrawn for agriculture, industry, and domestic purposes (accounting for recycling of return flows). This definition—relating water availability to water demand—implies that dry areas are not necessarily water scarce.
- Approaching physical water scarcity. More than 60% of river flows are withdrawn. These basins will experience physical water scarcity in the near future.
- Economic water scarcity (human, institutional, and financial capital limit access to water even though water in nature is available locally to meet human demands). Water resources are abundant relative to water use, with less than 25% of water from rivers withdrawn for human purposes, but malnutrition exists.

Source: Comprehensive Assessment of Water Management in Agriculture (2007, map 2.1, p. 63, © IWMI, http://www.iwmi.cgiar.org/).

Several researchers and agencies have computed the *water stress* of watershed and grid scales by incorporating domestic, industrial and agricultural water consumption, against renewable supplies of water from precipitation, rivers and groundwater. Figure 4.9 shows one such map, which is consistent with other maps (e.g. Maplecroft, 2011; Smakhtin et al, 2003; Veolia Water, 2011) as each is based on similar – if not identical – datasets. The Arab Region countries nations have the highest levels of water stress, as well as major parts of Eastern China, India and the south-western USA.

However, under this definition, low water stress does not automatically imply ready access to water, which is a paradox that a large swath of the global population currently face. Whereas *water stress* is a function of the *availability* of water resources, the concept of *water scarcity* is also a function of *access*. In this regard, *economic scarcity* – whereby access is not limited by resource availability, but by human, institutional and financial constraints over distribution of the resource to different user groups – forms a major part of this paradox. Figure 4.10 illustrates global physical and economic water scarcity.

According to UN-Water,[2] water scarcity is defined as the point at which the aggregate impact of all users impinges on the supply or quality of water under prevailing institutional arrangements to the extent that the demand by all sectors, including the environment, cannot be satisfied fully. Thus, where water 'stress' is a *physical* concept, water 'scarcity' is therefore a *relative* concept and can occur at any level of supply or demand. 'Scarcity may be a social construct (a product of affluence, expectations and customary behaviour) or the consequence of altered supply patterns – stemming from climate change for example' (UN-Water, n.d.).

The physical scarcity regions are consistent with the high-stress regions in Figure 4.9. However, regions such as central Africa, north-eastern India, north-eastern parts of South America and South-East Asia, which have medium to low water stress (Figure 4.9), experience water scarcity which is purely due to institutional and economic barriers.

Although finite, as described in Chapter 3, the world's freshwater resources can be highly variable over time and across rivers basins as a function of climate variability. Climate change will affect both precipitation patterns as well as the melting of snow and ice, resulting in increasing variability in the flows of surface waters from which most of our freshwater is withdrawn.

"Economic, social and political crises have been emerging at an accelerated rate. Although often described individually – the 'food' crisis, the 'energy' crisis, the 'financial' crisis, the 'human health' crisis, or the 'climate change' crisis, to name but a few – these crises are all inter-related though their causes and consequences. Their underlying causes often boil down to the ever-increasing competition for a few key – often-limited – resources, of which water is common to all."

Climate change models are constantly improving and generating new information, but additional research efforts are required to update our knowledge concerning possible future conditions, especially at regional and basin-level scales. Furthermore, several of the world's major aquifers, especially in arid and semi-arid regions, are being depleted due to intensive use of these limited and highly vulnerable reserves.

It is therefore highly unlikely that our increasing demand for water will be met solely through supply-oriented solutions. Rather, the key solutions to the global – and most regional and local – water crises resides in our ability to better manage demand while seeking to balance and maximize the various benefits of water.

4.6.2 Water as the nexus for sectors related to development and poverty reduction: Balancing the trade-offs

Food, energy, opportunity for economic growth, human and environmental health, and protection against water-related disasters are all necessary ingredients of development, including income generation and poverty reduction. They all depend on water. Yet these challenges have too often been dealt with in isolation rather than as part of an overarching and strategic framework across society and the economy. As a result, different developmental sectors often find themselves competition with each other for the finite water resources upon which they all depend. Therefore, in countries and regions where water resources are limited, decisions made to generate benefits from one sector often produce negative consequences for other sectors, through water, such that the overall economic and developmental gains from one sector are offset by losses to another.

This situation can ultimately lead to short-term and unsustainable decision-making and increase the number of people affected by water shortages. Climate change exacerbates this problem still further (Steer, 2010). Modern economic thinking and policy-making have created an economy that is so out of alignment with the ecosystem on which it depends that it is approaching collapse (Brown, 2011). Changing this situation will require the full inclusion of considerations for water within the existing governance frameworks under which water is managed – across sectors and regions, locally and globally – through representative institutions that have the appropriate authority. Water managers, in turn, need to be familiar with tools to measure social and economic impacts of their interventions. It is important that they have an understanding of the social context and existing power relations before introducing a new project and informing decision-makers accordingly. This approach will assist in selecting solutions best suited to the community, which will be sustainable in the long term.

Economic, social and political crises have been emerging at an accelerated rate. Although often described individually – the 'food' crisis, the 'energy' crisis, the 'financial' crisis, the 'human health' crisis, or the 'climate change' crisis, to name but a few – these crises are all inter-related though their causes and consequences. Their underlying causes often boil down to the ever-increasing competition for a few key – often-limited – resources, of which water is common to all. These inter-related crises also have consequences that negatively affect growth and development prospects and have disproportionate, negative effects on the poor and vulnerable.

Various approaches to international governance, as elaborated in Chapter 1 – whether the MDGs or such policy tracks for sustainable development as Rio+20 and the 'green economy'[3] – have failed to recognize the central role of water as a key ingredient of poverty reduction and sustainable development, cutting across the spectrum. In both cases, water is recognized as another 'sector', to be addressed more or less independently of the other sectors. This may seem appropriate from a purely 'drinking water and sanitation services' perspective, as is the case for the MDG target on drinking water and sanitation. It may also seem appropriate when calling for the investment in infrastructure, water-policy reform and in the development of new technology required to bridge the gap between global supply and water withdrawals (UNEP, 2011) as a specific sector of the green economy. However, such an approach across the board further compartmentalizes water in terms of national policies as different ministries and other authorities become responsible for their own commitments in terms of health, food and agriculture, energy or urban settlements. In fact, it is these policy decisions that ultimately determine how water resources are to be allocated. Therefore, the 'water-policy reform' (for example, as called for under the green economy in the statement above) would actually entail a broader reform of national policies whereby considerations for water are fully included in decisions regarding each political sector. And this is where water managers can inform the process.

A similar argument applies to the various global crises outlined above, for which proposed solutions are often compartmentalized and give little or no consideration to the central importance of water.

Over the past few years, the term 'nexus' has been used to describe the point at which different social, economic and/or environmental sectors are linked to each other. Climate change and energy are a perfect example; in this case the nexus is greenhouse gas. In agriculture, increased competition over land and water between crops grown for food and those grown for biofuels lead to the 'food-energy nexus'. Recognizing the important role of water, managing the water-food-energy-climate nexus has been the subject of analysis and discussion. Ecosystems, human health and urbanization/migration, with their links to competition over water, meet the others at the same nexus.

Although it may seem logical to accept that different sectors can be 'in competition' over water, it is clear that all the benefits of water are required for sustainable economic development. Where water resources are limited, certain trade-offs are required to allocate water towards different uses in order to maximize the overall return made up by the benefits water provides though different developmental sectors. This is a critical yet difficult and complex challenge. Chapter 10 focuses on this challenge, making the case that decisions about water allocation are not merely social or ethical, but are also economic, such that investing in water infrastructure and management generates increasing returns though these various benefits.

Notes

1 See Section 3.1 for a discussion of the teleconnections among different drivers of the global water cycle.

2 See the UN-Water website on the International Decade for Action 'Water for Life, 2000–2015' at http://www.un.org/waterforlifedecade/scarcity.shtml

3 According to UNEP (2011), the 11 key sectors of the 'green economy' are agriculture, buildings, cities, energy, fisheries, forestry, manufacturing, tourism, transport, waste management and water.

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CHAPTER 5

Water management, institutions and capacity development

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As described throughout the preceding chapters (1–4), water is central to all aspects of development, underpinning every social and economic sector. How humans manage water is therefore vital to the growth and prosperity of communities and societies. Yet the term 'water management' is often used (and misunderstood) with many meanings ascribed to it, even among experts within the water community. But what does the term *really* mean? Protecting and managing the natural resource? Providing water-related services? Meeting allocation and entitlement agreements and distributing (sometimes limited) supplies across a broad range of complex, interlinked uses with increasingly uncertain demands? The short answer is *all of the above – and more*.

Previous editions of the *World Water Development Report* (WWDR) included calls for *sustainable*, *improved* and of course *integrated* water resources management. And indeed these concepts, along with *adaptive* management, are scattered throughout this fourth edition too, in terms of challenges and opportunities facing water management in different regions (Chapter 7); valuing and allocating water resources and benefits (Chapter 10); transforming water management institutions to deal with change (Chapter 11); and responding to risk and uncertainty from a water management perspective (Chapter 13).

Building on the water management-related issues addressed in previous WWDRs, this chapter begins with a description of what water management actually is, including a brief examination of how approaches to water management in some regions have evolved over the past century and how they might continue to evolve to deal with increasing uncertainties and associated risks (a discussion which is continued in Chapter 11). The chapter also provides a descriptive overview of water-related institutions, which collectively set out the 'rules of the game' for water management, and outlines some of the challenges these institutions will face in an increasingly uncertain future. The chapter concludes with a section highlighting the importance of knowledge and capacity as a critical element of institutional effectiveness.

With the exception of Section 5.1, the material in this chapter has been condensed from the challenge area reports (Part 3/Volume 2) 'Water and institutional change: Responding to present and future uncertainty' (Chapter 25) and 'Developing knowledge and capacity' (Chapter 26).

5.1 Why do we need to manage water?

Water is a fugitive resource, flowing through space and time across landscapes and through economies. All benefit from it, but few understand how it is actually managed. The management of water is not merely a technical issue; it requires a mix of measures including changes in policies, prices and other incentives, as well as infrastructure and physical installations. Integrated water resources management (IWRM) focuses on the necessary integration of water management across sectors, policies and institutions.

Water management is underpinned by levels of *uncertainty*. These are changing as a consequence of global trends in demography, consumption patterns and migration, and climate change, resulting in increased levels of risk (see Chapters 8 and 9). Adapting to these uncertainties and developing strategies that mitigate against emerging risks makes water management policies, institutions and regulations more resilient, thereby increasing their chances of generating benefits to society. Adaptive water management extends to IWRM by focusing on a more flexible management process to address uncertainty and include actors whose decisions affect water, but who do not currently participate as an active part of the water management process.

5.1.1 Characteristics of water management systems

As water moves in time and space consistent with the hydrological cycle, the term 'water management' covers a variety of activities and disciplines. Broadly speaking, these can be divided into three categories: managing the resource, managing water services, and managing the trade-offs needed to balance supply and demand. Water *resource* management is about managing water found in rivers, lakes and groundwater. This includes water allocation, assessment and pollution control; the protection of water-related ecosystems and water quality; natural and man-made infrastructure for the redistribution and storage of these resources; and groundwater recharge. Water *service* management consists of managing reticulation systems from the bulk water supplier, through the processing phases, up to the point of need by the end user; and again capturing the waste streams for reticulation back to a wastewater treatment plant for safe onward discharge. The management of *trade-offs* concerns a range of administrative activities that meet allocation and entitlement agreements across a wide spectrum of socio-economic interests. Each activity has different requirements, but together they add up to what is called *water management*.

Water management is unique. It touches upon almost every aspect of human well-being with links to socio-economic development, safety, human health, the environment and even cultural and religious beliefs (Dalcanale et al., 2011). For example, all nations, developed as well as developing, are vulnerable to rare and extreme flood events. This was demonstrated in 2005 by the devastation wrought by hurricane Katrina in the southern United States of America, by the massive flooding which took place in Pakistan in 2010, and the inundations caused by tsunamis in various parts of southern and eastern Asia over the last decade. Less visible, but often no less disastrous, effects occur through droughts such as that being experienced in the Horn of Africa in 2011 (where loss of crops threaten the lives of thousands of people), or through slow onset disasters such as the shrinking of the Aral Sea, which has affected many livelihoods, the flow of toxic acid mine drainage from various mining areas of South Africa (Coetzee, 1995; Coetzee et al., 2006; Hobbs et al., 2008; Winde, 2009; Winde and van der Walt, 2004), and the lack of adequate water supply and sanitation, which causes a range of diseases and loss of lives in many parts of the world. Yet socio-economic development is dependent on, and therefore a function of, available water supplies. Thus, proper water management is of vital importance to human society in a world where increasing demands are being placed on a relatively finite but potentially renewable resource.

Water management over the twentieth century often involved large infrastructure projects such as dams and river diversions (WCD, 2000). This has often been described as the *Hard Path Approach* by certain authors (Wolff and Gleick, 2002), or the *Hydraulic Mission* phase of economic development by others (e.g. Allan, 2000). These projects were used to address both conditions of water scarcity and water excesses; namely, the construction of artificial water storage facilities (dams) or the exploitation of natural systems (aquifer storage and recharge), allowing water to be stored for use during periods of scarcity, and controlling its potentially devastating impacts during floods. The course of human development has not necessarily followed natural patterns of sustainability; rather, the sustainability of water resources has in many locations been overwhelmed by the continually expanding human activities associated with socio-economic development, including agricultural production, urbanization and industrialization. Many of these demands are naturally in conflict, raising the need to manage trade-offs. While

> "The world is transitioning to a new era where finite water constraints are starting to limit future economic growth and development."

all waters are under pressure globally, groundwater is of particular concern: increasing exploitation as a result of improved drilling and pumping technology has resulted in situations of severe depletion in many countries (see Chapter 3). The world is transitioning to a new era where finite water constraints are starting to limit future economic growth and development. It is becoming clear that even renewable water resources cannot supply enough water if not managed carefully (Patterson, 2009).

The twentieth century was characterized by the dam-building era, as engineering design improved and better steel-reinforced concrete became available. This gave rise to what can be termed the 'infrastructure approach', as an element of the *Hard Path Approach* or the *Hydraulic Mission*, in which it was believed that the mere provision of hard infrastructure would suffice to meet the varied needs of humanity (Allan, 2000). Over time the limitations of the hard infrastructure approach have become increasingly clear (Snaddon et al., 1999). For example, in the Netherlands, it was realized that continual heightening of dykes was ultimately unsustainable. This has led to a new approach that foregrounds respect for natural hydrological conditions and acknowledges the limitations to the benefit of hard infrastructure (van Stokkom et al., 2005). Experience is now showing that substantial alterations in hydrological conditions, most notably changes in the natural flood pulse (Junk et al., 1989; Puckridge et al., 1993) caused by interventions such as inter-basin transfers (Snaddon et al., 1999), have led to unintended consequences, sometimes called *revenge effects* (Tenner, 1996). These include the deterioration of ecosystems, especially wetlands, which if left unaltered offer a wide range of 'benefits that are often essential to maintaining a basic standard of living in both urban and rural areas' (Emerton and Bos, 2004, p. 20). Natural ecosystems such as forests and wetlands generate important economic services which maintain the quantity and quality of water supplies. Furthermore they help to mitigate or avert water-related disasters such as flooding and drought (Emerton and Bos, 2004).

Contemporary water managers have to deal with an increasingly complex picture. Their responsibilities entail managing variable and uncertain supplies to meet rapidly changing and uncertain demands; balancing ever-changing ecological, economic and social values; facing high risks and increasing unknowns; and sometimes needing to adapt to events and trends as they unfold. In short, the management of water increasingly focuses on risk and uncertainty, and the emerging range of drivers and impacts often lie outside the traditional water arena. Moreover, effective water management demands transboundary coordination in a context where a total of 276 international river basins cover almost half the earth's surface (Bakker, 2007; De Stefano et al., 2010; OSU, n.d., 2008 data), and some 273 identified transboundary aquifers underpin various national economies (Puri and Aureli, 2009).

Water management consequently is not only a technical issue, but also one that requires a much more nuanced and holistic approach to achieve its goals. During the twentieth century the focus was traditionally on structural options for water management – developing physical infrastructure to 'tame' or 'control' water. Today, in the countries that have achieved essential water infrastructure development, there is a need for increased attention on non-structural management options to deal with the limitation of infrastructural interventions in hydrological systems, underpinned by growing uncertainty. Emerging twenty-first century water management can be thought of as increasingly focused on soft infrastructure, most notably associated with the management of trade-offs, and increasingly dependent on institutions, policy, legislation and dialogue between competing users (see Chapter 11). Some authors refer to this as the *Soft Path Approach* (Brooks et al., 2009; Wolff and Gleick, 2002). Having benefited from decades of infrastructure development, the challenge for most developed countries is to incorporate soft measures into existing water management frameworks. However, most developing countries are still in the process of meeting the most basic levels of water infrastructure development. The challenge for these countries will be to adopt and balance elements of both the hard and soft paths, in order to maximize the benefits (and minimize the costs and risks) of both approaches.

Water management through infrastructure development

The hard approach to water management typically focuses on the construction of water storage, transport, treatment, flood protection, and other regulation and delivery (distribution and collection) systems; hydropower plants; and groundwater wells and pumps, consistent with the goal of seeking additional water supplies. The capacities of these structures have typically been based on historical records of flows, stages and demands projected into the future or for some return period (frequency). Some countries are busy constructing such infrastructure to make use of their often-scarce water resources, such as for irrigation, domestic and industrial uses, and sometimes for environmental purposes. Other countries are devoting considerable attention to the protection of their growing populations from flooding, while others remove or modify some of their hard infrastructure, mostly to enhance environmental and ecosystem services and their associated benefits.

Hard infrastructural measures include the high costs of maintaining hydrological fixes for prolonged periods and the risk of degraded performance over time. These are still required by countries facing economic water scarcity (see Section 4.6), where the social and economic benefits of such measures can greatly out way the costs. Moreover, the costs of reducing the unexpected negative impacts of these measures may be high. Long-term planning is therefore critical, although fraught with uncertainties. Increasing emphasis on stakeholder participation is designed to balance trade-offs between impacts on ecological systems and potential benefits. While this is more democratic, it places greater demands on political leadership and governance structures, and can sometimes delay project implementation, so it is not without risk.

Although water demand management can substantially reduce water needs and will always remain a central component to sound management (see Chapter 11), there is still a substantial requirement for increased water storage, which necessarily increases with socio-economic development and climate change. Innovative storage infrastructure can sometimes help to overcome the disadvantages of hard infrastructural measures, while maintaining their advantages. The potential of working with nature by using 'green' infrastructure (such as wetlands) and less intrusive dams, therefore offers very promising opportunities (Wolff and Gleick, 2002). One example is the use of permeable surface coatings in urban areas, rather than concrete, to reduce storm water runoff while enhancing the urban ecosystem; however, the implementation of such strategies is usually beyond the scope of water managers. In recognition of the fact that new physical infrastructure will be needed for food, energy and flood protection and enhanced storage to adapt to climate change, proper measures must be taken in the overall spectrum from planning to operation of such infrastructure. As with all hard approaches, however, whether directed to agriculture, urban or industrial water uses, new or updated water infrastructure may be necessary. It must be noted that this increases the complexity of water management, by virtue of the greater range of actors and issues being incorporated into the decision-making process. This means that an increase in risk and vulnerability is an inherent property of the system by which water is managed.

Twenty-first century water management: The emergence of a range of softer measures

In response to the shortcomings of approaches based on physical infrastructure, there has been a gradual shift towards policies based on institutional reform, incentives and behavioural change (see Chapter 11). These types of approaches seek to reduce the uncertainties and manage the risks related to water resources by embracing more of the non-traditional elements found outside the traditional 'water box'. Here the role of water managers is to inform the decisions taken by others. These include changes in human behaviour related to water usage and revised water governance processes and systems. They constitute a range of generally complementary actions, including cultural values, water pricing, water conservation, water reallocation, economic incentives/disincentives, and social recognition for reducing inefficient water use practices, diversifying water sources and similar activities. As all of these are considered to be out of the box, the *soft path* approach requires significant operational capacity and high levels of coordination among and across various ministries. This is where the 'I' in IWRM becomes of increased importance. Experience over the past half century has demonstrated that *soft* options present considerable potential for addressing water resource issues, but are increasingly complex because of the need to integrate across a range of previously uncoordinated actors. Meaningful stakeholder engagement and participation is likely to grow in significance when developing such measures, placing new demands on institutions and political leadership.

Solutions that embrace a range of softer approaches will make use of forecasting and modelling advances to facilitate more accurate risk assessment, thereby working to increase the resilience and decrease the vulnerability of water systems, while also working across and beyond the traditional range of water resource management to include out-of-the-box actors. This can provide useful information to those water users and stakeholders impacted by water resources management but currently not serviced, such as stockbrokers and institutional investors concerned about undeclared but embedded risk (ACCA, 2009; Chang, 2009; Klop and Wellington, 2008).

The public is often insufficiently informed to comprehend how its use of existing water resources can affect either the quantity or quality of these resources. As a result, the public is not always unaware of ways by which it might contribute to solving the relevant problems. Proper public education and awareness can help engage water stakeholders in needed actions, particularly with regard to reducing water demands and pollution, and it also puts pressure on governments and other decision-makers. At the same time, sustainable and equitable change requires water managers to understand the issues and perspectives of the users and community at the initial stage of implementation, paying attention to their ideas and facilitating institution-building. By identifying differences in power relations and recognizing women's needs and potential contributions, real change can be made in the functioning of water systems, livelihoods and food security. In return, the public can exert pressure, which can result in government agencies and other users and stakeholders refining their water-use policies and programmes.

Implementing non-structural management options usually requires strong operational capacity but limited investments that are often spread over time. Moreover, when non-structural interventions do not lead to the intended goals, contrary to structural measures, they can usually be modified or ended without substantial extra investments. This flexibility is beneficial, but will place increasing demands on political leadership and the management of trade-offs between competing interest groups.

5.1.2 Integrated water resources management

IWRM is defined as a process that 'promotes the coordinated development and management of water, land and related resources in order to maximize the resultant economic and social welfare in an equitable manner without compromising the sustainability of vital ecosystems' (GWP-TAC, 2000, p. 22). IWRM recognizes the interdependencies of multiple components of a regional water resource system: high irrigation demands and polluted drainage flows from agriculture mean less freshwater for drinking or industrial use; contaminated municipal and industrial wastewater pollutes rivers and threatens ecosystems; the slow-onset disaster of uncontrolled decanting of acidic water from abandoned mines; and if water has to be left in a river to protect fisheries and ecosystems, less can be diverted to grow crops.

IWRM implies that all the different uses of water resources are considered together. Water allocation and management decisions should consider the effects of each use on the other, thus taking into account overall social and economic goals, including the achievement of sustainable development targets, health and safety. This also means ensuring coherent policy-making related to all sectors, most notably between decision-makers concerned with national water security, national food security and national energy security. Competing user groups (farmers, communities, environmentalists, etc.) can influence strategies for water resource development and management, with the result that the process becomes more political and less purely technical as integration occurs and a potential basket of benefits emerges (Phillips et al., 2006, 2008). That brings additional benefits, as informed users can often apply local self-regulation in relation to issues such as water conservation and catchment protection (GWP-TAC, 2000). Integrated management contrasts with the sectoral approach where responsibility for drinking water rests with one agency, for irrigation water with another, for energy and mine water elsewhere and for the environment with yet another. Lack of cross-sectoral linkages may lead to uncoordinated water resource development and management that may result in chaos, conflict and waste of resources (CapNet, GWP and UNDP,

2005) and an unsustainable overall picture where components vie for suboptimal solutions at best.

The essential purpose of IWRM is to manage water more efficiently and effectively. IWRM entails the coordination of 'policies, institutions, regulatory frameworks … planning, operations, maintenance and design standards of numerous agencies and departments responsible for one or more aspects of water and related natural resources management' (Stakhiv and Pietrowsky, 2009, pp. 4–5). Multi-disciplinary and multi-agency coordination and cooperation is therefore an important feature of IWRM.

This edition of the *World Water Development Report* provides an update on the commitment to IWRM made by the international community and countries (see Section 1.3.3). It states that while important developments have been made around the world, the preparation by governments of national IWRM plans and the actual implementation rates of these plans remain unsatisfactory and well behind targets. 'Water management can work effectively (but not necessarily efficiently) in fragmented institutional systems (such as the federally based systems of Australia, Brazil and the United States of America), where there is a high degree of decision-making transparency, public participation, and adequate financial support for planning and implementation. It does not work well in most other cases where these prerequisites do not exist. Setting up the proper institutional framework is the first step toward IWRM' (see Section 11.2).

One of the goals of IWRM is to reconcile economic development and ecosystem maintenance. This is a challenge because economic development goals and environmental needs are associated with different temporal scales, and both have been based on traditional water management concepts that do not always consider the unexpected risks and uncertainties associated with the softer approaches. For this reason, ecosystem goods and services and their valuation are increasingly included in IWRM planning. However, they can also constitute a major source of uncertainty for a variety of reasons.

Workable and sustainable solutions in water management are achieved through *integration*: between land and water management; between the management of different urban water systems; between the water and energy, mining and agricultural sectors; and between construction and operation and maintenance procedures. Integration is generally achieved incrementally in a step-wise process that can be drawn out. In particular, dialogue between stakeholders facilitates integration, which is itself shaped by the context.

These processes, as well as dialogue between stakeholders, can also help to address broader issues of coordination and integration outside the realm of IWRM, which arise when water resources, use and management are impacted by actions taken by decision-makers in other, non-water sectors for other objectives, as established by the WWDR3 (WWAP, 2009).

"The public is often insufficiently informed to comprehend how its use of existing water resources can affect either the quantity or the quality of these resources."

5.1.3 Water resource management under uncertain demands

Hydro-climatologic information about frequencies, magnitude, duration and incidence of precipitation and runoff events ought to be the basic inputs into most water management decisions. They have been combined with more fundamental economic, environmental and socio-economic information and objectives to better inform water management decisions. Land use regulations, economic priorities, trade policies and cost–benefit criteria are among other inputs used to decide between water management options (Stakhiv and Steward, 2009). In all of this, water management now has to account for unforeseeable changes in the nature and timing of population growth, migration, globalization, changing consumption patterns, technological advances and agricultural and industrial developments. These issues were already present, but were for the most part neglected. The looming spectre of climate change has helped to draw attention to their importance, adding a new dimension to the ever-increasing complexity arising from the drivers mentioned above.

As the assumptions emanating from stable-state systems are no longer appropriate, one of the current challenges involves determining the capacities of new infrastructural components for a water resource system whose future inputs or design flows can no longer be predicted or calculated from the historical record. Under conditions of uncertainty it is no longer possible to use today's science, based on yesterday's experience, to predict the needs of the future (Turton, 2007). The challenge of predicting demands during an era of accelerated changes adds to the complexity. Drivers of water also interact among themselves (see Chapter 9), which creates a new set of uncertainties and associated risks, as well as a diverse and complex variety of combinations and possible paths. This may well be beyond the understanding of those dealing with various management challenges. For example, land-use change and urbanization, already resulting in pollution, the sealing of surfaces and a loss of forests and wetlands causes increased runoff, resulting in a higher risk of flooding, sedimentation and eutrophication. Demographic changes, including population growth and changes in consumption patterns and migration, frequently lead to increasing demands for water and food. The growing pressures on water often concentrate in coastal areas, where climate change is expected to have the highest impact. These areas are already under high water stress and increased pressure often results in the salinization of groundwater where rising water in the soil brings diluted salts to the surface, which are not fully flushed away (WWAP, 2009). Growing energy consumption increasingly impacts on water, through biofuel production that requires significant amounts of water; thermal power plants that need huge amounts of water for cooling, adding to the water temperature increase caused by climate change; and biodiversity and water chemistry arising from the acidification of rain due to the sulphur cycle. Finally, the state of infrastructure such as dams and irrigation systems can, if inadequate, lead to major risks of water waste, which exacerbate water stress, as well as to increased risks of major accidents. Both sets of risks can aggravate climate change impacts (UNECE, 2009).

Society in general, and the engineering profession in particular, 'through a historical accumulation of experience, laws, engineering practices and regulations, has defined a narrower acceptable range of "expected" events to which it chooses to adapt – hence, there is the 100-year floodplain for flood insurance purposes; criteria for the design of urban drainage systems for smaller but more frequent events; and dam safety considerations by designing spillways for very low-probability floods, for example a 10,000-year return period. These are societal judgments made on the basis of many factors, including affordability, relative population vulnerability, and national and regional economic benefits. They are not deterministic criteria made on the basis of empirical or simulation modelling. Defining social risk tolerance and service reliability is part of a "social contract" to be determined through the political process coupled with public participation' (Stakhiv and Pietrowsky, 2009, p. 8), which constitutes an element of uncertainty in the Soft Path Approach.

Discounting, a method used to compress a stream of future costs and benefits into a single present value amount, is an important concept, because it can have a major effect on the outcome of the cost–benefit calculation. A high discount rate will favour avoiding the costs of adaptation now, whereas a low discount factor encourages immediate action. Setting the discount rate is therefore basically defining the social welfare function across generations with substantial implications for the decisions taken. To deal with all the uncertainties, scenarios are developed that describe possible futures, depending on, among others, decisions based on societal values. Based on the scenarios, models help to predict the effects of these possible futures for hydrological conditions and help to identify vulnerabilities that water management measures would help solve (UNECE, 2009).

5.1.4 Adaptive management

The complexity of water management, combined with increased uncertainty, both through socio-economic developments and climate change, makes the traditional command-and-control approach less effective. An adaptive approach towards IWRM responds to this. Adaptive management can generally be defined as a systematic process for improving management policies and practices by learning from the outcomes of management strategies that have already been implemented (Pahl-Wostl et al., 2007). It is a continuous process of adjustment that attempts to deal with the increasingly rapid changes in our societies, economies, climate and technologies. In essence, adaptive water management is based on a series of feedback loops being hard-wired into the system, which enable many incremental adjustments to be made before a catastrophic problem manifests. It is learning to manage by managing to learn.

Learning in water management encompasses the range of ecological, economic and socio-political domains in testing the effectiveness of structural and non-structural measures. The quality of the management process in this approach is essential, including the realization that management strategies and goals may have to be altered during the process (Pahl-Wostl et al., 2007). Successful adaptive water management includes some approaches in addition to overall water management (Mysiak et al, 2010):

- It builds on collaborative governance – a joint effort of government, society and science – to ensure that measures will be effective and sustainable. Trust and social capital are important in ensuring that the problem-solving process takes place.
- It is embedded in an 'enabling environment': a political, institutional and legal setting that enables learning and does not hinder adaptive approaches (UNECE, 2009).
- It changes from water supply management to water demand management. The availability of water resources is the baseline, not the demand for water. Improving efficiency of water use will help ensure a sustained supply of water to different uses in times when resources become scarce.
- It pays more attention to non-structural ('softer') water management measures. Legal and policy agreements help to promote more sustainable use of water in all sectors while explicitly considering equity and poverty alleviation measures.
- It recognizes adaptation in water management to changing conditions such as energy and food prices, demographic trends, migration flows, changing production and consumption patterns, and climate change is a long-term continuous exercise, not a one-off set of measures.
- It bases the financing of water management on the valuation and pricing of water resources use without impacting the most vulnerable groups in a disproportional way nor unduly harming local competitiveness.

Implementation of these recommendations is highly demanding, and requires that managers overcome the inertia of traditional approaches and resistance from various actors. The major challenge for authoritative regulatory bodies at local and national levels, however, is to develop a coordinated 'vision of how to implement the ideas, as well as the courage to withstand criticism and to share power with other actors' (Timmerman and Bernardini, 2009, p. 2).

5.2 The importance of water institutions for sustainable development

5.2.1 Institutions: The rules of the game

According to the Nobel economic laureate Douglass North, 'Institutions are the humanly devised constraints that structure political, economic and social interaction'. They consist of both informal constraints (sanctions, taboos, customs, traditions, and codes of conduct) and formal rules (constitutions, laws, regulations, and property rights) (North, 1990, p. 97).

Institutions constitute the 'rules of the game', defining roles and procedures for people, possessing of permanence and stability, and determining what is appropriate, legitimate and proper (see Chapter 25). These 'rules' have evolved organically, responding to history, geography, culture and politics, and reflecting technical advances and the evolution of professional practices and local capacity. Actors other than water managers often dictate the rules of the game for water. In most cases, they are established without water as their central focus and lack recognition of its pivotal importance.

Institutions underpin the management of water resources and the delivery of key services that sustain health, welfare and economic growth. Global water problems can be traced to a deficit of *governance* resulting from a lack of appropriate institutions at all levels, and the chronic dysfunctionality of existing institutional arrangements (Lewis et al., 2005). Water management institutions are part of the broader institutional framework of countries (see Chapters 11 and 25). The potency of this framework will encourage or hinder effective approaches to managing water resources and its related services. Laws, policies, private and public entities, along with stakeholders outside the 'water box', can greatly influence how water institutions behave and perform under normal circumstances.

5.2.2 What institutions do, and why they matter

Water-related institutions function at different scales ranging from the local community to the transnational level, and oversee the allocation, distribution, management, planning, protection and regulation of water resources and services. Institutions define roles and procedures, which determine what is appropriate, legitimate and proper (see Chapter 25). In addition, traditional and contemporary social rules may be applied to water use and management.

Informal water rights systems are not just 'customary', 'traditional' or 'ancient'. On the contrary, they can form a dynamic mix of rules, principles and organizational forms that are highly relevant to contemporary problems. They combine local, national and global rules, and often mix indigenous, colonial and contemporary norms and rights. Local water rights exist in conditions of legal pluralism where rules and principles of different origin and legitimization co-exist and interact (Boelens, 2008).

Aflaj irrigation systems, widespread in many Middle Eastern countries, are an example of one such informal system for allocating water.[1] Clientelism[2] or even corruption can also be viewed as methods for determining the allocation of water resources and services among different sectors and groups. Informal systems can sometimes be assimilated into the formal economy, as in Paraguay, where small informal private drinking water supply systems have been recognized and agreements developed between local governments and small-scale private water vendors. The outcome has been easier control and monitoring of the pricing and quality of service (Phumpiu and Gustafsson, 2008).

In 2010, resolutions by the United Nations General Assembly and the Human Rights Council confirmed that access to safe water and sanitation is a human right (see Section 1.2.4). Member states are required to ensure the progressive implementation of the right to water and sanitation to everybody in their jurisdiction. It is hoped that this will contribute to accelerating much-needed progress in providing these essential services to billions of people who do not currently enjoy them. According to the measurements and standards of the Millennium Development Goals (MDGs), the reports of the WHO/UNICEF Joint Monitoring Programme (JMP) for Water Supply and Sanitation, and the Global Annual Assessment of Sanitation and Drinking-Water (GLAAS) processes, 884 million people still use unimproved sources for drinking water and 2.6 billion people do not use improved sanitation (WHO/UNICEF, 2010). Measured against the more precise and rigorous standards now defined under the right to water, these figures represent a significant under-estimation. Some estimates indicate that the number of people without access to safe and reliable tap water in their homes is between 3 and 4 billion. The push to increase access to drinking water and sanitation to meet the expectations of the right to water could become a major driver shaping the future development of water services.

5.2.3 Institutions 'fit for purpose'

The second edition of the *World Water Development Report* (WWDR2) noted that poor access to water resources and services is not the result principally of water shortages, but of an 'institutional resistance to change' due to a 'lack of appropriate institutions' for managing and securing resources for building both human capacity and physical infrastructure' (WWAP, 2006). For example, some countries, often those with the greatest need, are unable to absorb the current level of aid for sanitation and/or drinking water. These developing countries will need to strengthen their national and subnational systems in order to plan, implement and monitor the delivery of sanitation and drinking water services, especially for underserved populations (WHO/UN-Water, 2010). The WHO/UN-Water GLAAS (2010) document reports that defining appropriate institutional roles and responsibilities remains a challenge for both sanitation and drinking water. Even where national strategies are well developed, government institutions are well coordinated and adequate financing is available, progress in sanitation and drinking water may still be limited by the lack of adequately trained, capable staff and a work environment conducive to effective outputs (WHO/UN-Water, 2010). The WWDR2 referred to confusion in water governance in many developing countries, citing 'a lack of water institutions' and 'a display of fragmented institutional structures' as issues requiring immediate attention. GLAAS 2010 recommends that 'sound policies, allied to effective institutions, are important for optimizing service delivery. Establishing clear roles and responsibilities for the different institutions involved in sanitation and drinking water is also important, if good progress is to be made' (WHO/UN-Water, 2010, p. 2).

A recent business survey – in which firms chose between different types of possible constraints on doing business in the country concerned – showed the constraints imposed by prevalent institutional systems (Figure 5.1). Institutional and governance-related issues such as bureaucratic performance and corruption control appear to rank higher than quality of infrastructure in regions like sub-Saharan Africa and South Asia.[3] The implication is that investment in water development requires a combination of soft and hard measures, with priority being given to institutional reform – with emphasis on good governance, effective regulation, strong operational capacity and control of corruption – in many cases.

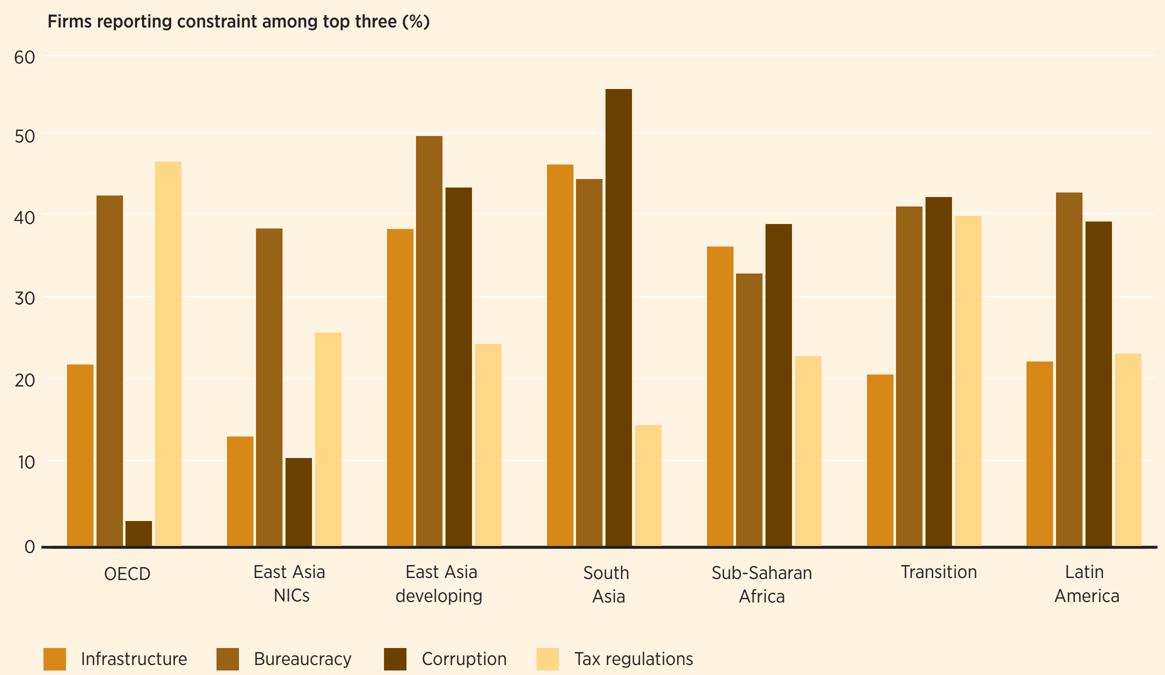
Countries show great variation in institutional design. In some countries and regions, for example China, the Middle East and North Africa, water institutions reflect strong government steering, top-down management and hierarchical control. Elsewhere, a greater diffusion of powers can be found among government, civil society and markets, with varying levels of emphasis on features such as transparency, multi-stakeholder participation and accountability. Irrespective of their type, institutions govern similar issues of resources allocation, quality protection, planning and so on. Allocation is becoming a widespread issue, particularly in countries such as those in the Middle East, which have already developed easily accessible water, and where additional water provision will come at a high cost. Currently, many countries in the region are using up to 90% of their water for irrigation, whereas agriculture is contributing less and less to GDP, and more economically vibrant sectors often face severe water constraints (Beaumont, 2005).

Effective institutions can reduce natural, economic, technical and social uncertainties. For example, the successful negotiation of tensions and conflicts over shared waters will reduce uncertainties for the parties concerned and lead to more rational water use and allocation. Effective water institutions fulfil several purposes:

Define roles, rights and responsibilities at different scales. 'Institutional arrangements define who controls

FIGURE 5.1

Key constraints to doing business in several geographic and economic regions



Note: The question posed to the firm was 'Select among the above 14 constraints the five most problematic factors for doing business in your country'.
Source: Kaufmann (2005, fig. 2, p. 85).

the resource and the extent of a property regime' (Ananda, et al., 2006). Institutions play a vital role in establishing the working rules of rights and duties, and in fixing the relationships of multiple or co-users to one another and to a specific natural resource. In Kenya, the recent water sector reforms have clearly delineated the institutional arrangements for the roles and responsibilities of agencies involved both in service delivery and water basin management. The reforms have, for example, encouraged a sector-wide approach to planning (SWAp),[4] which promotes good practice for partnerships, conduct, investment planning, coordination, monitoring and decision-making – all aimed at improved service delivery and accountability within and among sectors.

Determine restrictions and provide for mediation of conflicts. Institutions set certain individual and collective restrictions to water use: who can use what water, how much, when and for what purposes. A widening gap between water supply and demand intensifies competition and conflicts between water users, regions and economic sectors. This puts pressure on institutions dealing with resource allocation and management, and heightens the importance of mechanisms which deal with conflicting interests through economic incentives. The Mekong River Basin illustrates the complex relations between states and rivalry among water institutions. Transboundary water conflicts have generally been contained in this basin, but the growth of water scarcity due to environmental and developmental factors could lead to major conflicts in the future, driving the reform of regulatory and allocation mechanisms. In some instances, water conflicts have accelerated institutional change.

Reduce transaction costs and stimulate investments. Institutions underpin increased and more effective investments. Poor institutions pose increased investment risk and affect the competitiveness of countries and the performance of their firms. Effective institutions lower transactions costs, namely the various costs incurred in making an economic exchange and taking part in a market – costs such as those for search and information, bargaining and decision-making, and policing and enforcement.

5.2.4 Water institutions: Current status and future challenges

Water encompasses a wide range of sectors and uses throughout its natural cycle, at different scales, and with no overall unified system of management or governance. Even if some coherence could be brought into water management – in whatever sense this term is used (e.g. from applying the IWRM paradigm) – important influences on water would continue to be exerted from forces 'outside the box', such as national policies on regional development, international trade, tourism, housing, energy, agriculture and food security, environmental protection and so on. Due to these complexities, it is difficult for water institutions to adapt to current and future risks and uncertainties, and to develop any kind of consistent approach.

The diverse structure of water management in dealing with various resource and use/service-related issues is reflected in the complexity and fragmentation of the institutions that exist to govern and manage it. It is rare to find a 'ministry of water' (as in Bolivia, India or Tanzania) dealing with all aspects of the sector. It is more common to have separate ministries responsible for water resources, irrigation, environment, power, transport, health, urban water supply, rural water, and so on. Each of these subject areas impinges on water, yet each typically has separate ministerial responsibility and administrative structures, with financing usually determined independently of other interested parties.

The 'rules of the game' for water management are set in a diffuse institutional environment, where imminent decisions to be taken in response to climate change or environmental sustainability are heavily influenced by the specific needs of other sectors, with water a secondary consideration. Making coherent decisions on such momentous issues, with the various trade-offs they imply, will call for some institutional machinery linking decision-makers in key sectors with those responsible for water management. A wider group of stakeholders needs to be involved in the rule-setting process (Figure 10.2).

While some countries have made progress toward effective water governance, the success of institutional reform has been mixed: many countries have not overcome their shortcomings in governance, financial and capacity areas. For example, reforms in Ghana, India and South Africa came as part of a wider move to economic reform, but have not been uniformly successful.

Some common features of institutional reforms are the adoption of an IWRM framework, including water resources planning, the establishment of river basin management authorities, the encouragement of multi-stakeholder engagement, and the use of cost-effectiveness, cost recovery and cost–benefit analysis to determine investment priorities. Rights-based approaches to water services and the inclusion of integrity and accountability criteria are other recent developments.

The subject matter of water management and policy-setting is continuously being redefined due to cultural, economic, political, social and environmental changes. These shifting forces pose various challenges for institutional reform, some of which are detailed here:

Integration. The institutions governing water in its many facets need to be sufficiently comprehensive, and the policies for water management need to be coherent enough, to deal effectively with looming problems. A case in point is climate change, which is a major current driver of institutional change. Water will be a primary medium through which climate change impacts will be experienced by various sectors, and the way the process is managed will shape sustainable development and poverty reduction efforts. Changes in water availability and demand will worsen existing stresses in sectors such as health, food production, sustainable energy and biodiversity, while water-related risks due to extreme events, such as flash floods, storm surge and landslides, are set to increase. Effective institutions must therefore be able to accommodate the re-allocation of water in response to changes in its availability. The institutional response should include promotion of cost-effective conservation measures and efficiency enhancements under effective water demand management practices. The strengthening of local institutions and strengthening of social networks is an integral part of successful adaptation (Box 5.1).

Institutions should be sufficiently flexible and adaptable to account for uncertainties in both water supply and demand. A degree of formal recognition and assimilation might be justified in the case of informal water service providers, who typically deal with marginalized water users whose needs are not met by established formal supply networks.

Integrity, transparency and accountability. Attempts to tackle mismanagement, corruption, bureaucratic inertia and red tape can prove a major stimulus for institutional change. Corruption is a core symptom of poor governance, which distorts investment, increases transactions costs and discourages innovation. Petty corruption has a particular impact on the poor and disempowered. This calls for, among other things, the enforcement of regulations on the performance and expenditure of service providers. In most developing countries, such regulation is either weak or absent. Existing systems of monitoring, policing, sanctions and incentives are not applied on a systematic basis and are often derailed due to clientelism and corruption (Box 5.2).

Capacity development and resources. The delegation of responsibility to local water agencies should be accomplished by corresponding transfer of powers, tools and resources – in short, capacity. Any delegation should be based on careful analysis to help determine the appropriate level for decentralization or centralization, in accordance with technical considerations and economies of scale and scope. Because of the low profile and unfashionable character of water management and service agencies, their gradual loss of resources and capacity has gone largely unnoticed. This trend needs reversing if the agencies in question are to address the far-reaching changes required.

BOX 5.1

Adaptation to water stress in the Greater Himalayan Region

Five case studies from the Greater Himalayan Region looked at situations where people are responding to too much water (floods, water logging) or to too little water (drought, water stress). The regions examined were the dry mountain valleys of Chitral in Pakistan; the middle hills in Nepal; the flood plains of Bihar, India in the Koshi basin; the flood plains of Brahmaputra in Assam in India; and the hill areas of Yunnan, China.

Some of the key findings for adaptation comprised a mix of strategies to develop diversification of livelihoods and to make use of and strengthen local institutions and social networks. Cultural norms and rules affect people's adaptive behaviour, and need to be considered, but they are dynamic and can shift over time in response to different needs. In addition, it was acknowledged that national institutions and policies strongly affect people's ability to adapt at the local level, but the national level is rarely informed by adaptation concerns and priorities.

Source: ICIMOD (2009); see also Chapter 25.

Generating adequate and sustainable funding. Many water institutions in developing countries are weak and under-financed (Dinar and Saleth, 2005). New funding is required for institutional capacity-building and adaptation, but it is equally important to use existing funding more efficiently. Most water funding goes to infrastructure development and less is invested in operations and maintenance and developing institutions and human capacities. Of the 11 reporting countries in the 2009–2010 CSO and GLAAS country surveys, the contribution of recurrent expenses, including salaries, non-salaries and urban subsidies, to total expenditures for sanitation and drinking water ranged anywhere from 13% to 78% (note that only internal sources of financing for government expenditure are included) (WHO/UN-Water, 2010). Both public and private sector funding should be enhanced, if necessary, through innovative funding approaches.

BOX 5.2

Development of regulatory accounting in Latin America

Manipulation of accounting is a serious concern in the regulation of public utilities and regulators usually devote considerable attention to the methods of accounting used by the utilities they regulate. In general, a regulator cannot do an effective job if it does not have the authority to define the accounting systems under its jurisdiction. When water utilities were opened up to private investment in the 1990s in Argentina, it became necessary to develop a regulatory framework that would induce them to work towards the objectives set forth by the State. The Aguas Argentinas system was one of the first experiences of regulatory accounting for water and sanitation service providers in the region. The following lessons were learned about implementing this effective regulatory tool:

- To the extent possible, the project should be approached as a joint undertaking between the regulator and the regulated entity, with dedicated, multidisciplinary teams on both ends.
- Contributors to the project should be brought on board as early as possible, including technical, operational, commercial, administrative and information technology personnel to ensure effective collaboration and support.
- It should be understood that the modifications to information systems and procedures involved in the implementation of regulatory accounting take place in large, existing companies, which limit discretional authority and can increase the time it takes to implement changes.
- In order to foresee unintended consequences and have time to make any necessary adjustments, the possible effects of the project on the work culture in both the utility company and the regulatory agency should be taken into account.

Experience both at home and abroad indicates that information asymmetry is also present in the regulation and oversight of publicly owned service providers. Accordingly, once the Aguas Argentinas contract was revoked in 2006 and services were transferred to the largely state-owned Agua y Saneamientos Argentinos (AySA) in 2006, the new regulatory framework stipulated that the public company also had to implement a regulatory accounting system.

Sources: Jouravlev (2004) and Lentini (2009a,b).

Conventional water planning is too rigid to meet the challenges ahead, which require the development of adaptive governance frameworks and institutions. Calls have been made for more resilient institutions and approaches (GWP, 2009). In fact, the institutions that govern the management and use of water are not immutable, and have the capacity to change in response to circumstances, particularly crises. Many reforms are born out of conflict (Box 5.3)

Institutional reforms may impose transitional costs of their own, offsetting some of their expected benefits. In Kenya, for example, some stakeholders see institutional changes such as the introduction of sector-wide approach to planning (SWAP) as potentially increasing bureaucracy and complexity and removing decision-making further from the grassroots level. There is some concern regarding the potential for transaction costs to rise with SWAP, and some non-governmental organizations (NGOs) fear that SWAP may reduce their funding levels. These institutional reforms may require higher levels of transparency and higher government-monitoring capacity, both weak points in the sector at present.

Institutions that develop in the water sector inevitably reflect those in wider society. The privatization of water assets in England and Wales, and Chile, and the growth of markets for water in the latter, developed within a political and legal context favourable to the transfer of assets into private management and ownership. The active use of water tariffs, and the use of water markets for allocating scarce supplies, is likely to be more feasible in economies with widespread involvement of private producers, than in countries with a strong 'statist' tradition. The precise balance of public and private agencies in the management and delivery of water services differs from country to country – but almost always with the preponderance of the public sector – reflecting a mix of political, ideological and practical factors. It is important to underline that empirical evidence from developed economies reveals that there is little justification for a general presumption in favour of either type of ownership, and case by case evaluation of the various trade-offs is therefore in order (Renzetti and Dupont, 2003; Vickers and Yarrow, 1988).

Against a background of increasing risk and uncertainty, there is an argument for allowing different institutional models to coexist, which could increase resilience and the potential for both policy and technological innovation.

5.3 Institutional knowledge and capacity

5.3.1 The importance of knowledge assimilation and transfer

Water-related problems are commonly the result of ineffective institutions and inadequate water management. To improve water management requires comprehensive skills and training in, for example, engineering and infrastructure maintenance, financial and institutional administration, and policy analysis. Another valuable source of knowledge is experience gained by local water professionals from hands-on management. This local knowledge often goes unrecorded or even unrecognized. Importantly, local managers are aware of many risks and uncertainties related to the water system on which they operate, and they are often the first to identify new issues and problems, as well as their solutions. Local solutions are often workable as they reflect local and indigenous practices and knowledge, and are aimed at meeting local priorities. Local knowledge should be captured and communicated to decision-makers at higher levels, to inform policy formulation at the national level. This also process allows lessons learned to be widely applied, builds the capacity of local institutions and civil society, and empowers local actors.

Commonly, capacity is defined as 'the ability or power to do, or understand something'. UNDP defines capacity as the ability of individuals, groups, institutions and organizations to identify and solve development

BOX 5.3

Water conflict as an agent of change

Many recent changes in the governance of water and river basins have occurred as an outcome of conflict. In Australia, long-standing conflicts between environmentalists and farmers in the Murray–Darling Basin form the historical backdrop to the Landcare movement and to multi-stakeholder forums for managing water in its basin context. Over an even longer period, competing demands of states have served as the basis for institutional development of the Murray–Darling Basin water management framework. Conflicting visions of catchment management (for example, more and less participatory models) have shaped institutional approaches in New South Wales.

Conflict avoidance can itself be a driver for innovation in water governance. In South-East Asia, the spectre of resource-based conflict between the countries sharing the Mekong River has been a strong driver for cooperation through the Mekong River Commission, and an important justification for official assistance to the Commission. The Se San issue is a case in point. The impacts of the Yali Falls Dam in Viet Nam on downstream riparian communities in north-eastern Cambodia left indigenous minorities from a less powerful country having to deal with the impact of water resource development by the government of a neighbouring more powerful country. While not always able to deliver for local communities, such river commissions can generate improvements and innovative methodological approaches, such as the recently published rapid basin-wide assessment tool.

In Thailand, conflict has arisen over the drafting of a national water law, leading to a more robust public discussion of water legislation and governance issues such as water-pricing options and the creation of an inclusive national policy agenda. This has slowed down reform, compared with the process in Lao People's Democratic Republic and Viet Nam, whose water laws were passed by their respective national assemblies in 1997 and 1998 without much public discussion. However, even though there was limited public debate over the draft water law in Viet Nam, it went through more than 20 revisions and was extensively debated in the national assembly before eventually being passed.

Source: Boesen and Munk Ranvborg (2004). For more information see http://www.mrcmekong.org/news-and-events/news/innovative-tool-for-mekong-basin-wide-sustainable-hydropower-assessment-launched/

"Knowledge needs to be multi-disciplinary, based on an understanding of society and nature, and able to facilitate integrated approaches."

problems over time (UNDP, 1997). According to OECD-DAC GOVNET (2006, p. 12), capacity-building means a 'process whereby people, organisations and society as a whole unleash, strengthen, create, adapt and maintain capacity over time'. Internationally, capacity-building, or capacity development, is essential to meet the MDGs (Pres, 2008). It implies funding and resourcing of managerial systems to enable institutions to make and implement policies that lead to the effective and sustainable use of water. The ability to continue acquiring new knowledge is essential for improved performance and adaptation to changing physical and social conditions.

The balancing of 'community focus' and the 'technical approach' calls for strong intellectual leadership and authority, and striking a balance between bottom-up and top-down approaches. However, it is important to keep in mind that an attitude focused on applying knowledge is the most important element of capacity development.

5.3.2 Transforming institutions to become more effective

The water supply and sanitation sector has a low priority in many developing countries, where investments in health and education are often prioritized. Furthermore, 'since 1997 the proportion of development aid allocated to sanitation and drinking water fell from 8% to 5%, while development aid allocated to health increased from 7% to 11.5% and that for education remained steady at around 7%' (WHO/UN-Water, 2010, p. 15).

However, under-investment in both infrastructure and human resources leads to poor water management, which then commonly leads to water-related diseases (see Section 4.1). These diseases are among the worst killers in developing countries, where the poorest segments of the population are often hit hardest (Jønch-Clausen, 2004). The 'impact of diarrhoeal disease on children is greater than the combined impact of human immunodeficiency virus/acquired immunodeficiency syndrome (HIV/AIDS), tuberculosis and malaria' (WHO/UN-Water, 2010, p. 2). Therefore, there is a great need to strengthen water-related institutions to increase their effectiveness. Since the 1990s, capacity development has become a favoured approach to this end (OECD DAC GOVNET, 2006; Pres, 2008).

Capacity development demands a holistic approach through which people, organizations and societies continually mobilize, maintain, adapt and expand their ability to manage their own sustainable development (Batz, 2007). Unfortunately, conventional methods of water management are often not sufficient to deal with highly dynamic systems (Timmerman et al., 2008). A transition from these conventional methods toward management based on learning rather than only control, and inclusion of the human dimension as an integral part of the management system, is required. It has therefore been suggested that IWRM should be based on an adaptive water management (AWM) approach (see Section 5.1) – 'a systematic process for continually improving management policies and practices by learning from the outcomes of implemented management strategies' (Pahl-Wostl, 2007, p. 51). The reform requirements are different for each institution, depending on its core functions and mandates. Furthermore, each country and region has its specific characteristics and requirements with respect to its water resources situation and institutional framework (Hamdy et al., 1998). This implies that there are no generic solutions, and that problem-solving and institutional arrangements must be tailored for each country and region to meet its own specific needs and conditions.

Water institutions are still largely technology and water supply-driven. Conventional knowledge and capacity is commonly centred around disciplinary knowledge, based on technological know-how and natural science. Much of the information required is physical, pertaining to hydrology, biology, geology and other biophysical disciplines (Chambers, 1997). This type of conventional technocratic knowledge and capacity is important, and will remain necessary for water agencies and decision-makers. However, to improve the effectiveness of these institutions, the emphasis has to change from technological solutions to management of processes and people, involving inclusive decision-making and bottom-up approaches (Tropp, 2007).

BOX 5.4

Enhancing adaptive capacity in the Mekong Basin

In 2000, the Mekong Delta faced its worst floods in 40 years. About 800 people died, 9 million were affected, and the costs of damages reached over US$455 million. Since then, a range of initiatives have been implemented under the Flood Mitigation and Management Programme (FMMP). These include flood forecasting capacities, best practice guidelines for integrated flood risk management, guidelines for integration of flood preparedness plans in district and provincial planning processes, flood-probability mapping and land-use zoning, and an annual Mekong flood forum.

The FMMP's 2009 Flood Report highlighted the implications of climate change specifically for flood risk. Climate change was also a key theme at the FMMP's 2010 annual Mekong Flood Forum. The Forum promotes learning across the Mekong basin. It provides governments and others involved in the programme with the opportunity to gather data on changes in flow regimes and flood risks at different scales and to explore implications and responses by sharing experiences. For example, the Asian Disaster Preparedness Centre (ADPC) is providing lessons on integrating flood risk management at district and provincial scales across countries with decentralized disaster management systems facing similar challenges.

At a national level ADPC's participation in Cambodia's national Disaster Risk Reduction (DRR) Forum, comprising national NGOs and the Government Disaster Management Committee, has been a source of learning on approaches to DRR for both ADPC and the Mekong River Commission (MRC). It has also acted as a channel for linking local-level pilot schemes to national disaster risk management (DRM) policy processes. The MRC also hosts many regional summits and exchange visits to promote information sharing and learning across the basin. Increasingly, the programme is promoting dialogue with civil society organizations and experts outside MRC. A Mekong panel on climate change is due to be established under the Climate Change Adaptation Initiative (CCAI) for continuous learning and reflection on climate change in the region.

Source: Mitchell et al. (2010).

Knowledge needs to be multi-disciplinary, based on an understanding of society and nature, and able to facilitate integrated approaches.

The involvement and empowerment of all stakeholders is therefore required to make water institutions more effective. Coordination between institutions is necessary to achieve water resource management goals, as is awareness-raising and education for all stakeholder groups, from local communities to politicians. An example of an institution built on the involvement of all stakeholders is the basin (or watershed) management committee. Basin management committees are central to the IWRM approach, providing a forum where stakeholder groups can communicate their views and concerns regarding water resources management within the basin (Jønch-Clausen, 2004; see Dourojeanni, Jouravlev and Chávez, 2002 and Dourojeanni, 2001 for region-specific examples and issues).

BOX 5.5

Political leadership as a driver for better water management outcomes

In recent years there has been an increase in the number of women appointed as water and environment ministers in developing countries. This has been a major driver in improving long-term water security and more equitable access to water for domestic and productive purposes. For example, water ministers such as Maria Mutagamba of Uganda, and Buyelwa Sonjica (former Minister of Water Affairs) and Edna Molewa (Minister of Water and Environmental Affairs appointed in 2010) of South Africa have used a form of affirmative action to improve access through women's empowerment in Africa. All three ministers have served as Chair of the African Ministers' Council on Water (AMCOW), and have been leading the effort to bring more women into water management in Africa, and indeed in other regions through the Women Leaders for the Water, Sanitation and Hygiene (WASH) programme of the Water Supply and Sanitation Collaborative Council (WSSCC). In September 2010, AMCOW launched its Strategy for Mainstreaming Gender in Africa's Water Sector, 2010–2014, which provides guidelines for affirmative action to get women involved in water and sanitation management. In Lesotho, South Africa and Uganda, these affirmative action programmes provide special bursaries and incentives to train women for water and sanitation-related careers, including science and engineering.

Source: Brewster et al. (2006). For more information see http://www.amcow.net

For basin management committees to be able to contribute to the decision-making process, there needs to be a clear mandate outlining the roles and responsibility of the institution. Sufficient funding must also be allocated to allow the committee to fill key positions and to actively contribute to the management of the basin. There is a need for a solid information base providing up-to-date biophysical, societal, financial and technical information, which will provide the basis for monitoring, evaluation and decision-making. Finally, adequate human capacity among all involved is essential to allow all stakeholders fair representation, and to enable the committee to contribute meaningfully to management and decision-making at all levels.

Water professionals can serve as facilitators and knowledge-brokers, able to engage with stakeholders at all levels and build bridges between them. They can assist local communities, user associations, businesses, local governments and other stakeholders in better articulating their concerns and priorities, as well as sharing insights and experiences. They can also assist in articulating demands. For example, in Namibia, one central element of the capacity-building component of the IWRM plan is for the government to establish performance support teams. These are teams of water professionals that provide hands-on support to local authorities for such tasks as establishing water meter replacement policies and assisting with leak detection and repair, plumbing and general water reticulation maintenance. This is undertaken in close cooperation with the technical and administrative staff at the authority to ensure capacity development and ownership (MAWF, 2010*b*). In Namibia, the concept of performance support teams is implemented as an integral part of the IWRM plan. However, this concept can be applied regardless of whether a country adopts IWRM. The main focus of the support team is to provide hands-on support to institutions and departments to improve their capacity to do a better job.

While traditional technical knowledge and the capacity to manage water resources remains important in the context of AWM, the ability of water institutions and management actors to absorb, adopt and implement new forms of management is dependent upon additional knowledge and capacities. In AWM, capacity development refers to the development of the knowledge, skills and attitudes necessary for management actors and professional organizations to increase their *adaptive capacity* and create institutions that are flexible and responsive enough to support them in the context of increasing risks and uncertainty (van Scheltinga et al., 2009). Box 5.4 provides an example

BOX 5.6

Forum for integrated resource management (FIRM): An example from rural Namibia

The FIRM is an approach giving rural farmers living on communally managed farmlands a tool allowing them to be in charge of their own development (Kruger et al., 2003). In the centre is a community-based organization (CBO) of rural farmers or a water point committee taking the lead in organizing, planning and monitoring their own activities and development actions while coordinating the interventions of their service providers. Service providers include traditional authorities, government or private extension services, NGOs, other CBOs, and short or long-term projects or programmes. …

The key element of the FIRM approach is the collaborative planning, implementation and monitoring process led by the CBO representing the community involved (Kambatuku, 2003). This usually takes the form of an annual or semi-annual meeting to which all CBO members and associated service providers are invited. During the meeting, the vision, goals and objectives of the community are reviewed and either reaffirmed or revised. Results obtained from formal or informal monitoring of the previous year's plans and activities are thoroughly discussed and lessons learned are extracted. This analysis serves as the basis for the next step of the annual meeting: operational planning for the coming year. During this process, the various service providers commit themselves, within their mandate, to providing specific support to the community based on the community's own agreed objectives. This approach ensures that services provided by mandated service providers and project partners contribute to the agreed needs and wishes of the CBO and the greater community. It also minimizes the amount of time needed by communities to meet with their service providers, and further ensures ownership by communities of the interventions that take place in their area.

Source: Reproduced from Seely et al. (2007, p. 112).

of good practice for enhancing the adaptive capacity at different levels.

Gender-sensitive approaches in transforming institutions is another important key to success, as exemplified in Africa (Box 5.6).

5.3.3 Information and communications systems

For water managers to be able to adapt to change or to be prepared for uncertain future change, they need access to new information, and they need the capacity to process the information and implement changes based on their new knowledge (Pahl-Wostl, 2007). Local managers having access to consistent, timely and reliable information – in a format that is meaningful to them – empowers them to take part in decision-making, and to hold service providers and government more accountable. Information and communication systems (ICS) can be particularly useful to facilitating the sharing of information and knowledge at local, river basin, national and to some extent international levels. At the national level, it is essential to establish sustainable ICS frameworks for capturing, storing and disseminating data, information and knowledge to all stakeholders in the water sector. This significantly contributes to improved decision-making regarding water resource management (MAWF, 2010*a*). At the community level, concrete steps towards sharing information and knowledge, contributing to improved decision-making and resource management, can include creating dialogue platforms involving local stakeholders and their assisting service organizations, (e.g. government institutions, extension services, NGOs and other service providers). Box 5.6 presents an example of such a platform – the Forum for Integrated Resource Management (FIRM). The focus of such a community-driven forum is to plan and make informed decisions rather than dispute resolutions.

Scientific research – physical, technical or social – should ideally contribute to improved water resources management. Scientists need to 'disseminate results and communicate their findings in a way that can be understood and readily implemented by policy-makers, politicians and communities. At the same time, they must learn from experiences gained through implementation by users at all levels' (Seely et al., 2008, p. 236). A range of information communication technology (ICT) tools exist to communicate scientific knowledge effectively, including animations and role-plays. 'Hot' water issues can be used to raise public awareness and understanding. The

> "Local managers having access to consistent, timely and reliable information – in a format that is meaningful to them – empowers them to take part in decision-making, and to hold service providers and government more accountable."

construction of the Øresund bridge between Denmark and Sweden illustrates a successful application of ITC. The project involved experts from many disciplines, who had to work in partnership with different stakeholders, including the public. The establishment of an ICT-based real-time water information service allowed all stakeholders to monitor the progress of the project and results from different scenarios and participate proactively in the decision-making process (Velickov, 2007). According to Seely et al. (2008), several key factors contribute to making the connections necessary for facilitating application on all levels of research advances. These include translation, information dissemination, communication, communication platforms, boundary organisations and leadership contributing to knowledge, motivation and capacity. Encouraging 'research brokers' and science journalists to engage in interdisciplinary policy-making debates can facilitate this process. An assessment of the roles of Danish science journalists and communicators in informing the public and policy-makers shows that science communicators play an important role in providing the public with a greater and increased understanding of scientific knowledge, and putting sciences in a broader social and democratic context of value to decision and policy-makers (Hvidtfelt-Nielsen, 2010).

5.3.4 Knowledge and capacity development: An ongoing process

'Recent evaluations have demonstrated that water-related development projects are now decidedly more effective and sustainable than before the mid-1990s (World Bank, 2010). This can be attributed in large part to stronger institutions, better governance, and better technical and managerial competence in the developing countries whose capacity has been strengthened' (Alaerts and Dickinson, 2009, p. 29).

With appropriate mentors providing hands-on experience, incremental capacity development can start taking place almost instantaneously. However, it is important for individuals, organizations and institutions to recognize that capacity development is an unending process, as knowledge and the environment, natural, social and economic, in which water management is taking place is constantly changing. A key element of capacity development is instilling the concept of continuous change and how to adapt to and deal with evolving situations and conditions. Box 5.7 illustrates how the development of knowledge and capacity is a step-wise, ongoing process and touches upon several elements previously described in this section.

BOX 5.7

Social learning and adaptive water resources management in the South Indian Lower Bhavani

The Lower Bhavani Project (LBP) has 84,000 ha as a command area located in the South Indian state of Tamil Nadu. Among others, the most significant uncertainty factor is rainfall variability. The LBP suffers from water scarcity and high unpredictability, leaving the farmers to endure and adapt to frequent seasons without canal supply. The farmers have proved to be able to learn and adapt over the years. The large-scale development of wells in the area shows how the farmers have successfully managed to increase water availability to balance water scarcity during seasons without supply. The farmers have also acquired a capacity to swiftly adjust the cropping pattern to the highly unpredictable variability of seasonal canal water supply, and also to entirely rainfed conditions.

The entire chain of system changes shows that social learning is taking place within the LBP system. The different actors have together learned how to optimize the system within the limits of the technical infrastructure, the reservoir capacity and the canal discharge capacity, and the variability in available supply decided by the erratic precipitation. The way farmers have learned and been inspired by each other, like the benefits from conjunctive groundwater use and the acceptance of irrigated dry crops, are examples of social learning between actors at short timescales. On a long-term perspective, all the actors in the LBP system have learned from the environmental responses and each other's behaviour. Together they have contributed to the alteration of governance structures and have developed new innovative practices without being bound and limited by the original use of the existing technical infrastructure. All actors, thus, live with change, but few appear to remember what caused the change in the system and why it happened.

The AWM analysis shows that the LBP system has, over the years, fulfilled the criteria of a complex adaptive system more and more. Several changes have taken place and earlier mistakes or failures have been addressed in a stepwise way to reach the present complex human-environment technological system. The system proves to have an adaptive capacity and farmers not only cope in an ad hoc manner, but also have developed different adaptive strategies. To a large degree, the system fulfils the requirement of an adaptive regime. Social learning takes place at both system level and at the individual farmer's level. The uncertainty factors have been considered in a stepwise way during the system change cycles and have been included in the system design. The system has moved from a top-down project to a management system with multiple actors. Both farmers and the authorities have learned over the years and now have better possibilities to interact.

Source: Adapted from Lannerstad and Molden (2009, pp. 26–27).

Notes

1 *Aflaj* are traditional systems, sometimes with formal legal status, setting traditional practices for allocating water between different periods of time and between users. They contain a process of users' rights based on ownership or rental (see Chapter 25).

2 Clientelism refers to a form of social organization common in many regions and characterized by patron–client relationships. In such places, relatively powerful and rich 'patrons' promise to provide 'clients' with jobs, protection, infrastructure, and other benefits in exchange for votes and other forms of loyalty, including labour.

3 It is acknowledged that there can be wide variations between countries within a region. The results of the survey should be perceived as relative, not suitable for regional comparison.

4 An approach whereby donors agree to pool their resources to support a specific sector and follow common policies, including the use of national government procedures for the disbursement and accounting of aid funds.

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CHAPTER 6
From raw data to informed decisions

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The absence of systematic data collection in most countries impedes regular reporting on water resources and water-use trends. There is consequently a growing interest in and demand for better and more accurate and consistent water data and accounting. This needs to be translated into improved data availability and quality, more structured data acquisition and better information about water. Unfortunately, there has been no major progress since the third edition of the *World Water Development Report* in terms of observation methods, networks and monitoring (see also 'Bridging the observational gap', Chapter 13 in that report).

Global programmes such as WWAP need to focus on core data items from which different users can calculate indicators of specific interest to them. Technological advancements are also making it easier to monitor and report on various dimensions of water resources. The development and application of these new technologies should be made a priority.

6.1 Data, monitoring and the purpose of indicators

The theme of this edition of the *World Water Development Report* (WWDR) is *uncertainty*. This indicates a lack of adequate information on water resources and water-use trends, or that available information is not being used. Regardless of the enterprise in question, whether it is tending a household food garden, managing the business of a multinational food company, or guiding a national economy, successful risk management depends on the availability and collection of sufficient information to properly characterize relevant risks and uncertainties. Risk management for water resources and their uses implies the monitoring of water-related activities to obtain the data necessary to generate the information required by interested parties. Once sufficient data have been amassed, they can be summarized in the form of indicators to address specific areas of concern.

Since it was first published in 2003, the WWDR has included a comprehensive collection of data and indicators about the various dimensions of water resources and their uses. The WWDR has sought to update this information in subsequent editions, and in this fourth edition presents these data and indicators as part of Volume One (Table 6.1).

Table 6.1 presents the indicators that have been developed by WWAP in cooperation with prominent organizations (the members of UN-Water, NGOs, universities, etc). The list is categorized by major challenge areas that are central to the WWDR. Each indicator falls under one or more elements of the DPSIR analytical framework – Driving force, Pressure, State, Impact and Response. The indicator development process is closely linked to WWAP's overarching mandate of monitoring and reporting on water around the world. WWDR indicators are systematically updated and revised to reach the ultimate goal: to develop a set of indicators that are accepted across the entire UN system to monitor performance and track changes, not only in the natural environment (such as the hydrological cycle, the aquatic environment, water quality, and water availability and use) but also in the socio-economic and political environment of the water world (such as in governance, water pricing and valuation).

The goal has been to provide not just snapshots of information, but an indication of how different dimensions of water and its uses are changing over time in different parts of the world. This effort is based on the assumption that better management of limited water resources requires systematic monitoring to determine whether the many and varied public and private policy objectives set for the resource are being achieved. But it also intends to help readers and users of the WWDR to understand better the risks – and the uncertainties – that characterize water resources.

Information about water is becoming increasingly important to the following groups:

- *National governments.* Many countries want reliable and objective information about the state of water resources, their use and management, in order to safeguard their water security as a matter of national survival. In particular, they seek information about trends that may have an impact on them in the future. They often seek to understand their own situation by benchmarking it and making comparisons with other countries and regions.
- *Multilateral organizations.* Several multilateral organizations, such as the OECD, have set policy goals including environmental objectives such as 'decoupling environmental pressures from economic growth' (OECD, 2001, p. 11). The monitoring of parameters such as water-use trends play a key role in achieving such objectives. Many other regional and specialized organizations, ranging from the European Union (EU) and African Union to the G8 have raised related issues.

Water issues are also raised by different sectors at all levels, from local community to global multilateral organizations. Farmers, urban planners, drinking water and wastewater service companies, the disaster management community, business and industry, and environmentalists are all concerned by the current situation:

- The ability to produce sufficient food for growing and increasingly affluent populations is a global concern. Water is an essential resource for food production, therefore, it is important to remain advised of the availability, sustainability and variability of water supplies – whether from rainfall, abstraction from rivers and lakes, or groundwater. The risk that water-related events might affect local food production or prices is an increasingly important political concern.

TABLE 6.1

United Nations *World Water Development Report* indicators

Topic	Indicator	Category in cause–effect approach[a]	Type of indicator[b]
Level of stress on the resource	Index of non-sustainable water use	Driving force, Pressure, State	Key
	Rural and urban population	Pressure, State	Basic
	Relative water stress index	Pressure, State	Key
	Sources of contemporary nitrogen loading	Pressure, State	Key
	Impact of sediment trapping by large dams and reservoirs	Pressure	Key
	Coefficient of variation for the climate moisture index	State	Key
	Water re-use index	Pressure, State	Key
Governance	Access to information, participation and justice	Response	Developing
	Assessing progress towards achieving the integrated water resources management (IWRM) target	Response	Key
Settlements	Percentage of urban population	Pressure, State	Key
	Proportion of urban population living in slums	Pressure, State	Key
State of the resource	Total actual renewable water resources	State	Key
	Total actual renewable water resources per capita	State	Developing
	Inflow from other countries as share of total actual renewable water resources (Dependency Ratio)	State	Developing
	Proportion of total actual renewable freshwater resources withdrawn: MDG Water Indicator	State	Developing
	Groundwater development stress	Pressure, State	Developing
	Brackish/saline groundwater at shallow and intermediate depths	State	Key
Ecosystems	Fragmentation and flow regulation of rivers: dam Intensity	State, Impact	Key
	Dissolved nitrogen (nitrates + nitrogen dioxide)	State	Key
	Trends in catchment protection	State, Response	Key
	Freshwater species population trends index	State	Key
Health	Disability-adjusted life year	Impact	Key
	Prevalence of stunting among children under age 5	Impact	Developing
	Mortality rate of children under age 5	Impact	Developing
	Access to improved drinking water	Impact	Key
	Access to improved sanitation	Impact	Key

Note: An Indicator Profile sheet with a detailed definition and explanation of how the indicator is computed (as well as data tables for some indicators) is available for most indicators at http://www.unesco.org/new/en/natural-sciences/environment/water/wwap/indicators/. Exceptions are sub-indicators for 'Total actual renewable water resources'.

a. The categories are based on the DPSIR (Driving force, Pressure, State, Impact, Response) framework. For details, see WWDR1 (ch. 3, pp. 32–47; http://unesdoc.unesco.org/images/0012/001297/129726e.pdf#page=53) and WWDR2 (ch. 1, pp. 33–38; http://unesdoc.unesco.org/images/0014/001454/145405e.pdf#page=21).

b. Basic indicators provide fundamental information and are well established and widely used; data are generally widely available for all countries. Key indicators are well defined and validated, have global coverage and are linked directly to policy goals. Developing indicators are in a formative stage and may evolve into key indicators following refinement of methodological issues or data development and testing.

Source: Compiled by E. Koncagül, S. Saddhamangala Withanachchi and L. Dubin.

TABLE 6.1

United Nations *World Water Development Report* indicators (continued)

Topic	Indicator	Category in cause–effect approach[a]	Type of indicator[b]
Food, agriculture and rural livelihoods	Percentage of undernourished people	State	Key
	Percentage of poor people living in rural areas	State	Key
	Agriculture GDP as share of total GDP	State	Key
	Irrigated land as a percentage of cultivated land	Pressure, State	Key
	Agriculture water withdrawals as share of total water withdrawals	Pressure	Key
	Extent of land salinized by irrigation	State	Key
	Groundwater use as share of total irrigation	Pressure, State	Key
Industry and energy	Trends in industrial water use	Pressure	Key
	Water use by major sector	State	Key
	Organic pollution emissions (biochemical oxygen demand) by industrial sector	Impact	Key
	Trends in ISO 14001 certification	Response	Key
	Electricity generation by energy source	State	Key
	Total primary energy supply by source	State	Key
	Carbon intensity of electricity generation	Impact	Key
	Volume of desalinated water produced	Response	Key
	Access to electricity	Pressure	Key
	Capability for hydropower generation	State	Key
Risk assessment	Mortality risk index	State	Key
	Risk and policy assessment indicator	Response	Key
	Climate vulnerability index	State	Key
Valuing and charging for the resource	Water sector share in total public spending	Response	Developing
	Ratio of actual to desired level of public investment in drinking water supply	Response	Developing
	Ratio of actual to desired level of public investment in basic sanitation	Response	Developing
	Rate of operation and maintenance cost recovery for water supply and sanitation	Driving force, Response	Developing
	Water and sanitation charges as percentage of various household income groups	Driving force, Response	Developing
Knowledge base and capacity	Knowledge index	State	Developing

Note: An Indicator Profile sheet with a detailed definition and explanation of how the indicator is computed (as well as data tables for some indicators) is available for most indicators at http://www.unesco.org/new/en/natural-sciences/environment/water/wwap/indicators/. Exceptions are sub-indicators for 'Total actual renewable water resources'.

a. The categories are based on the DPSIR (Driving force, Pressure, State, Impact, Response) framework. For details, see WWDR1 (ch. 3, pp. 32–47; http://unesdoc.unesco.org/images/0012/001297/129726e.pdf#page=53) and WWDR2 (ch. 1, pp. 33–38; http://unesdoc.unesco.org/images/0014/001454/145405e.pdf#page=21).

b. Basic indicators provide fundamental information and are well established and widely used; data are generally widely available for all countries. Key indicators are well defined and validated, have global coverage and are linked directly to policy goals. Developing indicators are in a formative stage and may evolve into key indicators following refinement of methodological issues or data development and testing.

Source: Compiled by E. Koncagül, S. Saddhamangala Withanachchi and L. Dubin.

"The UN Statistical Division continues to support member countries to develop their physical water accounts so as to better understand where their water comes from and how it is used."

- Similarly, population growth and increasing urbanization raises questions for government planners about the availability of water resources to support such developments and the wastewater impacts they generate. Uncertainty about future pressures on the resource affects water management, but uncertain water availability may itself pose a risk to economic activity and urban development.
- At the community level, existing challenges of ensuring adequate supplies and avoiding undue impacts on water quality as a result of wastewater discharges are being supplemented by threats posed by vulnerability to extreme weather events. These are prompting a review of measures to build resilience to disasters such as floods.
- Water has been identified as a significant future risk to business activities. Many large businesses are seeking to understand better the challenges it poses to their operations, including reputational risk. They are also concerned about the availability of water and the impact of their operations on the quality of the resource. Absence of clear information may influence their investment decisions or even lead to curtailment of operations.
- Environmental stakeholders recognize that water resources are an ecosystem in their own right, as well as being essential to the health of other ecosystems. While both national and international law mandate environmental protection, it is important to monitor the status of aquatic ecosystems in order to assess the effectiveness of such regulation.
- Climate change has helped to focus attention on water-related issues and has raised the levels of uncertainty about parameters such as water availability. These were previously considered as essentially fixed and statistically predictable based on historical records. There is also concern that extreme weather events will occur more frequently. This has highlighted the need to monitor water resource systems more carefully to detect trends as early as possible and support the development of effective responses. As global approaches are developed to respond to this global challenge, it is important to monitor both the impacts on water resource systems of climate change mitigation strategies and the effectiveness of adaptation strategies.

Agreement on broad goals and management strategies, whether direct infrastructural interventions or 'soft policy' adaptive initiatives, is necessary for all these different areas of activity. Once goals and strategies have been defined, their effectiveness needs to be monitored. This requires the definition of appropriate indicators and the generation of adequate data. The key objective is to reduce uncertainty about water resources and their use, thereby supporting the management of risks posed by the complex natural systems of which they form a part.

6.2 Key indicators

A staggeringly extensive array of indicators have been developed, or are proposed, to monitor the state, use and management of water resources, for a wide range of purposes. While the first edition of the WWDR reported on over 160 indicators, only 49 were covered in WWDR4. This reduction occurred, in part, because of the difficulties encountered in obtaining updated data for the indicators, but also reflected consideration about their nature and purpose. As two OECD experts recently commented,

> Indicators are invariably developed to inform and influence different societal, political, technical and institutional processes … a composite indicator developed by an environmental NGO will probably have more success raising awareness among the general public, than as a widely accepted information tool among government analysts. (Scrivens and Iasiello, 2010, p. 9)

Many sector-specific indicators have been proposed and calculated. Aside from simple trends in water use, the water-use efficiency of different sectors in terms of output per unit of water can be a useful indicator. Similarly, monitoring the proportion of treated domestic wastewater can help to understand the impact of water use on the natural environment. But the focus on climate change has also highlighted the importance of selecting appropriate indicators. For example, in South Africa, energy planning requires an informed trade-off between carbon dioxide (CO_2) emissions and water-use efficiency (Box 6.1).

At a broader societal level, there is the widely used concept of national water stress (see Sections 3.1 and 4.6.1), which simply considers the amount of water available to a country per person (Falkenmark et al., 1989). At the other extreme, the water poverty index proposed by Sullivan (2002) seeks to combine a wide range of parameters, including available water resources, water use by three major sectors, four measures of water quality, information about fertilizer and pesticide use, environmental regulatory capacity, the number of EIA guidelines and the percentage of threatened species. Data availability on key issues itself is a formal component of the index.

Since the WWDR3 was published in 2009, a number of important global processes that seek to identify water resource issues and inform water-related policy decisions have gained momentum. One example is the collaborative exercise undertaken by the UN CEO Water Mandate group, including the World Wildlife Fund (WWF). It focused on encouraging its member companies to develop a better understanding of how their operations use water, both in their direct operations and in their supply chains. The Water Footprint Network, a spinoff of research into the virtual water trade between countries, also encourages companies to know and reduce their water use and 'footprint'.[1]

At the national level, FAO's AQUASTAT[2] collects statistics and data on water resources obtained from national sources. These are systematically reviewed to ensure consistency in definitions and between countries sharing the same river basin. A comparative analysis of available country water resources data is also carried out at regular intervals. On this basis, AQUASTAT compiles and updates its best estimates of the main elements of the water balance for each country. For Africa, Asia and Latin America and the Caribbean, AQUASTAT obtains water withdrawal values from ministries or other governmental agencies at country level, although some data gaps are filled using United Nations (UN) data. Eurostat and OECD are valuable sources of information for Europe, Australia, Japan, New Zealand and Northern America, and are also used to fill data gaps.

The Joint Monitoring Programme (JMP)[3] for Water Supply and Sanitation (WHO/UNICEF) is the official UN mechanism tasked with monitoring progress

BOX 6.1

Informing trade-offs: Water for electricity in South Africa

In most countries, economic activity and social stability depend on a sufficient and reliable supply of electrical power. This is explicitly stated in South Africa's National Water Resource Strategy, which regards water use for electricity generation as a matter of strategic importance. However, the strategy specifically states that 'Water use designated as being of strategic importance will be subject to the same efficiency criteria and water demand management requirements as is applied to other uses. Dry cooling of power stations should be applied where feasible when new generating capacity is built.' (DWAF, 2004, p. 52)

Performance measured on the basis of the 'water intensity' of electricity generation, first set as a target in 1970, has been encouraging. Between 1980 and 2006, national power utility ESKOM reported that it had decreased its water use from 2.85 L per kWh to approximately 1.32 L per kWh, largely by the use of dry cooling rather than water cooling for its inland power stations. The water consumption of its newest 4,000 megawatts Matimba Power Station, which claims to be the largest direct-dry-cooled station in the world, is in the order of 0.1 L per kWh (ESKOM, 2009).

Dry cooling carries not just a significant cost penalty but also has climate implications, since the hydrocarbon fuel use and CO_2 emissions of dry-cooled power stations are greater than those of water-cooled ones. However, given South Africa's water stress, this trade-off was considered as acceptable, and the use of a consistent indicator over 40 years has enabled performance to be tracked and sustained. Current electricity planning foresees that the total use of water will actually decline, even as electricity production increases, as more efficient power stations and renewables are brought into the generating mix over the next decade.

towards the Millennium Development Goal relating to drinking water and sanitation (MDG7, Target 7c). The MDG indicators measure access to drinking water and basic sanitation:

- Proportion of population using an improved drinking water source
- Proportion of population using an improved sanitation facility

In fulfilling this mandate, JMP publishes updated estimates every two years on the use of various types of drinking water sources and sanitation facilities at national, regional and global levels. Its success is largely due to the attention paid to generating the base data on which reporting is based.

These approaches all depend on the presence of sufficient, comparable and reliable raw data and processed

BOX 6.2

Australian water accounting standards

Australia is the driest inhabited continent and one of the highest per capita users of water in the world. Communities, irrigators, businesses and environmental groups are constantly debating the equitable distribution of water. Water is a fundamental resource and as competition for it increases, the need to fully and comparably account for how it is managed, maintained and distributed to meet economic, social and environmental needs becomes increasingly important.

In response to these issues, the Council of Australian Governments incorporated a directive into the National Water Initiative (2004) to develop water resource accounting. This would enable water information to be standardized, compared, reconciled and aggregated. In 2006, a stocktaking report recommended the establishment of water accounting as a discipline, similar to financial accounting, to serve external users' needs as well as the management requirements of water businesses.

Australia's approach to water accounting is a systematic process of identifying, recognizing, quantifying, reporting, assuring and publishing information about water, water rights or other claims to water, and obligations against that water. Unlike other types of water resource accounting that currently exist internationally, the development of water accounting in Australia is based on the principles of financial accounting, not statistics, and focuses on the volumes of water rather than their economic value. In addition, the potential audience is far greater due to the scalable size of the entity being reported on.

The role of issuing water accounting standards was given to the Bureau of Meteorology, which created an independent advisory board, the Water Accounting Standards Board, to assist in their development. Between 2007 and 2010, this board – with significant support and assistance from the accounting and hydrology industries – developed and successfully piloted the Water Accounting Conceptual Framework (WACF) and the Exposure Draft of Australian Water Accounting Standard 1 (ED AWAS 1). These documents together provide a principles-based approach to the preparation and presentation of General Purpose Water Accounting Reports (GPWAR).

Water Accounting Reports aim to assist users in making and evaluating decisions about the allocation of water resources by providing a comparable and reliable approach to reporting, while also giving water resource managers an opportunity to demonstrate responsible stewardship of a public good. Furthermore, the production of reports is expected to instil public and investor confidence in how much water there is, who has the rights to it, and how it is being used.

As information about water resources is made more available, better decisions can be made on a broad range of water-related matters. For instance how to:

- Distribute the resource
- Invest in better quantification techniques or infrastructure
- Decide where private enterprise could locate new operations that rely on water
- Cope with an expanding community need when additional water resources are required
- Invest in companies exposed to significant water-related operating risk

While significant progress has been made in the development and adoption of water accounting over a short period of time, the discipline is still in its infancy. In the end, it will be users who determine what information they require to be able to make and evaluate decisions about the allocation of resources.

Note: For more information see www.bom.gov.au/water/wasb information about both water resources and their use. In this area, too, there are encouraging developments. The UN Statistical Division continues to support member countries to develop their physical water accounts so as to better understand where their water comes from and how it is used. Meanwhile, at the national level, Australia – which faces severe pressures from, and difficult choices about, the management of its water resources – is developing sophisticated water accounting systems to support decision-making (Box 6.2).

In 2007, stakeholders of WWAP sought to produce a core group of indicators to address high-level information and policy objectives. In the light of the challenges faced, WWAP, as one of the three operational programmes of the UN-Water consortium, engaged in a systematic review of the different indicators required as well as the data challenges that need to be addressed in order to guide its future work.

In August 2009, a WWAP-led UN-Water Task Force on Indicators, Monitoring and Reporting (IMR) presented its outputs to UN-Water.[4] The Task Force's overarching objective was to contribute to public information and informed decision-making in the water and related sectors, including sanitation, at global and national levels, through improved monitoring and reporting. In particular, it aimed to support international and national decision-makers and advance the implementation of internationally agreed-upon goals and targets on water and sanitation.

This involved the development of a methodology for monitoring, at regular intervals, the state of water resources and their use, as well as the impact of policy and management interventions, including a set of measurable indicators that support both national decision-makers and the international community. A set of fifteen indicators was proposed, with detailed descriptions and methodologies for each one.[5]

While these indicators do not allow for an in-depth analysis of the issues, they serve their intended purpose of informing civil society of critical water issues at the global level. However, the IMR Task Force noted that the development and use of indicators is a dynamic process and that the proposed list is neither final nor exhaustive. Rather, it will evolve as knowledge and data availability improve. A precondition for any robust indicator is collection of accurate, timely and consistent data at country level. Part of this ongoing process will be the provision of technical assistance or tools to facilitate this work.

6.3 State of data and information

The monitoring of water resources and their use represents an immense challenge, especially given the renewable nature and general complexity of water resources, the variability of their distribution in time and space, and the different forms in which they appear. Furthermore, the diversity of monitoring objectives poses additional challenges. In addition, the data required to populate the indicators are seldom systematically or reliably available at global, national, regional or basin level.

The paucity of data is illustrated by Figure 6.1, which summarizes data availability in the countries of the Southern African Development Community (SADC).

A particular challenge is maintaining a regular flow of comparable data that can be used to monitor trends in different parameters over time. While data gaps have often been patched by the use of models, the quality of the information then becomes dependent on having sufficient field data to calibrate and 'ground truth' the model.

A WWAP Expert Group on IMR considered the availability of data and the actions that could be taken to enhance data flow. One finding was the existence of a limited set of key 'data items' needed to calculate a wide range of different indicators. For example, one key data item needed to calculate the values of many national level indicators is the Total Actual Renewable Water Resource (TARWR), whether at the basin, state, national or regional level. In the past, the TARWR has

> "Without actual use data, improvements in water productivity cannot be tracked, even if they are substantial."

been calculated on the basis of information collected over a 30-year period (the 1960–1990 period was a widely used benchmark). Important indicators, such as water scarcity (TARWR per capita) and water productivity (GDP per TARWR) are based on these measures.

However, the TARWR has not been routinely monitored and no methodology exists for its systematic updating. So, while indicators such as national water scarcity have changed over the past decade, these changes have usually simply reflected changes in underlying populations. Changes in water availability have not been systematically recorded and are not generally reflected in global water scarcity data. The general assumption was that hydrology is 'stationary' (see Chapters 5, 8 and 11).

However, concerns about climate change, one of the factors that have led to the growing interest in water indicators, have resulted in explicit recognition that the 'stationary hydrology' assumption can no longer be used as the basis for high-level reviews of water availability. This has focused attention on the limited availability of global data on stream flows, on which estimates of water resource availability need to be based. While there are a great deal of available data on precipitation, which can be measured by remote sensing, changes in runoff to rivers or recharge of groundwater are much harder to measure. In general, data availability is particularly poor for groundwater and water quality.

Water-use data are often even more difficult to obtain than data on the state of the resources themselves. As an example, data are needed to assess the productivity of water, in terms of GDP per unit of water used, to enable monitoring of the policy objective of decoupling economic activity from resource use. Similarly, the efficiency of water use in different industrial processes

FIGURE 6.1

Dashboard of data availability in SADC countries

	Surface and groundwater	Infra-structure	Water supply sources and returns to environment	Water uses and allocation	Wastewater	Water efficiency	Water charges (tariffs, taxes, subsidles)	GDP	Water financing and production costs
Angola	Substantial	No response	No response	Some but limited	No response	No response	Some but limited	Substantial	No response
Botswana	Substantial	Some but limited	Some but limited	Substantial	Substantial	Substantial	Substantial	Substantial	Substantial
Democratic Republic of the Congo	Substantial	Little	Little	Some but limited	No response	Little	Some but limited	Substantial	Little
Southern	Substantial	Some but limited	Some but limited	Some but limited	Little	Little	Some but limited	Substantial	Little
Madagascar	Substantial	Some but limited	Some but limited	Some but limited	No response	No response	Some but limited	Substantial	Little
Malawi	Substantial	Little	Some but limited	Little	No response	No response	Some but limited	Substantial	Little
Mauritius	Substantial	Little	Some but limited	Little	Some but limited	Substantial	Substantial	Substantial	Little
Mozambique	Substantial	Some but limited	Little	Substantial	Little	Little	Substantial	Substantial	Some but limited
Namibia	Substantial	Little	Some but limited	Substantial	Little	Substantial	Substantial	Substantial	Some but limited
Seychelles	Substantial	Little	Some but limited	Substantial	Little	Some but limited	Substantial	Substantial	Some but limited
South Africa	Substantial	No response	Some but limited	Substantial	No response	No response	Substantial	Substantial	Little
Swasiland	Substantial	No response	Some but limited	Substantial	Little	Little	Substantial	Substantial	Some but limited
United Republic of Tanzania	Substantial	Little	Some but limited	Some but limited	No response	Some but limited	Substantial	Substantial	Little
Zambia	Substantial	Some but limited	Some but limited	Some but limited	Little	Little	Substantial	Substantial	Some but limited
Zimbabwe	Substantial	Little	Some but limited	Some but limited	No response	No response	Substantial	Substantial	Little

Little information — Substantial information — Some but limited information — No response received

Source: SADC (2010, table 4, p. vii).

may usefully be monitored to determine the efficacy of water demand management programmes. In practice, however, water use is often estimated using standard assumptions of water consumption in specific industries. Without actual use data, improvements in water productivity cannot be tracked, even if they are substantial. The impacts of technological progress may thus be missed unless detailed surveys are carried out into water use by specific sector. Similarly, the lack of knowledge about water use in many sectors means that opportunities and priorities to promote more efficient use of water may not be identified.

These examples highlight the need for greater focus on data generation to enable water managers to monitor the trends of most concern to policy-makers.

6.4 Constraints on better monitoring and reporting

6.4.1 Institutional and political constraints

Many institutional and political constraints inhibit better monitoring and reporting of information on water resources and their use. Good management generates good data; poor management is frequently a consequence of poor data, while also contributing to the broader data gap.

Because of the relatively low value and wide distribution of water, its use, particularly in irrigation, is usually not measured directly. From an operational perspective, it is usually more important in conditions of scarcity to decide on the priorities and proportionate shares for available water, rather than to measure exact quantities. In many jurisdictions, water allocations are made at different levels of reliability for different classes of user to avoid detailed quantitative measurements.

Furthermore, because the production of water is a natural rather than a man-made process, there is little certainty in most situations about the initial supply. This distinguishes it from other utility operations and natural resource contexts. For example, in energy production the quantity of coal delivered from a mine to a power station is known; similarly, the amount of electricity that flows from the power station is measured by the generating company whose survival depends on measuring and billing its customers for the energy supplied. With water resources, however, there is no coal-burning or any other routine measurement of the amount of water that flows into the system.

In addition, because water resources are often shared between a number of different political jurisdictions, there is often a disincentive for upstream communities to share information about resource availability and use with downstream jurisdictions, as the information may be used in disputes about the division of the resource. It is also common for private companies to withhold and avoid disclosure of information on water availability and use, alleging that these data are of strategic importance for their business activities.

This phenomenon is best known in river basins shared between countries (as with large basins such as the Ganges and the Mekong); however, similar logic may also apply in countries with federal systems of government in which water resource management lies in the

BOX 6.3

Water resource information for conflict prevention in Central Asia

The dissolution of the Soviet Union in 1989 created a number of difficult water resource management challenges for the countries that emerged. Beforehand, the central government had taken decisions about the use and sharing of water between regions; afterwards, such decisions became the province of sovereign countries, which have different criteria. As a result, the potential exists for conflict between them. This in turn has been identified as a potential risk, and one that could aggravate existing conflicts in neighbouring countries. One simple response to this, identified by the United States of America, proposes the provision of better water resource information as the first essential step:

> Provide benchmark data to improve water management
> The countries in Central and South Asia, regardless of their level of development, lack publicly available access to consistent and comparable data on water supply, flow and usage. This creates tension over the management of water by both upstream and downstream countries. Providing basic technical information to all countries is a constructive way for the United States to help create a foundation for bona fide discussion and debate over water management. The United States should support data-related activities specific to measuring and monitoring water flow and volume for key rivers and river basins. We should also promote technical partnerships in the region to monitor glaciers, track shifts in monsoons, and model climatic changes across a range of water flow scenarios. (US Senate, 2011, p. 2)

hands of provincial or state administrations, which may have similar motivations. The corollary is that where a potential for conflict exists between neighbours, addressing the data challenge may constitute an important mechanism to manage disputes (Box 6.3).

6.4.2 Definitional issues: Performance measurement challenges

A further constraint on improved monitoring and reporting is the lack of agreement on what should actually be monitored. For example, the establishment of performance targets with effective measures is essential to achieving policy goals such as sustainable development and the MDGs, but there is often uncertainty about what data items will best serve this purpose.

It is necessary to address the potential impacts of decisions needed within a cost–benefit analysis. Criteria will be needed to guide the selection of measures. These will include considerations such as the value of ecosystem services that make optimization more complex, but also potentially more effective. Decision-support systems are needed that combine classical cost–benefit with participatory multi-criteria analyses, addressing different levels of uncertainties.

To achieve a balanced allocation and the protection of water resources, indicators should support carefully designed and selected policy instruments. They may include regulations (technical standards, performance standards, etc.), quotas, access rules and allocation procedures, as well as economic instruments (especially pricing mechanisms and payments for ecosystem services).

While economic theory suggests that pricing policies may be useful for achieving targets, in practice, prices serve several conflicting purposes: financing of water service-related infrastructure, incentives for efficient use of scarce resources, and fairness and distributional justice (see Chapter 10). Simply monitoring water prices does not necessarily provide a useful indication of policy success, unless it is done in a manner that reflects the real-life objectives of improved water management.

6.4.3 Technical and financial constraints

In addition to the political and institutional barriers to the generation and reporting of water resource availability and use information, there are also substantial technical and financial constraints.

Because water occurs in natural structures whose behaviour often varies from one season to the next, measuring simple parameters such as flow can be extremely expensive. The cost of a single river gauging station for a medium-size river can easily exceed US$1 million, and the costs of ongoing operation, maintenance and reporting can be difficult to justify in poor countries where such activities compete with basic water supply for limited funds, yet bring no immediate benefits.

One important yet underused resource is remote sensing. As yet, it has not resulted in a significant flow of useful processed information about water and its use. While the direct use of water by field crops can now be reliably assessed using remotely accessed data, it is more difficult to determine the amount of water actually abstracted from rivers and dams to irrigate the fields. This is because it is not yet possible to determine parameters such as the flow of water in rivers from remotely sensed information. This means that a critical indicator cannot be assessed: the efficiency with which abstracted water is delivered to the fields and actually used for crop production.

It is also possible to remotely monitor water quality-related parameters, which would assist management challenges such as eutrophication and the protection of natural ecosystems such as wetlands on a systematic basis. Existing remote-sensing technologies have a number of important applications; however, the relatively low priority accorded to water resource monitoring means that these are not applied.

While remote sensing is proving to be a useful tool, it will never substitute the need to gather local information. Using remote sensing data without ground truth may be risky and it would be ill-advised to suggest that governments not spend on hydromet networks in favour of remote sensing data. Remote sensing and hydromet measuring networks are not mutually exclusive, and strengthening hydromet networks and services is a necessary condition for proper water resources management, planning, design and operation.

6.5 Improving the flow of data and information

6.5.1 The emerging market for better data and indicators

While WWAP's mandate is to collate and report available information on the state of water resources and their use at a global level, it has become apparent that data constraints are limiting the programme's ability to do this, specifically in relation to the systematic monitoring of important trends. In order to carry out its mandate effectively, it must therefore identify the data requirements to enable the tracking of key policy goals and emerging changes, and to support efforts to implement monitoring systems that can generate the data required.

The most effective driver of efforts to improve the flow of information about water would be demands for information on the part of policy-makers and decision-makers in the socio-economic sectors of activity. There are, however, encouraging signs that more attention is being paid to the need to generate better data flows to support the monitoring of water resources and their use.

From a government perspective, economic policy-makers now recognize that water as a resource has an important influence on national economies, which is largely unaccounted for. As a result, there is a growing interest in water accounting in parallel with broader environmental accounting. The initiatives of the UN System of Environmental-Economic Accounting for Water (SEEAW) and Eurostat are particularly significant in this regard, as are the recent efforts of OECD.

The importance of water resource data for national and regional security is demonstrated by the example from Central Asia, cited above. And as the business sector turns its attention to managing the risks posed by water, it has found that the 'data drought' (IBM, 2009, p. 10) adds to existing uncertainties.

An important initiative from the perspective of business is the UN Global Compact CEO Water Mandate. Established in 2007, it recognized that emerging crises in water services and water resources posed a range of risks to the private sector – as well as opportunities. It also recognized that current water management practices are inadequate given the increasing materiality and importance of water as a resource. Mandate members acknowledge that, in order to operate in a more sustainable manner, they have a responsibility to make water resources management a priority, and to work with governments, UN agencies, NGOs and other stakeholders to address this global water challenge. They have also turned their attention to the challenge of data availability. Linked to this, business leaders at the World Economic Forum in 2009 issued a call to action to raise awareness about water challenges.

> "From a government perspective, economic policy-makers now recognize that water as a resource has an important influence on national economies, which is largely unaccounted for."

Specifically, they pledged action to work on unifying water data collection, management and disclosure approaches for business (Box 6.4).

There are many other initiatives underway. The World Business Council on Sustainable Development (WBCSD) has produced a 'water tool' to help business to monitor its use of and impact on water more systematically. The Water Footprint Network similarly encourages businesses, their customers and other stakeholders to become more aware of the water content of their products and operations (Hoekstra et al., 2011).

There is implicit competition between these different approaches, with one focusing specifically on corporate water use while others seek to engage and understand the resource in its catchment context: 'beyond the factory fence'. However, both approaches to monitoring and evaluating the state of water resources and their use are effective in that they depend on the availability of sufficient data to draw well-substantiated conclusions.

The interest from governments and corporate water users is also beginning to be complemented by an interest from the broader public. Civil society organizations such as the World Resources Institute have included access to information about water resources in their overall programme to promote greater public access to environmental information – a programme that has traditionally focused on more contentious natural resources such as minerals, land and forests.[6]

It would thus appear that, after many decades of decline, the market for water-related data may be growing and becoming demand-driven rather than supply-driven. This suggests that there are now significant opportunities for the global community of water practitioners, as well as water users and the much broader community that has a stake in water, to make substantial improvements in the availability and quality of information about the resource. Moreover, the new focus on monitoring water resources is helping to raise awareness among a broader community about the current limitations of available information.

6.5.2 Technological opportunity and data innovation

Technology is also making a contribution. One example is the development of techniques that enable evapotranspiration from crops to be measured directly at a variety of scales, including by remote sensing (Hellegers et al., 2009). New partnerships may also play a role; for example, data about signal attenuation between mobile phone towers can help to make accurate estimates of precipitation, which means that telecommunications service providers can help to fill data gaps. Another potentially more significant development is the deployment of the GRACE family of satellites, which have enabled the application of remote gravimetric measurement to determine changes in the total water stock in specific geographical areas. Although still only experimental and working at a large scale, this technology has already demonstrated the potential to monitor changing groundwater reserves in large alluvial basins. This is of substantial policy interest given the dangers of depletion that these resources face.

One pilot initiative of WWAP is a collaboration to produce a dynamic estimate of the basic data item, the TARWR (Total Actual Renewable Water Resources). The

BOX 6.4

Data as a gateway to progress for sustainable water management

At the 2009 World Economic Forum (WEF), data and information was identified as a key area requiring more attention. Why is the issue important?

Water security and pollution in water-stressed countries is a growing concern for many companies, especially in the power, mining, food and beverage, and semi-conductor sectors. The last few years have seen a plethora of reports from business associations, financial analysts and companies on the strategic importance of water security. The UN Global Compact CEO Water Mandate is a good example of this emerging trend.

Companies will increasingly be asked to provide details of their water-related risks to investors and their water-use efficiency measures to the public. They will also be attracted to countries with sound water management policies. Water security risks are difficult for businesses and investors to assess, due both to poor information about underlying supply conditions and inadequate and irregular reporting and disclosure practices by individual companies (Levinson et al., 2008).

> Quantitative indicators make it possible to spot problems, track trends, identify leaders and laggards, and highlight best management practices … What is shocking is how little water data is available on a methodologically consistent basis across countries. Much of the existing water data has been collected without regard to cross-country comparisons. (Daniel C. Esty, Director, Yale Center for Environmental Law and Policy, US, cited in WEF, 2009, p. 12)

There is also a need for better data at country level. A participative session on India concluded that one of the obstacles to implementing potential solutions to the country's water problems was the lack of understanding and awareness of the issue:

> Participants strongly agreed that water security is already a critical issue for India as the problem becomes more visible, but the sense of urgency has yet to percolate through to the general public and political leaders. Better quality of data and data transparency through an independent authority or group may help provide further insight into the situation.…
>
> Data, Transparency and Analytics: The impact of the water problem will need to be quantified by different stakeholders so that they can understand the extent of the problem. Additional analytics need to be produced by independent actors that will help or pressure governments and other stakeholders into action (such as additional water metrics/index/benchmarking tools/water footprint). (WEF, 2009, p. 52)

TARWR is used as a variable in many key indicators, but is currently only available on a static basis, largely based on estimates of river flows for the period 1960–1990. The key innovation is to base the estimate of available water on a combination of observed hydro-meteorological and surface elevation data and to produce long-term moving averages. This approach will move away from the constraints of 'stationary hydrology' and permit the identification of trends in TARWR. Although the approach still has to be further developed, its observational basis and dynamic nature strongly indicate that it could become the primary point of reference for national water availability (Box 6.5).

As mentioned in Section 6.4.3, there are a number of other areas in which remote sensing may be harnessed to improve the quality of information about critical water resource parameters, notably water quality and environmental protection. Further work in these areas could also produce methodologies to enable the systematic monitoring of global trends in, for example, eutrophication of water bodies and changes in wetland extent. However, as mentioned earlier, using remote sensing data without ground truth may be risky and will never be a substitute for gathering local information.

BOX 6.5

WWAP's dynamic TARWR pilot initiative with CUNY and GWSP

WWAP's pilot initiative is a collaboration with the City University of New York (CUNY) and the Global Water System Project (GWSP) to produce a dynamic estimate of the basic data item, the TARWR (Total Actual Renewable Water Resources). TARWR is the fundamental measure of water resource availability (in a country, river basin or region) and is used in many indicators. It is defined as the maximum theoretical amount of water actually available for the country (or other unit), calculated from:

- Sources of water within a country itself
- Water flowing into a country
- Water flowing out of a country (treaty commitments)
- Availability, defined as the surface and groundwater resource volume renewed each year in each country, means the amount of water theoretically available for use on a sustainable basis. In more specific terms, TARWR is the sum of:

External water resources entering the country
  - Surface water runoff (SWAR) volumes generated in the country
  - Groundwater recharge (GAR) taking place in the country

Less:
  - The volume in the country of the total resource effectively shared as it interacts and flows through both the groundwater and surface water systems; not to subtract this volume would result in its being counted twice (it is also referred to as 'overlap').
  - The volume that flows to downstream countries based on formal or informal agreements or treaties

The WWAP Pilot Study on Indicators (PSI) is being undertaken at the CUNY by Charles Vörösmarty in partnership with the Global Terrestrial Network for Hydrology (GTN-H) and GEO/IGWCO (Water Community of Practice), with support from the US Army Corps of Engineers (USACE). The group has developed an innovative methodology for estimating country-level TARWR. This approach is based on (but not limited to) a combination of hydro-meteorological and high-resolution (6 minute river network and ESRI country boundaries) surface elevation data, which will allow the identification of TARWR trends (e.g. if certain countries are getting wetter or dryer) and variability (e.g. variation of water supply from one year to the next).

This 'dynamic TARWR' is used to produce an alternative set of countries' per capita water availability. This data item will be further developed. Given its observational basis and dynamic nature, it is hoped that it will eventually become the primary point of reference, as it enables longer-term variations in water availability to be tracked over time. This will overcome some of the current constraints imposed by the assumption of stationary hydrology, which is considered to be inappropriate in the face of climate and related challenges

The present TARWR series is produced by the Food and Agriculture Organization of the United Nations (FAO)'s AQUASTAT programme (TARWR-FAO, 2003). It is computed on the basis of available country water resources data sheets and country water balance computational spreadsheets. FAO refers to the data as the 'Best Estimate' and updates the data when further information is provided.

6.5.3 Institutional responsibilities, constraints and opportunities

While many organizations collaborate to produce water resource information, for many of them water is not their primary focus. This can pose certain challenges. The three key water resource agencies in the UN system are UNESCO, FAO and the World Meteorological Organization (WMO), while the United Nations Environment Programme (UNEP) also has a growing interest in water resources and water quality through its Global Environment Monitoring System (GEMS) Water Programme. WMO addresses basic hydrological data through its science platform and the Global Runoff Data Centre (a repository for the world's river discharge data), while the FAO's AQUASTAT programme provides a platform for data on water resources and their use, which has progressed substantially beyond the agricultural domain. However, all three organizations already have substantial general mandates: FAO has global oversight of food and agriculture, UNESCO has a broad responsibility to support science, culture and education, and WMO's global remit is primarily to monitor the atmospheric dimensions of weather and climate. While water resources may not constitute a top priority for these organizations, they all maintain substantial water programmes, an example of which is FAO's recent announcement of the establishment of a 'water platform' to coordinate water-related activities across the organization. Other examples include WMO's Hydrology and Water Resources Programme and UNESCO's science-education-assessment 'suite' comprising its International Hydrological Programme (IHP), the IHE Institute for Water Education and WWAP, in addition to a network of regional hydrologists. As the coordination mechanism across the UN system, UN-Water can play a key role in linking these various programmes, and members of the aforementioned UN-Water Task Force on Indicators, Monitoring and Reporting has begun work on a Federated Water Monitoring System and Key Water Indicators Portal.

A further challenge is that the surface flow component of the water cycle is largely local in character. As such, it receives relatively little systematic attention from the scientific community, which is engaged in global earth observations. Thus, relatively few of the many programmes that together constitute the Global Climate Observation System address water on a broad as opposed to a local basis. One exception is the Global Water Systems Project (GWSP), although its resources are significantly smaller than those available for other dimensions of weather and climate.

However, these global approaches are complemented, if not fed in terms of data, by national level approaches, supported by emerging efforts to promote national water accounting. These too reflect different approaches. For example, while the UN System of Environmental-Economic Accounting for Water (SEEAW)'s model system seeks to address quantity (and to a lesser extent, quality), a financially based approach is being taken to water accounting in Australia, although this faces significant challenges to manage the impacts of dramatic variability on the national economy and society. As already indicated, similar diversity is apparent in the efforts of the business community focusing either on the specific water footprint of individual business enterprises or the broader dynamics of water resources and their use 'beyond the factory fence'. This diversity of approaches could be seen to reflect confusion. However, it should be understood as an important and encouraging indicator of the renewed global interest in the state of water resources, their management and use.

Notes

1 A review of the different approaches and their implications is contained in Muller (forthcoming 2012).

2 See http://www.fao.org/nr/water/aquastat/main/index.stm

3 For more information see http://www.wssinfo.org/about-the-jmp/introduction/

4 For more information see http://www.unesco.org/new/en/natural-sciences/environment/water/wwap/indicators/un-water-tf-on-imr/

5 For more information see http://www.unwater.org/indicators.html

6 For more information see http://www.accessinitiative.org/tai-global-meeting-2008/node/1

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CHAPTER 7

Regional challenges, global impacts

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Contributor Richard Connor

For the first time in the *World Water Development Report* series, this fourth edition reports at a regional level on the status of water resources, their uses and management through the introduction of five regional reports (in Part 3/Volume 2) and their respective summaries in this chapter. The regional reports cover:

- Europe and North America
- Asia and the Pacific
- Latin America and the Caribbean
- Africa
- Arab and Western Asia region

The delineation of the five regions follows the regional division of the United Nations regional economic commissions (UNECE, UNECA, UNESCWA, UNECLAC and UNESCAP; maps of the Member States are provided in the corresponding sections of this chapter), with the exception of the reports on Africa and the Arab and Western Asia region. For these two reports, it was decided (in agreement with UNECA and UNESCWA) that all the Arab countries would be reported on in a broad Arab and Western Asia report, rather than having some of them included in the Africa report and others in the Western Asia report. Each regional report was prepared by the corresponding regional economic commission, with the exception of the Africa report, which was prepared by WWAP in consultation with UN Water/Africa, the African Ministers' Council on Water (AMCOW) and UNECA.

The regional reports highlight the main issues the regions are facing today, and how they have been changing over recent years. Each report lists the most important external drivers for the region, analyzing the resulting pressures and effects the drivers have on water resources, their uses and management. In line with the main theme of the WWDR4, the principal risks and uncertainties and opportunities related to the regions are reported, as well as geographic hotspots and sectoral issues of particular concern. Findings are supported by specific examples. Response options are provided to help the decision-makers identify solutions to their specific issues.

In this chapter a summary of each of the regional reports (Chapters 29 to 33) is provided. The chapter closes with an examination of the inter-linkages between different regions and global challenges, which describes how actions in one part of the world can create negative impacts, as well as opportunities, in others.

7.1 Africa

Map 7.1 shows the UNECA member countries; however, for the purposes of this chapter, the Africa region comprises 46 countries and excludes the northernmost countries of Algeria, Djibouti, Egypt, Libya, Mauritania, Morocco, Sudan, South Sudan and Tunisia, which are covered in Section 7.5, 'Arab and Western Asia Region'. In other words, the Africa region here more or less corresponds to the political definition of sub-Saharan Africa. This region has a total area of 24 million km²,

MAP 7.1

UNECA Member States

Source: Economic Commission of Africa, Map No. 3975 Rev.8, November 2011. Department of Field Support, Cartographic Section, United Nations.
Note: The region is divided into subregions as follows.
Northern: *Algeria, Egypt, Libya, Morocco, Tunisia.*
Sudano-Sahelian: *Burkina Faso, Cape Verde, Chad, Djibouti, Eritrea, Gambia, Mali, Mauritania, Niger, Senegal, Somalia, South Sudan, Sudan.*
Gulf of Guinea: *Benin, Côte d'Ivoire, Ghana, Guinea, Guinea-Bissau, Liberia, Nigeria, Sierra Leone, Togo.*
Central: *Angola, Cameroon, Central African Republic, Congo, Democratic Republic of the Congo, Equitorial Guinea, Gabon, Sao Tome and Principe.*
Eastern: *Burundi, Ethiopia, Kenya, Rwanda, Uganda, United Republic of Tanzania.*
Southern: *Botswana, Lesotho, Malawi, Mozambique, Namibia, South Africa, Swaziland, Zambia, Zimbabwe.*
Indian Ocean Islands: *Comoros, Madagascar, Mauritius, Seychelles.*

which represents about 18% of the world's landmass (FAO, 2008). Africa's climate is influenced by the equator, the two tropics and its two major deserts: the Sahara in the northern hemisphere and the Kalahari in the southern hemisphere. Rainfall distribution is extremely uneven, both spatially and temporally, which has major implications for livelihoods and human well-being on the continent (FAO, 2005).

Water's crucial role in accomplishing the continent's development goals is widely recognized. Africa faces endemic poverty, food insecurity and pervasive underdevelopment, with almost all countries lacking the human, economic and institutional capacities to effectively develop and manage their water resources sustainably. Sub-Saharan Africa uses barely 5% of its annual renewable freshwater. Yet access to improved water supplies, in both urban and rural contexts, is still the lowest in the world. Most countries do not take full advantage of available arable lands for agricultural production and irrigation expansion, and hydroelectricity is underdeveloped in most places. The Economic Commission for Africa notes that the key issues in Africa are 'investing in the development of Africa's potential water resources, reducing drastically the number of people without access to safe water and adequate sanitation, ensuring food security by expanding irrigation areas and protecting the gains of economic development by effectively managing droughts, floods and desertification' (NEPAD, 2006, 2).

Africa Water Vision 2025 has been adopted by African governments, the New Partnership for Africa's Development and the African Union. This is evidence of a new focus on water and, potentially, better-targeted investment and more efficient water management. Africa Water Vision 2025 calls for enhanced institutional frameworks for the strategic adoption of the principles of integrated water resources management (IWRM). Most African countries have adopted IWRM as the basis for water governance and management. International water policy recommendations continue to play an invaluable and decisive role.

7.1.1 The driving forces and pressures on water resources

High population growth, poverty and underdevelopment are key drivers affecting how water is managed in the region. The development of drinking water and sanitation programmes and other water sector activities in Africa need to take into account the prevailing demographic, economic, political and climatic environments and their impact on water resources and water demands.

Demographics

Africa's rising population is driving demand for water and accelerating the degradation of water resources in many countries. By mid-2011, Africa's population (again excluding the northernmost states) was about 838 million and its average natural rate of increase was 2.6% per annum, compared to the world average of 1.2%. According to one estimate, its population will grow to 1,245 million by 2025 and to 2,069 million by 2050 (PRB, 2011).

An estimated 61% of Africans live in rural areas, exceeding the world average of 50%, and the average population density is 29 people per square kilometre. Urban population grew at 3.4% between 2005 and 2010, which is 1.1% faster than the rural population growth rate (UNEP, 2010*b*). The urban slum population in sub-Saharan African countries is expected to double to around 400 million by 2020, if governments do not take immediate and radical action (UN-Habitat, 2005). However, since remaining flexible is a survival strategy, urban slum populations are highly mobile and numbers are difficult to assess. It is clear, though, that improvements are not keeping pace with the rapid growth of sub-Saharan slum populations (UN-Habitat, 2010). This rapid and poorly managed growth of urban areas, especially in peri-urban slums, has overwhelmed most municipal water services and constitutes a major challenge to water and sanitation development.

On the other hand, population growth is stabilizing: there has been a progressive reduction in the growth rate from about 2.8% in 1990–1995 to a projected value of about 2.3% in 2010–2015 (FAO, 2005). This trend, coupled with increasing economic growth, is likely to contribute to increased socio-economic development, including better water management and the provision of water-related services.

Economic development and poverty

Sub-Saharan Africa is the world's poorest and least-developed region, with half its population living on less than a dollar a day. About two-thirds of its countries rank among the lowest in the Human Development Index (FAO, 2008). Even when opportunities exist to address outstanding water issues, deep and widespread poverty across the African region constrains the ability of many cities and communities to provide proper water and sanitation services, sufficient water for economic activities and to prevent water quality from deteriorating (UNEP, 2010*b*).

Far-reaching economic reforms adopted across the continent have begun to yield positive results in many countries. Negative trends in gross domestic product (GDP) have given way to progressively increasing growth, averaging around the mean figure for developing countries. Analysis by the Economist reveals that in the ten years up to 2010, six of the world's ten fastest-growing economies were in sub-Saharan Africa (*The Economist*, 2011). Nevertheless, average per capita GDP growth in Africa remains far below all other regions.

The economies of most African countries depend largely on rainfed agriculture as the major driver of economic growth. It represents about 20% of the region's GDP, 60% of its workforce, 20% of its export goods, and 90% of rural incomes. Agriculture is by far the largest user of water, accounting for about 87% of total water withdrawals (FAO, 2008). Investing in agriculture, and especially in irrigated farming, is at least four times as effective at raising poor people's incomes as is investment in other sectors (UNEP, 2010*b*).

7.1.2 Challenges, risks and uncertainties

Hydrological variability

Africa's climate is characterized by extremes, from a humid equatorial climate at the equator, through tropical and semi-arid in the middle of the region, to an arid climate towards the northern and southern fringes. Sub-Saharan Africa has a relatively plentiful supply of rainwater, with an estimated total average annual precipitation of 815 mm (FAO, 2008), but it is highly seasonal, unevenly distributed across the region (Table 7.1) and there are frequent floods and droughts. The greatest amount of rainfall occurs along the equator, especially in the area from the Niger Delta to the Congo River basin. The Sahara Desert has virtually no rainfall. In western and central Africa, rainfall is exceptionally variable and unpredictable.

At the continental level, renewable water resources constitute only about 20% of the total rainfall and represent less than 9% of global renewable resources (FAO, 2005). Internal renewable water resources per person in sub-Saharan Africa fell from an average of more than 16,500 m^3 per inhabitant in 1960 to about 5,500 m^3 per inhabitant in 2005. This was largely as a result of population growth (FAO, 2008). Groundwater represents 15% of total renewable resources, but an estimated 75% or more of the African population uses groundwater as their main source of drinking water (UNEP, 2010*b*). Because renewable resources are in short supply, capturing and storing precipitation is important. More importantly, the low volumes of renewable resources partly account for the endemic drought in areas of the continent. Although lack of access to water is mainly a function of economic scarcity (see Section 4.6.1 and Figure 4.10), significant variations both between and within subregions also contribute to the low average per capita water withdrawals of 247 m^3 per year. (FAO, 2005).

About 66% of Africa is arid or semi-arid and more than 300 of the 800 million people in sub-Saharan Africa

TABLE 7.1

Total and proportional renewable water resources in Africa's subregions

Subregion	Total water resources (km^3/year) (2008)	Percentage of internal water resources of Africa
Central Africa	2 858.08	50.66
Eastern Africa	262.04	4.64
Western Indian Ocean Islands	345.95	6.13
Northern Africa	168.66	2.99
Southern Africa	691.35	12.25
Western Africa	1 315.28	23.32
Total Africa	**5 641.36**	**100**

Source: UNEP (2010b, table 1.2, p. 15; original data from FAO AQUASTAT).

live in a water-scarce environment – meaning that they have less than 1,000 m^3 per capita (NEPAD, 2006). Access to scarce water is exacerbated by increased demand caused by growing populations, especially in urban areas, and a trend towards higher living standards in some places. This is compounded by dwindling supply and poor water management. These characteristics present significant challenges to water provision in Africa and contribute to food insecurity, poor health and damaged ecosystem in many places, especially where rainfed agriculture is crucial to livelihoods (UNEP, 2010*b*).

Access to drinking water and sanitation

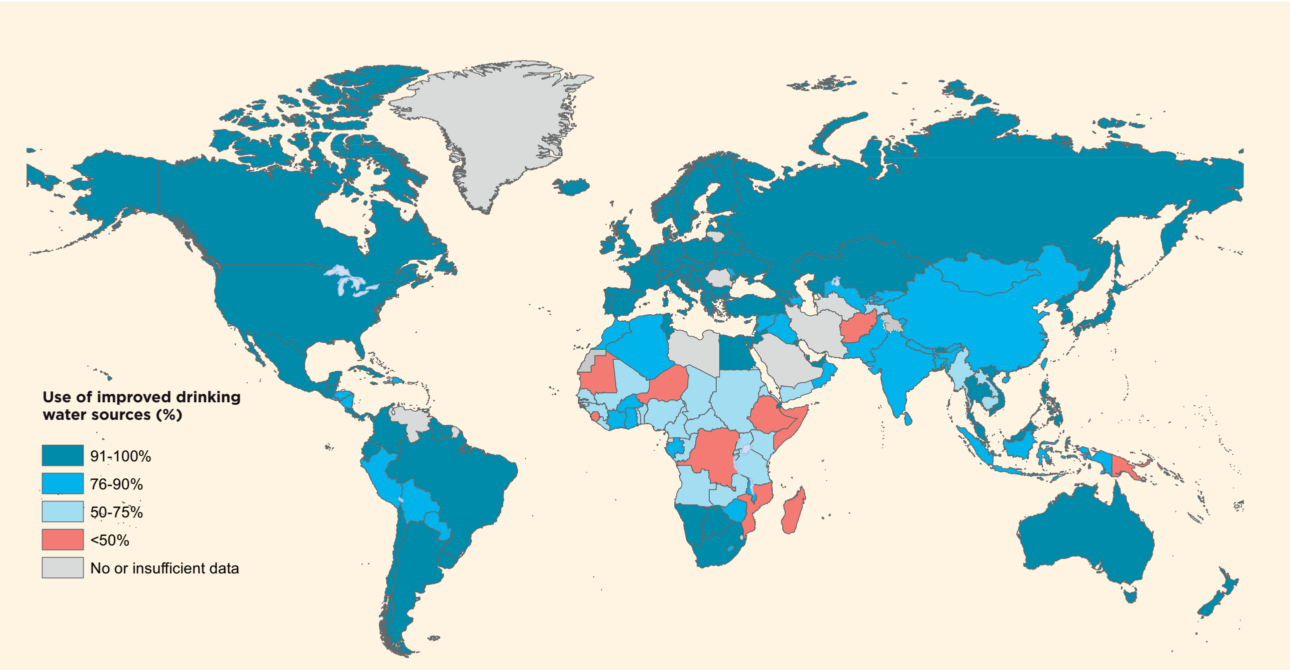
Although water is intimately linked with African culture, religion and society in myriad ways, modern African societies have not sufficiently developed the adaptive capacities they need to guarantee basic households for water and other vital services. Often, water is carried long distances, a burden borne mainly by women and children. In urban and peri-urban areas, water is often only available from vendors at an unfair price and the quality is often poor. The urban slum population in sub-Saharan African countries is expected to double, rising from 200 million in 2005 to 400 million in 2020, if governments do not take immediate and radical action (UN-Habitat, 2005).

The coverage of drinking water supply in sub-Saharan Africa[1] is barely 60%; the world average is about 87%. Of the 884 million people in the world still using unimproved drinking water sources, 37% live in this region. Provision of improved water sources in urban areas remained at 83% between 1990 and 2008. In rural areas, it was at only 47% in 2008, although this represented an 11% increase on 1990 figures, or 110 million more people gaining access to improved water supplies (WHO/UNICEF, 2010). Figure 7.1 gives a country-by-country breakdown of the proportion of the population using improved drinking water sources.

Lack of sanitation facilities is an even greater challenge to water management in Africa. Many water bodies and other sources are polluted with microbiological organisms from indiscriminate disposal of excreta, impairing human health through waterborne diseases such as diarrhoea, cholera, trachoma, schistosomiasis and others. Water-related vector-borne diseases, such as malaria, are also a major health concern. In sub-Saharan Africa, only 31% of the population uses improved

FIGURE 7.1

Use of improved drinking water sources (2008)



Source: adapted from WHO/UNICEF (2010, fig. 4, page 7).

> "About 66% of Africa is arid or semi-arid and more than 300 of the 800 million people in sub-Saharan Africa live in a water-scarce environment."

sanitation facilities, with large differences between urban coverage, which was about 44% in 2008, and rural provision, which was 24%. Although the proportion of the population practising open defecation in the region is declining, in absolute numbers, it increased from 188 million in 1990 to 224 million in 2008 (AMCOW, 2010).

The Millennium Development Goals (MDGs) for water are to 'halve, by 2015, the proportion of people without sustainable access to safe drinking water and basic sanitation'. It is estimated that only five countries in sub-Saharan Africa have more than 75% of what is needed to achieve the target for drinking water and only two countries, Kenya and South Africa, have more than 75% of what is needed to achieve the sanitation target (WHO/UNICEF, 2009). The lack of safe water and proper sanitation affects not only human health and well-being, it hampers economic growth and security too.

Food insecurity

Between 2000 and 2007, 25.5% of the total population was undernourished and 30% of children under five years old suffered from malnutrition. Between the mid-1990s and 2008, undernourishment in sub-Saharan Africa increased from 200 million people to about 350 million to 400 million people (FAO, 2008). Climate change and climate variability are likely to severely compromise agricultural production and food security in many African countries (Boko et al., 2007).

Since the mid-1960s, agricultural production has increased by an average of less than 2% annually, while the population has grown by about 3% (UNECA, 2006). Some 97% of the region's croplands depend on rainfed agriculture, which produces most of Africa's food (FAO, 2008). Africa needs to increase its agricultural output at a rate of 3.3% a year if it is to achieve food security by 2025. Water is a key component of its ability to feed its population because irrigated cropland accounts for only 20% of its irrigation potential. In fact, in all but four countries in the region, less than 5% of the cultivated area is irrigated – so there is considerable scope for expanding irrigation to increase food security (UNEP, 2010*b*).

On the other hand, scenarios suggest that increasing the area under irrigation by a factor of three would only represent a 5% contribution to the increase in food production needed by 2025 (UN Water/Africa, 2004). However, there is even greater scope for expanding rainfed agriculture, harvesting water runoff and wisely using large untapped groundwater reserves that exist in some areas (UNEP, 2010*b*).

Energy insecurity

Sub-Saharan Africa is the world's largest consumer of biomass energy, which includes wood, crop waste, charcoal, manure, candles and kerosene (see Section 2.2 and Chapter 19). Biomass provides 15% of South Africa's energy consumption, 86% of energy consumption in the rest of sub-Saharan Africa, and more than 90% of the rural population's energy consumption. Overall, only one person in four in Africa has electricity. Electricity provision is also often unreliable as a result of a lack of investment, growing demand, conflict, unpredictable and variable climatic conditions and aging equipment – all of which hampers economic activity. Hydropower supplies 32% of Africa's energy, but it is underdeveloped. Only 3% of its renewable water resources are exploited for hydroelectricity (UNEP, 2010*b*). UNEP's *Africa Water Atlas* notes a number of constraints to further hydro development, including the unequal capacity of Africa's subregions. For example, despite its enormous potential for hydroelectricity generation, the Central Africa subregion is the least electrified. The *Africa Water Atlas* also notes that climate change will exacerbate rainfall variability and could hinder hydropower potential in some areas.

Africa has enough hydropower potential to meet the entire continent's electricity needs – and boosting hydropower will stimulate the economy, improve human welfare, help the move away from biomass, produce less greenhouse gas than fossil fuels and provide a reliable base load that could enable other renewable energy resources. Developing this sector in an appropriate manner could prevent the environmental and social impacts historically associated with large dam developments (UNEP 2010*b*).

Financing for infrastructure and maintenance

Although there is a general recognition of the need to boost finance for water infrastructure across Africa, the amounts required can be difficult to determine. One of the most serious recent regional efforts at costing investment for water, sanitation and irrigation infrastructure is the Africa Infrastructure Country Diagnostic (AICD) (Foster and Briceño-Garmendia, 2010). This study is unprecedented in its efforts to analyse both the condition of infrastructure and the way to address the challenges of providing and financing infrastructure services. The study estimates that US$22 billion is needed annually by the water supply and sanitation (WSS) sector to close the infrastructure gap, meet the MDGs and achieve national targets in Africa within ten years (see Box 7.1).

The AICD report also assessed the potential investment needed for irrigation systems in Africa, reported to be approximately US$18 billion for small-scale irrigation systems and US$2.7 billion for large-scale systems over a fifty year investment horizon (Box 7.2).

BOX 7.1

Africa's WSS investment needs

An annual investment of about US$22 billion (roughly 3.3% of Africa's GDP) is the estimated requirement for Africa to meet the water and sanitation MDGs. Projections were built on a base scenario, which assumes the same distribution across modalities as 2006 and applies in both urban and rural areas

Water and sanitation spending needs, 2006–2015, US$ billion per annum

	Total	Investment	Maintenance
Water	17.2	11.5	5.7
Sanitation	5.4	3.9	1.4
Total	22.6	15.4	6.1

Capital investment needs were estimated at US$15 billion a year – around 2.2% of the region's GDP. Capital outlay estimates, which include both new infrastructure and the rehabilitation of existing assets, are based on minimum acceptable asset standards. In addition, it is assumed that access patterns (or relative prevalence of water and sanitation modalities) remain broadly the same between 2006 and 2015 and that services are upgraded for only a minimum number of customers.

Maintenance requirements stand at about US$6 billion per annum (1.1% of GDP). Operation and maintenance of network and non-network services amount to 3% and 1.5% respectively of the replacement value of installed infrastructure. Rehabilitation estimates were based on a model that takes into account the maintenance backlog of network infrastructure in each country.

Source: Foster and Briceño-Garmendia (2010).

Transboundary water management

Africa has about one-third of the world's major international water basins – basins larger than 100,000 km^2. Virtually all sub-Saharan African countries, plus Egypt, share at least one international water basin. Depending on how they are delineated, there are between 63 (UNEP, 2010*b*) and 80 (UNECA, 2000) transboundary river and lake basins on the African continent. Water interdependency is accentuated by the fact that high percentages of total flows in downstream countries originate outside their borders (UNECA, 2001). Often, downstream countries are at a disadvantage in comparison with their upstream neighbours. Examples of this occur in the Niger basin, the Juba–Shabelle basin and the Okavango basin.

Another challenge facing transboundary water management is the lack of complete, reliable and consistent data about transboundary water resources, especially groundwater (Box 7.3). Thus, there is a potential for conflict over these waters. Nevertheless, there are also over 90 international water agreements that were drawn up to help manage shared water basins on the African continent (UNEP, 2010*b*). For example, the 2000 Southern African Development Community (SADC) Protocol on Shared Watercourses (SADC, 2008) promotes the setting up of shared watercourse agreements. It also institutionalizes and enshrines the principles of reasonable use and environmentally sound resource development.

Another African model is the Nile Basin Initiative. Formally launched in February 1999 by the Council of Ministers of Water Affairs of the Nile Basin States, it 'seeks to develop the river in a cooperative manner, share substantial socio-economic benefits, and promote regional peace and security' (UNEP, 2009, p. 50).

Climate change and extreme events

The Intergovernmental Panel on Climate Change (IPCC) states with very high confidence that 'Climate change will aggravate the water stress currently faced by some countries, while some countries that currently do not experience water stress will become at risk of water stress' (Boko et al., 2007, p. 435). A growing body of evidence links unmitigated hydro-climatic variability to poor economic growth in developing countries, especially in Africa. In most poor countries, climate variability is high, infrastructure is poor and GDP is correlated with rainfall.

Drought is the dominant climate risk in sub-Saharan Africa. It destroys economic livelihoods and farmers' food sources and has a significant negative effect on GDP growth in one-third of the countries. For example, in Kenya, the drought associated with La Niña between 1998 and 2000 caused a 6% reduction in GDP. Floods are also highly destructive to infrastructure, transport

BOX 7.2

Africa's irrigation investment needs

Two categories of irrigation development were assessed looking at a fifty year investment horizon:

- Large-scale, dam-based irrigation category was associated with hydropower reservoirs identified by a companion study for hydropower. This irrigation assumed a medium investment cost of US$3,000 per ha for on-farm development; US$0.25 per m^3 for water delivery and conveyance; a proxy for canal operations and maintenance; and US$10 per ha for on-farm operations and maintenance. Dam costs were not included because they are assumed to be fully justified and fully covered by the hydropower schemes associated with the relevant dams.
- Small-scale irrigation was based on small reservoirs, farm ponds, treadle pumps, and water-harvesting structures that collect local runoff. These assumed a five-year investment cycle, a medium investment cost of US$2,000 per ha for on-farm investment, and US$80 per ha for operation and maintenance.

Crop prices, based on commodity-specific world prices for 2004–2006, were adjusted for country differences in price policy and market transaction costs.

The estimates were based on a spatial analysis study that combined hydro-geographic and economic parameters to estimate the potential investments needs for irrigation.

	Large-scale irrigation			Small-scale irrigation		
	Increase in irrigated area (million ha)	Investment cost ($ million)	Average IRR (%)	Increase in irrigated area (million ha)	Investment cost ($ million)	Average IRR (%)
Sudano-Sahelian	0.26	508	14	1.26	4 391	33
Eastern	0.25	482	18	1.08	3 873	28
Gulf of Guinea	0.61	1 188	18	2.61	8 233	22
Central	0.00	4	12	0.30	881	29
Southern	0.23	458	16	0.19	413	13
Indian Ocean Islands	0.00	0.00	–	0.00	0.00	–
Total	**1.35**	**2 640**	**17**	**5.44**	**17 790**	**26**

Note:
Sudano-Sahelian: *Burkina Faso, Cape Verde, Chad, Niger, Senegal, South Sudan and Sudan*
Eastern: *Ethiopia, Kenya, Rwanda, Tanzania and Uganda*
Gulf of Guinea: *Benin, Côte d'Ivoire, Ghana and Nigeria*
Central: *Cameroon and the Democratic Republic of Congo*
Southern: *Lesotho, Malawi, Mozambique, Namibia, South Africa and Zambia*
Indian Ocean Islands: *Madagascar*
Source: Foster and Briceño-Garmendia (2010, table 15.2, p. 291); You (2008).

and goods and service flows, and they can contaminate water supplies and cause epidemics of water-borne diseases such as cholera.

In the Mozambique floods of 2000, over 2 million people were affected, and damages were estimated at 20% of GDP (Brown and Hansen, 2008). Throughout sub-Saharan Africa, the effect of these hydrological extremes can be devastating, especially where there is high dependence on agriculture and where infrastructure is deficient. In the coming decades, when the impact of climate change is likely to worsen, droughts and floods associated with climate variability will continue to ravage vulnerable communities in African countries.

Although African farmers have already developed techniques to adapt to inherent weather variations, these may not be sufficient to adapt to the combined impacts of the interaction of multiple stresses at various levels caused by climate change and climate variability (Boko et al., 2007).

Data challenges

Insufficient, inconsistent and unreliable data about water, water needs (from socio-economic indices) and weather-related extreme events are among the key challenges facing Africa as the continent tries to manage its water resources (Young et al., 2009). For example, economic planners factor assumptions about demographic changes such as population growth and urbanization, into national plans despite high levels of uncertainty. This is especially evident in instances where there are disputes over the results of population censuses that arise out of ethnic, religious or political considerations. The *Africa Water Atlas* notes that, 'Building on a foundation of detailed, consistent, accurate and available data is one of the central challenges for Africa's water future' (UNEP, 2010b, p. 38). In the case of scientific information, for example, the sustainable use of the groundwater resources that underlie the Lake Chad basin is hampered by a lack of hydro-geological datasets (Box 7.3).

7.1.3 Response measures

Institutional, legal and planning responses

African Union initiatives – such as the African Ministers' Council on Water (AMCOW), the African Water Facility, the increasingly important African Development Bank (AfDB) and the Rural Water and Sanitation Initiative – all vividly testify to ongoing commitment to

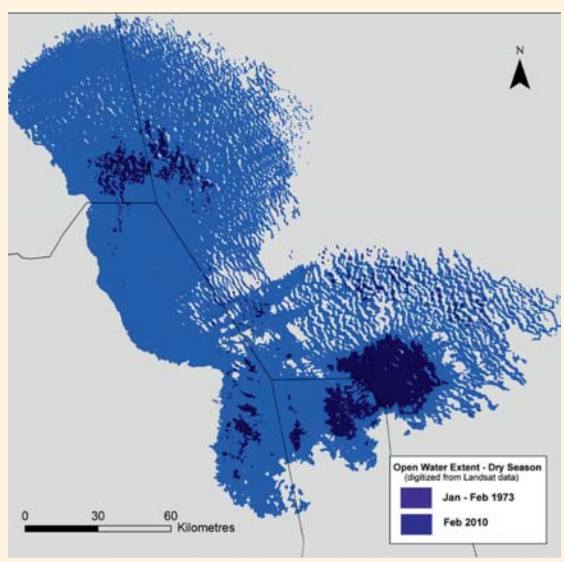
BOX 7.3

Groundwater resources in the Lake Chad basin

Lake Chad is one of the Sahel's largest freshwater reservoirs, and a focal point for more than 3 million people – most of whom farm, herd animals and fish for a living, and who live within a 200-km radius of the lake. Seasonal, yearly and decadal rainfall is extremely variable across this region. The basin is fed by the Chari, Logone and Komadougou Yobé rivers, but since the mid-1960s, droughts, water diversions and irrigation have led to a 75% drop in water flows (see the figure). Ecosystems have been unable to adapt fast enough, fishing communities have had to move away and the quality and coverage of dry-season grazing has declined.

Some 35 million people in the larger Lake Chad basin have been affected to some degree. Water shortages have caused the increased use of groundwater, although some studies suggest that declining precipitation has also affected water levels in the Quaternary aquifer that underlies the Lake Chad basin. There is not enough information about the groundwater reserves, however, and there is an urgent need to improve the availability and completeness of hydro-geological datasets so policy-makers can respond appropriately to the Lake Chad basin's diminishing water resources (UNEP, 2010b).

Approximate extent of open water in Lake Chad digitized from Landsat images, 1973–2010



Source: UNEP (2010b, p. 49)

water-related development. One of the most important events was the Second Extraordinary Session of Heads of State and Governments of the African Union, which was held in Sirte, Libya, in February 2004 and dedicated to agriculture and water. Another important event was the African Union Summit of Heads of State on Water and Sanitation in Sharm el-Sheikh, Egypt in July 2007. The Africa Water Week, under the auspices of AMCOW, has added another impetus to information sharing and awareness of water resources development and management. However, there is an urgent need for wider international cooperation to augment regional and continent-wide efforts in line with the ongoing collaboration with the European Union (EU). Though in many instances, transboundary agreements have been successful in addressing potential conflicts over shared waters (Box 7.4).

African nations have also begun to seek ways to address transboundary water issues related to hydropower development, especially by fostering regional integration through power pools such as the South African Power Pool (SAPP) and the West African Power Pool (WAPP). Using such pools, countries can reduce their costs while maintaining their own power supply, rely on mutual help when power systems break down, enjoy social and environmental benefits, and strengthen cross-border relationships (UNEP, 2010*b*).

BOX 7.4

Joint management of the Senegal River

Potential conflict was averted in the Senegal River basin when a constructive compromise was reached on joint management. This was made possible through the establishment of the Organization for the Development of the Senegal River (OMVS) in 1972; through the adoption of the Senegal River Charter in 2002; and by using a financing mechanism to ensure the generation of revenues and benefits for the four basin countries.

Agreements in the Lake Chad basin have not been as inclusive because some riparians are not party to the 2008 legal agreement and strategic action programme for Lake Chad. Within the transboundary agreements that are in operation, it is still necessary to improve understanding and clarify regional perspectives on international water law principles.

Africa-wide efforts are being taken to address the uncertainty of climate change. African climate institutions – such as the African Centre of Meteorological Applications for Development; the Inter-Governmental Authority on Development's (IGAD's), Climate Prediction and Applications Centre (ICPAC); and the Southern African Development Community (SADC) Drought Monitoring Centre – have worked on the climate risk management approach in collaboration with the International Research Institute for Climate and Society. They are building capacities for its smooth integration into sectoral decision-making processes such as agricultural production, food security, water resources management, health protection and disaster risk management. These climate institutions also help to synchronize regional legal frameworks that protect and sustain shared water resources through a benefit-sharing paradigm. And they can arrange inter-basin water transfer schemes to save dying water ecosystems like Lake Chad (see the figure in Box 7.3) or transfer water from water-rich basins to drier zones.

Concerted efforts at the regional, continental and international levels can help African countries to face the challenging task of harnessing water resources for sustainable development in the face of climate variability and change. It is therefore important to pool all human and institutional resources in order to tackle common challenges by improving the understanding of and quantitative knowledge about the various sources of uncertainty. It is also important to improve the way this knowledge is communicated to water resources managers and other stakeholders, and the way uncertainty is incorporated into water resources management decision-making (Hughes, 2008).

The challenges are not all infrastructural. They also include early-warning systems to help predict the onset of and duration of rainfall seasons, intra-seasonal dry spells, rainfall anomalies based on inter-hemispherical teleconnections, and lead times on the impacts of El Niño and La Niña.

7.2 Europe and North America

The United Nations Economic Commission for Europe (UNECE) region comprises the 56 countries of the European Union; Western, Central and Eastern Europe; the Caucasus; Central Asia; and North America, which comprises the United States of America (USA) and Canada (see Map 7.2).

Dams and diversions that were built to provide hydropower and irrigation and to manage floods have significantly altered the region's watersheds. While dams, weirs and diversions provide water management services, they have also changed hydrological regimes, interrupted river and habitat continuity, disconnected rivers from adjacent wetlands and floodplains, and changed erosion processes and sediment transport. Most point-source pollution from industrial and municipal effluent has been addressed in the most developed countries, but discharges of untreated or insufficiently treated wastewaters continue to exert pressures, especially in Eastern Europe, South-Eastern Europe (SEE), the Caucasus and Central Asia.

Nutrients from agricultural runoff, however, are of growing concern throughout the UNECE region. Moreover, pressures from irrigated agriculture to extract water are rising, especially in more water scarce parts of the region, as are demands to satisfy growing urban needs. Meanwhile climate change is threatening available water resources and leading to increased competition among users. Some parts of the region are subject to floods and droughts, and climate change is exacerbating these threats.

All the region's nations except three island states share water resources with at least one other country, and transboundary watersheds cover more than 40% of the European and Asian parts of the UNECE region (UNECE, 2007*a*). There are more than 100 transboundary rivers, with a basin area over 1,000 km^2 each, and over 100 transboundary groundwater aquifers (UNECE, 2011*a*). This has led to strengthened bilateral and multilateral cooperation and agreement on these shared waters.

There is a marked difference in the state of water quality and management between the countries of the EU and North America, and those in Eastern Europe and Central Asia. There is a long history of environmental legislation, including water management, in the EU and North America, through Conventions and Protocols, supplemented by regulations, recommendations and guidelines for action. Eastern Europe, the Caucasus and Central Asia, as well as a number of new EU countries, are still struggling to adequately manage water provision and pollution.

7.2.1 The driving forces and pressures on water resources

Population, affluence and poverty

More than 1.2 billion people live in Europe and North America, with the latter representing just over one-third of the total. Between 1960 and 2000, Central Asia (more than 120% population increase) and the Caucasus (60% increase) have experienced considerably higher growth rates than other countries. For most countries in Western and Central Europe, populations are stable or declining (PRB, 2008). People are permanently or seasonally migrating from many Eastern European countries to western cities where economic prospects are better.

In North America, the population of the USA grew by 9.7% between 2000 and 2010, and it is expected to increase by more than 50% in the 60-year period from 1990 to 2050 (US Census Bureau, n.d.). Total water withdrawals in the USA grew between 1970 and 1980, declined by more than 9% between 1980 and 1985, and have been relatively constant since then despite continued population growth (National Atlas of the United States, 2011). In Canada, total water withdrawals have been rising steadily (CEC, 2008). In 24 European countries, total water abstraction decreased about 12% over the past 10–17 years, but one-fifth of Europe's population (approximately 113 million inhabitants) still lives in water-stressed countries (EEA, 2010).

European and North American populations also consume a considerable amount of virtual water embedded in imported food and products. According to one calculation, each person in North America and Europe (excluding former Soviet Union countries) consumes at least 3 m^3 per day of virtual water in imported food, compared to 1.4 m^3 per day in Asia and 1.1 m^3 per day in Africa (Zimmer and Renault, n.d.).

The per capita water used for food production in Western Europe and North America has decreased substantially in past decades (Renault, 2002).

Reductions in total water consumption are due to increased efficiency, economic factors, regulations and increased awareness of the need to conserve water. The economies of countries in transition in Europe are still catching up, but with increasingly high living standards, consumption is projected to rise.

The contribution made by primary production and heavy industry to the economies of Western and Central Europe and North America has fallen, while that of service industries and knowledge-based industries has risen. With this has come a decline in point-source water pollution (UNEP, 2006*b*). Despite the marked transition to a post-industrial economy, demand for water is likely to remain high in Eastern Europe, Central Asia and the Caucasus because of the dependence on agriculture, mining and other export commodities. The poor in lower-income countries such as Armenia, Georgia, Uzbekistan, the Republic of Moldova, Kyrgyzstan and Tajikistan are often unable to afford basic domestic water services.

MAP 7.2

UNECE Member States

Source: Economic Commission for Europe, Map No. 3976 Rev. 11, November 2011. Department of Field Support, Cartographic Section, United Nations.
Note: North America members are listed but not shown on the map.
For the purposes of this chapter, the UNECE Member States are divided into the following groupings:
***EU countries:** Austria, Belgium, Bulgaria, Cyprus, Czech Republic, Denmark, Estonia, Finland, France, Germany, Greece, Hungary, Ireland, Italy, Latvia, Lithuania, Luxembourg, Malta, Netherlands, Poland, Portugal, Romania, Slovakia, Slovenia, Spain, Sweden, United Kingdom.*
***Western Europe:** Andorra, Austria, Belgium, Denmark, Finland, France, Germany, Greece, Iceland, Ireland, Italy, Liechtenstein, Luxembourg, Monaco, Netherlands, Norway, Portugal, San Marino, Spain, Sweden, Switzerland, United Kingdom.*
***Western Europe EU-15 countries:** Austria, Belgium, Denmark, Finland, France, Germany, Greece, Ireland, Italy, Luxembourg, Netherlands, Portugal, Spain, Sweden, United Kingdom.*
***Central and Eastern Europe:** Albania, Bosnia and Herzegovina, Bulgaria, Czech Republic, Croatia, Cyprus, Estonia, Hungary, Latvia, Lithuania, Malta, Montenegro, Poland, Romania, Serbia, Slovakia, Slovenia, the former Yugoslav Republic of Macedonia, Turkey.*
***Central and Eastern Europe countries that became EU Member States in the course of the EU enlargement process:** Bulgaria, Cyprus, Czech Republic, Estonia, Hungary, Latvia, Lithuania, Malta, Poland, Romania, Slovakia, Slovenia.*
***Balkan countries (as a subgroup of Central and Eastern Europe):** Albania, Bosnia and Herzegovina, Croatia, Republic of Macedonia, Montenegro, Serbia.*
***Mediterranean:** Albania, Bosnia and Herzegovina, Croatia, Cyprus, France, Greece, Israel, Italy, Malta, Monaco, Montenegro, Portugal, Serbia, Slovenia, Spain, Turkey.*
***Eastern Europe, the Caucasus and Central Asia:** Armenia, Azerbaijan, Belarus, Georgia, Kazakhstan, Kyrgyzstan, Republic of Moldova, Russian Federation, Tajikistan, Turkmenistan, Ukraine, Uzbekistan.*
***The Caucasus:** Armenia, Azerbaijan, Georgia.*
***Central Asia:** Kazakhstan, Kyrgyzstan, Tajikistan, Turkmenistan, Uzbekistan.*
***North America:** Canada, United States of America.*

Climate change

Europe and North America make a disproportionately high contribution to climate change. The Intergovernmental Panel on Climate Change (IPCC) states that 'freshwater resources are vulnerable and have the potential to be strongly impacted by climate change' (Bates et al., 2008, p. 135). High northern latitudes are expected to experience the most extreme warming, increasing the risk for indigenous peoples in the Arctic as snow and ice conditions change dramatically. The poorest and most vulnerable are likely to suffer the most, since they have fewer resources with which to cope.

Projections vary considerably across the UNECE region, but climate change is expected to bring higher temperatures, drought, reduced water availability and lower crop yields to Southern Europe, the Caucasus and Central Asia. Hydropower potential and summer tourism are also likely to be affected. In Central and Eastern Europe, summer precipitation is projected to decrease, causing higher water stress. While climate change is likely to have positive effects in the short term in Northern Europe, these are expected to be outweighed by negative effects as climate change progresses (UNECE, 2009*a*).

North America is expected to experience warmer temperatures, increased rainfall, summertime droughts and more intense and frequent extreme weather events such as tornadoes and hurricanes. The risks and uncertainties associated with climate change impacts are discussed later.

Water and agriculture

Agricultural practice in the region has changed considerably over the past decades: mechanization, increased use of fertilizers and pesticides, farm specialization, growth of farm size, land drainage and developments in animal husbandry have led to adverse impacts on the aquatic environment with some specific subregional differentiation of water use and water pollution. Water use for crop and animal production, for example, in Central Asia, Greece, Italy, Portugal and Spain, accounts for 50–60% of the total use. In other countries, agriculture accounts for only around 20%, while the bulk is used by manufacturing industries and for cooling purposes.

Agrochemicals have had a detrimental effect on water resources throughout the region as nitrogen, phosphorus and pesticides run into water courses. In Eastern Europe, the Caucasus and Central Asia, these diffuse pressures are 'widespread but moderate' (UNECE, 2007*a*, 2011*a*). As the economy revives, however, they will increase, threatening domestic and transboundary waters as well as human health. In some basins, particularly in Central Asia, irrigation has led to soil salinization and high levels of mineral salt in water bodies (Box 7.5).

> "European and North American populations also consume a considerable amount of virtual water embedded in imported food and products."

Since the 1960s, land under irrigation has doubled in Canada, and has increased by more than 50% in the USA, with much of the growth in arid or semi-arid regions. In many parts, groundwater levels are declining as withdrawals outweigh recharge (CEC, 2008). Since the 1950s, nitrate loads from agricultural runoff have increased enormously in the Mississippi River, which drains more than 40% of the land mass of the USA's 48 contiguous states (EPA, 2008).

The legal frameworks and best management practices to reduce pollution from agriculture were established some time ago in the EU and in North America. In EU countries in the drainage basins of the Mediterranean Sea, the eastern Atlantic Ocean, and the Black Sea, implementation of these frameworks and practices is lagging, and water quality is still suffering. High applications of both mineral and organic fertilizer are used in the farming areas of Western Europe. Source apportionment studies indicate that agriculture generally provides 50–80% of the total nitrogen load, with wastewater providing most of the remainder (EEA, 2005). Nitrogen application rates had increased dramatically over past decades, but are now widely declining. However, it takes a long time for this to translate into reduction in the concentration of nitrogen compounds in water bodies (UNECE, 2011*a*).

Water in the industrial and municipal sectors

Modern pollution abatement technologies have stemmed the most egregious pollution from large industrial processes in Western Europe and North America. Recent concerns relate to modern chemicals, including new pharmaceuticals and hormones. Pollution from the great number of small and medium-sized industries and small municipal wastewater treatment plants in Eastern Europe, the Caucasus, Central Asia and several of the new EU countries, which do not operate according to standards, are still important sources of water pollution (Box 7.6). Despite assistance from Western Europe, the impact of economic decline in the 1990s remains visible as wastewater treatment is still inadequate and waters continue to be polluted with heavy metals, phosphorus, nitrogen and oil products (EEA, 2010). Mining has an impact more locally in SEE, in the Caucasus and some areas in Northern Europe.

BOX 7.5

Agriculture and water use in Central Asia

In Central Asia, the agricultural sector accounts for more than 90% of surface water extracted and 43% of groundwater extracted, but it supports half the regional population. Irrigated agriculture and the entire water-based sector contribute about 40% to 45% of regional GDP (Stulina, 2009). Central Asia represents 50% of the total irrigated area of the regions of the former Soviet Union, (FAO, 2011).

Agricultural water pollution, sedimentation and algae blooms have had some serious and well-documented impacts. These have included the loss of biodiversity, the extinction of whole ecosystems, a deterioration in drinking water quality, human health problems, declining crop yields, poverty, unemployment, migration and the risk of conflict (Yessekin, et al. 2006). Although many measures have been taken to address the situation, scarce financial resources have led to delays in implementing them. The importance of stakeholder involvement in negotiating water allocation, especially in transboundary situations, has only recently been recognized. The International Fund for Saving the Aral Sea is steering a process to improve conditions.

Infrastructural changes to water courses

Throughout the region, structural modifications to watersheds have altered natural flows, disrupted or destroyed wildlife habitats and ecosystem services, and disconnected rivers from their floodplains – and so increasing the risk of floods in many places. Some countries have plans to re-naturalize water courses. In Western and Central Europe, partly because there the degree to which water bodies have been modified has been assessed, there is a higher awareness about the issue and response measures have started to be taken to address it. Considerable time and financial resources are needed to restore, for example, rivers in the Danube basin (see Box 30.5, 'Hydromorphological alterations in the Danube Basin', in Chapter 30). Current economic conditions and prospects are delaying the process.

The US Environmental Protection Agency is providing grants to some states to restore rivers and streams, while there is a growing movement to remove dams where the environmental and other costs outweigh the benefits (American Rivers, n.d.).

The Danube, in the basin of which courses of rivers have been changed for hydropower generation, flood defence and navigation since the sixteenth

BOX 7.6

Wastewater treatment infrastructure in the Republic of Moldova

The 1990s economic downturn resulted in a huge decline in the operational capacity of Moldova's municipal wastewater treatment plants. By 2010, only 24% were still operating and only 4% of these were adhering to legal requirements for the disposal of wastewater. In rural areas, 70% of homes were not connected to the sewerage system. As a result, an increasing amount of untreated wastewater was discharged into rivers. EU and other funds began supporting an enormous assistance programme to rehabilitate municipal infrastructure and improve rural sanitation. New wastewater treatment legislation, modelled on EU laws and drawn up under the National Policy Dialogue process came into force in October 2008, replacing outdated Soviet-style law. Existing plants can now be rehabilitated and new ones constructed according to state-of-the-art treatment technology (UNECE, 2011*b*).

century, has hydropower impoundments along 30% of its length. It is now subject to plans to improve ecosystem quality in accordance with the Danube River Protection Convention, which came into force in 1998 and addresses hydropower as well as polluted discharges from agriculture, municipalities and so forth (ICPDR, 2007). In Western Europe, the Water Framework Directive has led to programmes to enhance and protect aquatic ecosystem services, and the innovative Payment for Ecosystem Services approach is being explored in the UNECE region (Wunder, 2005; UNECE, 2005).

Table 7.2 summarizes the relative importance of these various pressures on water resources over subregions (UNECE, 2007*a*). As economies grow or revive, however, shifts in the relative importance of some of these pressures will occur, especially in Eastern Europe, the Caucasus and Central Asia.

7.2.2 Challenges, risks and uncertainties

The situations and places in which uncertainty and risk are most evident in Europe and North America include highly populated areas that are prone to flooding and drought. The projected impacts of climate change also include increased risks of extreme hydrological events. Uncertainty and risk can lead to conflict in conditions where limited amounts of declining or increasingly polluted water resources are shared between sectors or among different populations in situations that are also changing, such as in burgeoning urban areas. A particular challenge for countries in Eastern Europe and Central Asia is water use efficiency in irrigated agriculture. Finally, human health is at risk where water and sanitation provision is inadequate.

Floods and drought

Overabstraction, water scarcity and drought have a direct impact on citizens and economic sectors, and large areas of Europe and North America are already affected (Boxes 7.7 and 7.8). Climate change will bring higher temperatures to the region, exacerbating drought events.

Between 1976 and 2006 in the EU, both the area affected by drought and the number of people whose lives were influenced doubled (Figure 7.2). These impacts can include declines in cereal and hydropower production (as exemplified by the situation in Russia in 2010), and economic repercussions. Many Western European countries have drawn up or are preparing drought management plans (EC, 2009). To address the impact of drought and water scarcity on human health, UNECE and WHO/Europe have developed specific guidance and recommendations, which include adaptation measures for drainage, sewerage and wastewater treatment (UNECE, 2009*a*).

TABLE 7.2

Main pressures on water resources in order of priority (from high to low)

Countries in Eastern Europe, the Caucasus and Central Asia	EU-15 countries and North America
Pressures on water quality: Municipal sewage treatment, non-sewer population, old industrial installations, illegal wastewater discharges, illegal disposal of household and industrial wastes in river basins, tailing dams and dangerous landfills	Pressures on water quality: Agricultural (especially nitrogen) and urban sources of pollution
Abstraction pressures: Agricultural water use	Abstraction pressures: Agricultural water use (particularly in Southern Europe and the south-western USA), major urban centres
Hydromorphological alterations: Hydropower dams, irrigation channels, river alterations	Hydromorphological alterations: Hydropower dams, river alterations
Other pressures: Agro-chemical pollution (becoming more severe), mining and quarrying	Other pressures: Selected industries discharging hazardous substances, mining and quarrying

Source: Chapter 30.

Floods have affected more than 3 million people in the UNECE region since the beginning of the century, and the associated costs have increased rapidly. They have exposed people to various health hazards and caused deaths, displacement, and economic losses. Contributing factors include population growth in flood-prone areas, deforestation and wetland loss. Recognizing the benefits of natural flooding to ecosystems and the role of wetlands in flood protection has led to a shift towards an integrated approach to flood management in many European countries and in North America. A number of transboundary watersheds have initiated integrated water management plans (Roy et al., 2010; UNECE, 2009*b*).

Climate change and uncertainty and risk

The IPCC predicts with high confidence that water stress will increase in Central and Southern Europe, and that by the 2070s, the number of people affected will rise from 28 million to 44 million. Summer flows are likely to drop by up to 80% in Southern Europe and some parts of Central and Eastern Europe. Europe's hydropower potential is expected to drop by an average of 6%, but rise by between 20% and 50% around the Mediterranean by 2070 (Alcamo, et al. 2007). In North America, the IPCC reports with high confidence that the impact will include increased competition among users for over-allocated water resources. Climate change will also stress the bi-national relationship over the shared Great Lakes[2], where water levels are likely to decline and population growth will fuel demand (Field et al., 2007). Much uncertainty exists about how national water management bodies in the region can adapt to these changes, especially where financial and human capacities are constrained by widespread poverty, as in Eastern Europe, the Caucasus and Central Asia. In addition, climate mitigation measures may produce adverse side effects for water management, heightening uncertainty and risk (UNECE, 2009*a*). One example is the debate over water for food production versus water for bio-energy crops.

Water and human health

Some 120 million people in the European region do not have access to safe drinking water. Even more lack access to sanitation, resulting in the spread of water-related diseases. In North America, native peoples are often ill-served by piped water and sanitation facilities. For example, over 10,000 homes on reserves in Canada have no indoor plumbing, and the water or sewer systems in one reserve in four are substandard (UNDESA, 2009).

Concerted international efforts to address water-related health matters in the region only began at the end of the 1990s, culminating in the Protocol

BOX 7.7

Uncertainty and risk on the North American prairies

In the prairies of Canada and parts of the United States of America, water flows are highly variable, which is reflected in the occurrence of severe floods and drought. The lack of predictability, exacerbated by melting glaciers and snowpacks (as a result of climate change), affects the economy and has led to competition for water between agriculture, the oil and gas industries and growing municipalities. Watershed planning and management strategies have been instituted to attempt to address the risks associated with the changing conditions, which include a decline in water yield of 20 km^3 between 1971 and 2004 in the Canadian Prairies (UNEP, 2007; Statistics Canada, 2010).

BOX 7.8

Satisfying municipal water needs in drought-prone regions

In dry years, there have been problems supplying sufficient water to the 12 million people living in Istanbul and the 4 million inhabitants of Ankara. As a result, water has been rationed. In response to the IPCC's projection that demand in Istanbul will rise while supply falls, a number of remedial actions are being taken, from water saving campaigns to water transfers from as much as 150 km away (Waterwiki.net, n.d.).

During the 2008 drought, Barcelona turned off civic fountains and beachside showers and banned hosepipes and filling swimming pools. In the same year, Cyprus applied emergency measures that included cutting the water supply by 30% (EEA, 2007, 2010). In a growing number of cities, such severe emergency restrictions became part of a consultative process with stakeholders, a change that was also influenced by the requirements of the Aarhus Convention (UNECE, 1998).

on Water and Health under the UNECE Water Convention. This is dedicated to ensuring that everyone has adequate drinking water and sanitation. It has resulted in increased efforts to attain, and move beyond, the water-related MDGs (UNECE, 2010). Basin organizations, such as those for the Rhine, Meuse, Scheldt and Danube, also challenge the basin countries to develop a more coordinated approach and address the effects that pose the highest risk and uncertainties to human health and water management, and to develop appropriate adaptation measures to new risks as they become better understood (UNECE, 2011*a*).

7.2.3 Response measures

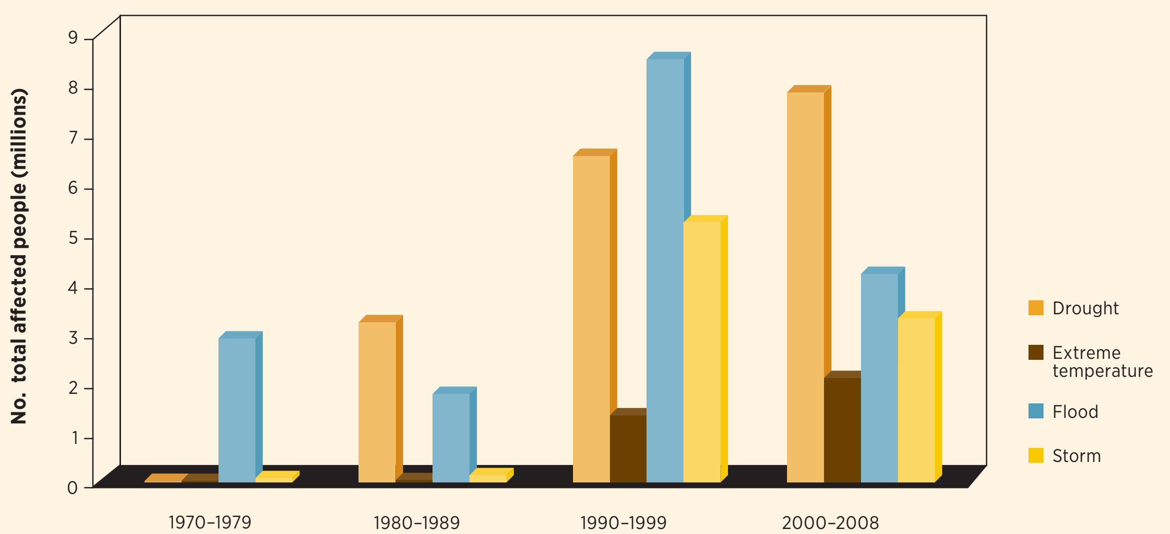
Institutional, legal and planning responses

Institutional and strategic responses to manage water issues have a relatively long history in the region. In North America, water governance was strengthened in the 1970s with the passing of regulations such as the Clean Water Act and the Safe Drinking Water Act in the USA, and parallel legislation in Canada, including the Canada Water Act. In Canada, however, water governance is generally more decentralized and fragmented as a result of the constitutional division of powers between provincial and federal governments. There were recent demands for a federal water policy – a four-year project running from 2008 to 2012 to create a Water Security Framework (Norman et al., 2010). There has been a recent devolution of water governance from federal to state levels in the USA, which has led to an increase in local participation in water management (Norman and Bakker, 2005).

Water-related institutions in countries in transition are still generally weak, with water competences spread among institutions with weak enforcement capacities. Supported by the EU on many fronts, new EU Member States have made better progress in building new institutional structures in comparison with other Eastern European countries, the Caucasus and Central Asia (UNECE, 2010). The Water Framework Directive (WFD), which was concluded in 2000 apart from some more recent directives on standards and groundwater, is the most important piece of EU water legislation (EC, 2000). Other directives with direct relevance to water quality and its protection are the ones related to urban wastewater treatment (1991), to control and limit nitrate pollution from agriculture (1991), to regulate the quality of drinking water (1998), and to other

FIGURE 7.2

Number of people affected by selected extreme weather events in the UNECE region, 1970–2008



Note: At least one of the following criteria must be fulfilled: 10 or more people reported killed; 100 people reported affected; declaration of a state of emergency; or call for international assistance.
Source: Produced in 2009 by the Italian National Institute for Environmental Protection and Research (ISPRA) based on data from the EM-DAT database by the Centre for Research on the Epidemiology of Disasters (CRED) at the Catholic University of Louvain.

areas related to water and health issues. The WFD expands the scope of water protection to all waters, and requires the achievement of a 'good status' for all waters in EU countries by 2015. Apart from its effect to improve water management in EU countries, the application of principles of the WFD is of immense importance to improving water management and cutting down pollution in countries at the Eastern border of the EU (Belarus, the Republic of Moldova, Ukraine, Armenia, Azerbaijan and Georgia).

The use of transboundary waters, and their protection, is governed by the 1992 UNECE Water Convention. This requires parties to enter into specific bilateral or multilateral agreements and to create joint institutions. The EU Water Framework Directive (WFD) has accelerated and deepened a historical process of transboundary water management across the EU's 40 international river basins, exemplified in the Danube and Rhine basins (EC, 2008).

Canada and the USA have been leaders in the bilateral management of shared waters, through the International Joint Commission in particular. As a result, the status of many watercourses in the regions has been considerably improved, and there are far fewer disputes over shared waters (UNECE, 2009*c*). Addressing transboundary groundwater issues remains an exception, as the work of many joint bodies in the area of transboundary groundwaters is still insufficient, except perhaps in some parts of Western Europe.

7.3 Asia-Pacific

For the purposes of this chapter, the Asia-Pacific region[3] comprises the 55 member states of ESCAP in five subregions: Central Asia, North-East Asia, Oceania and the Pacific, South Asia, and South-East Asia (see Map 7.3 for the ESCAP Member Countries). The region is extremely diverse, with seven of the world's most populous countries and many of its smallest nations, several of which are located in the Pacific (ESCAP, 2011).

The Asia-Pacific is home to 60% of the world's population but it has only 36% of its water resources (APWF, 2009). Nevertheless, this represents the world's largest share of renewable freshwater resources, with an annual average of 21,135 billion m^3. Given its large population and economic growth, its water withdrawal rate is also high, averaging about 11% of its total renewable water resources, which is on par with European rates, and ranks it second in the world after the water-scarce Middle East (ESCAP, 2010*a*). Per capita availability here is the lowest in the world (ESCAP, ADB and UNDP, 2010).

The region includes the Russian Federation, India and China, three of the five BRICS countries, with their increasing water demands to support their burgeoning economic development. Growing populations, rapid urbanization, industrialization, economic development and climate change continue to put pressure on the region's freshwater resources, exacerbating already difficult conditions. The Asia-Pacific's socio-economic development pattern previously relied primarily on cheap natural and human resources. The consequences have been two parallel economies: rapid advances in economic performance alongside persisting poverty and environmental degradation.

Between 1990 and 2008, significant achievements were made in meeting the MDG on access to safe drinking water. But progress has generally been slower in providing improved sanitation, except in North-East and South-East Asia. About 480 million people still lacked access to improved water resources in 2008, while 1.9 billion still lacked access to improved sanitation.[4] Even when access is established, natural disasters and functionality levels can significantly influence whether or not drinking water and sanitation systems can continue to respond to the region's needs. The Asia-Pacific is highly vulnerable to extreme events and climate change is expected to increase climate variability and the magnitude and frequency of floods and droughts.

Water availability, allocation and quality remain major issues. Irrigated agriculture is the biggest water user. Some countries, such as Cambodia and Lao People's Democratic Republic, use less than 1% of their total available water resources, while others have withdrawn significant quantities of their total combined surface water and groundwater – in one case leading to the disaster at the Aral Sea. Population growth, growing water consumption rates, environmental degradation, damaging agricultural activities, poor catchment area management, industrialization, and groundwater overuse are causing a deterioration in water quality.

7.3.1 The driving forces and pressures on water resources

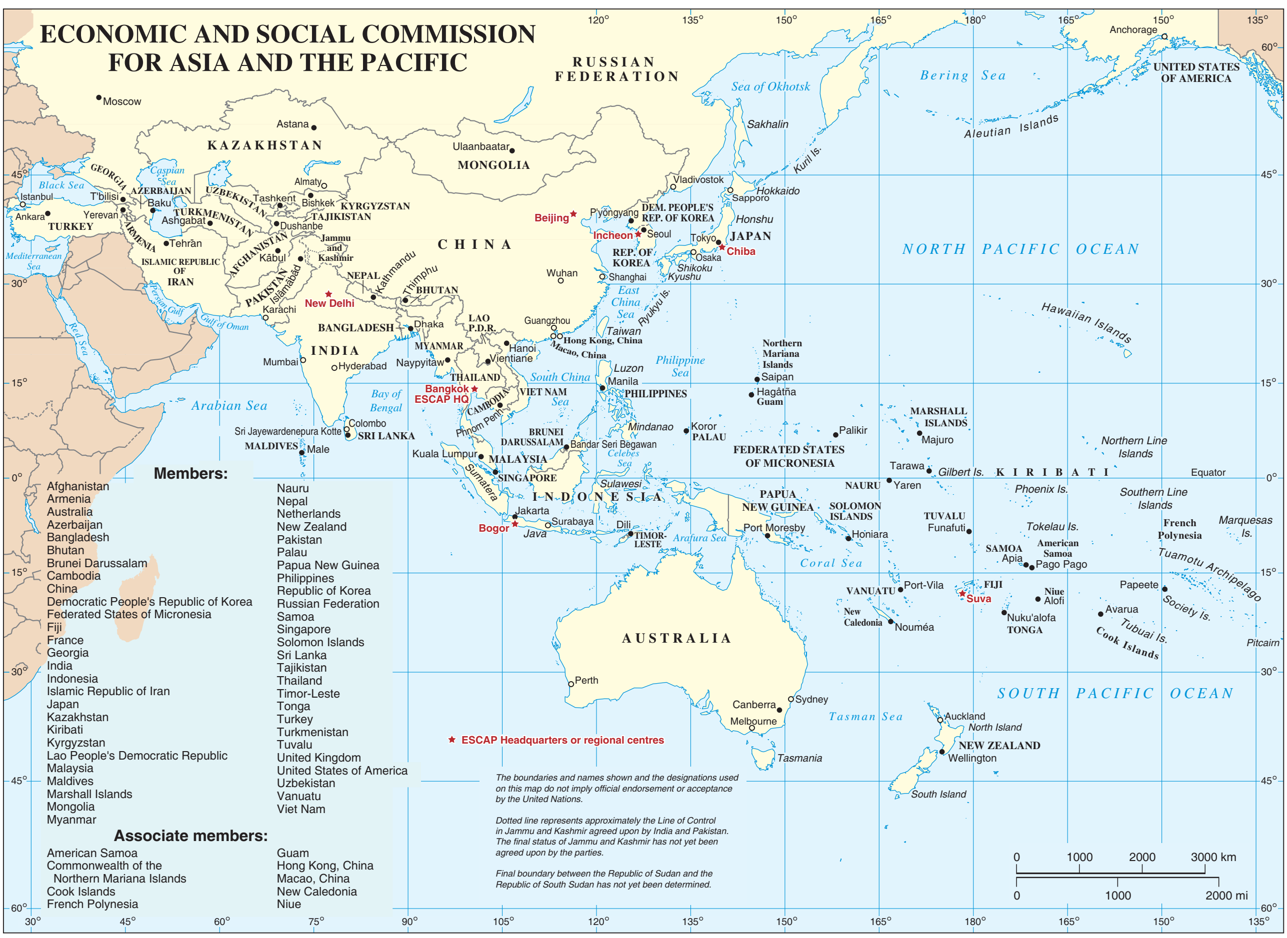
The Asia-Pacific region is extremely dynamic, undergoing rapid urbanization, economic growth, industrialization, and extensive agricultural development. Although these are desirable trends in many ways, they also represent drivers that are affecting the region's capacity to meet its socio-economic water development needs.

Demographics

Between 1987 and 2007, the region's population grew from just under 3 billion to about 4 billion people (UNEP, 2007). Average population density, at 111 people per km^2, is the highest in the world (UNEP, 2011). The demographic transition is taking place in all countries, but at different times and at a different pace. Although fertility rates have declined steadily, population growth rates remain high in some areas. Food security is an important issue since about two-thirds of the world's hungry people live in Asia (APWF, 2009). Internal migration and urbanization are driving the rise in the number of megacities (ESCAP, 2011). The region has some of the world's fastest-growing cities and between 2010 and 2025 a predicted 700 million people were added to the growing numbers requiring municipal water services (ESCAP, 2010*a*).

MAP 7.3

UNESCAP Member States



Source: Economic and Social Commission for Asia and the Pacific, Map No. 3974 Rev. 17, November 2011. Department of Field Support, Cartographic Section, United Nations.
Note: The ESCAP Members States in the Asia-Pacific subregions are as follows.
***North-East Asia:** China, Democratic People's Republic of Korea, Japan, Mongolia, Republic of Korea, Russian Federation.*
***Central Asia and the Caucasus:** Armenia, Azerbaijan, Georgia, Kazakhstan, Kyrgyzstan, Tajikistan, Turkmenistan, Uzbekistan.*
***South-East Asia:** Brunei Darussalam, Cambodia, Indonesia, Lao People's Democratic Republic, Malaysia, Myanmar, Philippines, Singapore, Thailand, Timor-Leste, Viet Nam.*
***South and South-West Asia:** Afghanistan, Bangladesh, Bhutan, India, Islamic Republic of Iran, Maldives, Nepal, Pakistan, Sri Lanka, Turkey.*
***The Pacific:** American Samoa, Australia, Cook Islands, Fiji, French Polynesia, Guam, Kiribati, Marshall Islands, Federated States of Micronesia, Nauru, New Caledonia, New Zealand, Niue, Northern Mariana Islands, Palau, Papua New Guinea, Samoa, Solomon Islands, Tonga, Tuvalu, Vanuatu.*

> "Food security is an important issue since about two-thirds of the world's hungry people live in Asia."

Economic development

Since 2000, the Asia-Pacific's GDP growth rate has surpassed 5% (UNEP, 2007). Industrial activity, often shifting from other regions, continues to grow. It is accompanied by the intensive use of resources that exert considerable pressure on aquatic ecosystems, which continue to deteriorate. In late 2008, the global food, fuel and financial crisis pushed millions of people below the poverty line in the recession that followed, but by 2010, rapid growth resumed in China and India and in some other countries. In 2010, ESCAP noted that 'enhanced incomes facilitate investments in much-needed technological change, infrastructure and job creation; however, current economic growth patterns increase the stress on limited resources and competition for access to them' (ESCAP, 2010a, p. 3).

Agriculture consumes an average of about 80% of the region's renewable water resources, but it is faced with the challenge of increasing food production in degraded ecosystems (APWF, 2009). In addition, the irrigation sector is generally inefficient, and demand-management mechanisms are ineffective where they exist. Water quality also suffers from the impacts of industrial development, urbanization and agricultural intensification (APWF, 2007).

Water conflicts

Water competition has led to increased water conflicts in the region, particularly over the past two decades. Conflicts within countries have dominated since 1990, with more than 120,000 water-related disputes in China alone during this period.[5] Water management efforts and resources in India often focus on 'conflict management' between different states. Direct conflict most commonly arises at the local level, and is often based on the construction of an 'ill-thought-out' dam, ambiguous water withdrawal rights or deteriorating water quality.

The allocation of increasingly scarce water resources, however, is the principal cause of water conflicts, with the most important challenge in the region's socio-economic development being to balance different water uses and to manage their economic, social and environmental impacts. In water-stressed countries, there are competing demands for water for urban, industrial, agriculture and ecosystems upon which livelihoods depend. In addition, water disputes arise over inter-basin water transfers, which have environmental, social and financial challenges (ESCAP, 2010*a*).

7.3.2 Challenges, risks and uncertainties

Hotspots

The many threats to water resources in the Asia-Pacific region reveal a complex picture and raise many concerns. To better prioritise regional action, ESCAP has identified 'hotspots' where there are multiple challenges. The hotspots are countries, areas or ecosystems that have overlapping challenges such as poor access to water and sanitation, limited water availability, deteriorating water quality, and increased exposure to climate change and water-related disasters. In the summer of 2010, for example, approximately one-fifth of Pakistan was inundated, affecting more than 20 million people in the flooded areas along the length of the River Indus. Flooding also destroyed more than 1.6 million acres of crops (Guha-Sapir, et al., 2011). South-East Asian countries in particular are at a development crossroads (Figure 7.3). Although high economic growth rates provide finances for better water resources management, many current development priorities ignore the risks from natural disasters, climate change, and poor household water and sanitation access. For example, India is in danger of being ill-prepared for natural disasters and climate change, while unsustainable water-use patterns are evident in Pakistan and Uzbekistan. Basic access to sanitation remains a major concern for Bangladesh.

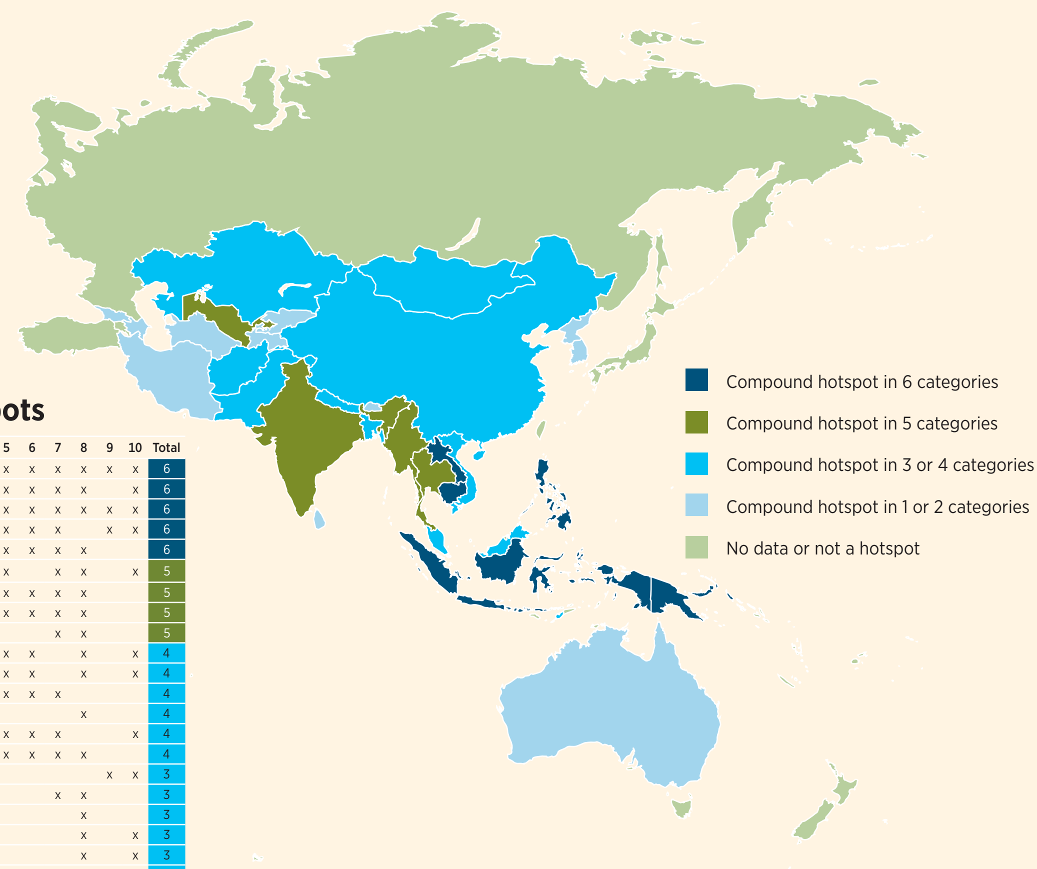
Areas of concern include some of Asia's major breadbaskets, such India's Punjab and the North China Plain. Water tables in these areas are falling by 2 m to 3 m a year, with serious impacts on agriculture and food security. Tropical deltas, where water productivity for food production is already low, are degrading and are at risk from sea-level rises. Food security is a challenge for many areas in the Asia-Pacific region – 65% of the world's undernourished people are concentrated in seven countries, five of which are in the Asia-Pacific region: India, Pakistan, China, Bangladesh and Indonesia (APWF, 2009).

Both high and low water-user groups are at risk of water scarcity because water endowment alone does not guarantee a sustainable water supply to support socio-economic development. Water scarcity can occur even in countries with rich renewable resources if it is not properly conserved, used and distributed among households, farms, industry and the environment (ESCAP, 2010*a*).

The ecological carrying capacity of the Asia-Pacific region is also affected by deteriorating water quality, with even relatively water-rich countries (such as Malaysia, Indonesia, Bhutan and Papua New Guinea) facing urban water supply and quality constraints. Domestic sewage is a particular concern because it affects ecosystems near densely populated areas. Approximately 150 to 250 million m^3 per day of untreated wastewater from urban areas is discharged

FIGURE 7.3

Asia-Pacific water hotspots



Compound hotspots

	1	2	3	4	5	6	7	8	9	10	Total
Cambodia					x	x	x	x	x	x	6
Indonesia			x		x	x	x	x		x	6
Lao PDR					x	x	x	x	x	x	6
Papua New Guinea				x	x	x	x		x	x	6
Philippines	x		x		x	x	x	x			6
India	x				x		x	x		x	5
Myanmar				x	x	x	x	x			5
Thailand			x		x	x	x	x			5
Uzbekistan	x	x		x			x	x			5
Bangladesh					x	x		x		x	4
China					x	x		x		x	4
Malaysia			x		x	x	x				4
Pakistan	x	x	x					x			4
Timor-Leste					x	x	x			x	4
Viet Nam					x	x	x	x			4
Afghanistan	x								x	x	3
Kazakhstan				x			x	x			3
Maldives	x			x				x			3
Mongolia				x				x		x	3
Nepal				x				x		x	3
Pacific Islands						x		x		x	3
DPRK				x	x						2
Kyrgyzstan				x			x				2
Tajikistan				x			x				2
Turkmenistan				x			x				2
Australia							x				1
Azerbaijan				x							1
Bhutan				x							1
Georgia				x							1
Iran								x			1
Republic of Korea					x						1
Sri Lanka								x			1
Prevalence (countries affected)	6	2	5	14	15	13	17	19	4	12	

Legend

1 Increasing water scarcity threat
2 High water utilization
3 Deteriorating water quality
4 Poor water quality and low water endowment
5 Flood-prone countries
6 Cyclone-prone countries
7 Drought-prone countries
8 Elevated ecosystem/Climate change risk
9 Poor access to drinking water
10 Poor access to sanitation

Sources: ESCAP (2006, 2010a); Dilley, et al. (2005); FAO AQUASTAT database (accessed 2010).

into open water bodies or leached into the subsoil.[6] This has consequences ranging from poor human health and increased infant mortality, to widespread environmental degradation. Degraded watercourses in cities exist because of demands on land, a lack of proper sanitation, insufficient drainage, or simply a lack of appreciation of their economic, environmental and ecological values.

Access to drinking water and sanitation

There is unequal access to drinking water and sanitation services throughout the Asia-Pacific region. This includes stark contrasts between urban and rural areas, and between rich and poor households – with sanitation being the most striking disparity. Even if adequate access to water and sanitation systems is established, the built facilities must be financially sustainable, functional, reliable, affordable, responsive to needs, socially acceptable for both genders, and appropriate for children and adults. Many social programmes are providing sanitation facilities that may be incompatible with the needs of women, for example, including lack of segregated toilets in schools, which can directly affect how frequently girls attend school.

The proportion of the region's population that has access to an improved drinking water source increased from 73% to 88% between 1990 and 2008 – that's an increase of 1.2 billion people (ESCAP, 2010*a*). China and India together account for a 47% share of the 1.8 billion people globally who gained access to improved drinking water sources over this period. Since 1990, 510 million people in East Asia, 137 million in South Asia, and 115 million in South-East Asia gained access to piped water connections on their premises (WHO–UNICEF, 2010).

However, the situation regarding access to sanitation is much less encouraging. Of the 2.6 billion people who do not use improved sanitation facilities, 72% live in Asia (WHO–UNICEF, 2010). Rapid progress in improved sanitation occurred in North-East Asia, with a 12% increase in access between 1990 and 2008, and in South-East Asia, with a 22% increase. In contrast, the situation in South Asia and South-West Asia is a concern. Although the number of people with sanitation access doubled since 1990, the 2008 average coverage was still only 38%, with the number without access actually higher than in 2005. Some 64% of the world population that defecate in the open live in South Asia. This is despite the fact that the practice decreased most in this area, down from 66% in 1990 to 44% in 2008 (WHO–UNICEF, 2010). In India alone, 638 million people still defecate in the open.

Climate change and extreme events

The Asia-Pacific is the world's most vulnerable region with respect to natural disasters, which undermine economic development to varying degrees. Much economic growth is generated in coastal and flood-prone areas, which are especially vulnerable to typhoons and rainstorms. Increased climate variability and extreme weather conditions are expected to severely affect the region, with floods and droughts predicted to increase in both magnitude and frequency. Excluding those affected by tsunamis, an annual average of 20,451 people were killed by water-related disasters in the region between 2000 and 2009. The annual global average for the same period was 23,651 (CRED, 2009).

The Pacific's small island developing states (SIDS) are particularly vulnerable to environmental natural hazards such as tropical cyclones, typhoons and earthquakes turning into disasters. One major tsunami or tropical cyclone can negate years of development effort. Climate change will further exacerbate the vulnerability of SIDS (and other low-lying coastal areas) with anticipated sea-level rise and the risk of storm surge and beach erosion.

The structure of gender relations is part of the social and cultural context that shapes a community's ability to prepare for, cope with, and recover from disasters. For example, in many Pacific islands men are responsible for activities related to the ocean and women for land-based ones. These roles are reflected in the way they prepare for an approaching hazard – men secure the physical structures, such as canoes, and women secure the food and families. These different roles need to be taken into account when addressing risk reduction equitably (Herrmann et al., 2005).

These observations about risk and uncertainty raise the issue of the sustainability of water supply and sanitation systems. Achievements in providing basic infrastructure, for example, should not only be assessed against a one-time coverage target. It is also important to ensure that what is built is functional, reliable, affordable, responsive to needs, and financially sustainable. The available information, however, suggests a regression in achievements, with many systems in the region functioning ineffectively, mostly as a result of a limited capacity to manage these systems and poor financial management.

7.3.3 Response measures

Institutional, legal and planning responses

The Asia-Pacific region has increasingly applied integrated water resources management (IWRM) principles in policies, strategies, plans and legal frameworks for water resources management throughout the region. Their actual implementation 'on the ground' has proven complicated, however, because of the need to involve water stakeholders at all levels of governance and civil society, and to establish a culture of inclusive consultation processes.

Various efforts are being made in the Asia-Pacific region to facilitate a sustained flow of ecosystem services (see Box 2.2 in Section 2.5). Innovative policies to support payment for ecosystem services are being established, or are under consideration, with examples in Viet Nam, Indonesia, the Philippines and Sri Lanka. Promoting household water security, recognizing the need to adapt to climate change threats, and initiating a 'wastewater revolution' are proposed priorities for regional cooperation, and are fundamental to unblocking the developmental difficulties attributable to poor water resources management in many countries in the region. Some countries have introduced a specific policy to prioritize sanitation in their national development plans. Examples include Thailand's Rural Environmental Sanitation Programme, which has been incorporated into its national economic and social development plans over the last 40 years, and the Total Sanitation Campaigns introduced in West Bengal and other locations in South Asian countries (CSD, 2008).

The Asia-Pacific region is attempting to reverse unsustainable consumption and production patterns by embarking on a greener development path. China, for example, is currently among the world's top exporters of green technology. 'Green Growth' was adopted at the 5th Ministerial Conference on Environment and Development in Asia and the Pacific in March 2005. It is the key regional strategy for inclusive and sustainable development, has emerged as a promising approach for pursuing greener development goals (also see Chapter 1 and Chapter 4). If put into operation in water resources management, Green Growth has the potential to address the development dilemma of providing basic water and sanitation services to all and sustaining economic growth, while also ensuring environmental sustainability.

> "Governments need to facilitate the creation of market conditions for developing sustainable and eco-efficient water infrastructure for better provision of water services."

Infrastructure responses

Water infrastructure in the Asia-Pacific region is shifting from predominantly short-term benefit planning and development, to a more strategic and long-term benefit planning concept that also addresses ecological efficiency in economic development. Governments need to facilitate the creation of market conditions for developing sustainable and eco-efficient water infrastructure for better provision of water services. This goal is envisaged for the region in three different contexts. The first is as a component of eco-city development programmes for addressing urbanization challenges. Possible eco-efficient infrastructure solutions in this context include urban river rehabilitation, modular water treatment design, integrated storm-water management, decentralized wastewater treatment, and water re-use and recycling. The second context focuses on rural areas, where the distance from urban centres makes traditional infrastructure expensive and inefficient. Modern irrigation systems, decentralized drinking water and sanitation services, water reuse and recycling, and rainwater harvesting are some promising solutions in the rural context. The third context relates to the urgent need to clean the region's waterways through a 'wastewater revolution'.

Treating wastewater for re-use is an essential consideration. Centralized wastewater treatment typically requires a large area, substantial funding and technical knowledge for sustained operation and maintenance. In some places, current technology for small, compact wastewater treatment plants has improved, offering advantages over larger, centralized systems.

Water resources management in the Asia-Pacific region appears to be shifting from a supply-oriented approach to a more demand-management approach. Large savings in water, energy and financial resources are expected as a result of increased efficiency and reduced consumption in the region. Continuing challenges facing the demand-management approach include evaluation of availability and demand in watersheds, possible reallocation or storage expansion in existing reservoirs, balancing equity and efficiency in water use, inadequate legislative and institutional frameworks, and the rising financial burden of aging water infrastructures.

Although the implementation of demand-management measures has been uneven across the region, interest in improving water-use efficiency continues to grow. Household water security, Green Growth, wastewater concerns and adaptations to climate change are driving this interest. Singapore, for example, reduced its urban domestic water demands from 176 L per capita per day in 1994, to 157 L per capita per day in 2007 (Kiang, n.d.). Leak detection programmes in Bangkok and Manila have lowered estimated unaccounted-for water, allowing new infrastructure development to be postponed (WWAP, 2009, Chapter 9). Since 2008, Sydney Water in Australia has offered a dual reticulation service where houses in the Hoxton Park area are given two water supplies – one for drinking water, and the other a recycled supply for general use (Sydney Water, 2011).

7.4 Latin America and the Caribbean

There is a long tradition of water management in the countries of Latin America and the Caribbean (LAC) (see Map 7.4), but with marked contrasts in its effectiveness among both countries and sectors. Commonalities among the countries can be seen in the advances that have been made. However, these advances have not always had the same pace and have not yet resulted in universal increases in water use efficiency or in any overall improvement in the levels of water quality.

Nonetheless, there has been an increase in the contribution of water to social and economic development. Although isolated advances can be observed in water management institutions, various countries have undertaken ambitious water management reforms, perhaps most notably Brazil and Mexico, but also, for example, Argentina, Chile, Colombia and Peru.

The main issues in water management facing the countries of the region have not changed significantly in the recent past (see Box 7.11). There has been a widespread inability to establish institutions that are able to deal with water management issues under conditions of increasing scarcity and conflict. The reasons for this lack of improvement include weak management institutions, insufficient operational capacity, informality, absence of self-financing and consequent dependence on fluctuating political support, and lack of reliable information in most areas of water management, including on the resource itself and its uses, users and future needs.

Contrasts abound, however, and these are not only due to variations in climate and hydrology or to the scale at which water management must operate (Brazil has 100,000 times the area of Dominica, for example) but equally or more so are due to differences in the nature and effectiveness of institutional systems, dissimilarities in the distribution and demographic structure of the population, and sizeable variations in levels of income. Impressive advances have been made in some countries in specific water management activities; for example, the high level of development of urban water supply and sewerage services in Chile.

7.4.1 The driving forces and pressures on water resources

Water management in LAC has always had to confront not just drivers arising within the 'water box', but also external drivers affecting both water management and the resource itself. The more significant external drivers include economic events, such as changing domestic policies, international financial crises (such as that in 2008–2009) and political instability; more subtle changes are produced by external influences related to gradual economic and social change. Extreme climatic events, especially hurricanes in the Caribbean, have long had a negative influence on water management. Recently, new uncertainties related to global climate change have been added to this list.

MAP 7.4

UNECLAC Member States

Source: Economic and Social Commission for Latin America and the Caribbean, Map No. 3977 Rev. 4, May 2011. Department of Field Support, Cartographic Section, United Nations.
Note: For the purposes of this chapter, the following ECLAC members are not considered part of the LAC region: Canada, France, Italy, Netherlands, Portugal, Spain, United Kingdom and United States of America. In addition, for the purposes of the chapter, only Aruba, British Virgin Islands and Cayman Islands are considered associate members of ECLAC.

Demographic change

More than 8% of the world's population lives in LAC – some 581 million people – with half of them in Brazil and Mexico (UNEP, 2007). The region is going through a period of rapid demographic change. Following the great migration to the cities in the 1960s and 1970s, the main characteristic of the current demographic situation is a rapid decline in birth rates resulting in a slowing in the rate of population growth – currently 1.3% for the region as a whole, which is expected to fall to less than 0.5% by 2050. If current trends continue, the population will even begin to fall absolutely in some countries, notably Cuba and Uruguay (CELADE, 2007). In contrast, annual population growth is still above 2% in several Central American countries. Increasing population will continue to contribute to rising demands for water throughout the region (UNEP, 2010*a*).

The decline in birth rates also means that, even if the total national population remains stable, many regions will lose population, especially those more rural and isolated. Smaller populations tend to mean reduced human and financial resources to support the operation and maintenance of infrastructure. This is particularly important where management responsibilities are decentralized. In the case of water supply and sewerage it can also mean that facilities may end up over-designed, hampering their operations. This can pose difficult questions in countries still expanding their water and sewerage infrastructure.

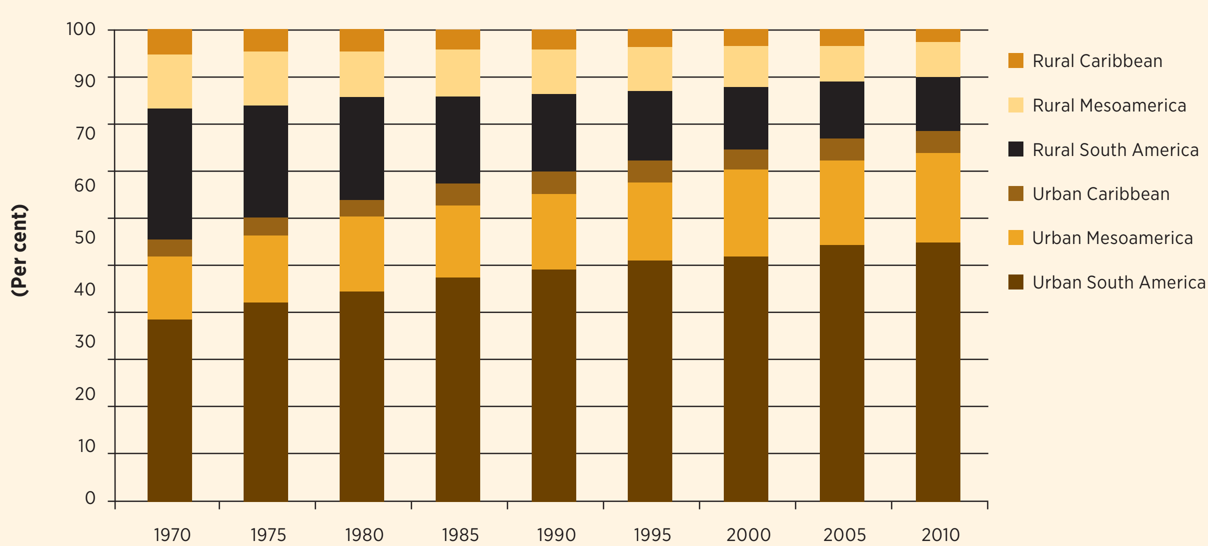
Latin America and the Caribbean is the world's most urbanized developing region; more than 80% of the population live in towns and cities (ECLAC, 2010*a*) (Figure 7.4). The urban population has tripled over the past 40 years and is expected to grow to 609 million by 2030. There are many cities with more than 1 million inhabitants, and in some countries, a high concentration in just one or two large cities (UNEP, 2010*a*). A recent trend has been the growth of population in medium-sized and small cities. There has also been recently an increasing settlement of what has historically been sparsely populated land, particularly in the Amazon and Orinoco river basins.

Economic development

Economic and social changes have obvious consequences for water use and the demands placed on the resource. The influence of these changes goes beyond the short-term effect of global financial crises, and beyond national economic unrest such as the so-called Mexico peso crisis of 1994 or the collapse of the Argentinean economy in 2001 (Klein and

FIGURE 7.4

Increase in urban populations between 1970 and 2010



Source: UNEP (2010a, p. 28, with statistics from the CEPAL STAT database [http://www.pnuma.org/geo/geoalc3/ing/graficosEn.php]).

Coutiño, 1996). Such events may hamper or interrupt the development of ongoing programmes, but they rarely have long-term effects. Far more important are the new demands for water arising from long-term changes in both LAC societies and the global economy. This is particularly the case with such apparently disparate changes in demands as that for tourism in the Caribbean and that for energy almost everywhere, both of which tend to be closely related to rising per capita income within the region and in the rest of the world (OECD, 2009). Sometimes these increasing demands for goods and services from water resource development produce conflicts which can pose serious problems for water management agencies. There are a number of examples, particularly regarding the construction of large hydroelectricity generating plants: the global controversy surrounding the decision of the Brazilian government to approve the construction of the Belo Monte Dam on the Xingu tributary of the Amazon is one such example, and the proposed construction of plants in the Río Baker in Chile is another.

As per capita incomes increase and the middle class grows, poverty levels have dropped in the region. In many countries, half the population has incomes 1.8 times above the poverty level, and in Uruguay, Chile and Costa Rica it is almost two-thirds (ECLAC, 2009). However, poverty remains an unresolved issue in all Latin America and most of the Caribbean. Although average poverty rates have fallen steadily over the past 20 years, an estimated 30% of the population of the region, or some 177 million people, still live in poverty, and 12% are considered extremely poor[7] (ECLAC, 2011). Decisions regarding water management and allocation have a role to play in poverty reduction through both the provision of public utility services and the creation of favourable conditions for economic development, as many economic activities, such as agriculture, mining and electricity generation, depend on water.

One result of the emergence of a larger middle class has been increasing demands to give more emphasis to the resolution of environmental conflicts. Examples include the cited opposition to dam construction, the acceptance of tariff increases to finance the ambitious programme of urban wastewater treatment in Chile (by the end of 2010 almost 87% of urban sewage was receiving treatment [SISS, 2011]), and the decontamination plan of the Matanza-Riachuelo basin in Argentina.

"One result of the emergence of a larger middle class has been increasing demands to give more emphasis to the resolution of environmental conflicts."

With the exceptions of Mexico and some of the small countries of Central America, the countries of the region base much of their economy on the export of natural resources. The global demand for these products has increased notably in recent years. Moreover, much of the production of these goods is financed by external capital and many of the facilities are foreign-owned. The result is that the major engine of economic growth in the region with heavy demands on the water resources is subject to many factors outside the direct control of the governments of the countries of the region.

For water management, this dependence on many natural resource-based activities is complicated by their location. The expansion of copper and gold mining in Chile and Peru has mainly occurred in arid areas and has led to competition for scarce water with both export agriculture and the needs of the indigenous population. Tourism demand has increased water stress on many Caribbean Islands (Box 7.9). Coffee production uses large quantities of water and its processing can seriously affect water quality. Similar issues arise with many other natural resources. One potential future demand for irrigation could come from the production of biofuels, although in Brazil, the only current significant producer, sugar cane production is rainfed and only 3.5% irrigation demand is for biofuel production (de Fraiture et al., 2008).

The uncertainty in the level and nature of demands of the global market and their changing nature have always complicated water management in LAC as local economies expand, contract and adjust according to the fluctuations of the global economy and so change the environment in which management decisions must be taken and policies applied.

Water availability and use

The annual average availability of water per capita in the region amounts to about 7,200 m^3. However, it is only 2,466 m^3 per person in the Caribbean. The Lesser Antilles, where rainwater is the primary water source, suffers the most acute water stress (UNEP, 2010*a*). In continental Latin America, overall demand on water resources remains low and spatially concentrated. Water withdrawals are estimated to be about 1% of available water, but they are much higher in the Caribbean – even in the mainland region,[8] they are equivalent to 14% of the available water (ECLAC, 2010*a*). Population concentrations, however, do not always coincide with plentiful water sources. Approximately one-third of the population in the region lives in arid and semi-arid areas. Northern Mexico, North-eastern Brazil, coastal Peru and northern Chile, among other areas, have great difficulty meeting their water needs. Population growth, expanded industrial activity, especially mining in Andean countries, and high irrigation demand have led to a ten-fold increase in total water extraction in the last century. Between 1990 and 2004, extraction grew by 76% (UNEP, 2010*a*). By the mid-2000s, it amounted to some 263 km^3 per year, with Mexico and Brazil together accounting for just over half that amount (UNEP, 2007).

BOX 7.9

Water management in Barbados

Barbados, with a population of about 290,000, is one of the world's most densely populated countries. It is a drought-prone island, almost entirely dependent on groundwater, and the available water supply is less than 390 m^3 per person per year. It is a country living under conditions of absolute water scarcity.

Universal water metering, via a variable tariff based on consumption, has been introduced, but the tariff was set too low. Some fairly successful water efficiency methods have been introduced but water consumption has increased with rising living standards. Tourism, which is very important to the economy of the island, is an especially large water user. Overall, water management has worked well although the water authority has suffered from poor management. Recently, Barbados received a loan from the Inter-American Development Bank to improve the water authority's efficiency, coastal zone management and climate change adaptation (IDB, 2009).

Source: BWA (2009).

7.4.2 Challenges, risks and uncertainties

The most significant risks and uncertainties facing water management in LAC are likely to stem from

- the impact of global economic events;
- continuing growth in domestic water use with increasing urbanization and rising living standards;
- the consequent need to improve the quality and extend the provision of water and sanitation services, especially to urban and peri-urban areas; and
- the impacts of climate change, especially on extreme events that affect water.

The effectiveness of improvements in water resources management, services and infrastructure, associated investments, and the relevant legislation and organization are very dependent on macroeconomic policies and the environment they create. 'Macroeconomic policy has a pervasive influence on the structure of incentives and performance in the entire water sector' (Donoso and Melo, 2004, p. 4). Unfavourable macroeconomic context erodes even the best water management policies, which has been evident in the countries of the region. For example, high rates of inflation can destroy attempts to develop effective charging systems for water use or to protect water quality. Similarly, in the long run, no water policies can be sufficient to compensate for the problems affecting sustainable water use, reflected in the lack of maintenance of infrastructure caused by economic stagnation or in underinvestment in expansion because of macroeconomic instability.

Conversely, successful macroeconomic policies leading to high rates of growth, as in Chile in the 1990s and in Argentina and Peru more recently, also impose challenges to water managers as new demands can emerge rapidly. Traditional polices often prove unable to resolve the problems created by the new economic environment and innovative institutional approaches can be required as water management becomes more complex. This can be especially critical in smaller countries where limited resources available, particularly those of professional and technical staff, meaning that institutional change can only come slowly.

Future demands and competition for water

As economic growth continues in the region and global demands for its mining, agricultural and energy resources increase, consequently so will the demand for water. For example, water use for energy can be expected to rise throughout the region in line with economic growth. Hydropower produces 53% of the region's electricity, and installed capacity grew by 7% between 2005 and 2008. Hydropower is expected to provide a significant proportion of the new energy demand (UNEP, 2010*a*). Balancing current and future water demands between competing uses (including ecosystems and their services) will become an issue. International demand has led to a 56% increase in mineral extraction in recent years, and despite the current slowdown in the global economy, it can be expected to continue to expand. Significant volumes of water are required for extraction, especially for precious metals, copper and nickel. Toxic waste and effluents from mining can run into water bodies, and this is one of the region's main sources of water pollution, as well as posing health and safety risks for local populations (Miranda and Sauer, 2010).

Agricultural demands will also increase. Around 14% of the region's cultivated area is under irrigation (FAO, 2011) and irrigation has expanded steadily since the 1960s. Given the intention of a number of countries in the region to play a major role in satisfying increased global demands for food and biofuels, irrigation will need to become more water-efficient.

On the whole, the region is doing well in providing improved water and sanitation for its urban populations, but is doing much less well for its rural populations. However, many cities still have substandard drinking water supplies and sewerage networks. Growing urban populations, especially in medium-sized cities, adds to the risk of not meeting water supply and sanitation needs. Expanding urban areas also not only require more water for domestic supply, but also are likely to expand onto floodplains and into catchment areas. These increasing demands can create significant risks for water management in dealing with local water scarcities and conflicts among water users (Box 7.10).

Climate change and extreme events

Many parts of LAC have always been subject to a variety of extreme weather events such as floods and droughts, especially climate variability related to the El Niño-Southern Oscillation (ENSO) phenomenon. The frequency, duration and intensity of extreme weather events are expected to rise with climate change, increasing the need for risk management. Figure 7.5 shows that these events have already increased since the 1970s.

Flash floods and droughts affect the productivity of water ecosystems, living conditions and human welfare in both flood-prone areas and arid regions (IPCC, 2007). Urban flooding is a perennial problem in the region. For example, floods occur in most cities in the La Plata basin. The lack of storm sewers in many cities exacerbates the problem. In some densely populated cities, such as Caracas and Rio de Janeiro, where much housing is located on steep slopes, landslides worsen the impact of floods.

BOX 7.10

Competition for water in the Copiapo Valley

The Copiapo Valley in Northern Chile is an example of the conflicts that can arise from large-scale investments to serve global markets in areas where water is scarce. The region is the site of an increasing number of copper and other mines (which are even considering seawater desalination to meet their future demands), but it also produces large volumes of export crops, particularly table grapes – all in addition to the water needed for human supply which is also on the rise. The valley's surface waters have long been committed and there is increasing competition for groundwater among the fruit farmers. Wells are dug ever deeper and extraction rates exceed recharge. Chile's generally high level of governance of water user organizations and the operation of water markets have not prevented the problem. The trading of water rights has had little influence in relieving the water use conflicts in the valley. The form in which groundwater rights are defined, lack of controls and the impossibility to reach consensus on the measures to be adopted and to effectively implement them ('free-riding') have contributed to the current state of over-exploitation of water resources.

Sources: Personal communications in 2011 in Santiago, Chile with Michael Hantke-Domas and Humberto Peña.

The region's glaciers are already receding because of climate change. Glacier retreat affects the water supply of an estimated 30 million people in the region (UNEP, 2010*a*). Some 60% of Quito's (Ecuador) and 30% of La Paz's (Bolivia) water comes from glaciers. Glaciers in Peru have lost 7 billion m^3 of water – a quantity that could supply Lima for 10 years. Droughts already occur regularly, and between 2000 and 2005 they caused serious economic losses and affected 1.23 million people (UNEP, 2010*a*).

The number of people living in already water-stressed watersheds in the absence of climate change is estimated at 22 million. The IPCC (2008) expects that with climate change, this number will increase to between 12 and 81 million in the 2020s and to between 79 and 178 million in the 2050s. Models also project an increase in the number of people at risk of malaria and dengue due to changes in the geographical limits of transmission.

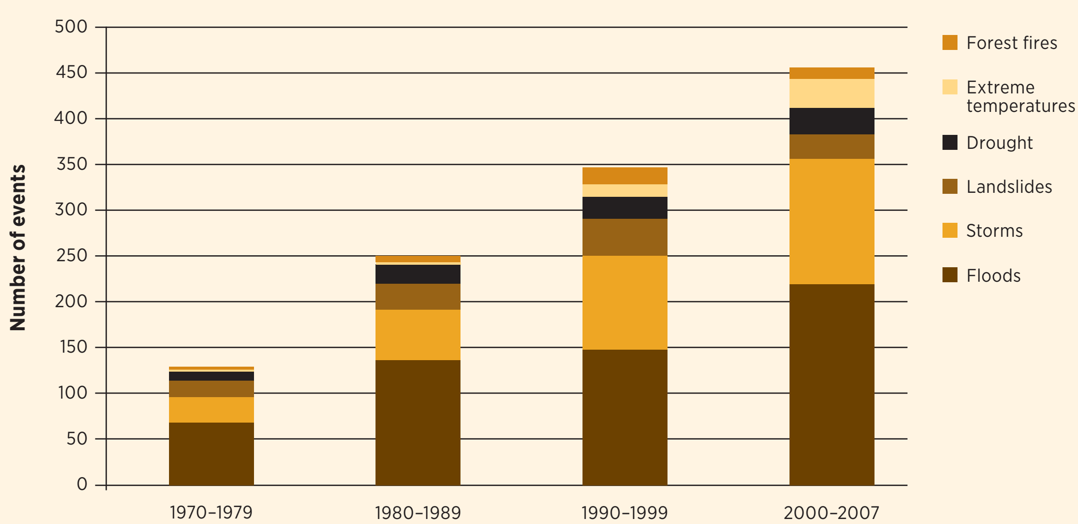
Climate change is likely to damage the important tourism industry of the Caribbean islands (UNEP, 2007). Sea level rise is also predicted to start affecting small island states, as well as continental coastal areas and river regimes, contributing to the deterioration in the quality, quantity and availability of water (ECLAC, 2010*b*). Climate change is expected to have adverse repercussions on the Pantanal, one of the world's largest wetlands, which stores water and regulates flows in the Paraguay River and its tributaries, helping mitigate droughts and floods (Roy, Barr and Venema, 2010).

The region's poorest countries in Central America, the Caribbean and the Andean region, with relatively weak water management capacities, will be at the highest risk from the effects of climate change and extreme events. The most serious example is Haiti, which is particularly vulnerable to extreme events because of deforestation, difficult topography, poverty and a lack of public infrastructure (ECLAC, 2010*a*).

Inadequate hydrological and meteorological observation networks hamper response to extreme events. On the positive side, lessons learned from adapting to the consequences of, for example, ENSO events in the region (e.g. in Peru) and the cycle of droughts and wet years in the drought polygon of North-eastern Brazil, have led to technological innovations that are applicable to water management in the face of climate change, and these have also led to increased human capacity (NOAA, n.d.). Extreme events would seem to bring only costs, as lives are lost and water and other infrastructure is damaged or destroyed. However, if water infrastructure resists serious damage or can be restored quickly, then the key role of water and

FIGURE 7.5

Frequency of hydrometeorological events, 1970–2007



Source: UNEP (2010a, p. 40, with statistics from the CEPAL STAT database [http://www.pnuma.org/geo/geoalc3/ing/graficosEn.php]).

water-related services is likely to win in public perception and will raise its influence within government.

Access to drinking water and sanitation

Over the past two decades there has been a slow but steady increase in most countries of LAC in the provision of both water supply and sanitation. By 2008, improved water supply was available to 97% of the urban population and 80% of the rural population (86% and 55% in the case of sanitation), more than meeting the MDGs at the regional level (WHO and UNICEF, 2010). These aggregate statistics, however, hide significant variations in the quality of the services. In many countries, the water supply and sanitation services are plagued by what has been defined as a vicious circle of low quality. Political interference, poor management and low tariffs all conspire to produce low quality services, and poor maintenance leads to interruptions in supply and low pressure, both of which can produce contamination within the system or the release of untreated wastewaters from sewage treatment plants (Corrales, 2004).

There remain large variations in access to services within countries. For example, in Central and Southern Mexico, Honduras and Nicaragua, there are many municipalities where less than 10% of the population have access to drinking water. In sanitation, the definition of what improved sanitation comprises is very general so that the published statistics provide little guidance to the real situation in many countries of the region (ECLAC, 2010*a*). It is estimated that almost 40 million people still lack even minimal access to secure water, and some 120 lack access to sanitation. In some areas, the cost of water is rising as a result of inefficient service provision, increasing demand and ever more intractable accessibility issues. Often, the poorest and most vulnerable people end up paying the most for water, as they depend on expensive but often poor-quality water purchased from tank trucks (UNEP, 2010*a*).

Undeniably, there has been improvement in most countries, but this in turn has brought to the fore other issues. It is estimated, for the region as a whole, that at best only 28% of sewage is treated before discharge, leading to serious contamination of water courses, including the sea, from both sewage outfalls and industrial discharges from urban areas (Lentini, 2008). The principal exception is Chile, where wastewater treatment will soon be universal (Box 7.11). Too often the political and technical complexity of introducing measures to control pollution has produced mixed results. For example, it is not clear that the introduction of charges for wastewater discharges in Colombia has been the determining factor in reducing water pollution.

There remain many problems to be resolved, including the recurring issue of under-financing water supply and sanitation services so that any gains in provision are negated, or at least reduced, by lack of maintenance, through the low levels of operating efficiency and the failure to adequately ensure sustainable financing. Lack of maintenance leads to large losses in piped water systems; for example, in Cuba the government estimates losses in distribution to amount to at least half of the water leaving the treatment plants (Business News America, 2010). Even in Chile, few systems have unaccounted for water under 30% (SISS, 2011).

7.4.3 Response measures

Institutional, legal and planning responses

The greatest challenge for water management in LAC is to continue to improve overall governance, a fact which governments are aware of (Comunidad Andina de Naciones, 2010). Responding to these challenges requires institutional arrangements for effectively

BOX 7.11

Investment in sanitary infrastructure in Chile

High levels of investment are a major factor in Chile's success in providing superior water and sanitation services to the urban population. Between 1999 and 2008, Chile invested more than US$2.8 billion in the water supply and sanitation sector, in addition to millions in controlling industrial pollution and building dedicated storm-drainage networks. An important impetus was the government decision to protect its export of agricultural products.

The main factors explaining the success of the reforms are (i) the creation of solid and high quality institutions with a long-term vision; (ii) discipline in criteria for investing fiscal resources; (iii) that the sector has always been managed responsibly and given high effective priority; (iv) that reforms were the result of a broad consensus built up at both the political and the professional level; and (v) the strategy of gradual change was governed by realistic and pragmatic judgment and a concern for ensuring overall coherence and keeping sight of the country's actual capacities.

Source: Valenzuela and Jouravlev (2007).

protecting public interest; defining and enforcing water use rights and discharge permits; setting standards, control and inspection mechanisms; and mobilizing significant financial resources.

If water management is to respond to the many needs for improvement, governments must establish a clear separation of policy and regulatory activities from day-to-day operations, improve incentives for efficiency, promote management training, adopt greater transparency in decision-making, and develop better systems for conflict resolution through a clear framework, increasing the participation of stakeholders in management decisions.

The magnitude of the challenge should not deter water managers and decision-makers from confronting them and making every effort to further strengthen water management within the social and economic sectors that depend upon it. A few countries have undertaken large-scale reforms in their water management institutions, notably Mexico, Chile and Brazil. In some instances, however, there remain problems with implementation, as in Brazil, where charges for bulk water and user fees are not being collected on a regular basis (Benjamín, Marques and Tinker, 2005). In other countries, institutions often do not have the capacity to succeed in undertaking major reform or consensus in this field continues to be elusive.

There have been a number of interesting experiences in the region over the past few decades in the establishment of water institutions outside sectoral ministries. For example, in Mexico water resources are managed by the National Water Commission (CONAGUA); and Brazil recently set up the National Water Agency (ANA) with the principal objective of overcoming traditional conflicts and limitations imposed by a system in which, until recently, water had been the responsibility of functional ministries. Other examples of institutions that are not directly linked to the functional aspects of water allocation and management include the Ministry of Environment, Housing and Territorial Development in Colombia; the Water Resources Authority in Jamaica; the Ministry of Environment and Natural Resources in Venezuela; and the General Water Directorate of the Ministry of Public Works in Chile. Reform of water laws is being discussed in most countries, but in practice, innovations are slow to materialize under real-world conditions (Solanes and Jouravlev, 2006). In recent years, new water legislation has been adopted in some countries (e.g. some provinces of Argentina, Nicaragua, Honduras, Peru, Uruguay and Venezuela) and several others have reformed their water laws (e.g. Chile and Mexico). Common tendencies include explicit adoption of the integrated water resource management paradigm, improvements in water governance, creation of water authorities and river basin organizations, and attention to public or water users participation, water resources planning and economic instruments. This, although in the early stages of implementation, is a major change in how some countries in the region manage their water resources.

Virtually all countries have reformed the water supply and sanitation sector, with emphasis on institutional separation of the functions of sectoral policy-making, economic regulation and service provision; extension of the decentralization process; an interest in private participation, although this trend was later reversed with the exit of large international private operators from most countries and renationalization of many services; formulation of specific regulatory frameworks; and the requirement that services should move towards being self-financing and that subsidy arrangements should be set up for low-income groups. Unfortunately, in many cases, reforms have failed to take account of the structural limitations of national economies as well as of sound principles in the area of public interest, economics of service provision and

> "As for private sector participation, regional experience indicates that it is not the magic formula for addressing the multiple problems that affect the provision of water supply and sanitation services."

public utility regulation, and so have not met expectations. Some countries have recognized the right to water (Bolivia and Ecuador) or have set up mechanisms that improve the affordability of water services creating subsidies for the poor (Argentine, Chile and Colombia). As for private sector participation, regional experience indicates that it is not the magic formula for addressing the multiple problems that affect the provision of water supply and sanitation services.

The LAC region has 61 basins and 73 aquifers that cross national borders (UNESCO, 2010). Many countries have entered into transboundary water agreements, especially for hydropower development. Many political obstacles remain to wider cooperation in the management of international basins and there are some examples of potential conflict. Increasingly, bilateral and multilateral treaties do incorporate environmental concerns, including integrated water resources management or sustainability goals, but any application of such agreements is still in its infancy (Roy, Barr and Venema, 2010). One example of international cooperation at least in research is the studies undertaken on the Guarani aquifer (Box 7.12).

BOX 7.12

The Guarani Aquifer System (GAS) project: Managing transboundary groundwaters

The Guarani aquifer is shared by Argentina, Brazil, Paraguay and Uruguay. It extends over 1.2 million km^2 and some 15 million people live in the area overlying it. The four countries with the support of the World Bank cooperated in a study of current uses between 2003 and 2007. The aquifer is thought to contain about 40,000 km^3 of freshwater. Current exploitation is relatively modest, but demand is growing amid fears of over-pumping.

In August 2010, the presidents of the four countries signed an agreement for cooperation on extending knowledge of the aquifer and on identifying critical areas, which is noteworthy because agreements on transboundary aquifer systems are rare. The four countries have committed themselves generally to 'promote the conservation and environmental protection of the Guarani Aquifer System so as to ensure multiple, reasonable, sustainable, and equitable use of its water resources' (Article 4 of the Guarani Aquifer Agreement).

These initiatives show that it is possible to reach a basic consensus on what should be done so that proposals can be made to governments for reform in water management. It is a mistake to think that complex problems can be solved only by top-down initiatives or through the creation of new organizations and extrapolating from the experience of effective legislation and organizational structures that were achieved elsewhere only after a significant effort of coordination.

It is not sufficient to have reform proposals that are drafted only by experts: it is essential that any proposals have the widest public support if reform is to be placed on the political agenda. Water experts can inform the process towards building a consensus on the direction to be followed. If such a consensus does not exist, no true climate of confidence can be created for change and any proposed reform, or even adopted legislation, will never produce results. The challenge is to open water management to society as a whole. In doing so the water sector can build on its previous achievements to continue to make sustainable contributions to the betterment of society in all countries of the LAC region.

7.5 Arab and Western Asia region

The 22 countries of the Arab region, including the 14 members of the United Nations Economic and Social Commission for Western Asia (ESCWA) (see Map 7.5) include some of the most water scarce countries in the world. At least 12 of these countries suffer 'absolute' water scarcity because they have less than 500 m^3 of renewable water resources available per capita per year (see Chapter 33). Even the Arab countries that are relatively better endowed with water resources are often highly underdeveloped countries or countries in crisis. Several social, political and economic drivers have exacerbated this water scarcity, increasing the risk and uncertainty associated with water quantity and quality issues.

Rural development and food security policies further complicate regional water resources issues. Striving to address these regional challenges in a coordinated manner, Arab Governments established the Arab Ministerial Water Council (AMWC) under the auspices of the League of Arab States (LAS). The AMWC has responded to requests arising from the January 2009 Arab Economic and Social Summit in Kuwait to prepare an Arab strategy to assist the region in addressing current and future regional water scarcity and sustainable development challenges. The resulting

Arab Water Security Strategy (2010–2030) proposes measures to respond to these challenges, including implementing projects directed at water use efficiency, non-conventional water resources, climate change, integrated water resources management (IWRM), and water security. Risk reduction at the national level is being sought in developing water sector strategies, incorporating water issues into national development plans, pursuing institutional and legal reforms, and addressing uncertainties related to the management of shared water resources.

7.5.1 The driving forces and pressures on water resources

The key drivers affecting the Arab region's water resources are population growth and migration, growing consumption patterns, regional conflicts and governance constraints. These drivers have increased the pressures on already scarce freshwater resources, increasing the risks associated with water quantity and quality issues, the sustainable management of shared resources, and the uncertainties of policies promoting rural development and food security.

Demographics and socio-economic development

The Arab region has experienced a population increase of approximately 43% in over the past two decades. The total estimated population in 2010 was more than 359 million, and it is expected to reach 461 million by 2025 (ESCWA, 2009*b*). Over 55% of the population lives in urban areas, with rural to urban migration trends being observed in Egypt, Lebanon, Morocco,

MAP 7.5

UNESCWA Member States

Source: Economic and Social Commission for Western Asia, Map No. 3978 Rev. 11, December 2011. Department of Field Support, Cartographic Section, United Nations.

Note: For the purposes of this chapter, the countries of the Arab region are identified as those that are members of the League of Arab States: Algeria, Bahrain, Comoros, Djibouti, Egypt, Iraq, Jordan, Kuwait, Lebanon, Libya, Mauritania, Morocco, Oman, Palestine, Qatar, Saudi Arabia, Somalia, Sudan, Syrian Arab Republic, Tunisia, United Arab Emirates, Yemen.

the Syrian Arab Republic and Tunisia (UNDESA, 2007). This urban migration can be attributed mainly to reduced incomes and employment opportunities in the agricultural sector, combined with a burgeoning youth demographic. Arab governments have tried to slow this trend with rural livelihood policies that link agricultural production and rural development, even though this link resulted in a skewed allocation of scarce water resources to the agricultural sector throughout much of the region. Urban area water demands have also increased because of migration associated with economic development, and influxes of people displaced by regional conflicts. In addition to being concentrated along coastlines, urbanization is promoting settlement in reclaimed deserts, along expanded coastlines and urban peripheries. This has increased public and private sector investment in non-conventional water resources, particularly desalination, to ensure adequate freshwater resources.

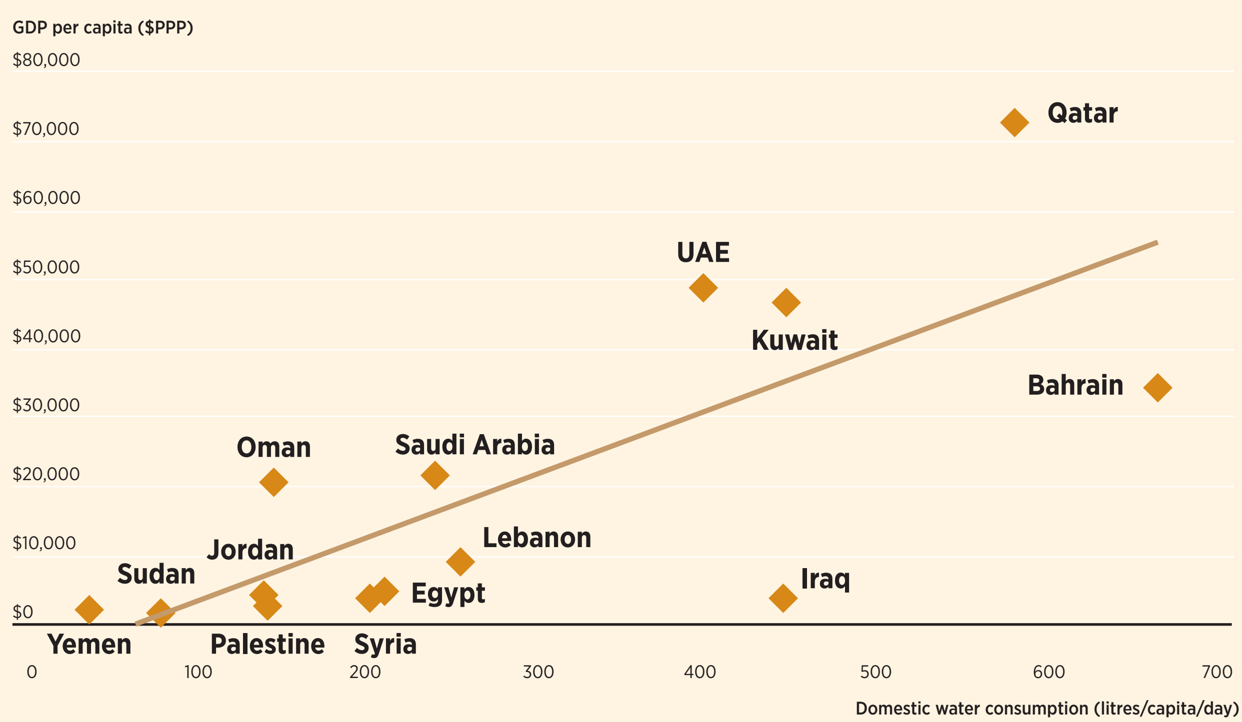
Water consumption in ESCWA member countries is largely tied to GDP (Figure 7.6), although this is mainly a consequence of their heavy reliance on desalination. Water consumption in other parts of the Arab region is largely tied to agricultural activities, which contribute only marginally to their GDP. Freshwater consumption in the Gulf Cooperation Council (GCC) countries continues to increase as a result of high incomes, comfortable lifestyles, real-estate development, the availability of energy for desalination, and growth in the tourism industry. In contrast, regional agricultural water consumption is characterized by low productivity, and has been significantly affected by droughts in recent years.

Regional conflicts and displaced persons

Cyclical conflict has characterized the Arab region for decades, generating large numbers of internally displaced persons. It has also caused increased regional migration and has strained water resources and services in areas receiving the displaced populations. The ESCWA region contains 36% of the world's displaced persons (ESCWA 2009*d*). Examples include 2 million Iraqi refugees in Jordan and Syria, Somalis in Yemen, Palestinians in refugee camps, and migrant workers and Libyans fleeing Libya for Egypt and Tunisia during the uprising which led to the regime change. Violent conflicts have destroyed water infrastructure at different times in Beirut, Kuwait and Lebanon, necessitating

FIGURE 7.6

Domestic water consumption relative to GDP per capita in the UNESCWA region



Source: ESCWA (2009c, p. 7).

the rehabilitation of damaged systems, instead of expanding water delivery.

The management of freshwater resources is further complicated by the fact that many major rivers in the Region are transboundary. The rivers in this category include the Tigris, the Euphrates, the Orontes (or Ali-Assi), the Jordan (including the Yarmouk), the Nile and the Senegal. Lake Chad too is transboundary, sometimes leading to political conflict between riparian neighbours. An estimated 66% of the Arab region's available surface freshwater originates outside the region. Subnational and local-level water conflicts can also exist between administrative districts, communities and tribes (Box 7.13).

At the same time, however, the 'Arab Spring' that started sweeping through the region in December 2010 can offer opportunities to revisit water governance structures and facilitate greater consultation at the community level. Soon after the respective regime changes, government officials in Tunisia and Egypt, for example, engaged with the issue, fostering greater public participation at the local level in planning and decision-making for the water sector.

BOX 7.13

Water conflicts in Yemen

Sana'a and Taiz in Yemen suffer from acute water scarcity – access to water has become a survival issue, and a cause of conflict. Some researchers believe that between 70% and 80% of the country's rural conflicts are about water. The situation is affected by a growing population, poor water management, illegal well drilling, a lack of law enforcement, a dependence on secure energy to deliver water, competition for water between urban and rural users, an influx of Somali refugees to Yemen, and unsustainable water allocations involving water use for agriculture, including qat (a mild narcotic plant popular in the area and which requires five times as much water as, for example, grapes).

Exacerbating the conflict is the fact that Yemen is one of the world's most water-scarce countries, with an annual per capita water availability of only 125 m^3, compared to the global average of 2,500 m^3. With their current usage rates, experts predict Sana's wells will run dry by 2015 (Kasinof, 2009).

7.5.2 Challenges, risks and uncertainties

Water scarcity

Nearly all Arab countries suffer from water scarcity, with water consumption in the Arab region significantly exceeding total renewable water supplies. Nearly all Arab countries can be characterized as water-scarce, while those formally endowed with rich water resources have seen their total annual per capita share of renewable water resources drop by half over the past four decades as their populations increase (Figure 7.7). This declining trend presents the most significant challenge to the water sector in the Arab region.

Egypt, Iraq, Jordan, Lebanon and Sudan derive 70% of their freshwater from perennial rivers. Surface water is the primary source in Oman, Saudi Arabia, the Syrian Arab Republic, the United Arab Emirates (UAE) and Yemen. These countries also have intermittent rivers (*wadis*) whose seasonal floods might be used to recharge aquifers. Other Arab countries obtain at least one-third of their total conventional water supply from groundwater, the extraction of which has increased to the extent that it threatens the sustainability of many national and shared aquifers, thereby increasing the risk of conflict.

The region's non-renewable shared aquifers, or 'fossil' aquifers that are being increasingly exploited include the Nubian Sandstone Aquifer, shared by Chad, Egypt and Libya; the North-Western Sahara Aquifer System shared by Algeria, Libya and Tunisia; and the Basalt Aquifer underlying Jordan and Saudi Arabia.

Water quality

The degree to which governments consider water quality a problem depends on differences in freshwater regimes and water scarcity conditions. Saltwater intrusion from over-pumping groundwater makes a major challenge of managing coastal aquifers, such as those along Egypt's northern coast, those along Lebanon's coast, those in the Gaza Strip, and the aquifers around several eastern Arabian Gulf coastal cities.

Expected rises in sea level will further increase stresses on coastal aquifers and river outlets, including the Nile Delta and at the Shatt Al-Arab. Pesticides and fertilizers from agricultural runoff, post-harvest processes, garment production, and domestic sewage are also contaminating surface water and groundwater in many areas. Impacts include eutrophication and fish kills in Lebanon, declining fish stocks in Lake Tunis (Harbridge et al., 2007), and negative aquaculture effects in the Egyptian Delta, thereby increasing food security risks. Pollution from oil production is a problem in some areas, although this is associated primarily with marine ecosystems. Rapid population growth in the Arab region, combined with migration pressures, inadequate urban planning and regulation enforcement, and large numbers of people living close to, or at, the poverty line, exacerbate the difficulties in protecting municipal water sources from contamination. Bifurcated water governance structures at the inter-ministerial level, and overlapping jurisdictional mandates between ministries and municipalities further complicate the situation.

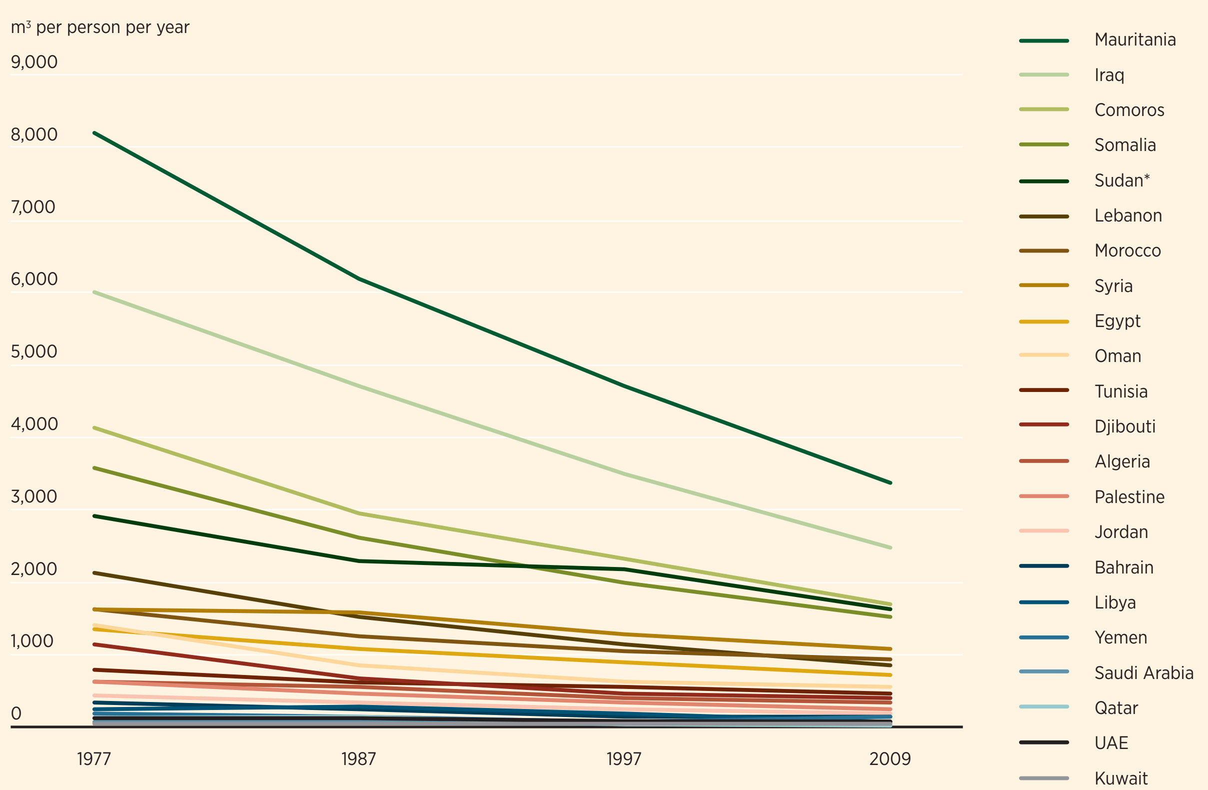
Food security

Agriculture is a primary source of water stress in the Arab region. It accounts for more than 70% of the total water demand in most ESCWA countries. In Iraq, Oman, the Syrian Arab Republic and Yemen, agriculture accounts for more than 90% of water use. Nevertheless, the region is unable to produce sufficient food to feed its populations, with ESCWA members importing 40% to 50% of their total cereal consumption. And the situation seems likely to worsen – studies predict climate change will cause a decline of as much as 25% in agricultural productivity in most countries in the region by 2080 (Cline, 2007).

Price increases in the global cereal market over the past few years, combined with unstable supply, also threaten food security, particularly since some countries are buying half or more of their cereal crops from abroad. The existing social structure also increases food supply vulnerability. In some countries, there is a concentration of wealth at the top, against the background where the majority of the population is clustered around or below the poverty line. Increased drought frequency, dependency on food imports and population growth leave the Arab region highly

FIGURE 7.7

Decline in renewable water resources in the Arab region per capita



*Note: *Area covering South Sudan and Sudan.*
Source: FAO AQUASTAT.

vulnerable to food insecurity. And in some countries, such as Egypt and Sudan, some are considering growing crops for more profitable commercial biofuels that will compete with food crops for the scarce water resources (ESCWA, 2009*e*).

As such, food security in the region has not been achieved at the national or regional level through food self-sufficiency. Subsidies and guaranteed price supports were used initially in some countries (including Egypt, Jordan and Saudi Arabia) to encourage food production. Subsequent initiatives to promote cereal production included greater investment in irrigation networks, increasing the capacity of reservoirs, and more pumping of groundwater. Intra-regional agricultural trade was encouraged through the Greater Arab Free Trade Agreement. As a result, there has been a shift in Arab food self-sufficiency policies towards a broader concept of food security, with governments that have the available financial resources able to pursue alternative measures within the global marketplace to achieve their food needs. Still others are re-examining their development and trade policies.

For instance, some countries are acquiring long-term leases on land outside their borders for food production, thereby increasing their imports of virtual water as a means to increase food security in face of growing water scarcity. Agribusiness firms and investment funds are leading this trend. Such land deals have become both popular and significant, with nearly 2.5 million ha of approved land allocations being made in African countries since 2004 (excluding allocations of less than 1,000 ha [Cotula et al., 2009]), which includes investments made by Arab countries. Although some aspects of this are controversial, this action provides some Arab countries with a relatively stable food supply, while providing host countries with infrastructure investments and potential economic returns.

Climate change and extreme events

The Arab region is particularly sensitive to the effects of climate change, particularly because it already suffers from extreme climate variability and water scarcity. Small changes in climatic patterns can result in dramatic ground-level impacts. Although the impacts remain uncertain, the expected consequences of climate change include increased soil temperatures and aridity, shifts in seasonal rainfall patterns (already being experienced in some rainfed agricultural areas such as the Syrian Arab Republic and Tunisia), reduced groundwater recharge rates, more frequent extreme weather events, including floods and droughts, reduced snowfall and snow-melt in some mountainous regions, and increased sea levels and water salinity in coastal aquifers. Droughts have already occurred more frequently in Algeria, Morocco, Syrian Arab Republic, Somalia and Tunisia over the past 20 to 40 years.

Larger populations, higher standards of living, and the associated increase in demand for water have contributed to the region's vulnerability to drought (ESCWA, 2005). The drought cycle in Morocco, for example changed from an average of one year of drought in every five before 1990 to one year of drought in every two between 1990 and 2000 (Karrou, 2002). In 2011, the Horn of Africa experienced one of the worst droughts in decades. Drought vulnerability is particularly significant in Arab countries that depend significantly on rainfed agriculture as a major economic activity. Drought also contributes to increased land degradation and desertification. Vulnerability to floods in the region has also increased as a result of rapid, often haphazard development in high risk areas such as *wadis*. Lax building codes and weak regulation and enforcement have played a part too, resulting in buildings and infrastructure that is not equipped to withstand major flood events.

Data and information

Lack of consistent and credible water resources data and information is hindering informed decision-making in the Arab region. It also is preventing the development of coherent and cooperative policy frameworks for shared water resources management and for assessing changes and progress. Some efforts have been made to increase the water resources knowledge base in the Arab region, including inter-governmental processes related to statistical reporting at the regional and global levels. Other processes have been established through regional reporting mechanisms or as academic initiatives.

Nevertheless, the difficulty of narrowing the gaps in the knowledge base rests to a large degree with political sensitivities and the national security concerns that are sometimes tied to this information. The result is that a patchwork of information and data from different sources is being used by the research and professional community, while official data often remains a resource that's sometimes difficult to obtain from governmental institutions.

7.5.3 Response measures

Institutional, legal and planning responses

Recognizing the need for a common approach to improving water resources management and achieving sustainable development in the Arab Region, the AMWC adopted the Arab Water Security Strategy in the Arab Region to Meet the Challenges and Future Needs of Sustainable Development (2010–2030) in 2011. Among its components, the strategy identifies priorities for action at the regional level focusing on the following: (1) socio-economic development priorities (including access to water supply and sanitation, and water for agriculture), finance and investment, technology, non-conventional water resources and IWRM; (2) political priorities that include managing shared water resources and protecting Arab water rights; and (3) institutional priorities associated with capacity building, awareness raising, research, and participatory approaches that involve civil society.

Regional institutions and initiatives have also been launched in the Arab region to respond to these priorities. These include the Arab Ministerial Water Council, whose first ministerial session was hosted by Algeria in June 2009. The Ministerial Council is an inter-governmental council established within the framework of the League of Arab States. It is supported by an Executive Bureau, a Technical Scientific Advisory Committee and a Technical Secretariat. Another example is the Arab Countries Water Utilities Association (ACWUA), which focuses on dialogue and capacity-building for water supply and sanitation. These institutions, among others, coordinate several regional water initiatives in the Arab region focused on climate change, shared water resources, integrated water resources management, MDGs and so forth.

At the national level, different ministries and authorities in the Arab region have the responsibility of managing water resources and delivering water services. Although only a few joint committees or units exist to support shared water resources, efforts have been enacted or are underway to improve institutional and legal frameworks in the water sector, including an increased incorporation of issues previously limited to IWRM planning. Institutions for addressing various issues associated with these goals have been established in Morocco (Makboul, 2009), Egypt, Yemen, Jordan, Palestine and Lebanon. The range of the various mechanisms include decentralization, private-public partnerships, public utility performance indicators, the integration of water resources management into development planning, groundwater management, infrastructure management, and sanitation and water resources management.

To strengthen resilience and preparedness regarding food security, some Arab countries have sought to ensure food security through trade, investment and contractual arrangements with other countries. Long-term leasing of agricultural lands in other countries has emerged as a tool for overcoming domestic agricultural production problems arising from water, land, energy and technological constraints, resulting in reduced food security risk. The host countries, in turn, can secure investments over an agreed time horizon allowing for the development of transport, water and energy infrastructure in the leased areas, as well as enhanced primary and secondary agro-industries. Areas targeted by the Arab region for future investment include Egypt, Sudan, Turkey, Ethiopia, Philippines and Brazil. The private sector and private investment firms also are involved. Putting such efforts into operation, however, has proven controversial, especially where indigenous communities and

> "To strengthen resilience and preparedness regarding food security, some Arab countries have sought to ensure food security through trade, investment and contractual arrangements with other countries."

pastoralists have traditionally used the leased lands. Chapter 33 provides further details on this topic.

In efforts to increase resilience to climate change adaptation and improve disaster preparedness, the Arab Ministerial Declaration on Climate Change (2007) expressed commitment to focus more on climate change adaptation and mitigation. It was followed by the drafting of a climate change action plan in the region. At the same time, Arab countries have worked to assess the effects of climate change on natural water resources as a means of informing their national adaptation plans and communications to the Inter-Governmental Panel on Climate Change (IPCC). A unified assessment was launched by the League of Arab States (LAS) and UN organizations serving the region under the Regional Initiative for the Assessment of the Impact of Climate Change on Water Resources and Socio-Economic Vulnerability in the Arab Region, being reported to the AMWC and the UN Regional Coordination Mechanism.

Risk and uncertainty related to climate change and extreme weather events have also facilitated national and regional efforts directed at reducing disaster risk, planning and preparedness. The Arab Strategy for Disaster Risk Reduction for 2010–2015, adopted in 2010 by the Council of Arab Ministers Responsible for the Environment (CAMRE) and supported by the UN International Strategy for Disaster Reduction (UNISDR) and regional partners, focuses on national disaster inventories and capacity-building directed at improving land use planning, regulatory frameworks, financing and access to user-friendly information and communications tools.

Infrastructure responses

All Arab countries have pursued supply-side approaches to address increasing water demands. This has included dam building, desalinisation and water reuse, reservoirs, and new technologies to improve the efficiency of traditional and non-conventional methods such as water harvesting. Although large dams can have important negative environmental and social impacts, they also help reduce the uncertainty and risk related to floods and climatic variability.

A number of Arab countries have increased their total dam capacity. Egypt is at the forefront of this with a capacity of at least 169 km^3 added since 2003. Total dam capacity in Iraq for water supply nearly tripled between 1990 and 2000, from 50.2 km^3 to 139.7 km^3, while the Syrian Arab Republic increased its capacity from 15.85 km^3 in 1994 to 19.65 km^3 in 2007. Dams have also worked to counter the damage associated with flood events. The Sinai and Aswan dams effectively stored water during the 2010 flood, for example, protecting Ne'ama Bay, Nuweiba'a and Dahab in Egypt from floods (Government of Egypt, 2010), while also raising the groundwater table and preventing coastal saltwater intrusion.

One other approach being used by Arab countries to address water-associated risk and uncertainty is better management of aquifer recharge, as a means of both countering saltwater intrusion into coastal aquifers (particularly along the Mediterranean and Arabian Gulf coastlines), and for storing excess desalination-produced water as a buffer for future water demands or desalination plant failures in the GCC countries.

Arabian Gulf countries rely heavily on desalination for freshwater resources. Saudi Arabia currently has the world's greatest desalination capacity, followed by the UAE as the second largest producer. Jointly, they produce more than 30% of global freshwater production (ESCWA, 2009*c*). Desalination capacity also is supplying a growing share of freshwater in Algeria, Egypt, Iraq and Jordan. Co-generation, where power and desalinated water are produced at joint facilities is expanding in the Gulf region (Zawya, 2011), although this is not a cost-effective solution in energy-poor countries. Jordan, Morocco, Saudi Arabia and the UAE are advancing nuclear desalination prospects. Small household-level desalination units are being used by about 100,000 households in the Gaza Strip as a secondary drinking water source (World Bank, 2009), although health problems arose when the filters were overused because replacements could not be found.

The reuse of treated wastewater currently accounts for about 15% to 35% of total water resources produced from non-conventional sources in Egypt, Iraq, Saudi Arabia, the Syrian Arab Republic, and the UAE. Rainwater harvesting has expanded in the Arab region, and water harvesting through forest condensation is being increasingly considered. Other innovative approaches include fog harvesting and cloud seeding. Advanced remote sensing techniques (Shaban, 2009) have facilitated the identification of underwater springs in the region, although this approach could cause territorial disputes over shared sea and submarine resources. The Arab and Western Asia Regional Report provides further details on non-conventional water sources in the Arab region.

In the face of inherent water scarcity, coupled with rising populations and water use, demand-side management is another strategy to address the risks associated with water scarcity in the region. These actions include reducing water consumption, increasing water use efficiency, and adopting new types of regulations such as permits and tariffs for improved water services.

Despite these various risks and uncertainties, water is at the core of Arab culture and consciousness. Nevertheless, the Arab region faces continuing water scarcity, population growth, food security, climate change, extreme weather events, and existing and potential new conflicts over shared water resources. These factors, individually and collectively, will continue to influence the ability of Arab countries to manage the region's surface water and groundwater resources.

7.6 Regional–global links: Impacts and challenges

7.6.1 Linking the regional to the global

On a global scale, human activity, climate variability and other external pressures have taken their toll on both the availability and the quality of water. They have also weakened the ability of aquatic ecosystems to perform essential functions which support sustainable development (UNEP, 2006*a*). Over the last two decades, there has been international recognition that there is a need for a more sustainable use of water resources.

As demonstrated in Chapter 9, the global picture is composed of a number of inter-related environmental, economic, political, technological and social drivers. In order to understand the complex relationship between regional water challenges and global water problems, it is necessary to examine how regional challenges are linked to global water problems. Water challenges do not occur in a vacuum – through a series of interconnected webs they affect diverse countries and communities in many ways. The negative effects of the environmental degradation of water supply and excessive water withdrawals are borne not just by the regions in which such activities occur – their impact can be felt worldwide. Yet international cooperation through trade and other means can help to alleviate local pressures in areas of water scarcity by focusing water intensive activities in areas of greater water abundance and sharing those benefits with regions that may not have the water resources necessary to meet all the basic needs of their increasing populations (see Chapter 1). This interconnectedness will be demonstrated in this section by examining regional threats and their global outcomes, by looking at the ways in which economic and trade policies have influenced regional water management, and by considering a number of governance challenges.

Commitments to address water scarcity and shortages are made at international level, but the gap between these international objectives and the reality on the ground seems more and more evident. This stresses the need for a regional focus. For instance, a variety of global instruments addressing water issues have been established over the last decade: the United Nations General Assembly and the Human Rights Council of the United Nations recognized in July and September 2010, respectively, the right to water and sanitation as a human right (see Section 1.2.4); the G8 endorsed the Evian Action Plan; the World Economic Forum endorsed the Water Initiative in 2010, which encourages public private partnerships to work towards for a more water secure world; and a host of other initiatives have also been set up, including the World Water Council and the World Water Forum.

However, on the ground, many countries are becoming more water insecure, disparity of access is increasing, and all too often water administrators lack operational capacities and are becoming less coordinated in their efforts to address the water issue. Throughout the world, billions of people live in countries that do not have the water resources to meet their basic needs. Because much of the expected population growth will occur in regions that are increasingly unable to grow their own food, there will be more pressure on neighbouring countries and other regions that are better endowed with land and water. This is likely to create a very particular dynamic of inter-regional dependency, and a fragile balance between the 'haves' and the 'have nots' will need to be maintained.

When looking at the very tangible example of transboundary basins, which provide the bulk of water resources for drinking, sanitation, agriculture and industry, one notes that only 40% of transboundary basins

> "Poorly regulated foreign investments in lands that could be otherwise used to feed local populations, could potentially have devastating consequences on the fragile state of food security at the national level."

actually have even one agreement in place to govern the way the basin is used and managed (De Stefano et al., 2010). This is particularly worrisome as Africa has been identified by the IPCC as one of the continents that is most vulnerable to water stress, and which has increasing levels of desertification (IPCC, 2007). Unless these issues are addressed at the regional level, global commitments simply cannot be fulfilled.

The case of large land acquisitions

When addressing regional issues it becomes clear that policies and actions implemented in one geographic area have repercussions in other places. For instance, in efforts to conserve their scarce water resources, a number of countries are investing in agriculture abroad (Box 7.14). There are three main sources of law that govern foreign investment in agriculture: domestic law, international investment contracts, and international investment agreements, or IIAs. The interplay between them determines the extent to which international law will prevail over domestic law in any given instance and provide additional rights and remedies to foreign investors. In developed states, the domestic law provides a broad base that protects domestic stakeholders and governments and sets obligations for all investors. When this is not the case, as in many developing states, a weak or incomplete domestic legal base on social, economic or environmental issues can allow international contracts and treaties to enjoy much more liberal rights and entitlements. This is particularly relevant to foreign investments in agriculture, where domestic land tenure rights, water rights, environmental management regimes relating to chemicals, labour law on farms and so on can be weak or absent (Mann and Smaller, 2010). Saudi Arabia, one of the Middle East's largest cereal growers announced it would cut cereal production by 12% a year to reduce the unsustainable use of groundwater. In order to protect its water and food security, the Saudi government issued incentives to Saudi corporations to lease large tracts of land in Africa for agricultural production. By investing in Africa to produce its staple crops, Saudi Arabia is saving the equivalent of hundreds of millions of gallons of water per year and reducing the rate of depletion of its fossil aquifers. Saudi investors have already leased land in Sudan, Egypt, Ethiopia and Kenya. India is growing maize, sugarcane, lentils, and rice in Ethiopia, Kenya, Madagascar, Senegal and Mozambique to feed its domestic market, while European firms are seeking 3.9 million ha of African land to meet their 10% biofuel target by 2015 (Cotula et al., 2009).

This clearly demonstrates how policies enacted in one region have an impact on others through water. But there may be unforeseen negative consequences in many of the African states where these transactions are taking place. For instance, countries such as Ethiopia, where India has purchased 1 million ha of land, is one of the most food insecure countries in the world. Poorly regulated foreign investments in lands that could be otherwise used to feed local populations, could potentially have devastating consequences on the fragile state of food security at the national level. Other consequences include the displacement of populations, the dispossession of land, potential conflicts and instability as various groups are uprooted. There are also considerable negative environmental consequences as large-scale industrial agriculture requires fertilizers, pesticides, herbicides and large-scale transport, storage and distribution. Many of the states where such activities are taking place also have weak governance structures, with little legal protection for local communities and no benefit sharing mechanisms As a recent World Bank report notes, such agro-investments have deprived local people, particularly the most vulnerable, of their rights without providing appropriate compensation, while neglecting environmental and social safeguards (Deininger et al., 2010), and

BOX 7.14

Water dimensions of the surge in transnational land acquisitions

The current surge in large-scale transnational land acquisitions (also known as 'land grabs') results in fact from several drivers that have been accumulating for decades: the increase in population, coupled with changes in consumption habits, the stagnation of investment in and reduced aid to agriculture, reforms and structural adjustment programmes, and, more recently, the increase of land areas devoted to biofuel crops, often at the expense of food crops. Land degradation and water resource depletion have also constrained the ability of the agriculture sector to cope with the escalating demand for food. These drivers have increased the dependency of many developing countries on food imports and made small farmers – and, more generally, the rural and urban poor – more vulnerable than they had been to international food price fluctuations. More immediate triggers of land grabs were the food price hike in 2008, the oil price hikes during 2007–2008, and unfavourable weather conditions experienced in key cereal producing countries at around this time.

As there is currently no regulating or monitoring mechanism for these deals, the acreage of transnational land acquisitions is subject to great variability according to source and date, ranging from 15–20 million ha in 2009 (aggregate of the land deals listed in von Braun and Meinzen-Dick [2009]) to more than 70 million in 2012 Land Matrix Project data quoted in Anseeuw et al. [2012]). The database of the Matrix contains more than 2,000 deals, of which approximately half, totalling some 70 million ha, have been cross-checked. Africa consistently appears to be the prime target for these deals, with sub-Saharan Africa accounting for two-thirds of their acreage.

Some of the most active investors in large-scale transnational land acquisitions are oil-rich but food-insecure Gulf states, land-scarce, populous Asian countries, and developed countries. Non-state investors include Western food producing, processing and exporting companies – new actors attracted by biofuel demand and opportunities related to investment funds.

While the drivers behind land acquisitions have been discussed at length in the recent literature, the importance of access to water (in particular for irrigation) in driving the transnational search for land has not received adequate attention.

For China and India, water scarcity constrains the possibilities of responding to the growing food demand and therefore food security challenges through increasing domestic agricultural production, so alternatives must be explored. The land available for agriculture is also closing in these countries. Because of rapidly depleting fossil groundwater resources, Saudi Arabia had to reduce wheat production, leading to resumption of wheat imports in 2007 (Cotula et al., 2009; Smaller and Mann, 2009; Woertz, 2009); at around the same time (in 2008), an agricultural fund was established to promote agriculture investment abroad (Smaller and Mann, 2009).

Because of the growing unreliability of rainfed agriculture and growing freshwater scarcity, investors' crops often need irrigation, so a secure supply of water is a key aspect of the decision whether or not to invest. Agriculture trade specialists have long recognized the notion of trade in virtual water. Today, investment in water rights in foreign states through the purchase or lease of land with associated water rights and access is a critical motivation and part of the new process of securing long-term farming investments.

Nevertheless, water is typically not explicitly mentioned in the disclosed land deals. In the few cases where water is referred to, the amount of permitted water withdrawals is not specified. Evans (2009) quotes the Chief Executive Officer of Nestlé as saying, 'with the land comes the right to withdraw the water linked to it, in most countries essentially a freebie that increasingly could be the most valuable part of the deal. And, because this water has no price, the investors can take it over virtually free.' The consequences of this trend is harmful for the rural poor when they are forced to compete for scarcer water with actors who are more financially powerful and technically better equipped. Potential inter-state tensions and conflicts, especially in transboundary basins, are also a cause for concern. The current pace of land acquisitions and the related concessions of water rights to investors carry great threats to transboundary cooperation in many river systems, such as the Nile, Niger and Senegal basins.

In this context, approaching lack of land access and tenure insecurity in isolation from water rights is anachronistic – traditional solutions confined to the land sector are in many settings no longer effective. Water and land have become key strategic resources, more interlinked than ever before, so an integrated management approach to respond to the challenges of these resources' degradation and depletion is likely to be more effective than considering them in isolation. It is also imperative that investors take into account the possible impacts of these projects from the early planning stages on and incorporate appropriate measures.

Source: Madiodio Niasse (International Land Coalition Secretariat), Praveen Jha (University of Delhi), Rudolph Cleveringa (IFAD) and Michael Taylor (International Land Coalition Secretariat).

proposes principles for responsible agro-investments for fostering mutual benefits from agricultural investments abroad.

Similarly, the People's Republic of China has invested heavily in land in Indonesia, Thailand, Malaysia, Mozambique and the Democratic Republic of Congo, among others, to fulfil its biofuel policy. By 2020 the Chinese government anticipates that 15% of China's transport energy needs will be met by biofuels. As part of a massive plan to reduce greenhouse gases, China will replace 12 million tons of oil with 2 million tons of biodiesel and 10 million tons of bioethanol each year (Kraus, 2009). Despite the positive goal of investing in 'green and clean' energy, China's interventions have succumbed to negative externalities such as deforestation, biodiversity threats caused by monocultures, increased food prices and decreased food stocks (the International Monetary Fund estimates that that the increased demand for biofuels accounted for 70% of increased maize prices and 40% of soya bean prices between 2006 and 2008). The interventions have also caused population displacement, as land is converted into plantations, and water scarcity because water is a major input for growing primary biofuel commodities (Kraus, 2009). The amount of water required for biofuel plantations could be particularly devastating to regions such as West Africa, where water is already scarce (UNCTAD XII, 2008). For example, 1 L of ethanol from sugarcane requires 18.4 L of water and 1.52 m^2 of land (Periera and Ortega, 2010).

7.6.2 Regional threats and global outcomes

Weather-induced regional natural disasters and global impacts

The impacts of natural disasters are being felt more deeply in most regions of the world (see Section 4.4 and Chapter 27). Of all the natural and anthropogenic adversities, water-related natural disasters are the most recurrent, and pose the most serious impediments to achieving human security and sustainable socio-economic development (Adikari andYoshitani, 2009).

The factors that are thought to have contributed to the more severe impacts of water-related disasters include natural pressures, such as climate variability; management pressures, such as the lack of appropriate organizational systems and inappropriate land management; and social pressures, such as an escalation of population and settlement in high-risk areas, particularly by vulnerable populations (Adikari and Yoshitani, 2009).

Droughts, in addition to causing decreased access to water for particular communities, have significantly affected agricultural production – which has contributed to soaring food prices and food shortages (Krugman, 2011). For example, the cost of wheat almost doubled between the summer of 2010 and the summer of 2011 as a result of a sharp decrease in world production. According to the US Department of Agriculture, the bulk of this drop in wheat production can be attributed to Russia and Central Asia, which experienced record drought and heat in the summer of 2010 (Krugman, 2010). Fires in Russia and the ensuing decision to temporarily halt wheat exports led to sharp and rapid price hikes around the world (Hernandez, 2010). Increasing the price of a commodity like wheat does not merely affect its by-products and related foodstuffs. These increases have other major socio-political impacts, and can lead to far-reaching consequences such as food riots and political instability.

For instance, in Egypt the price of wheat is now 30% higher than it was in 2010 (Biello, 2011). Egypt consumes a great deal of wheat and rising bread costs coupled with other socio-political issues, resulted in considerable political instability and civil unrest. The relationship between food prices and political unrest in Egypt did not go unnoticed by other Middle Eastern countries – Algeria, Jordan, Libya, Morocco, Saudi Arabia, Turkey, Qatar and Yemen have all been purchasing larger supplies of wheat on the world market to limit soaring prices. This clearly demonstrates the link between drought-based food shortages and larger socio-political impacts.

Similarly, floods can have devastating effects on safe water supplies and have global impacts that go far beyond the regional scope. Floods, as the IPCC has concluded, are projected to increase in magnitude as a result of global warming and its effect on the hydrological cycle (IPCC, 2007). These are predicted to affect crop yields and livestock beyond the impacts of mean climate change. The number of people vulnerable to flood disasters worldwide is expected to mushroom to two billion by 2050 as a result of climate change, deforestation, rising sea levels and population growth in flood-prone lands (Adikari and Yoshitani, 2009).

As was seen in the case of drought, the damage caused by floods has worldwide consequences. For instance, in the January 2011 floods in Australia, over 900,000 km^2 of Queensland was flooded. That the floods had devastating effects on the socio-economic structures of Australia was to be anticipated, but what was surprising was the effect they had on a number of emerging economies too. Queensland is the biggest hub for Australia's coal exports and produces 28% of the world's total traded coal. In particular, Australia produces metallurgical coal on which 70% of steel production worldwide is dependent. Japan, India, China, Taiwan and South Korea were all affected by water damage in Queensland because their economic growth is heavily reliant on coal. Such consequences are not restricted to merely economic output, they also have an impact on livelihoods and infrastructural development.

7.6.3 Conflict, competition and cooperation

Water shortages can cause conflicts of varying intensities and scales. Although conflicts may appear localized, they present challenges to the broader context of peace and security. The multifaceted effects of conflict, such as displacement, mass migration, disruption to livelihoods, social breakdown, violence, health risks and human casualties, all have ripple effects that are felt throughout the global context. Conflict over water resources can also turn into, or fuel, ethnic conflicts. Because ethnic conflict is most commonly fuelled by collective fears for the future (Lake and Rothchild, 1998), it is easy to see how water scarcity could play to such fears.

Water has never been the sole cause of a major war, but nation states as we know them have also never experienced the kind of water shortages that are anticipated. Although there may have not been an outright war over water, it has still, historically, caused sufficient violence and conflict within and among states to warrant attention (Postel and Wolf, 2001). Where water is scarce, it can be viewed and interpreted as a security threat (Gleick, 1993).

When examining the case of Pakistan and India for instance, it is clear that water can be a potentially divisive issue in a context where the two countries are otherwise pursuing cooperative talks and negotiations. For instance, in order to feed its booming growth, expanding population and soaring energy needs, India is building numerous multipurpose dams. Currently it is at various stages of executing 33 projects that are raising concerns in Pakistan. The most controversial project, the 330 megawatt dam on the Kinshanganga River has sparked a reaction in the Pakistan. Although studies indicate that no single dam along the waters regulated by the Indus Water Treaty can stop or reduce water supply to Pakistan, the cumulative effect of all the dams can give India the ability to limit water supply to Pakistan at crucial moments during growing season, according to the US Senate Committee on Foreign Relations in 2011. It is important to note however, that this Senate Committee Report is contested by Indian government officials.

In today's global security context, no region is truly immune to conflict or strife in another. Despite political tensions however, nations have managed to successfully cooperate on water. For instance, India and Pakistan, despite fighting wars in 1965 and 1971 and facing cross-border confrontation in 2001–2002, have managed to adhere to the water commitments embedded in the Indus Waters Treaty (1960). Thus, collaboration on water issues is possible, and offers potential for cooperation between states. There is also a long tradition of successful cooperation in the field of transboundary water resources in Latin America (Querol, 2002).

Economic and trade policy impacts on regional water management

Economic and trade policies play a crucial role in promoting the sustainable use of water resources. The question that arises is what sort of policies are best suited to ensuring sustainable outcomes at national, regional and global levels. There is a tendency towards protectionist policies that protect national or regional resources, particularly as water becomes scarcer and more valuable. Protectionism argues that use of economic instruments and the market mechanism risks having water resources diverted to regions that have more economic prowess, leaving the vulnerable further marginalized. However, enacting protectionist policies can also foster a climate of inequality where water-poor regions cannot afford products that have high water footprints.

Policy-makers have to be cognizant that neither the market-based nor the exclusive reliance on command-and-control approaches can be a 'one-size-fits-all' approach. After all, what may seem like a beneficial intervention in one place, may have unintended consequences in others, given the complexity of the links between countries and regions. As some theorists suggest, resource scarcity in one region can have significant indirect effects on the international community. For instance, it can encourage powerful groups to capture vulnerable resources and force marginal groups to migrate to ecologically sensitive areas. This can lead to regional power struggles and instability within the international community, which could possibly provide elements for broader intra-state and inter-state conflict (Homer-Dixon, 1994).

In Chile, the existence of secure property rights in water appears to have made a noticeable contribution to the growth in the value of agricultural production (Lee and Jouravlev, 1998). The introduction of water markets coincided with a major increase in agricultural production and productivity. The influence of water markets, however, cannot be fully separated from the effects of economic stability and other economic reforms, especially trade liberalization and secure land rights. Trading does appear, however, to have succeeded in reallocating – with little conflict – water rights to higher value uses such as export-oriented agriculture, urban water supply and mining (Donoso, 2003).

"Countries have also subscribed to international processes to harmonize perspectives and approaches to particular uses of water. Despite this, one of the major challenges is that countries attach different valuation to water and do not approach the resource with a common understanding."

There are useful reasons for incorporating the positive aspects of the market-based mechanisms when considering water resources. For instance, one of the reasons for water resource depletion is that water has been generally undervalued as a resource. It is thus important to place a value on it. Whether earmarking it as a commodity is the best way to place a value on it, is subject to debate. However, whether through norms or values, water resources must be valued for their worth, otherwise the trend of degradation will ensue. As highlighted in the Millennium Ecosystem Assessment, the heterogeneous nature of water makes it neither a public good nor private good, and it should not be treated uni-dimensionally (MES, 2005).

When attempting to make choices about how to place value on water resources in particular regions (in order to contextualize trade and economic policy), it may be useful to couch decision-making within the rights-based approach that the UN has adopted (see Section 1.2.4 about water and sanitation as a human right). Despite varying trends on how to treat water resources in different regions, the rights-based approach can provide a baseline where the protection of water rights, particularly of the most vulnerable, underpins other enterprises, legislation and policies governing transactions.

7.6.4 Governance challenges

'Water governance refers to the range of political, social, economic and administrative systems that are in place to regulate development and management of water resources and provisions of water services at different levels' (GWP, 2003, p. 7). Although many initiatives have been established to address the weaknesses in water governance, there remains a large chasm between regional governance and global governance structures.

In many ways, national structures are unable to address regional water resources issues, some of which may have global impacts. Regional and global mechanisms intervene when local- or national-level structures are insufficient to address water problems. Countries have also subscribed to international processes to harmonize perspectives and approaches to particular uses of water. Despite this, one of the major challenges is that countries attach different valuation to water and do not approach the resource with a common understanding (Langridge, 2008) (see Chapter 10). There are therefore challenges involved in transposing a governance structure that works in one region to another region – and harmonizing water policy objectives remains an elusive goal. As water is so closely linked to society, economy and the environment, there are no simple or easy answers that would ensure proper governance irrespectively. Although governance may be expressed in different organizational systems and its formal content arranged differently (such as laws and institutional arrangements), designing the governance system for a society must consider the natural conditions, power structures, and needs that are specific to that society.

Because international governance is driven by national member states, it is not surprising that it is often fragmented. Yet positive examples exist where different elements of individual systems can be replicated. For instance, the USA, France and Australia have developed highly sophisticated and resilient regimes for integrated river basin management (Shah et al., 2001). Many developed countries address the natural variability in terms of supply-side infrastructure to assure reliable supply and reduce risks. Although developing countries may not be able to import these structures because of their differing realities (for instance supply-side solutions alone may not be adequate to address the ever increasing demands from demographic, economic and climatic pressures), these countries may replicate other aspects such as waste-water treatment and water recycling and may promote demand management measures to counter the challenges of inadequate supply (UN-Water, 2008). Chapter 14 highlights other such instances where various elements of differing systems can be adopted by water managers, and adapted to particular contexts.

The needs of particular constituencies have to be at the heart of any effective regional governance mechanism. Although what has worked in one region may not necessarily work as effectively in another – such as in the case of the 'user pays' principle, which was successfully enforced in Australia, but abandoned in the Solomon Islands where it was determined that it was not sustainably viable because of major differences in political structures, national priorities, living standards, technical capacities, financial and infrastructural growth and change management competency (Shah et al., 2001). But common aspects of different systems can be explored (see Chapter 14).

Despite the variations that may occur in regional governance frameworks, there are also commonalities. These could support the basis of effective structures, and would include:

- Improved technical systems for water management
- Strengthened local managers
- Efficient resource management at the local level
- Improved horizontal and vertical coordination between different levels of authorities
- Improved information and monitoring systems
- Consensus-building, especially in professional groups, enhanced public participation in knowledge management of water resources
- The promotion of both regional and international cooperation

These improvements may be administered and implemented in different ways, but could yield to strengthened governance structures across different regions.

One of the challenges of strengthening governance structures is financing – this applies at both the international and the national levels. The resources may simply not be available for giving an overhaul to inefficient or underdeveloped administrative systems. As water scarcity becomes a pressing issue, synergies will have to be sought in different sectors. Water will not only have to be addressed by sustainable development or poverty alleviation schemes, but will have to be integrated more substantially into international cooperation, diplomacy, security and migration efforts.

Water law and science cannot be discrete areas of research and expertise. They must be integrated into areas which may seem unrelated – areas such as education, urban planning and social development. Addressing water shortages in the future has to integrate new levels of cross-sectoral and cross-regional thinking and coordination and should include a long-term vision.

Notes

1 See http://www.who.int/about/regions/afro/en/index.html for the WHO's definition of northern Africa and sub-Saharan Africa (SSA). SSA excludes Algeria, Egypt, Libya, Morocco and Tunisia.

2 This situation is further complicated by the fact that minimum water levels are fixed to account for navigation.

3 The terms 'Asia and the Pacific' and 'ESCAP region' refer to the group of members and associate members of the Economic and Social Commission for Asia and the Pacific.

4 Calculation by ESCAP staff based on the Joint Monitoring Programme 2010 report, accessed on 10 May 2010 at http://www.wssinfo.org/datamining/introduction.html

5 For the purpose of this analysis, conflict is not limited to armed conflict, but includes all water-related disputes necessitating mediation. Whether violent or not, these disputes have threatened the stability of the socio-economic development process in the region.

6 Calculation by ESCAP based on data from UNEP (2002).

7 The UNEP figures are based on ECLAC (2009), which defines 'extremely poor' as unable to meet basic nutritional requirements, even if all money is spent on food.

8 Caribbean countries in Central America and South America: Suriname, Guyana, French Guiana and Belize.

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PART 2

Managing Water under Uncertainty and Risk

INTRODUCTION

Author Daniel P. Loucks

Acting in an environment of uncertain change

The world is undergoing considerable change. Political and social systems are transforming in ways that are not always predictable, producing a variety of impacts. Technology is evolving and living standards, consumption patterns and life expectancies are all changing. Human populations are growing and increasingly moving to expanding urban areas while agriculture is expanding to feed them. Consequently, land use and cover is altering, as is the climate. The rates at which these changes occur are in many cases increasing, while their long-term impacts often remain uncertain. Discontinuities are possible and tipping points can exist beyond which change is irreversible. These changes can impact regional water cycles in ways that alter the quality, distribution and quantity of freshwater supply and demand.

Changes in daily lives, lifestyles, technology and environment will likely continue at an accelerated rate. Each day can bring new risks, uncertainties and opportunities. Humans experience more stress when expected to accomplish more of everything faster, more efficiently and with fewer resources. Change is a fact of life for everyone and everything that lives. Seasons change, people change, goals and emotions change, businesses change, and in part because of changing lifestyles and technology, so does the supply and quality of water available to meet the demands that result from these changes (see, for example, Jackson et al., 2001; Kates and Clark, 1996; Marien, 2002; Ostrom, 1990; Tansey and O'Riordan, 1999).

How can water managers plan for and adapt to increasingly uncertain future water resource conditions? How can water users plan for and adapt to the uncertainty of future water supply and quality? How can the people who create, regulate and adapt governance structures from local to global levels, within which we all operate and interact, meet the needs of all users living now and those who will live in the future? This includes the needs of our environment and the underprivileged and voiceless. How can society work together to increase levels of sustainability given uncertain future change (Vincent, 2007; Watkins and McKinney, 1997)?

Adapting to change presents an opportunity. What has happened in the past cannot be changed, but the future can be influenced by the decisions being made now. Water is a primary medium through which changes in human activity and the climate interact with the Earth's surface, its ecosystems and its people. It is through water and its quality that people will feel the impact of change most strongly. Without proper adaptation or planning for change, hundreds of millions of people will be at greater risk of hunger, poor health, energy shortage and poverty, water scarcity and pollution, and/or flooding (Anderies et al., 2004; Folke et al., 2002; Ganoulis, 2004; Holling et al., 2002; Lu, 2009; NRC, 1983; Pahl-Wostl et al., 2007).

Many people are concerned about the environment, but most tend not to take or advocate environmental action. Often the costs of possible remedial actions are deemed to be near term, whereas the benefits can be perceived to be further in the future. Another reason for inaction is uncertainty in determining the relative merits of different actions. Effective public policy-making requires that professionals work to clearly communicate the uncertainties surrounding alternative futures, how those uncertainties can be reduced, and which actions can provide the best assurance of desired outcomes in the face of those uncertainties (Cabinet Office Strategy Unit, 2002).

Uncertainty about the future is not an excuse for inaction. Decisions on water infrastructure investments, operation and management need to be made in the near term if benefits are to be obtained in the long term, that is, in the future. Waiting decades for more precise knowledge is not a feasible or acceptable excuse for inaction. Decisions regarding water infrastructure investments and operation are needed before the benefits of their services can be obtained, and hence such decisions will undoubtedly be based on uncertain data and assumptions. Exact knowledge about futures will never be available. All who impact water availability, how it is managed, and how it is used, even indirectly, need to make decisions based on non-precise information available at that time (Cosgrove and Rijsberman, 2000; Funtowicz and Ravetz, 1990; Morgan and Henrion, 1990).

Increased interaction among the interested public and scientists and policy-makers enables improvement in decision-making processes. This interaction needs to question and expand the range of policies that are proposed, debated and implemented. Participants need to help inform policy-makers and the public, and the public needs to make inaction unacceptable. Stakeholders can offer new ideas for political debate about how society and nature can be organized. They can test and explore all ideas to assess their relative merits. All stakeholders should visualize alternative futures, develop alternative policies for meeting the futures they like, and assess their likely impacts and uncertainties (NRC, 1996; Wildavsky and Dake, 1990).

What is known now or what can be assumed now? It is important to:

- Recognize that decision-makers in governments, the private sector and civil society, and all of us individually, deal with multiple issues involving risk and uncertainty. Particular decisions may or may not have been influenced by considerations of water, even though they may have an impact on water.
- Be aware of and understand the broader picture and what is happening in other sectors of the economy and society, so as to help inform the people making decisions in those sectors of their impacts on water, and of the impacts of water on them. Coordinated and synergistic management in related domains improves overall outcomes. After all, these sectors and domains are subject to the same or similar uncertainties that challenge water managers and users, and are continually engaging in risk management.
- Accept that change will continue into the future, and that much of it is largely beyond society's control. Consequently, approaches to water management should be adaptive, responsive and anticipatory.
- Approach sustainable water management as a journey along an adaptation pathway, rather than an arrival at a destination.
- Favour adaptation decisions that are robust to uncertainty in economic, social and ecosystem domains.
- Track emerging patterns and associated responses by strengthening monitoring networks and freshwater indicators.
- Shift from 'impacts thinking' to 'adaptation thinking', and adopt strategies that have a good chance of resulting in minimal, if any, regrets.
- Build change adaptation into all hierarchies of water resources management, from national to river basin and local actions.
- Secure environmental flows as one of the core objectives of water resources management to achieve balanced benefits for all.
- Manage existing and build and operate new water infrastructures in climate-smart ways.
- Include 'natural infrastructures' (e.g. wetlands, floodplains) in response options and employ them wherever feasible.
- Improve freshwater ecosystem connectivity and integrity.

'Impacts thinking' relies on the ability to predict the impacts of decisions. Current practice places great faith in the ability of analysts to predict the specific impacts of alternative decisions, which drive, or at least influence, change adaptation activities. This is reactive 'impacts thinking'; the problem is that the assumptions made and the impact topics selected by analysts can be too narrow, and are often uncertain. This is reflected in the estimated impacts or outcomes. 'Adaptation thinking' acknowledges the inherent uncertainty associated with model-based impact predictions and treats economic, social and ecosystems as dynamic entities that will likely differ from current and past states for multiple reasons. This approach promotes flexibility and continuous scenario development and analyses (Alcamo et al., 2000; van Notten, 2005).

Uncertainty constrains our ability to precisely qualify and quantify the risks associated with different management actions. The precautionary principle suggests that the greater the uncertainty (i.e. the less our capacity to precisely define or quantify risk) and the more catastrophic the possible outcome, the more cautious and 'reversible' the management actions should be (UNESCO, 2005). Although future research may help reduce some uncertainties, it may also uncover new uncertainties, which in fact increases our knowledge about what is uncertain and perhaps the range of that uncertainty. Uncertainty impairs future projections, and some of this uncertainty includes lack of confidence about what is uncertain. Surprises and unpredictable shifts in societal goals and needs are by their nature uncertain and as such cannot be accurately predicted.

Water planners, managers and users, and anyone who in any way impacts on the quantity, quality, distribution and use of water, can actively address uncertainty. Not all uncertainties can be reduced by further research, and even where reduction is possible it comes at a cost. Science can help articulate where and how to reduce uncertainty and under what conditions it cannot be reduced. There are limits to scientific knowledge and the role of scientists in decision-making.

The need to consider risk and uncertainty was acknowledged in the closing chapter of the third edition of the *World Water Development Report* (WWAP, 2009), with an emphasis on the consequences of inaction. Risk and uncertainty have long been a routine challenge for people managing and using water across all economic sectors and regions of the world. What is new is the recognition of the nonstationarity of hydrological processes, brought on by climate change, accelerated and unpredictable societal and economic development, and demographic dynamics (Koutsoyiannis, 2006; Milly et al., 2008). This has increased uncertainty and the associated risks, and made the task of risk management more complex and integral to decision-making.

Part 1 describes the national and global challenges of meeting planetary socio-economic objectives. What futures are possible? This second part of this report discusses the concepts and consequences of making decisions under risk and uncertainty, and how these can be factored into the decision-making process that impacts water resources. Water, being an input to all economic activities and life itself, is impacted by decisions made in a wide range of sectors or domains, themselves often having no direct involvement with water. Decision-makers also face multiple risks and uncertainties. Decisions are made and risk is managed in different ways in each sector or domain. Providing decision-makers with tools that show the broader water resource consequences of various decisions (actions, inaction) can substantially contribute to better overall resource management and reduced threats and adverse impacts (Bier et al., 1999).

Given uncertain future climates and land-use changes that alter water flows and storage, water managers are now asking: What level of protection is provided by the particular design of a levee or flood storage capacity in a reservoir? What protection against droughts is provided by specified active storage capacities in reservoirs together with particular operating policies? Exactly where is the 100-year floodplain boundary for the purposes of floodplain land-use zoning, and possibly insurance? Those responsible for making or influencing policy and investments are asking: Which among the various priorities are the most important if trade-offs become necessary? What measures can be taken to reduce risks? How much uncertainty can be incorporated into decisions, taking into account climate change and plausible social, economic, financial, cultural and environmental futures?

Part 2 discusses ways of analysing and responding to some of the challenges and risks. It concludes with examples of how both water management and socio-economic policy are already being used to address uncertainty and associated risks.

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CHAPTER 8

Working under uncertainty and managing risk

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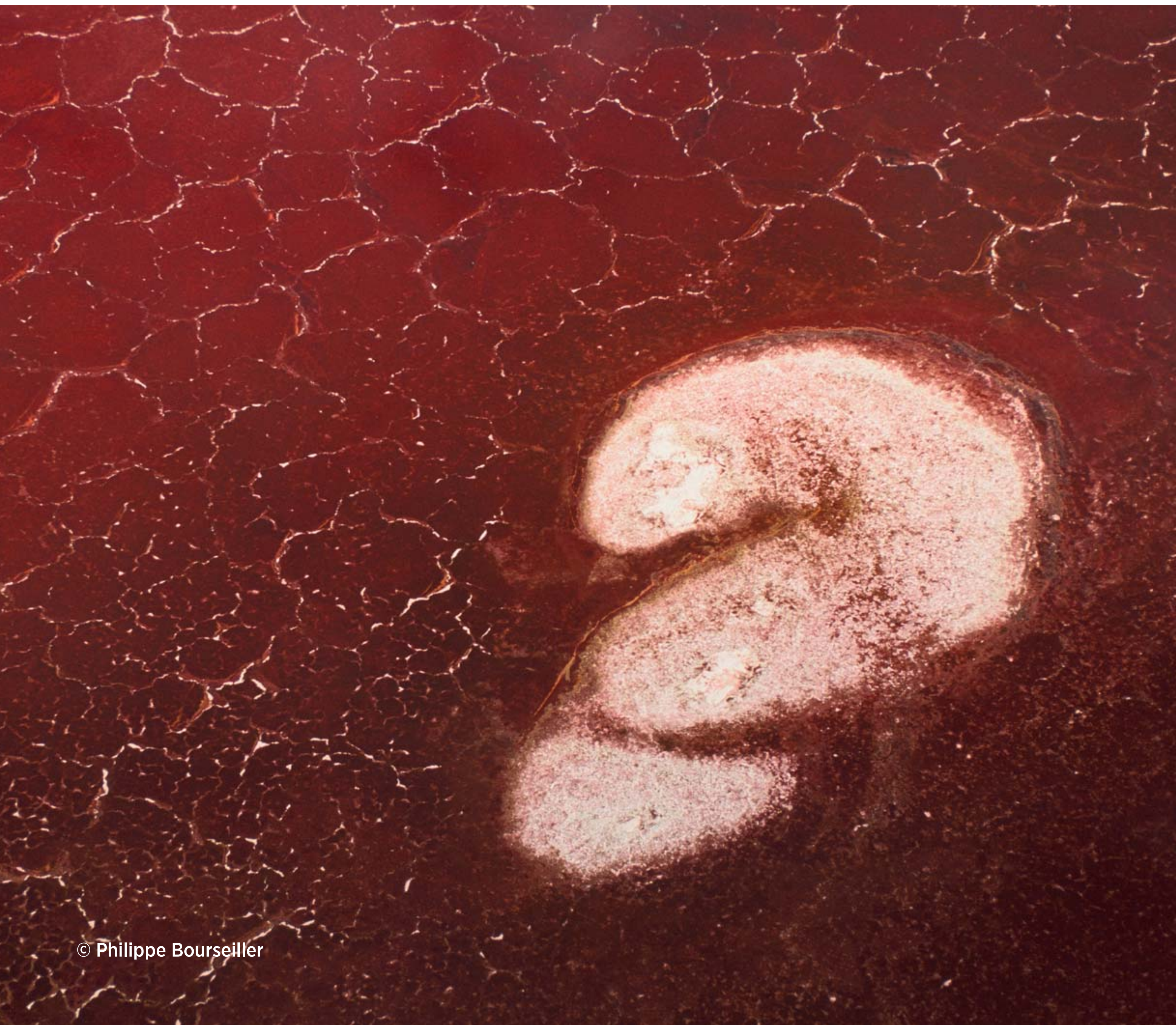


Water managers and users are accustomed to working with – and making decisions under conditions of – risk and uncertainty. The predictability of water supplies derived from watersheds depends in part on nature, but precipitation, which typically becomes stream or river flow or infiltrates into a groundwater aquifer, is variable in character. The demands of water users can also vary and depend on uncertain population size and distribution, as well as on unpredictable weather and changing social and economic conditions. Costs and benefits of water treatment, distribution and use are always subject to uncertain market (and other) conditions. Technologies evolve and can offer new solutions, some as yet unknown or unimagined. Communities, corporations and irrigators, to mention a few users whose economic and social welfare depend on reliable supplies and qualities of water, have hedged their exposure to possible shortages and pollution, even prior to awareness that such uncertainties and risks are increasing due to changes in climate, population increases, lifestyle shifts and watershed conditions.

Water is vital for the production of almost everything. An average car tyre requires about 2 m^3 of water to manufacture; a ton of steel calls for 237 m^3; an egg requires about 0.5 m^3; and a single 200 mm semiconductor that powers a computer requires 28 m^3 of ultrapure water. As 'water footprints' grow, individuals, companies and entire cities will need to face the threat that there may soon not be sufficient water to meet all demands, both off and within watercourses (Hoekstra and Chapagain, 2008).

Some people may feel that water scarcity is not yet a cause for concern; after all, the world is covered with water. However, 97.5% of the planet's water is saltwater. The remaining 2.5%, of which only a fraction is accessible surface or groundwater, is used for essential functions, such as sustaining life, growing food, supporting various economic activities and ecological processes, producing energy, transporting cargo and assimilating wastes (Kumma et al., 2010; Palmer et al., 2008; UN-Water, 2006).

Uncertainties are exacerbated by the paucity or complete lack of reliable data on both supply and demand. In any region, no one can predict when and to what extent droughts or floods will occur. Both droughts and floods provide the potential for damage, in other words, risks; both create uncertainties regarding what action to take and when (Berstein, 1998; Brugnach et al., 2008; Giles, 2002; Hoffmann-Riem and Wynne, 2002; Kasperson et al., 2003; Rayner, 1992; Slovic et al., 2004; Tversky and Kahneman, 1974).

8.1 Concepts of uncertainty and risk

8.1.1 Some definitions

Risk commonly refers to an adverse event or the consequence of a decision. (see Section 8.1.2; see also Aven, 2003; Bedfore and Cooke, 2001; Cooke, 2009; Covello and Mumpower, 2001; Kaplan and Garrick, 1981; Kasperson et al., 1988; Mays, 1996; Slovic, 1992; Yoe, 1996).

Uncertainty is often used in connection with the term risk (sometimes even interchangeably). The most widely held meaning of uncertainty refers to a state of mind characterized by doubt, based on a lack of knowledge about what currently exists or what will or will not happen in the future. It is the opposite of certainty, which is a conviction about a particular situation (Bogardi and Kundzewicz, 2002; Morgan and Henrion, 1990; Pindyk, 2007).

Confidence level or interval applies to a population sampling, where variation or differences of opinion exist. Suppose a study needed to ascertain the percentage of homeowners on a floodplain who believe they will be safe from floods for the next 10 years, or the percentage of simulated floodplain development scenarios in which no flood occurred over a 10-year period. Depending in part on the sample size compared to the population size, that is, the number of people who could have been asked that question or the number of scenarios that could be simulated, a confidence level and interval can be determined. If the results in both cases were 85%, the results might be stated as 'We are 95% confident that 85% of those living on the floodplain think they will be able to avoid any flood damage in the next 10 years, with a margin of error of plus or minus 3%.' In other words one can be 95% sure that between 82 and 88% of the population believe they will stay dry over that ten-year period (Berger, 1985; Coles, 2001).

8.1.2 Risk and uncertainty in water

It is impossible to fully predict how well any water resource system will perform in the future. Such systems are subject to changing and uncertain inputs, and serve changing and uncertain demands. Risk and uncertainty characterize much of what water managers and socio-economic policy-makers must deal with. The more they understand these uncertainties and risks, the more effectively they can plan, design and manage water systems to reduce them.

Those who depend on water supplies or services provided by water cannot be certain that they will always have the water they need or want, or freedom from water hazards (i.e. floods or droughts or pollution). No one can fully depend on the recreational use of water in storage or in rivers or streams. No one dependent on hydropower can be assured of its reliable supply. In fact, nobody dependent on any energy type can be assured of its reliable supply, in part because of the uncertainty of needed water. This is the rationale behind the balanced development of water and energy options.

Knowledge in dealing with risks and uncertainties often comes from past experiences, observations and records. However, these are no longer adequate indicators of the risks and uncertainties faced by future water planners, managers, users and policy-makers, due to uncertainties generated by future changes in population growth and spatial distribution, water consumption patterns, socio-economic development, and climate variability and change. It is therefore crucial to understand the sources of uncertainty and learn how to analyse, internalize and cope with the risks that arise due to these uncertainties.

8.1.3 Understanding sources and types of uncertainty

Uncertainty can result from variability of an underlying process or incomplete knowledge of that process. Decision-makers are often required to make decisions, sometimes having considerable consequences and involving considerable expenditures of money, without knowing with adequate certainty the extent of those possible consequences and expenditures (Knight, 1921).

Sources of uncertainty related to water systems and their management include lack of data or random and systematic errors in data acquisition, recording and storage, inability to predict future processes that determine future supply and demand, and uncertainty about the various natural or physical processes of the water cycle.

Another source of uncertainty is social uncertainty. Human behaviour is unpredictable and, therefore, the behaviour of individuals, society and its institutions is also uncertain, as is, for example, market behaviour. Technical innovations, their perception and use, and their impact on our environment are also often unpredictable, and thus uncertain.

Uncertainty about the value of empirical quantities can also arise from imprecise use of language describing

“Risk perception and tolerance depend on a person’s likelihood of harm, control over harm, extent of harm or hazard, voluntariness of exposure to possible harm, and trust in the sources of risk information.”

information, and disagreement among different experts about how to interpret available evidence.

Finally, there is ignorance. Some aspects of hydrological systems are still not understood and some of these aspects are even unknown, so the question of what is not understood is itself not well understood. This makes it hard even to ask the right questions. These are the ‘unknown unknowns’. Things we know we do not know may often be addressed and sometimes better understood through research. Things that we do not even recognize we do not know are only revealed by adopting an always-questioning attitude towards what we hear and see and measure and analyse (Walker et al., 2003).

8.1.4 Estimating the extent and duration of uncertainty

Changes in populations and their distribution on Earth, their lifestyles and their institutions, together with changes in the climate will undoubtedly change the water environment over the coming decades and centuries. The question is how. Uncertainties of supply and demand both in the short and long term will likely remain. While observations and analyses can reduce these uncertainties, in most cases, no single piece of evidence or experimental result can provide definitive answers to eliminate these uncertainties. In fact just the opposite is likely to happen over time. Decision-makers, planners responsible for making recommendations to decision-makers, and researchers predicting the likely future impacts of possible decisions are facing increasing uncertainties the further one looks into the future. Nevertheless, everyone making decisions that will impact future events needs informed judgments about plausible futures, even though they are uncertain. Probabilistic estimates of key quantities can all be useful to planning and assessment activities, such as the various extents to which it is drier or wetter or hotter or colder than usual due to the increase of atmospheric concentration of greenhouse gases; or estimates of the various heights of sea level rise as the average temperature of the Earth increases; or of various increases in demands for food in response to population and lifestyle changes, which in turn will impact demands for irrigation water and water use efficiency. Analysts seek to incorporate probabilistic descriptions into their models and analyses, usually by performing multiple simulations on fast computers, each simulation using a different input scenario or set of assumptions about the design and/or operation of the system being simulated. The results of these analyses can be presented along with their probabilities. Designs or policies that yield results acceptable to stakeholders across a wide range of model inputs are considered robust to changes in future conditions. Some of the tools used to identify such policies are described later in this chapter.

8.1.5 Understanding risk

Risk and its various descriptions are highly influenced by individual and social perceptions. Risk perception and tolerance depend on a person’s likelihood of harm, control over harm, extent of harm or hazard, voluntariness of exposure to possible harm, and trust in the sources of risk information. As risk perceptions can affect collective and individual choices, decisions may benefit from making risk more explicit. Examples of current water-related risks are water scarcity, quality degradation, loss of ecosystem services and extreme hazardous events, which in turn may be influenced by socio-economic developments and decisions (Ganoulis, 1994).

Awareness of risks and the importance placed on them depends in part on time horizons. This is an issue for climate change, because changes are expected to occur over decades rather than years. Society has a problem with deciding what to do about events whose probabilities of occurring are very low but will provoke severe consequences if they do happen, such as the collapse of a dam or the occurrence of a one-in-a-thousand-year flood or a catastrophic water-related epidemic. These problems have given rise to criteria like the precautionary principle and the concept of safe minimum standards, which will be discussed later. However, concern for the extreme consequences of low probability events to the exclusion of dealing with much more common variations with much higher probabilities is not desirable.

8.1.6 Model uncertainty

Any model of a social or natural system is a simplified approximation of that system. Models are used to better understand such systems and estimate the possible impacts of various decisions affecting those systems.

In general, the most preferred and useful model is the most simple and understandable one that provides the needed or desired information with the needed or desired accuracy. The choice of model used for any analysis will depend in part on the available scientific knowledge and data, and the intended use of the model output. In this sense, the choice of a model is subjective and pragmatic.

Uncertainty about the functional form of (the assumptions built into) a model can arise just as can uncertainty about the quality of its input data. Both can lead to disagreements among different experts about how to interpret the model output. A fundamental problem and potential source of uncertainty is that the people who perform analyses are often not clear about the objectives and decision rules that they should assume and incorporate within their models. In such cases it makes sense for model operators to provide a range of options to the stakeholders and decision-makers, each representing a different mix of various objectives.

8.1.7 Thresholds and tipping points

The term 'tipping point' commonly refers to a critical threshold at which a relatively small perturbation can qualitatively alter, perhaps irreversibly, the state or development of a system (Brugnach et al., 2003; Gladwell, 2000; Lenton et al., 2008; Keller et al., 2008; Walker and Meyers, 2004). Tipping points related to changes in Atlantic thermohaline circulations, the die-back and loss of Amazon rainforest, and the melting of the Greenland ice sheet have received recent attention in the press. In each case, scientists believe that there is a chance that the gradual changes that take place in the state of these systems over time will at some point in the processes become irreversible. This can have long-term consequences for those systems.

The definition of tipping point could in principle be applied in other situations at any time, for example, decisions made with respect to governance of countries, or with respect to military actions. More common examples of tipping points apply to structures made by engineers. Metal fatigue is a well-known phenomenon, associated with aircraft. With increased use aircraft begin to exhibit cracks in the wing and tail structures. Periodic inspections provide a way to monitor these cracks and prevent them from reaching a tipping point, which can result in entire wing failure or control failure due to loss of tail components.

BOX 8.1

Dutch Delta Approach

In 2007, the government of the Netherlands implemented a study of the impacts of sea level rise as a result of expected climate change in combination with land subsidence, urbanization and increasing peak discharges of major rivers. Their goal was to determine how best to make the country resilient to worst-case climate change conditions. Problems surrounding the upkeep of long-term livelihoods in fragile deltas under climate change, urbanization and land subsidence are universal, but strategies to cope with them require tailoring to local circumstances. The national Delta Commission oversaw the study, members of which included renowned scientists (not only in the field of water, but also food, spatial planning and climate), as well as representatives from the finance sector and private contractors. All interests were represented. Their tasks included exploring where present policies are inadequate to cope with worst case (climate) change, identifying what and when 'tipping points' may apply, that is, the point at which certain policies or measures become technically impossible, financially unaffordable or socially unacceptable; developing a future vision about where Delta people would wish to live in 2100; deriving strategies starting from the tipping points for how to realize the desired vision or move towards it; ensuring flexibility to be able to adjust to slower or faster changes or changed values of future generations, starting with no-regret measures; and ensuring long-term implementation through a Delta Fund, a Delta Commissioner and a Delta Law. Within three years the Dutch Government had a vision to make the country climate resilient, passed a Delta Law in Parliament, created a Delta Fund, appointed a Delta Commissioner and agreed on a Delta Implementation Plan.

Source: Policy Research Corporation (2009).

Box 8.1 refers to tipping points that some may consider as 'branching points' in scenarios. They would argue these branching points or decision points are not tipping points in a strict scientific sense.

8.1.8 Nonstationarity

Water resources management, water infrastructure planning and design rely on an understanding of the water cycle and hydraulics as they apply to particular sites. For the purposes of planning and design, engineers have typically assumed that the hydrological processes in a particular watershed or basin could be described by probability distributions that were not changing over time; that is, the historical statistical characteristics of those processes were assumed essentially constant over time, or stationary. The more these extreme events happen due to changes in the Earth's climate or from unpredictable human behaviour, the more challenging it is to plan and manage water. The question is how best to include these nonstationarity considerations of both water supply and demand in water planning and management. Because of this, water resources planners and managers must apply a significant amount of judgment in their analyses, due to changes in land use, urbanization, and the impacts of a changing climate that influence future precipitation, evaporation, groundwater infiltration, surface runoff and channel flow (Aerts et al., 2011; Block and Brown, 2009; Folke et al., 2004; Hamilton and Keim, 2009; Holling, 1986).

The more these extreme events happen due to changes in the Earth's climate or from unpredictable human behaviour, the more challenging it is to plan and manage water. Understanding the changes taking place in river and aquifer systems constitutes an important challenge for water managers. The question is how best to include these nonstationarity considerations of both water supply and demand in water planning and management.

8.1.9 Other key concepts

Lack of knowing what is unknown is an extreme state of uncertainty. Many of the defining events, technological developments and scientific discoveries of recent times were unknowable and even unimaginable a few decades ago.

Indeterminacy is the uncertainty that comes from not fully understanding the performance characteristics of complex systems. It arises because complete or perfect knowledge of complex systems, which would permit the credible calculation of probabilities of various outcomes, rarely exists. Likewise, the full range of potential outcomes is usually not known.

Reliability indicates the probability of one or more performance indicator values being considered satisfactory. The concept depends on a threshold value that separates satisfactory and unsatisfactory values of each indicator or measure of performance. There can be various levels of reliability associated with multiple threshold levels (Duckstein and Parent, 1994; Hashimoto et al., 1982; Plate and Duckstein, 1988).

Robustness indicates how well a system performs over a range of possible input scenarios pertaining to what is uncertain (Hashimoto et al., 1982).

Resilience is a measure of the ability to adapt to changes and recover from disturbances, while providing options for future developments (Fiering, 1982, Hashimoto et al., 1982; Holling, 1973; Walker et al., 2004).

Regret is a measure of an unsatisfactory state resulting from a decision. Systems can be designed and operated to minimize the maximum (worst) regret that could occur or maximize the minimum (worst) level of performance. Both minimax and maximin objectives attempt to reduce the most extreme risks or consequences of failure.

Surprise occurs when there is an abrupt or discontinuous change in a physical or socio-economic system that is unexpected.

Vulnerability is an important measure, along with reliability, associated with any performance indicator. Its various forms (expected, maximum, confidence level) indicate the consequences of a failure, should a failure occur (Hashimoto et al., 1982; Heltberg et al., 2009).

8.2 How uncertainty and risk affect decision-making

It is common for decision-makers dealing with water to have to make choices without knowing with certainty the outcome of their decisions. This uncertainty of outcome and the decision-makers' attitudes towards risk invariably impact their decisions (Walker et al., 2003).

For example, a farmer must make planting decisions without knowing how much rain will be available, and its distribution over the growing season. The outcome of his planting decisions will be unknown until the time of harvest. Alternatively, an expanding firm wants to construct a new building and must choose a location. New Orleans is a location which poses significant rewards, but the company is uncertain if weather (e.g. hurricanes) will strike and result in a large loss. In another example, the price a potential homeowner is willing to pay for a house may depend on the risk of it being flooded. Whether the house is going to be flooded is uncertain, but if it is built on a floodplain the risk exists. That risk may be mitigated in part by flood-proofing or by purchasing flood insurance to recover the economic loss.

The decisions people make under uncertainty also depend on their attitude towards risk. For example, if a mayor of a town is face with the choice of increasing the level of protection of a levee, which could reduce flood damage considerably, or spending that money on road maintenance, that mayor must consider the likelihood of a flood occurrence as opposed to generating, perhaps, more immediate and continuing public appreciation and support by improving the condition of the town's roads. If the mayor opts for road maintenance and a flood does occur, resulting in damage, public appreciation and support will disappear. If the mayor is risk averse, even though the probability of a flood may be low, he or she may not wish to take the risk of incurring a large loss and lose public support, as a result of lack of adequate flood protection (see Box 8.2).

BOX 8.2

Queensland, Australia, warned of floodplain risks

The interim flood inquiry report into the January 2011 state-wide flooding disasters, entitled *Understanding Floods: Questions and Answers*, by the Queensland Floods Science, Engineering and Technical Panel, calls for a new test of what constitutes appropriate development. The report says that flood-risk planning should consider 'a combination of the chance of a flood occurring and the consequences of the flood for people, property and infrastructure'.

'It is estimated that flooding so far this year (August, 2011) has caused AUS$2 billion damage to local government infrastructure in Queensland, with total damage to public infrastructure likely to reach AUS$6 billion. Damage to the Australian economy from flooding, in New South Wales and Victoria will top AUS$30 billion. ... There were 37 deaths, 35 in this state.' This shows that flooding of some locations may have significant economic and social consequences for a much wider region.

Source: Hoffman (2011).

Different people perceive risk differently, depending on the context or environment in which the decisions are made. Managers do not always consider the risks as inherent to the situation, and avoid accepting risk by considering it as subject to control. Many believe that by using their skills they can reduce risk. Others rely more on their subjective judgments than on mathematically based analyses. The more catastrophic the consequences of making the wrong decision, the less likely managers will make decisions that accept risks explicitly.

When faced with a problem or decision that involves risk, managers can either accept the risk or attempt to reduce it before making the decision. Ways of reducing risk include conducting further analyses and collecting more information. In some cases, such as for hedging against incurring flood damage, it might be possible to buy insurance. This transfers some of the risk to a third party, reducing the consequences of a risk. It might also be possible to carry out pilot studies before making major infrastructure decisions, for example, advanced desalination or wastewater treatment technology, or letting the supplier take part of the risk and making this clear in the purchase contract. Finally, the decision once made can include provisions for future modifications, if possible, or if not it should be sufficiently robust for a range of future conditions (Alerts et al., 2008; Burton, 1996; Callaway et al., 2008; Dessai and van der Sluijs, 2007; DETR, 2000; Elshayeb, 2005; Liu et al., 2000; Lofstedt, 2003; Miller and Yates, 2006; NRC, 2000; UNDP, 2004; van Aalst et al., 2007; UNDRO, 1991).

8.2.1 Approaches to inform decision-making under risk and uncertainty

When sufficient information is available to determine probabilities of decision outcomes and evaluate the consequences, decision-making can be based on risk analysis. Decision-making may be assisted by the use of a wide variety of analytical tools and techniques, varying from the simple to the sophisticated (Downing et al., 1999; Frederick et al., 1997; Green et al., 2000; Hobbs, 1997; Karamouz et al., 2003; Li et al., 2009; Loucks and van Beek, 2005; NOAA, 2009; Simonovic, 2008; Willows and Connell, 2003). The result is either

BOX 8.3

US Corps of Engineering risk analysis

Risk analysis has been used and is applicable to a wide range of decision problems within the US Army Corps of Engineers. Risk analysis is not only for extreme or low-probability events, but also for any situation in which there is a range of possibilities. Ongoing examples of the use of risk analysis include:

- Examination of economic benefits of rehabilitation of the levees along various rivers and lakes, taking into account uncertainties of storms, river or lake stages and levee performances.
- Comparison of alternative rehabilitation plans for hydropower generators/turbines, making use of probabilities of failure of generators and turbines and maintenance and rehabilitation costs.
- Examination of navigation improvement plans for portions of the Gulf Intracoastal Waterway based on minimizing delays to barge traffic and incorporating uncertainty in tow trips and travel time.
- Flood Damage Assessments using a software system for performing an integrated hydrological and economic analysis during the formulation and evaluation of flood damage reduction plans. This embodies risk-based analysis procedures to quantify uncertainty in discharge-exceedance probability, stage-discharge and stage-damage functions. These approaches have been used in the Louisville, New Orleans, Mobile, Fort Worth, Galveston, Honolulu, Kansas City, Los Angeles, Omaha, Portland, San Francisco, Savannah, St. Louis and St. Paul districts among others.

Source: Males (2002, pp. 3–4).

a benefit–cost–risk analysis (or simply a cost–risk analysis), or a reliability analysis, depending on the purpose of the modelling exercise. Any risk analysis should provide estimates of the level of confidence that a particular performance measure or criterion will be met (Box 8.3).

Informed decision-making is increasingly becoming a bottom-up process. Where risks and uncertainties prevail the experts have no monopoly on what might happen in the future or what might be sustainable. Everyone's opinion is needed, especially the impacted stakeholders, who can determine the success or failure of any decision. Integrated water resources planning and management (IWRM), by definition, involves the participation of all interested stakeholders. Interactive decision-support models have been developed and successfully used to facilitate stakeholder participation. The purpose of such modelling tools is to help achieve, if possible, a shared vision of how a particular water resource system functions, and the likely impact of any decisions on system performance.

8.2.2 Strategies for dealing with uncertainty

The importance of reducing the structural vulnerability of (water) systems has gained increasing attention during the last few years. The development of water management strategies and infrastructure with high levels of flexibility – or robustness – will almost certainly contribute to system resilience, including recoveries from the unexpected. However, the question remains of how to evaluate the appropriateness of such strategies. Traditionally, this has been done through risk management on the basis of historical data and statistical analysis, with strategies selected using, for example, a cost–benefit–risk analysis. Other decision-support tools are required when risks cannot be quantified or isolated, as in cases where the many factors described in Chapter 1 interact.

In complex water management problems where climate is a factor, many years or decades may pass during which understanding of the problem may increase, but so might the uncertainty. This applies even more to socio-economic and behavioural uncertainties. There are two decision-making/management strategies that may help inform decision-makers:

1. *Adaptive strategies:* Choose strategies that can be modified to achieve better performance as one learns more about the issues at hand, and how the future is unfolding. These adaptive strategies can be responsive to new goals or objectives of system performance as well as changing inputs over time.
2. *Robust strategies:* Identify the range of future circumstances, and then seek to identify approaches that will work reasonably well across that range. This strategy applies especially to decisions that cannot easily or cost-effectively be modified in the future.

Adaptive strategies are based on the assumption that the future impacts of any decision taken now are unknown. In such cases, one could engage in further research to better understand the potential results of any decision, and make a decision following successfully completion of the research. However, in the intervening time, opportunities for increased economic and environmental benefits or reduced costs or damages may have been missed. Alternatively, a decision can be made now, based on the best judgment and knowledge at hand, followed by monitoring of the results to see if the decision was correct, or requires further adjustments in the future. The latter is termed 'adaptive decision-making'. Monitoring is critical to the success of adaptive strategies. They work best when the decision timescales are well matched to the changes being observed (Box 8.4).

Alternatively, a robust strategy performs well over a wide range of future scenarios. It is especially appropriate when adaptive strategies cannot be easily implemented, such as for establishing the capacity of a reservoir or flood control structure intended to last a long time. A robust strategy contrasts with an optimum design strategy, whose performance may degrade rapidly under different assumptions regarding inputs and parameter values. Such a strategy may result in slightly less than optimal performance so as to improve performance if unlikely events actually happen.

“Adaptive strategies are based on the assumption that the future impacts of any decision taken now are unknown.”

In contrast to a robust design, whose performance will be satisfactory under a range of future possible scenarios, a *resilient system* is one in which failure or an unsatisfactory state are quickly remedied (i.e. the system can recover or enter a satisfactory state relatively quickly). One definition of resiliency is the probability of becoming satisfactory over a set period of time, given an unsatisfactory state. A resilient system can recover speedily from a failure state. Often design and operation options are available to make a system more robust and resilient, and hence less vulnerable.

Risk-adverse decisions may often reflect a minimax regret criterion for determining which of many possible alternative decisions is 'best.' Deciding on the alternative that minimizes the maximum regret, or 'risk' that could result from the decision, satisfies this criterion. Consequences of decisions depend on unknown outcomes. For example, deciding to drill a water supply well entails a cost that will be wasted if water is not present, but will bring major benefits if it is.

Additional information related to adaptive and robust policies applied to the management of water and aquatic ecosystems can be found in Blumenfeld et al. (2009); Carpenter, Brock and Hanson (1999); Chen et al. (2009); Folkes et al (2002), MA (2005); Sanders

BOX 8.4

Adaptive strategies for responding to drought and flood in South Asia

'Floods and drought are fundamental challenges throughout South Asia, and their impact is heavily influenced by larger water management issues. Current responses to both floods and drought are dominated by humanitarian relief, without concurrent development of long-term adaptive mechanisms with functioning institutional support. In the current era of globalization and … of global climate change, global and regional searches for effective climate change response strategies are taking place.

'Effective small-scale, innovative local coping strategies that are influenced by a range of economic, demographic and social factors do exist, and these need to be given attention, but up-scaling these to a higher level is difficult. The lack of information flow in both directions is a key problem. Despite an expanding network in this field, few have solid field level strategies and few local groups have links to regional and global debates.

'[An Adaptive Strategies project was initiated in India in an] attempt to reconcile differences in perceptions of and responses to extreme weather events in the context of climatic and social change. The project was designed to document and flesh out concepts and opportunities for more effective approaches to water management and flood and drought mitigation through an integrated set of studies in four field locations: two drought affected areas in the arid regions of Rajasthan and Gujarat (India) and two flood affected areas along the Rohini and Bagmati River basins across the India-Nepal border.'

The studies identified existing coping strategies of communities in drought and flood affected areas and suggested patterns of social and economic change that influence the vulnerability of livelihoods to drought and flood conditions and the opportunities for reducing the risks of damage and hardship during such events in those areas.

Source: Reproduced from ISET (2010).

and Lewis (2003); Stuip et al. (2002); Tallis et al. (2008); and Le Quesne and Matthews (2009, 2010).

8.2.3 Scenario analysis

Scenarios are an appropriate and tested approach for dealing with uncertainty for many reasons:

Need for a long-term view. To analyse water issues in the context of sustainable development requires a long-term view that takes into account the slow unfolding of some of the hydrological and social processes involved, and allows for the necessary time for waterworks investments to yield their benefits.

High uncertainty about the system. In situations where it is difficult to assign probabilities to possible events or future outcomes, for whatever reason, one can still generate possible scenarios of what could plausibly happen in the future that would have an impact on the performance of the system being planned, designed, or operated. Even though the probability of any created scenario actually happening will likely be 0, such a set of possible scenarios helps planners, designers and operators to learn how their system will likely perform under a range of possible futures. These future scenarios will typically include both uncontrolled natural events, as well as human decisions. The future behaviour of people and institutions is as much a part of a scenario as is, for example, the climate.

Need to include non-quantifiable factors. To understand system impacts associated with any of the generated scenarios, each scenario is usually simulated over time, and various indicator values are computed for each time period simulated. These indicators will inevitably include qualitative as well as quantitative values. Both qualitative and quantitative simulations may be appropriate to capture and evaluate as best as possible the cultural and political impacts that one might expect from the particular system being considered.

Need scenarios that provide integration, breadth and perspective. Water systems serve numerous agricultural, domestic and industrial demands, as well as demands for in-stream recreational as well as environmental flows. They are impacted by changes in land use, human lifestyles, economic and social conditions, political decisions and the need for energy. Scenario development must capture all of this interdependency and complexity among system components, as appropriate. It must also provide a perspective that covers the interests and concerns of stakeholders at the local, regional and national levels, again as appropriate.

Need to organize understanding for decision-making. The use of scenarios and associated simulation models addresses the need to simulate decision-making and stakeholder participation. Ideally, such simulations will be interactive involving potential planners and decision-makers, as well as stakeholders, making decisions in response to events taking place in the simulations. Alternatively, decision rules can be defined that will serve to make the decisions in a simulation run, but it is preferable if there is interaction between the simulation models and participants during the simulation. This allows more attention to be focused on cause and effect, on when decisions need to be made, and on what constitutes a branching point, where human actions can significantly affect the future. Such simulations should aim for a shared vision of how a system may perform, among stakeholders who may hold different points of view as to how they wish it to perform.

Change, discontinuities, 'wild cards', potential surprise and other altered conditions, whose probability may be assumed to be very low, are often ignored and omitted even though their impact could be great (see, e.g., Marien, 2002; Rahmstorf and Ganopolski, 1999; van Notten, 2005, 2006).

One way to make this class of uncertainties operational is through surprise scenarios. Different methods have been proposed, such as 'historical analogy' or 'surprise theory', in which underlying principles of surprise are studied systematically by 'thinking the unthinkable' – imagining unlikely future events followed by the construction of plausible scenarios that could be associated with them.

8.2.4 Backcasting

Backcasting is an alternative scenario approach for the exploration of alternative futures. It aims to circumvent the tendency of treating the future as an incremental continuation of the past, and to provide as much information as possible on future uncertainties. Instead of taking the present as the starting point, backcasting starts with the articulation of one or more desired (or even undesired) futures and then tries to identify possible actions that lead to them and bottlenecks that would hinder or prevent reaching them. Backcasting is an iterative process in which future visions and policy interventions are (re)adjusted (see also Figure 8.1). Iteration is usually required to resolve internal inconsistencies and mitigate adverse economic, social and environmental impacts that are revealed in the course of the analysis. The main results of backcasting studies are generally alternative images of the future, thoroughly analysed in terms of their feasibility and consequences.

A backcasting exercise generally follows four different steps. The first step is a creative process of defining a desired (or undesired) future (or futures). The next step works backwards from that defined future to identify strategies, measures, policies and programmes that will connect the future to the present. This creative phase is then followed by an evaluation of assumptions underlying these futures in terms of feasibility, and the consequences of alternative images of the future, reflecting on the implications of the long-term perspective for short-term policy-making. After identifying policy interventions, actions and events needed to realize (or avoid the realization of) the (un)desired future, the original future vision is generally adjusted.

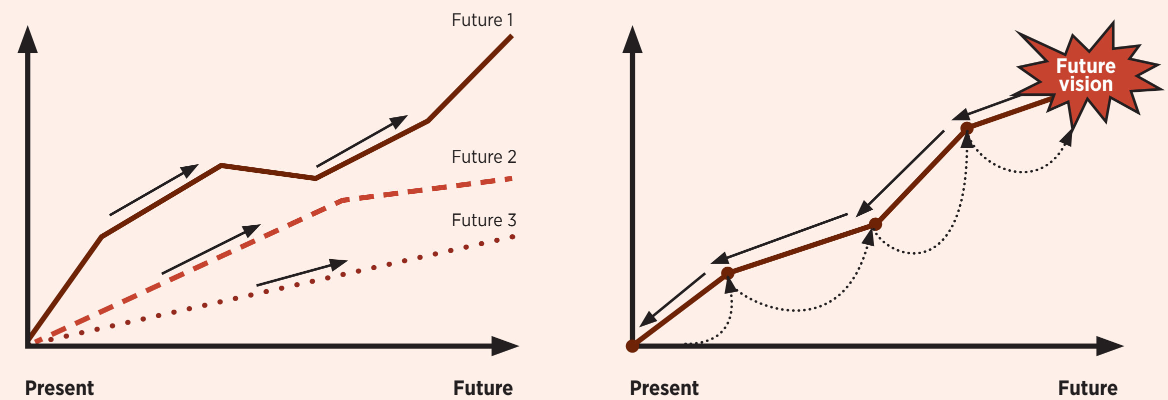
Over the years, backcasting has been applied regularly in the development of climate-mitigation strategies (for the reduction of greenhouse gas emissions). For water management discussions, backcasting is a relatively new approach. The World Water Vision of the World Water Council (Cosgrove and Rijsberman, 2000) was a qualitative backcast scenario using elements of three other scenarios. Backcasting was recently used to develop adaptation strategies to 'climate proof' the Netherlands.

8.2.5 Institutional decision-making principles and paradigms

Today decisions are being made under conditions of risk and uncertainty where the probabilities are nonstationary. Their values are unknown and incapable of being estimated based on the current state of modelling. This makes the estimation of risks of adverse impacts virtually a meaningless exercise for the purposes of water management and water use. Hence when dealing with nonstationarities, a substantially different water management approach seems appropriate, yet one based on a foundation of existing principles and evaluation techniques. This approach, essentially an adaptation of existing proven principles and techniques, has been termed 'robust decision-making': a

FIGURE 8.1

Backcasting versus forecasting scenarios



The forecasting scenario process:
- Identification of drivers
- Formulation of narrative storylines
- Fleshing out of storylines
- Identification of robust solutions

The backcasting scenario process:
- Formulation of (un)desirable future(s)
- Identification of policy interventions, actions and events
- Evaluation in terms of feasibility
- Adjusting original future(s)

Source: van 't Klooster et al. (2011).

process designed to accommodate uncertain scenarios with evaluation and project justification principles that focus less on optimal outcomes and more on producing robust solutions.

Planning the design and operation of water resources infrastructure, whose life extends decades into the future, is a challenge for several reasons, especially if the design cannot easily or inexpensively be changed once built, such as a reservoir. One reason is the change nature of hydrology, and the uncertain nature of those changes. What will constitute hydrology in the next 50 to 100 years is simply unknown. Again, we can guess using hydrological scenarios. It is likely that the changes over the next decade or two will not be significant, which will enable historical records to be of assistance in predicting future scenarios. Another reason is that the future benefits and costs derived from the infrastructure project or system being considered are negligible when discounted to the present, but not so for those living some 50 or 100 years from now. Clearly, there is a need for evaluation criteria that consider the value of sustainable systems now and on into the future. This needs to be responsive to the interest rates used in any benefit/cost analysis, performed at any time by future users of the system, as well as to the level of risk and uncertainty, even if the latter cannot be quantified. (Bardhan, 1993; Hall, 2003; Keeny and Raiffa, 1993)

8.2.6 Acknowledging the need to adapt design procedures

There is no doubt that recent years have witnessed changes in land use, water consumption and global climate, while uncertain future changes and rates of change give real cause for concern. Water management agencies should be as troubled by this as scientists, and need to work towards improved methods of assessment, so as to better incorporate the uncertainty introduced by lack of stationarity in future conditions.

A major question for planners and engineers should be: Is there a better way to plan and design and operate sustainable, reliable, resilient and non-vulnerable water resources systems in the face of this nonstationarity?

If the assumption of stationarity is no longer justified, a replacement strategy is needed to meet planning and design requirements. If a consensus is then reached among scientists and engineers on the best replacement, it must be accepted and implemented in government water management agencies.

Water management agencies with issues and policy matters need to participate in the development of alternate methodologies that incorporate nonstationarity, so as to make water resource projects more adaptable, sustainable and robust. Participation in any improved planning and design methodology that takes into account the nonstationarity of hydrological, as well as social processes, will help in its implementation within the agency bureaucracy. This may entail new legislation and authorization.

It may be easier to implement new methodologies into the planning and design of new projects than into the operating rules of existing projects, as these are often specified by law and may be harder to change. To enable operating rules to take into account nonstationarity, it may be necessary to determine whether or not to develop and adopt new operation plans. Model studies of potential changes resulting from nonstationary might suggest the need for increased flexibility, so as to adaptively manage operations to increase system performance with respect to various criteria. Institutions involved in implementing any planning model are obligated to achieve some level of consensus on exactly what parameters will be impacted by nonstationarity, and what range of variation can be expected on a regional basis. The method of

> "The results from quantitative and qualitative analyses, based on science and economic principles, are often considered less relevant than political factors, emotion, religious beliefs and just gut feelings based on intuition."

implementation must be consistent and reproducible. Changes in established procedures are never easy in large governmental institutions. Considerable study and collaboration and communication among all interested stakeholders should be expected before a change can be implemented.

Until consensus on a new methodology is reached, agencies will continue to use existing procedures, even though the uncertainty associated with these procedures is increased due to potential impacts of changes in climate variability and land use. In addition, there is always less risk of being criticized if established procedures are used, even if they may be inferior to others.

It is unlikely that water management agencies will want to modify existing water management operations without a convincing argument that there is a better way that leads to better results, however measured. Considerable study of alternative methods is needed. The ultimate solution will surely involve a multidisciplinary approach to understanding the science and the development of guidelines and regulations that integrates the relevant science into water resources planning approaches and activities (Baggett et al., 2006; Frederick and Major, 1997; Palmer et al., 2008; Wardekker et al, 2008).

8.2.7 Behavioural decision theory

Most important real-world decision problems are determined by more than one decision-maker. Decisions are worked out and implemented through government, private sector and civil society organizations. The results from quantitative and qualitative analyses, based on science and economic principles, are often considered less relevant than political factors, emotion, religious beliefs and just gut feelings based on intuition. One of the more important aspects of decision-making under uncertainty concerns the processes by which organizational structure influences the success of an organization in coping with uncertainty, and the strategies they adopt to make themselves less susceptible to failure.

These factors are discussed extensively within the 'behavioural decision theory' or risk-related decision-making literature. In contrast to decision analysis, which outlines how decisions should be made in the face of uncertainty, behavioural decision theory describes how people actually make decisions when not influenced or supported by analytical procedures such as decision or benefit-cost-risk analyses. It describes how rational and emotional parts of the human psyche interact in decision-making (Camerer and Weber, 1992; Loewenstein and Cohen, 2008; Marris et al., 1997; Wolt and Peterson, 2000).

8.2.8 Precautionary principle

In the presence of uncertainty, many actions and decisions taken to achieve increased economic, environmental and social benefits will have impacts that one cannot now predict. Actions may be needed to reduce these risks if there is a chance that any of these impacts will be harmful to people or the environment in the future, the precautionary principle places on those proposing such actions the burden of proving that the proposed decisions, including those needed to protect people and the environment from future harm, will not be harmful to anyone or anything in the future. This introduces a condition to be met before such decisions can be made and places the responsibility for meeting this condition on decision-makers. This principle comes from the belief that there is a social obligation to protect people and their environment from damages that could result from any decision being considered. Following this principle, decisions to proceed with a project or programme can only be taken once evidence is available that no harm, especially irreversible harm, will result (UNESCO, 2005).

8.2.9 Diversification

Other strategies for enhancing robust decision-making under uncertainty accept that the future is unpredictable and aim at developing methods and measures that build on existing knowledge. The more diverse the current water system is, the more resilient it should be to unexpected events.

There are several steps required to diversify water management decisions and investments. The first step is to assess possible interventions and their related costs. Consider, for example, a semi-arid area that is largely dependent on water for its main economic activity: rainfed agriculture. As the economy depends on the success of rainfed crops, the challenge for a water manager is to develop new drought mitigation measures, such as increasing storage capacity of surface water, increasing groundwater capacity, and devising irrigation schemes for local farming communities. Water managers inform decision-makers, who can also play an active role by introducing water pricing policies, subsidies or other financial mechanisms, or by deciding on a different development strategy, among others. The choice of which measures to invest in depends on available budget, acceptance by the public (voters and tax payers) and major user groups, and geographical conditions. The cost-effectiveness of each measure will depend on how trends such as climate change or future economic conditions determine the effectiveness of each measure, and hence the success of combinations of measures.

Investment diversification – in analogy with portfolios in the stock market – can reduce the risk of the total portfolio of water measures if a country can afford it. Uncorrelated (or partly-uncorrelated) investments in water management measures that aim to achieve similar returns can result in different effects under the same future trends. For example, investing in sustainable irrigation may have a profound effect on the volume of water saved, but is only viable if water and financing is available. Water pricing aims at achieving the same water savings, but only works if the public accepts it. A third investment that increases subsurface water storage capacity will probably increase the water saved through the decreased effect of evaporation, but its long-term success also depends on the level of maintenance to prevent failures.

The key is to find mixes of the three investments that will result not only in the highest possible returns (cost–benefit analysis) in terms of water availability, but also a mix of water management investments that is capable of absorbing unexpected events; in other words, a mix that values uncertainty as part of the decision-making process (Brown and Carriquiry, 2007; Figge, 2004; Johansson et al., 2002; Perrot-Maitre, 2006).

8.2.10 Long-term versus short-term decisions

Depending on the timeframe and scope of an issue and the political time horizon, different uncertainties can have different relevancies to the decision-making process. The timeframe is of critical importance when looking at ambiguous information or irreversibilities. Long-term decisions are associated with capital investments in infrastructure projects that involve substantial fixed costs (costs that are independent of the scale or capacity of the project), and that require payment before the project can begin. Long-term investment decisions pertain to infrastructure design or land-use policy expected to exist over a long period. In many cases, it is difficult to reverse such decisions once implemented. For example, decisions to build reservoirs are easier to make than to reverse once the reservoirs exist. The challenge of long-term decision-making is to adequately consider future impacts given the uncertainty of future supply and demand conditions.

Consider decisions with respect to protecting from floods or reducing flood damage. The design of dykes or levies along the Mississippi River in the United States of America or along the coast of the Netherlands constitute examples of long-term decisions. No one can predict the degree of protection required for the future, even if such analyses are based on past hydrological events or future projections influenced by current knowledge of climate change. Hence, no matter what design is chosen there is a risk of failure. Questions that plague anyone making long-term decisions include what levels of risk are acceptable, and just how much more money, if any, should be spent on designs that reduce the costs of infrastructure expansion in the future, should future conditions warrant. Capacity-expansion models that include future uncertainties can provide guidance for making such decisions, but their results are also uncertain. Compared to long-term decisions, short-term decisions are much easier to make as their impacts are much more predictable. Short-term decisions typically involve changes in operating policies, whose performance depends on the long-term decisions made. For example, the proportion of storage in a reservoir that should be allocated to flood storage and the various beneficial purposes water serves (agricultural, domestic and industrial water supplies, hydropower, recreation, environment) – some of which are complementary, while others compete. These decisions may be influenced by recent hydrological and economic events or conditions, and in the case of farmers, forecast future crop market prices.

As with long-term decisions, short-term decisions made in uncertain environments also pose risks. But unlike many long-term risks, short-term risks are often more manageable and reducible. All those who face risks learn to live with or manage such risks. One approach to reduce individual risks is through insurance. Insurance is not always available, but when it is it can serve to reduce the economic consequences of flood events, or droughts leading to crop failures or famine, or disease brought on by excessive pollution. It serves as a way to mitigate the risks of economic loss. The problem for insurance companies is to determine their risks under changing climates – changes that are themselves not predictable. Index insurance avoids the need to make judgments on actual losses, say due to climate variability or human failure – a difficult task – as index insurance payments are made based on an independent indicator or measure that is correlated with outcomes, but not influenced by the insured individual (Brown and Carriquiry, 2007).

8.2.11 Policy uncertainty

The outcomes of any long term or short-term decisions depend in part on external factors. One such factor, which can have a significant influence on the success or effectiveness of any decision, is the set of policies or rules and regulations or laws established by public agencies. Changes in broader public policy can have substantial consequences on the potential effectiveness of a pollution control policy, or the success of a cascade of hydropower reservoirs in meeting energy targets or reducing damages resulting from floods. This source of uncertainty can be just as significant as the uncertainty resulting from natural events (Camerer and Weber, 1992).

8.2.12 Necessity and uncertainty of monitored data

As discussed in Chapter 6 of this report and Chapter 13 of WWDR3, there is a real need to commence global, systematic monitoring of the world's water resource systems and land-use patterns. Many signals suggest that climate is changing the rate, if not the nature, of hydrological processes taking place today in many regions. More research is needed to fully understand these events, their causes and the directions and rates of change. Improved hydrological and climate modelling and downscaling methods are badly needed by water resource planners and managers, who are facing problems that often need solving at sub-basin scales – spatial scales much smaller than those considered by global and even regional climate models.

But in addition to the need for more research on climate modelling, there is a need to learn more from the hydrological data recorded over the past century. During this period, humans had a major impact on land use and discharged a significant quantity of greenhouse gases into the atmosphere. Global CO_2 concentrations in the atmosphere increased by about 35% compared to levels at the beginning of the industrial revolution. This increase and the accompanying warming is highly likely to have had a measurable impact on the water cycle, which should be possible to detect by studying the hydrological records. As with climate and land cover changes, there is a need to monitor and better understand hydrological changes (e.g. soil moisture, frozen ground, nutrient dynamics, algal dynamics). Improved

> "Unlike many long-term risks, short-term risks are often more manageable and reducible."

decision-making relies not only on better ways of modelling land-water-atmospheric interactions and the climate and its impacts at basin and watershed scales, but also continued monitoring and analyses of hydrological records (Murdoch et al., 2000; Naiman and Turner, 2000; Vörösmarty et al., 2000).

Monitoring and measuring are the only ways to determine the nature of changes occurring in the watersheds. This involves keeping records, decade after decade, and analysing those records. The fact that the probability distributions of water flows, storage volumes and their qualities and uses over space and time, are non-stationary increases the importance of continued monitoring, data management and analyses. Informed decision-making depends on observations of the systems being managed, understanding what those observations are telling us, and acting on this knowledge – continuously.

8.3 Using ecosystems to manage uncertainty and risk

History shows that pressures on water resources decrease ecosystem resilience and thereby increase ecosystem-related risks and uncertainties – reducing those pressures reduces this risk and uncertainty. Ecosystems can serve to reduce uncertainty, help manage risk, and achieve increased benefits from water security and water quality enhancement, recreation, hydropower, navigation, wildlife and flood control. Ecosystems include all the components involved in the water cycle, including land cover (vegetation) and soil functions in watersheds, wetlands and floodplains.

Ecosystems are used widely and have demonstrated their utility, particularly in reducing uncertainty associated with water quality, water extremes (drought and floods) and storage-related needs. Hard engineering approaches (see Chapter 5) have successfully reduced risks in rich nations, but at considerable capital and maintenance (and sometimes environmental) cost. Not all developing countries have the financial capital to adopt the same strategy. But as risks or priorities change (e.g. through climate change or urban expansion), physical infrastructure can be difficult and certainly expensive to modify or remove. This can limit adaptation options under changing conditions, and thereby increases risk. The use of built and natural infrastructure options should be considered together in order to manage medium to long-term risk.

History also shows that many risks associated with water arise through management that is blind to the ecosystem changes it drives, and their consequences for humans. Ecosystems are central to sustaining the water cycle, therefore, understanding this role provides a tool to assess how risks are generated and transferred. An inclusive, holistic and participatory approach to water policy and management permits identification of the full range of ecosystem services involved, where the risks are, who is vulnerable to them and why. Improved information can reduce, but never eliminate, uncertainty. A new paradigm is required and is already emerging (as indicated in Section 2.5), which shifts from regarding the ecosystem (environment) as an unfortunate but necessary cost of development to being an integral part of development solutions (Box 8.5).

Reducing the direct human demand for water will also reduce pressures on water, and thereby increase the sustainability of ecosystems, the delivery of ecosystem benefits, and therefore reduce risk. Other sections of this report address opportunities to reduce water footprints, including improving water use efficiency. At the implementation level, water managers may be called upon to actively manage various elements of the ecosystem and/or to inform those who have that responsibility. Identifying opportunities to proactively manage ecosystems to reduce uncertainty and manage risk involves a three-step process:

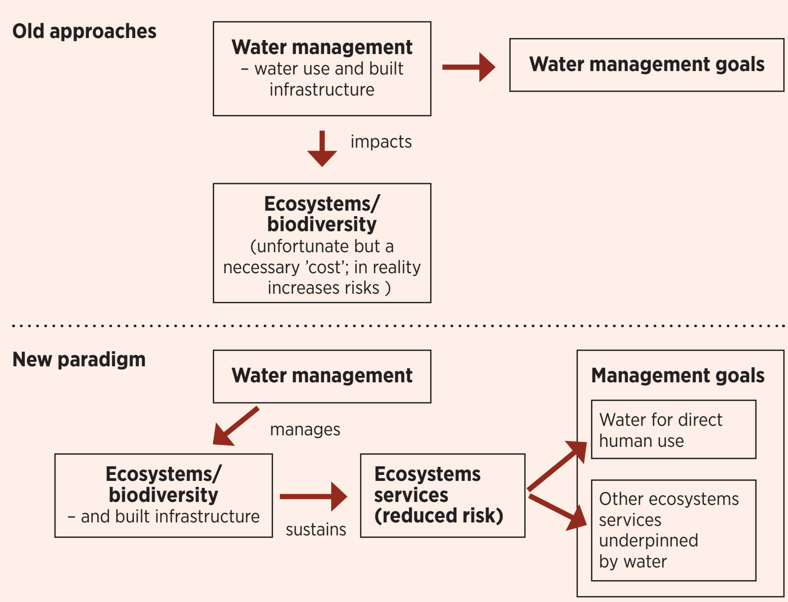
1. Identify the water management objectives as opposed to focusing on infrastructure (e.g. objectives are water storage or clean water, not dams or treatment plants).
2. Explore what ecosystems offer in terms of meeting the identified management objective(s) (e.g. storing water, reducing pollution), including through their conservation and/or restoration.
3. Reduce the uncertainties and risks involved in decisions by considering all ecosystem services directly involved or potentially impacted by various management options. This includes valuing multiple co-benefits, and examining trade-offs between them to determine desirable courses of action.

BOX 8.5

Changing paradigms for water management

Traditional approaches were aware that water management impacted ecosystems, but proceeded on the assumption that water use (for humans) was more important than the ecosystem (environment). The values of the full suite of benefits (services) provided by the ecosystem were therefore not included in decision-making. The result is increased overall risk with the ecosystem and its needs perceived as in conflict with human needs.

In the 'new paradigm' ecosystems are managed (together with built infrastructure) to achieve a water management goal of delivery of the full suite of required ecosystem services (including water quantity and quality), thereby reducing overall system risks. The ecosystem is seen not as a problem, but as a solution.



Ecosystem-based approaches harness the capacity of ecosystems as water infrastructure to improve resilience and deliver multiple water-related benefits more sustainably and often cost-effectively, thereby addressing risk. The term 'ecosystem' (or 'natural') infrastructure (see discussion in Section 5.1 concerning 'soft infrastructure') reflects an acknowledgement that the water-related services provided by ecosystems are analogous and complementary to those provided by conventional, engineered water infrastructure. Capital and operating costs of physical infrastructure should reflect the costs of lost ecosystem services. For example, the costs of drinking water treatment reflect this cost of ecosystem degradation (loss of clean water as an ecosystem service). There is a compelling cost–benefit case for public and/or private investment in green infrastructure, in part because of its significant potential as a means of adaptation to climate change (TEEB, 2009).

The global consequences of heavy reliance on hard-engineering solutions are beginning to be better understood in risk management terms. For example, Batker et al. (2010) present a convincing case study of the Mississippi Delta, where ecosystem restoration options offer significant economic gains to address the problem of risk increase in the delta, in particular disaster risk brought about by historical hard-engineered water management approaches (see Box 2.3 in Section 2.5). The policy of wholesale hard (physical) engineering approaches to water risk reduction has been debated between and among engineers and environmentalists for at least two decades. This discussion is increasingly subject to more rigorous science enabling the emergence of a less emotive, more impartial and balanced strategy towards risk (Box 8.6).

Demonstrations of the pitfalls of ecosystem-blind approaches make for a convincing case in themselves. But ecosystem solutions for dealing with uncertainty and risk are best demonstrated through practice, and there is currently a wholesale shift towards this approach. Some stakeholders in the business sector are leading by example (Box 8.7). For example, the World Resources Institute (WRI), working in conjunction with the World Business Council for Sustainable Development (WBCSD), has developed the 'Corporate

BOX 8.6

Rethinking physical infrastructure approaches

Vörösmarty et al. (2010) have presented human water security and biodiversity perspectives within the same spatial accounting framework. They used data depicting 23 stressors (drivers), grouped into four major themes representing environmental impact: catchment disturbance, pollution, water resource development and biotic factors. The results show that nearly 80% of the world's population is exposed to high levels of threat to water security, based on year-2000 figures, implying a much greater level of risk than indicated by previous assessments.

Developing countries, in particular, need to reduce water risk. In addition to 'hard' engineering solutions as well as when a lack of adequate levels of financial resources impedes appropriate infrastructure development, a sensible option is to employ ecosystem-based solutions, wherever possible. This also reduces medium-term risks and minimizes the possible need to eventually dismantle much of the physical infrastructure used to achieve sustainable balanced outcomes, once wealthy.

BOX 8.7

Ecosystem solutions for water quality risks

The use of natural infrastructure to protect water supplies, particularly drinking water for cities, is already widespread. For example, the Water Producer Programme, developed by the Brazilian National Water Agency, provides compensation to farmers to safeguard critical headwaters that supply water to 9 million people in the São Paulo metropolitan region. Success has spawned similar approaches in other regions of Brazil (Nature Conservancy, 2010). Likewise, the páramo grassland of Chingaza National Park, in the Colombian Andes, plays a crucial role in maintaining water supplies for 8 million people in the capital city, Bogotá, Colombia. An innovative public/private partnership has set up an environmental trust fund through which payments from the water company are transferred for managing the páramo sustainably, potentially saving the water company around US$4 million per year (Forslund et al., 2009). Box 21.5 in Chapter 21 describes how the potential for contamination by diffuse or point-source pollution, which represented a serious commercial risk to bottled water production, was dealt with by Nestlé S.A., France. A key mechanism for implementing these approaches is payments for ecosystem service schemes, whereby the users of a service (e.g. clean water) pay others to sustain its delivery. In 2006, the Convention on the Protection and Use of Transboundary Watercourses and International Lakes adopted recommendations on payments for ecosystem services (PES) as a part of integrated water resource management (IWRM) (UNECE, 2007).

Ecosystem Services Review', which helps companies to identify and measure the risks and opportunities arising from their impact and dependence on ecosystem services (WRI, Meridian Institute and WBCSD, 2008), within which water plays a prominent role. WBCSD (2011) also makes the case for ecosystem valuation as an integral part of business planning and corporate decision-making. There is a need to upscale such approaches across all relevant business activities.

The use or restoration of ecosystem infrastructure to sustain or improve water quality is already a widespread practice with a proven track record (Box 8.7). Using ecosystem infrastructure to manage risks associated with flooding is another area in which interest, practice and demonstrated feasibility are rapidly developing. Flood management also demonstrates clearly that water management involves risk transfer (Box 8.8).

Another relevant example is the successful experience of the Water Protection Fund (FONAG) in Ecuador, which is a water trust fund created to protect the watersheds that supply water to the Metropolitan District

BOX 8.8

Ecosystems and flood risk reduction

Catastrophic flooding is emerging as one of the most significant sources of increasing vulnerability due to three main factors: increasing human populations and infrastructure development in high flood risk areas (particularly megacities in developing countries); loss of wetlands services that regulate water flows; and most probably the increasing frequency and severity of extreme weather events under climate change.

Most modern flood management plans now include the use of floodplains and wetlands. Key services of these lands include their ability to rapidly absorb and slowly release (regulate) water, and to increase ecosystems resilience by regulating sediment transfer. These services alone account for some of the highest land/nature values thus far calculated, for example, US$33,000 per ha of wetlands for hurricane risk reduction in the United States of America (Costanza et al. 2008). Potential damage from storms, coastal and inland flooding and landslides can be considerably reduced by a combination of careful land-use planning and maintaining/restoring ecosystems to enhance buffering capacity. For example, a Viet Nam report (Tallis et al., 2008) shows that planting and protecting nearly 12,000 ha of mangroves cost US$1.1 million, but saved annual expenditures on dyke maintenance of US$7.3 million. Similarly, according to Emerton and Kekulandala (2003), the Muthurajawela Marsh, a coastal wetland in a densely populated area in North Sri Lanka, provides several more visible ecosystem services (agriculture, fishing and firewood), which directly contribute to local incomes (total value: US$150 per ha and per year), but the most substantial benefits, which accrue to a wider population are related to flood attenuation (US$1,907 per ha) and industrial and domestic wastewater treatment (US$654 per ha).

However, the economic arguments for natural infrastructure are not always clear-cut. In the case of the Maple River Watershed, US, Shultz and Leitch (2001) stated that ecosystem restoration delivered insufficient risk reduction.

China runs one of the largest payments for ecosystem services schemes worldwide: the Grain-to-Greens Programme to tackle soil erosion. Soil erosion is believed to be a principal cause of the extreme flooding that took place in 1998. Planting trees or maintaining pasture has restored 9 million ha of cropland on steep slopes. In addition to flood risk reduction, co-benefits include wildlife conservation, including positive impacts on Giant Panda habitats (Chen et al., 2009).

Managed risk transfer can be a solution to overall risk management. For example, London is very vulnerable to flooding, and its physical flood protection infrastructure is ageing rapidly. But flood risk managers are now committed to creating space for floodwater where possible through river restoration activities, for example, the London Rivers Action Plan (RRC, 2009). Dykes have historically been used in the upper catchment to protect agriculture, which has in effect diverted water more quickly towards London, increasing risks there. Based on the unsurprising fact that crops, livestock and agriculture infrastructure are less valuable than national monuments, major financial centres and high-priced housing, and the high population densities there, part of the flood management strategy now includes removing dykes, thereby restoring wetlands, and compensating farmers for their increased risks. Massive infrastructure maintenance costs and flood insurance premiums for city inhabitants are reduced in the process. Agricultural productivity is not significantly affected, and indeed could increase, except during the occasional extreme flood – providing evidence that restoring floodplains does not necessarily result in significant losses in longer-term agricultural output. The issue is clearly one of risk, not productivity, and the solution is to compensate where increased risk exposure occurs, thereby increasing overall benefits.

of Quito and surrounding areas, seeking to ensure the medium- and long-term availability of water (Box 8.9). FONAG's achievements have led to the creation of similar funds in other areas of Ecuador (Ambato, Riobamba, Cuenca, Loja and Espíndola) and elsewhere (Colombia and Peru) (Lloret, 2009).

Water-related ecosystem infrastructure involves all biological/ecological components of the water cycle, and is not limited to managing surface and groundwater water availability and quality. Examples of the role of forests in sustaining regional water balance, including avoiding tipping points, are provided in Chapter 4, Section 4.3. The role of land cover (vegetation) and soils in reducing hydrological risk illustrates the need to rethink water storage in ecosystem terms (Box 8.10).

Increasing uncertainty in water management is the result of less than optimal understanding of ecosystem functions and their impacts on ecosystem services in conjunction with serious gaps in data and monitoring. The historical focus of nature/environment interests and science on 'conservation' has contributed to this uncertainty. The objective is important in itself but the influence of conservation interests on water policy

BOX 8.9

Lessons learned in the implementation and operation of the Water Protection Fund (FONAG, Ecuador)

- The financial resources of FONAG are provided by direct users of water, part of whose payments goes towards the protection of water sources. The trust fund is fed by locally generated funds and is not dependent on foreign or government capital.
- Given the weak governance of natural resources, particularly water, the availability of long-term financial instruments is a guarantee that interventions and programmes to protect water resources are sustainable.
- The greatest impact is achieved by sustained and long-term programmes; thus a trust fund represents a way of achieving high-impact intervention.
- Given that the Fund's plans are developed in a participative way, they are always viewed as complementary to financing, resulting in the strong engagement of actors with the actions being taken.
- The rules of the Fund clearly specify the destination of investments and the maximum amounts that can be assigned to administration, current spending and other expenses, thus safeguarding the quantity and quality of investments.

Source: Lloret (2009, p. 6, Lessons Learned, with minor modification).

BOX 8.10

Rethinking water storage: Restoring soil functionality

Soil moisture is a major component of the water cycle. It contributes to groundwater and maintains surface vegetation and soil health. Soil ecosystems are biodiversity rich and support important and inter-dependent ecosystem services, including nutrient cycling, carbon storage, erosion regulation, water cycling and purification and in particular all agricultural production.

Loss of water degrades soil and drives desertification (see Section 4.5 and the CAR on Desertification, Land Degradation and Drought). Apart from changing rainfall patterns, the major cause of soil degradation is land-use practice, in particular soil disturbance (excessive tillage), pollution and loss of land cover (vegetation). Loss of soil moisture is a major risk challenge for agriculture and restoring water retention in soils is a key to sustainable agriculture. The Comprehensive Assessment of Water Management in Agriculture (Comprehensive Assessment of Water Management in Agriculture, 2007) concluded that improving rainfed agriculture, including rehabilitating degraded lands, is a major opportunity to increase agricultural production and achieve global food security. This issue is largely about managing moisture in soil ecosystems.

Conservation agriculture addresses soil water risks with three principles: minimal soil disturbance, permanent soil cover and crop rotation. Agricultural benefits include organic matter increase, in-soil water conservation and improvement of soil structure, and thus the rooting zone. Other enhanced ecosystem services include regulated soil erosion (reducing road, dam and hydroelectric power plant maintenance costs), water quality, air quality, carbon sequestration, biodiversity/nature benefits, and regulated water availability (including flood-risk reduction). Conservation agriculture holds tremendous potential for all sizes of farms, agro-ecological systems and zones. Using ecosystem-based management, it delivers profitable and sustainable agricultural production and greatly improved environmental benefits, including flood-risk reduction and regulated soil erosion. The approach is being adopted on a large scale, for example, in Brazil and Canada. It is also widely used to address water risks for food security in dryland areas where its multiple benefits offer significant advantages over high risk and capital-intensive irrigation options.

For further reading on conservation agriculture see the FAO website: http://www.fao.org/ag/ca/index.html.

(and hence in turn on nature conservation) is erratic and limited in areas where development priorities dominate, especially where water resources are limited. The past two decades have, however, brought a visible and welcome shift towards nature conservation interests, proposing solutions to water problems. Most major, international nature-based NGOs, for example, now see nature in a broader development context. This is particularly so for biodiversity, which as a topic has gravitated towards the central role it plays in delivering ecosystem services. But the science associated with this shift is lagging. Trends in species, populations and habitats remain the cornerstone of biodiversity monitoring, although they are increasingly used as proxies for ecosystem change. Limited data availability for the condition and extent of wetlands continues to constrain science – an important gap considering their hydrological functions. Advances have been made in the monitoring of desertification (a process driven principally by water availability) and its impacts on desert ecosystem services and the well-being of affected communities (e.g. UNCCD, 2011), but water quality data remain patchy at best. But the biggest gap in information relates to the continuing difficulties encountered in direct monitoring of many relevant ecosystem services. The most advanced ecosystem service monitoring areas remain confined to the direct benefits people receive, such as food and hydropower. Significant gaps exist in other key services, in particular nutrient cycling, sediment transfer and deposition (land formation, coastal erosion regulation), water regulation (including the role of evapotranspiration), and the capacity to tease out ecosystem influences within data on the economic and human impacts of water-related disasters (drought and flood mitigation services). Attempts to make the relevant connections between water, ecosystems and people are improving, but it remains essentially a process of storyline building, based on case studies and limited global data. The importance of the topic merits better resources to underpin the monitoring and improve understanding, and to reduce the current over-dependency on complicated, and occasionally controversial, science.

One characteristic of ecosystem infrastructure solutions is that they offer less opportunity for corruption. In the harsh realities of water management, this is likely a major reason why they have not been adopted more widely. But they are increasingly becoming part of the water management dialogue. Practitioners need to strengthen, in particular, the rigour of their economic assessments. Promoting ecosystem infrastructure as a panacea for managing all water risks must be avoided. It is best placed among a suite of options (including hard-engineered solutions) to address risk on a case-by-case basis, then assessed through transparent and participatory means, where better information reduces uncertainty. Such an approach will enable the most cost-effective, holistic and sustainable risk management strategies to emerge. Current evidence suggests that under these conditions ecosystem-based approaches will increasingly become the foundation of water security.

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CHAPTER 9

Understanding uncertainty and risks associated with key drivers

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Managing water is managing risks old and new. Water management has always included managing risk and a significant body of knowledge exists about the management of the water cycle and its physical processes. Water management is also a cross-sectoral activity in which water managers are responsible for meeting the requirements of different economic sectors and the environment while caring for equity issues. This is not an easy task. The water system is dynamic and is characterized by large spatial and temporal variability in precipitation and runoff, with water-related risks such as floods and droughts. The allocation frameworks that regulate the distribution of water among different uses do not always reflect physical realities including the inherent variability in resource availability. Moreover, dynamics within sectors often create new and unexpected demands on water resources, increasing stress on its capacity to supply water for society and the environment.

The United Nations World Water Assessment Programme (WWAP) is currently undertaking a project to develop potential scenarios for the world's water resources and their use up to 2050. The last global water scenarios were published over ten years ago (Cosgrove and Rijsberman, 2000), and although they took into account most uncertainties and risks known at that time, they did not consider climate change. Furthermore, demography, technology, politics, societal values, governance and law are demonstrating accelerating trends or disruptions. Linkages are being made with other scenario processes being undertaken at the global level, such as new global environment scenarios (Global Environment Outlook 4) and the new Intergovernmental Panel on Climate Change (IPCC) scenarios on climate change. This chapter reflects findings to date.[1]

9.1 Possible evolution of key drivers

Traditionally, analysis of past climate coupled with stochastic analysis has provided a fairly reliable basis for examining the water cycle with its hydrological extremes. Historical climatic and hydrological information often forms the starting point for water managers and extrapolations of the past are routinely conducted in order to simulate future hydrological conditions. However, projected pressures on water resources lie outside the control of water managers. These can significantly affect the balance between water demand and supply – sometimes in uncertain ways – and thus create new risks for water managers and users. Such increasing uncertainties and risks necessitate a different approach to water management strategies.

The first phase of the WWAP World Water Scenarios Project has undertaken research on ten drivers of change. The relevance of each of these drivers varies in different regions of the world.

Water stress and sustainability are functions of the available water resources and their withdrawal and consumption. Both resources and consumption are variables that depend on many factors. Drivers that directly impinge upon water stress and sustainability are the ecosystem, agriculture, infrastructure, technology, demographics and economy. The ultimate drivers, *governance, politics, ethics* and society (values and equity), *climate change* and *security* exert their effect mostly through their impacts upon the proximate drivers. Experts in each of the fields covered by the drivers were asked to read one of the ten research reports and give their views about the future developments that were identified. Some participated in an exercise where they were asked to identify the relative importance of the developments and when it was likely they would occur. Others completed a survey in which they indicated which developments were more likely to occur, and when. The following text highlights developments considered most important or likely to occur.

9.1.1 Water resources: Surface water, groundwater and ecosystems

Any study of strategy, planning, design, operation and management of water resources systems must take as its basis *variability* of quantity and quality in water sources and supply systems. The new dimension that now must be considered is the importance of these possible variables and the uncertainty of the limits of their variability.

Expert survey participants in the WWAP World Water Scenarios Project ranked increases in water productivity in agriculture as the *most important* development affecting water. Water productivity for food production increased by nearly 100% between 1961 and 2001. Participants estimated that it would likely increase another 100% by 2040. They further estimated that rainfed agriculture globally will likely yield an average of 3.5 tonnes per ha of grain by around 2040.

The *second most important* development affecting water was the percentage of land area subject to droughts. The participants estimated that this could increase by at least 50% for extreme events, 40% for severe droughts and 30% for moderate ones by the 2040s.[2] Water availability issues were among the *most likely* developments to occur before 2050.

The participants considered global water withdrawals likely to increase by 50% from 2000 levels before 2020, with a probable 10% reduction in annual mean streamflows by 2030 in most of the populated areas of the world. By the beginning of the 2030s, groundwater recharge rates could be reduced by 20% in areas already suffering from water stress in 2010. The participants further considered that global agricultural trade by 2020 could contain the virtual water equivalent to 20% of the total water withdrawn globally for food production.

Solutions for the monitoring and management of water availability were seen as unlikely to occur in the short term. Conjunctive groundwater and surface water management were seen as unlikely to occur almost everywhere before the 2040s. This was also the case for management of withdrawals from aquifers to ensure they do not exceed the mean recharge rates of the previous decade.

The participants predicted that the Pacific Decadal, El Niño-Southern and North Atlantic Oscillations would likely be understood by the 2020s, and hence included in climate forecasting models. Recognition of the context of non-stationary climates and hydrological and anthropogenic forcing in all water management planning and operations was seen as likely to follow at the beginning of the 2030s.

Desalination was not viewed as a likely solution to water availability before the end of the 2040s. It was considered likely that desalination could produce 25% of

> "The survey participants expected that a strong, effective universally binding international agreement to combat climate change would likely be in place by 2040; this was viewed as an event of high importance."

the drinking water for cities by the end of the 2040s, and 5% of water used for food production by the middle of the century. The slow adoption rate of desalination technologies was also reflected in responses to the consultations on Agriculture, Economy and Technology.

The loss of species diversity was viewed as both important and likely to occur by the beginning of the 2030s. Diversity of freshwater biological species could be significantly reduced as early as the beginning of the 2020s, and was seen as likely by 2030 due to higher temperatures, reduced flows, atmospheric carbon dioxide and increased nitrogen caused by climate change. Organisms with strong adaptive capacity to extreme environmental variability could also increasingly dominate ecosystems by the beginning of that decade. The implementation of appropriate countermeasures to limit biodiversity and loss and reduce the rate of loss by 50% was seen as likely to occur by the beginning of the 2040s. However, the participants considered it unlikely that the presence and spread of water-borne invasive alien species could be brought under control before 2050.

9.1.2 Agriculture

The most important development related to water resources according to participants was increasing water withdrawals for agriculture. Withdrawals were seen as likely to increase from the current level of approximately 3100 billion m^3 to 4500 billion m^3 per year by 2020, or more likely, 2030. In several regions of the world – South Asia, Latin America and Africa, in particular, sub-Saharan Africa – availability of water in these volumes is not physically possible. In other regions, the significant investment in infrastructure required for storage is not economically possible for many countries concerned.

The second most important ranked development was deforestation. Regions might seek to increase their agricultural areas by continuing to expand deforestation, albeit more slowly. Participants viewed this development as more likely to occur than the slowing of expansion of agricultural lands as a result of ecological concerns.

Looking at *probable* developments, the probability was seen that fertilizer prices would continue to track energy prices. If energy prices continue to rise, the cost of produce will also rise unless offset by other measures. Another probability was that investments in infrastructure would improve the production potential of rainfed farming (e.g. by improving rainwater collection and storage systems) by 2020. Such a development would make more efficient use of available land and water.

9.1.3 Climate change and variability

Climate change will affect the hydrological cycle and hence the availability of water for its users. It is expected that extreme water-related events such as floods and droughts will occur more frequently and with greater intensity (Bates et al., 2008). Extrapolations using historical data are no longer valid for these events – as for the hydrological cycle as a whole – which increases uncertainty about the future. Furthermore, the spatial resolution of global climate change models is relatively coarse. As a result, conversion to the more detailed scale necessary for water managers can prove difficult. The problem is compounded by the fact that these projections are not available at the jurisdictional level (state and local), or at the river basin level where much of water resources planning takes place.

The *important* developments for this driver are related to water availability. The survey participants estimated that the number of people at risk from water stress was likely to reach 1.7 billion before 2030 (before 2020 at the earliest), and 2.0 billion by the beginning of the 2030s. This number was not likely to reach 3.2 billion before 2050. This is roughly consistent with, though possibly slightly ahead of, the IPCC SRES scenarios (Nakicenovic, 2000).

Another important development was the increase in delta land vulnerable to serious flooding. This could expand by 50% and was seen as likely to occur by the beginning of the 2040s.

These events could have a significant impact on agriculture. Inter-annual freshwater shortages combined with flooding were seen as likely to reduce total global crop yields by 10% by the 2040s.

Another important development was the potential for a worldwide rise in living standards and population growth to greatly increase the demand for energy, causing a 20% increase in GHG emissions. This was considered likely by the beginning of the 2030s. Alternative energy technologies and solutions were likely to emerge more significantly around this time. Battery-powered electric cars could have a 30% share of the world automobile market by the 2030s. Wind power could generate 20% of the world electricity demand towards the end of the same decade. By the 2040s, 30% of the world power consumption could be connected to 'smart' power grids, while hydrogen fuel cells could power 20% of the world automobile market during the same decade. Carbon capture and storage could be used in 50% of all new fossil power plants, most likely after 2050, with existing plants being retrofitted or closed.

The survey participants expected that a strong, effective universally binding international agreement to combat climate change would likely be in place by 2040; this was viewed as an event of high importance.

The positive development with *earliest likelihood* of occurring is an extensive well-planned and financed multi-national campaign to support public education on the facts, causes, effects and costs of climate change, by the beginning of the 2020s. Increased public information and knowledge transfer about climate-related issues are likely to occur after this. For example, indisputable global precipitation and temperature changes could be reported publicly in the 2020s, with effective international coordination in place covering activities in climate analysis, mitigation and adaptation, and continual exchange of related up-to-date data, knowledge and experience by the 2030s. The 2030s will also likely see the integration of funding for climate change adaptation into funding for adaptive water management – a priority for water-reliant socio-economic sectors.

9.1.4 Infrastructure

Aging water infrastructure, lack of data and deteriorating monitoring networks represent major risks for the future in nearly all regions.

Survey participants viewed access to potable water and appropriate sanitation facilities as the *most important* developments in this regard. They considered that 90% of the global population would likely have reasonable access to a reliable source of safe drinking water by the beginning of the 2040s. Their view that the beginning of the 2030s would see the routine use of nanofilters in the treatment of potable water in over 30 countries may also have influenced this appraisal. The technology survey provided a similar time horizon for the roll out of this technology: it was considered likely that economically viable nanotechnology (such as carbon nanotubes) could yield new and effective membranes and catalysts useful in desalination and pollution control by 2030. The participants further considered that 90% of the global population would most likely have reasonable access to appropriate sanitation facilities towards the end of the 2040s.

A second important development was the annual inspection of all dams and dykes over 50 years old, and all those with significant risks from hazards for structural soundness. This was estimated most likely to begin in the 2030s. The development of emergency evacuation plans with clear implementation responsibility for these dams and dykes was also considered most likely to occur in the 2030s. This is particularly relevant as the increased siltation of dams due to climate change and deforestation could shorten the estimated remaining lifetime of a significant number of large dams by 30%. This development was also viewed as important and most likely to occur within the same timeframe as the previous developments.

Investments in infrastructure were considered also to be of importance. Income for water services (tariffs, taxes and transfers) covering all operating costs and depreciation of infrastructure globally were considered likely to occur at the beginning of the 2040s. This was also the case for the write-off of external debt of low-income countries, freeing funds for investment in water infrastructure.

Inland navigation needs would continue to influence river operations and flow allocations. The 2020s would likely see national water planning taking into account the need to provide appropriate environmental flows in the regulation of water infrastructure.

With the the beginning of the 2030s would likely come robots to remotely and reliably mend underground pipes in at least ten countries, and the use of chemical, biological, radiological and nuclear (CBRN) sensor networks to monitor hazardous incidents in water systems. Participants also estimated that remote sensing technologies and GPS could be used to supplement local water resource monitoring systems and other technologies, by the 2030s, to identify, map and explore underground infrastructures whose location was unknown or forgotten.

9.1.5 Technology

Survey participants expected most of the largest water consumers using products to conserve water between 2020 and 2030. These include pressure-reducing valves, horizontal-axis clothes washers, water-efficient dishwashers, grey-water recycling systems, low-flush tank toilets and low-flow or waterless urinals.

Inexpensive technologies for water desalination in large volumes, enabling nearly everyone within 100 miles (160 km) of coastlines to have water for their drinking and industrial water needs, were considered likely by 2020 with increasing likelihood by 2030. This was linked to economically viable nanotechnology (such as carbon nanotubes), which could yield new and effective membranes and catalysts useful in desalination and pollution control by removing heavy metal and other dissolved pollutants from water. Participants saw this as likely between 2020 and 2030. These dates probably reflect an appreciation of the delays in adopting and building systems with the new technology.

The widespread adoption of a well-known technology, rainwater harvesting, combined with new, simple and cheap ways of purifying the collected water was also considered likely between 2020 and 2030. The same likelihood was accorded to the use of affordable technology by agriculturists to capture real-time data on their crops and soil moisture, enabling them to make informed decisions on efficient irrigation schedules. Both would help increase the efficiency of land and water use.

9.1.6 Demography

Population dynamics including growth, age distribution, urbanization and migration lead to increased pressures on freshwater resources through greater demand for water and higher pollution levels.

Unsurprisingly, overall world population size figured as an *important* issue for developments in this section. Survey participants felt that the world population could reach 7.9 billion by 2034, 9.15 billion at the beginning of the 2050s, and 10.46 billion beyond 2050. This is in keeping with the UN Population Division's 2008 Revision medium variant, which estimated a population of 9.1 billion by 2050 (UNDESA, 2009).

Population growth could overwhelm past gains in water and sanitation accessibility. Participants (mainly demographers) considered that by the 2030s, population growth in the majority of developing countries could reduce the percentage of those with improved access to water supply and sanitation achieved since 1990 by 10%.

Education and employment of women was seen as a development influencing fertility, particularly in least developed countries. By the 2030s, the rise in levels of women's education and employment in a majority of least developed countries could cause a significant decline in fertility levels.

Efforts to reduce mortality in least developed countries were considered as developments with the *earliest likelihood*. In the group of 58 countries for which HIV/AIDS prevalence is above 1% and/or whose HIV population exceeds 500,000, most could achieve anti-retroviral treatment coverage for people living with HIV/AIDS of 60% or more by the 2020s. In the same decade the number of interventions to prevent mother-to-child transmission of HIV in these countries could reach an average of 60%. The coverage level for both interventions was 36% in 2007.

The combined global deaths per year from diarrhoeal diseases and malaria could decrease to 1.54 million or less before 2030 (compared to 2.53 million in 2008), and to 710,000 or less before 2040.

The infant mortality rate was seen as likely to drop. The average estimated mortality rate in 2005–2010 in less developed countries was 78 deaths per 1,000 live births.[3] By 2030 the rate was projected to drop in 60 developing countries to 45 deaths per 1,000 live births. Expected successes in overcoming these challenges could explain why participants estimated that all developing countries have a life expectancy of 70 years or more by the 2040s.

Developments that could diminish longevity were seen as possible. By the 2030s, the worsening of the epidemiological environment with regards to the spread of pandemics, re-emerging pathogens and the evolution of drug-resistant diseases could prevent the average world life expectancy from growing above 75.5 years. By the late 2030s, delayed impacts of obesity could act against increasing life expectancy beyond 75.5 years.

Growth in urban population was also deemed important. By the end of the 2030s 70% of the world population was seen as likely to become urban. The proportion of the world population living in slums was likely to decrease just to 25% by the end of the 2040s, from 33% today.

The proportion of world population living in coastal areas could reach 75% in the 2030s, increasing from 60% in 2010. The number of migrants due to the impacts of climate change was likely to reach 250 million in the 2040s. Migration following natural disasters and conflict-based events often occurs principally to coastal urban areas, including large peri-urban slums with little or no access to basic services and increased risk exposure to disease and epidemics.

9.1.7 Economy and security

Survey participants on the economy and security gave almost equal importance to two possible developments.

First, the demand for water in developing countries could increase by 50% over current 2011 levels. Participants considered this likely to happen between 2020 and 2030. This reinforces the issues raised by the participants who reviewed agricultural developments.

Second, over 40% of countries could experience severe freshwater scarcity by 2020. This would occur mostly in low-income countries or regions in sub-Saharan Africa and Asia. It was considered more *likely* that unequal access to water would create new economic polarities, between 2020 and 2030. Such economic polarities would increase the dangers of political unrest and consequent conflict.

"A water footprint measure will likely be available and published widely on an annual basis between 2020 and 2030."

A water footprint measure will likely be available and published widely on an annual basis between 2020 and 2030 (e.g. in 2030 the ecological footprint is expected to be around twice the size of the Earth's surface). Such a tool would provide useful information to decision-makers, although the question remains as to whether they will have the resources and will to respond appropriately. Several types of cost-effective desalination or other technologies could be widely available and increase safe water supply by 20% globally between 2020 and 2030. This applies to drinking water and water for industrial use, but desalinated water will probably remain prohibitively expensive except for high value crops or new, more intense types of food production.

9.1.8 Governance

Many survey participants saw the failure of urban water supply infrastructure in many cities as important (underscoring the need to upgrade urban water systems). This could happen in more than two-dozen major cities by 2030. That this item appears so high in a review on governance indicates that participants feel that urban water system governance is badly in need of attention.

'The development of online forums on water issues including local government and civil society was also considered important, reducing the asymmetry of information between user, provider and policy-maker. Networked coordination at the national level to share information and best practices between local water agencies was similarly viewed as important and likely to be achieved in at least 95% of countries between 2020 and 2030. Clearly, public consultation and information sharing are considered key factors with a fair degree of likelihood.

The adoption of an international convention specifically dedicated to groundwater was considered important, reflecting the lack of attention to groundwater in the past. Yet while participants thought it important, it was considered likely to occur only by 2030, probably reflecting the delays in ratification of the 1997 United Nations Convention on Non-Navigational Uses of International Watercourses (which has received 24 ratifications as of October 2011).

9.1.9 Politics

The survey participants on politics had similar views on the *importance* of establishing and following transparency and participation procedures in matters of water governance. However, they saw little likelihood that this would take place in at least 120 countries by 2020–2030. They also saw as important the number of people living in insecure or unstable countries that run a significant risk of collapse. Two billion people were living in such conditions in 2010, according to the Failed States Index 2010 – a collaborative between the Fund for Peace and *Foreign Policy* that uses 12 indicators of state cohesion and performance to assess the vulnerability of 177 states.[4] That this could be reduced to less than 1 billion people by 2030 was viewed as unlikely. As noted earlier, water (and related food and energy) scarcity could have a major negative impact on achieving this objective. In fact, participants saw a much greater likelihood that social instability and violence could spread to most states faced with chronic water scarcity.

Politics respondents considered that resistance within government and from vested interests could keep governments from becoming more participatory, flexible and transparent, leading to further mistrust and/or increased activism. The group thought it likely that at least 100 countries would fall into this category between 2020 and 2030. They thought it almost as likely that most people could agree upon the interconnectedness of living systems. Participants felt that while the population at large might eventually agree upon action to be taken, governments as presently constituted would be unable to respond.

9.1.10 Ethics and culture

The survey group on ethics and culture considered a shift in human values, whereby people agree that the present has an obligation to preserve opportunities for the future, as an important development. This was deemed likely within the 2020–2030 timeframe. This development is related to recognition of the interconnectedness of living systems, which was considered to have about the same probability by survey participants in the politics group. Such shifts in public perception can provide opportunities for improved water management.

The deepening of current inequalities in access to water in poor countries caused by increasing water scarcity was also ranked as important by this group, and deemed likely to occur in the 2020–2030 period.

The acknowledgement of access to safe water as a basic human right by most countries in the world also was considered important. However, despite international recognition, the survey participants considered that respect of the right was likely to occur closer to 2030. Of similar importance was the development of water-related anti-poverty strategies including employment of poor people at water points, in irrigation and in food production. The participants considered that these strategies could be in place in at least 30 countries within the same timeframe. Knowledge sharing was considered likely, with the emergence of collaborative international research and development on the ethical uses of water probable within the 2020–2030 timeframe.

9.2 Responding to the challenges: The past is a poor guide to an uncertain future

Water managers work in an uncertain world. Their first priority is to ensure the security of water supplies. These depend on geophysical parameters that dictate water availability (precipitation, runoff, infiltration), and the determinants of human activities that affect the quality and natural flow of water (e.g. how land use affects storm water runoff), as well as its distribution in space and time. Until recently, the analysis of historical data coupled with stochastic[5] analysis has provided a good basis for examining extremes and sensitivities of water supplies and their robustness, resilience and reliability under past climate variability. For water managers this is the starting point for any realistic analysis, conducted routinely in most managed systems. However, the likelihood of increased variability of future water supply, as a result of climate change, will make analyses based on historical data less reliable.

There is also greater uncertainty on the demand side due to an increase in the number and complexity of choices, which are outgrowing managers' abilities to assimilate and analyse data and make decisions. As an example, there are difficulties in predicting the demand for specific goods and services, including energy, which affect water through production, transport or disposal. These create new uncertainties and associated risks for water managers.

Technological development can address these challenges, but not always. The development of new technologies can help address issues of water production and quality and thus reduce risks, but narrowly targeted technological development that does not take into account impacts on water can worsen existing risks (e.g. the first, current generation of biofuel technologies).

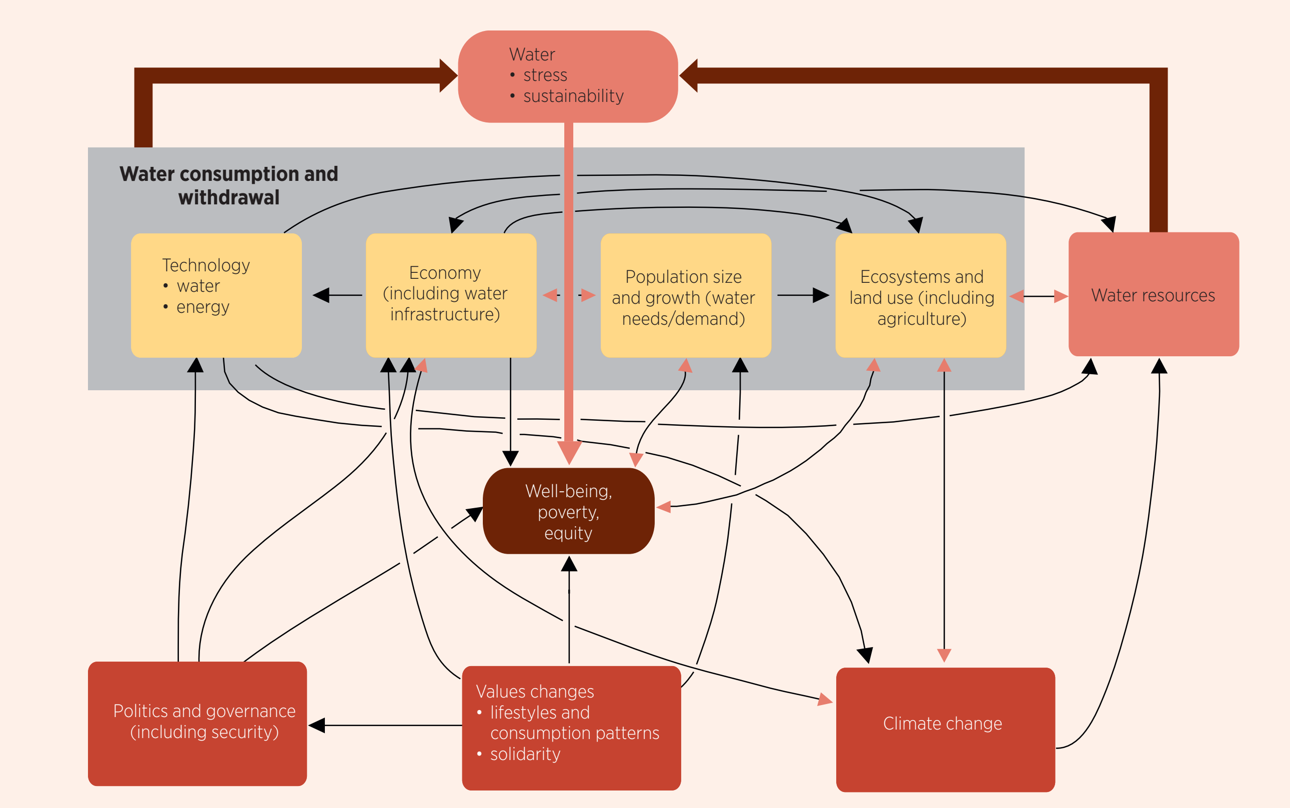
Water managers are aware of the existing and potential vulnerabilities within the systems in which they operate. However, the gathering speed of forces outside their control pose challenges to water management and affect the financial and institutional resources available to meet them. The timescale for agreement on solutions and their implement can stretch to decades, especially for issues with a regional or international dimension. The pace of change reduces the time available for recognizing the problem and agreeing and implementing the right decision at the right time. Decision-makers 'outside the water box' are themselves affected by the uncertainty of how shaping forces will evolve. Water managers can only inform their decisions and manage with the available tools. In this context, it is important to develop relevant information as close as possible to the geographic scale at which they work. Figure 9.1 illustrates the multiplicity of drivers and the complex interactions between them.

9.2.1 Scenario analysis

Scenario analysis is a planning tool for assessing responses to a potentially very different future, depending on how key drivers develop and interact. There are myriad drivers that determine the future situation; therefore, it is rarely possible to consider all of them simultaneously (ten have been discussed

FIGURE 9.1

Key drivers and causal links affecting water stress and sustainability and human well-being



Source: Gallopíin (2012, fig. 2, p. 8).

"The timescale for agreement on solutions and their implement can stretch to decades, especially for issues with a regional or international dimension. The pace of change reduces the time available for recognizing the problem and agreeing and implementing the right decision at the right time."

earlier). Consequently, scenario analysis takes a limited number of drivers at a time, and assesses their combined influence on the variables likely to be of particular significance for shaping the future (e.g. population growth and distribution, size of agriculture, and the amount of water used). Sensitivity analysis is undertaken for drivers not included explicitly, to confirm the validity of the scenarios that have been generated. These projections may then be used in the evaluation of policy and planning responses, to maximize benefits and/or minimize losses in achieving the desired state.

World Water Scenarios Project

The major focus of the World Water Scenarios Project[6] is future water availability and its impacts on human well-being, including the health of ecosystems that provide life support. The principal causal links needed to build the logic (or plot) of the scenarios have been tentatively identified. As shown in Figure 9.1, water stress and sustainability (top oval) are functions of the available water resources and their withdrawal and consumption. In turn, both resources and consumption are variables that depend on many factors (only the most relevant are shown). The main drivers are arranged in a sequence from top to bottom showing the proximate drivers (top row of boxes) that directly impinge upon water stress and sustainability, and the ultimate drivers (bottom row of boxes) that exert their effect, mostly through their impacts upon the proximate drivers. Arrows indicate causal influences from and between drivers. In some cases there is reciprocal (feedback) causality between drivers. The next phase of the Scenarios Project will entail developing scenarios and scenario-development tools that can be used by decision-makers.

9.3 Peering into possible futures

Section 9.1 highlighted some of the most important trends likely to affect water and its key drivers over the next forty years, and offered insight on the pressures, uncertainties and risks these create for water resources uses and management. Section 9.2 demonstrated the complexity of the interlinkages between these drivers of change. These will be qualitatively and quantitatively analysed using models as WWAP's World Water Scenarios Project moves ahead.

Even without the benefit of the systematic and analytical approach employed in the World Water Scenarios project, it is useful to consider how certain drivers could interact with each other, and how the trends cumulate in order to examine possible futures for water resources. A set of possible future outcomes are examined here in terms of the positive and negative pressures they are most likely to generate, and the types of uncertainties and risks their evolution may produce, both regionally and globally.

Contemporary crises (food, energy, poverty, health, economy, environmental degradation, climate change) are the result of a combination of various unanticipated pressures or drivers. While reflecting upon these crises and searching for possible solutions, it is also important to try to find ways to avoid future crises. This section provides a superficial exploration of some of the possible outcomes resulting from combinations of the various trends discussed in Section 9.1, and analyses the short and long-term risks involved in each situation. The three scenarios examined below relate to: how we can feed the world population, how the evolution of technology might help, and the role of policies in encouraging a transition to a sustainable economy.

9.3.1 Feeding or not feeding 9 billion people

One possible future aims to analyse the impacts on water of a policy status quo, or to describe what might happen in the absence of any intervention.

The global population is likely to reach 9.1 billion in 2050, if not sooner. While this alone has potentially dire consequences in terms of pressures on natural resources, especially water, a deeper look at demographic trends provides a more concrete portrait of life in 2050. According to the UN Population Division (2010 revision), (UNDESA, 2009) 68% of these 9 billion people will reside in urban settings. At least 32% of the total world population will be under 24 years of age, and on average, people will live longer lives (75.5 years) (UNDESA, 2009). As mentioned in Section 9.1, population growth alone could reduce the percentage of those with improved access to water supply and sanitation by 10%.

Growth in food demand resulting from population growth and changes in nutritional habits, hand in hand with increased urbanization, will likely lead to a multiplied increase in water demand. Other impacts of human settlements will also increase with encroachment on fragile or marginal lands, deforestation and pollution. Most climate change scenarios predict that increasing variability and unpredictability will seriously affect global water availability. As seen in Section 9.1, water availability is expected to decrease in many regions (groundwater recharge, streamflow, rainfall). Yet future global agricultural water consumption alone (including both rainfed and irrigated agriculture) is estimated to increase by about 19% by 2050, and will be even greater in the absence of any technological progress or policy intervention (see Chapter 2). In fact, current trends show that water withdrawals are expected to increase by at least 25% in developing countries (UNEP, 2007).

Natural resources and ecosystems that form the basis of livelihoods are increasingly under pressure from highly intensified and often unsustainable use. For example, 60% of the world's 227 largest rivers are moderately to greatly fragmented by dams or diversions (UNEP, 2007), and the rate of dam construction is increasing worldwide. Deforestation for energy supply and agricultural expansion is leading to soil erosion and declining soil fertility, as well as siltation in many water bodies and reservoirs (reducing the efficiency of dams). As cleared land retains less water, aquifer replenishment decreases and water loss through run-off increases. Paradoxically, land clearing for agriculture does not always lead to significant or proportionate yield increase, particularly in the long term, as soil fertility rapidly declines and cropping becomes more labour-intensive (see e.g. Gibbons, et al, 2009; Juo et al., 1995).

While agriculture continues to use at least 70% of water resources globally, other economic sectors will continue to compete for water resources, and some intensely, without an explicit mechanism for allocation decision-making. In most cases, water will continue to remain an afterthought of economic and sectoral policy. As industry develops, particularly in emerging countries and countries actively pursuing non-agricultural diversification schemes, various sectors present the potential for significant increases in water use. Decisions about allocations between sectors are usually not subject to specific regulations, although some countries explicitly recognize drinking water as a priority.

Pressures on natural resources and the increasing interconnection between national economies mean that the world is likely to continue to grapple with periodical crises, such as the recent food and financial crises, and the impending energy crisis. To add to uncertainty, these complex situations are closely linked, for example, the price of food is closely linked to the price of energy through the costs of transport and fertilizers. Single-market perturbations, caused by political (e.g. conflict in oil-producing countries) or climatic extremes (drought in crop-producing countries) are difficult to predict and have far-reaching and often long-lasting consequences well beyond traditional sectoral boundaries.

Responses to these crises can also have negative impacts on water resources and management, because they inadvertently create a bias towards a given solution focused on a particular water user; more often than not, an intensive water user. For example, attempts to pre-empt an energy crisis through production of biofuels or by tapping into harder to reach, and more water intensive, fossil fuel deposits (oil sands, shale gas) could have negative impacts by diverting land and water from food production, and by creating a more lucrative competing sector. For example, water used for cooling power plants in the United States of America represents 40% of the country's industrial water use. This figure is expected to reach 30% in China in 2030.[7] Increased energy production using current technology, at current levels of efficiency, is therefore likely to exert multiplied pressures on scarce water resources.

In the absence of technological improvements or policy interventions, economic polarities will increase between water-rich and water-poor countries, as well as between sectors or regions within countries. This would mean higher numbers of people with higher needs competing for less water, of lesser quality. Because allocation will inevitably go to the highest paying sector, region or country, this may result in an increasingly significant portion of people not being able to satisfy their basic needs for food, energy, water and sanitation. This would not be mere stagnation, but would likely take the form of a distinctly regressive trend compared to current conditions.

More importantly, this possible outcome represents a high degree of risk and uncertainty. This is because the underlying links between the various drivers are not well understood or are not considered as part of decision-making, and because the long-term impacts on water of key sectoral decisions are being largely ignored. Therefore, this possible future remains highly volatile, with water – despite being an asset for all economic sectors – severely impacted regardless of the outcome or evolution of any single driver. Paradoxically, while this future outcome represents the highest risk for society overall in the long term and the highest degree of uncertainty regarding future water availability and management, it also represents a future in which individuals, governments and the private sector are the least risk-averse in their daily decisions, focusing on short-term benefits rather than long-term potential.

9.3.2 Technological evolution and greater awareness for a greener economy

A second possible future would be determined by the evolution of current technology development trends, highlighted briefly in the previous section. This outcome assumes that technology development is almost exclusively a product of private sector mobilization, responding to existing levels of awareness, market conditions and existing pressures for increasing profit margins in developed countries. The technologies considered here are not necessarily applicable uniquely to water management activities (e.g. filtration technologies), but also to water-using sectors (e.g. agriculture, energy). However, they are all assumed to have the effect of reducing water demand and waste or improving water management.

Among the key anticipated and most likely developments over the next decades is desalination, which has the potential to increase water availability, and would become more efficient and more affordable. Although slow in terms of operationalization, desalination shows potential for providing drinking water in coastal regions within the next 50 years. However, no projections are available for the potential negative impacts of the technology, which at the present moment result in ever-decreasing efficiency because of pollution discharge and over-salinization of the immediate ecosystem. If left unchecked, this technology could have high positive impacts on water supply, but negative impacts on marine and coastal environments from by-products (brine) or excessive intake (WWF, 2007). Desalination uses high levels of energy, raising the issue of yet another trade-off between water supply and energy production. Solar-powered desalination plants, currently being tested in some countries (e.g. Saudi Arabia), might provide a more suitable avenue in sun-rich countries.

A more promising trend, one with fewer trade-offs, but slower private sector mobilization, encompasses various technologies applicable to agricultural water uses and which, combined, could lead to significant water conservation in the most important water-using sector. The further dissemination of water-harvesting technologies, efficient irrigation (e.g. drip irrigation), as well as technologies for the re-use of grey water in peri-urban agriculture could also lead to an increase in water availability for food production. The development of sustainable urban agriculture could also provide resilient avenues for ensuring local food supply. Already, the FAO estimates that 70% of urban households in developing countries participate in agricultural activities (FAO, 2010). The development of bio-fertilization techniques would also increase water use efficiency by promoting higher nutrient absorption and crop growth rates. Increases in on-farm efficiency, brought about by the timely availability of agro-climatic information (to help deal with increasing climate and rainfall variability), early warning systems and mechanization, which is still lagging behind in many countries, could also lead to an overall increase in water use efficiency.

There is a risk that the response of producers to the evolution of these profitable technologies could offset (or even nullify) any gains in water use efficiency; for example, if producers continue to expand agricultural land into marginal or fragile areas (such as wetlands, slopes or forests), resulting in an accelerating rate of deforestation and soil erosion. Nevertheless, the combination of these technological developments would mean an increase in water requirements for agriculture of close to 20–25% (see Chapter 2), rather than an agricultural water requirement increase of 70–90% (as described in Section 9.2.1).

Further technology developments applicable to urban water production and waste handling that are likely to increase due to sheer urban population growth are also expected to contribute to reducing absolute water withdrawals and waste. For example, the development of nanotechnology, cited as one of the most probable anticipated technologies in Section 9.2.1, will help reduce pollution and accelerate the pace of filtration, making water re-use possible and increasingly affordable. Grey-water reuse, along with simple water conservation technologies for urban applications (more efficient toilets, in-house grey water recycling, more efficient showers) would also make water conservation practices for urban dwellers more affordable. The opportunity cost of selecting ecological options would decrease both at the individual and the community scale. This will mean more efficient options for urban planning and an increase in green building design, which will facilitate the efficient integration of new urban migrants.

Similar developments can be expected from anticipated growth in renewable energy technology, and in energy efficiency measures, which are themselves driven by pressures on current energy resources. As water is a key input in almost all energy production (from extraction to cooling), industrial demand for water is expected to increase as population growth is paired with increasing energy demand. The growth in renewable or alternative energy technology will therefore have a beneficial impact on water demand, potentially freeing resources for more efficient uses, perhaps for agriculture. Photovoltaic panels and wind turbines, which have recently expanded in number in many countries, require much less water for production and very little for maintenance. Urban development using cheaper solar energies would therefore reduce water demand.

Rapid uptake of these technologies would be paired with the anticipated evolution of global consciousness regarding human impacts on environment, and in particular, an increased understanding of water scarcity issues (see Section 9.1). Developed country markets, already beginning to show a preference towards 'responsible' products, would continue to encourage technology development, while the availability of affordable green products, practices and options would induce a gradual transformation towards a green economy. This applies to food as well as other consumer goods. It also has the potential to effect a gradual shift in agricultural practices towards organic farming, local or peri-urban agriculture, and overall more sustainable and equitable agriculture, which uses fewer pesticides, maximizes efficiency in its use of inputs including water, and produces higher yields and socio-economic benefits. Recent data shows that markets for organic food and beverages expanded 10–20% on average per year between 2000 and 2007 (Sahota, 2009), resulting in a similar expansion of sustainably managed farmland (UNEP, 2011).

UNEP defines the green economy as 'one that results in improved human well-being and social equity, while significantly reducing environmental risks and ecological scarcities' (UNEP, 2010, p. 4). A naturally evolving green economy – one brought about without a conscious policy effort through the combined result of technology development and increased awareness – would result in a decreased water footprint in most water-using sectors, in particular agriculture, because of increased conservation, reuse and recycling, and greater efficiency. This would also have positive results on overall poverty reduction and socio-economic development.

In such a future, voluntary labelling of products according to their water efficiency or water use would become more frequent (although not necessarily subject to well-established norms and standards). Fairtrade, green or sustainable labelling would increasingly include a measure of water footprints.

These somewhat spontaneous technology developments (extrapolated from current trends) would produce benefits for water, but might not produce the complete set of expected green-economy benefits for a variety of reasons. First, there may be delays in adoption because of cultural obstacles to technological uptake (for example, resistance to the recycling of sewage water for drinking). Second, there may be structural or policy obstacles to technology transfer and dissemination because of intellectual property barriers, or a lack of investment in research and extension (particularly in the agricultural sector), or a lack of funding, which could lead to regional disparities in access, potentially aggravating current income gaps. Such gaps in access already exist, with small pockets of private sector interests holding the majority of public-interest patents and intellectual property rights. There is a risk that the unregulated development of technology could lead to perpetuated polarities between the 'haves' and 'have-nots'. Finally, inadequate governance and decision-making systems may create market distortions towards inefficient technologies, for example, through inappropriate subsidies or for lack of long-term vision. As a result, this second possible future, although realistically achievable in some targeted places or pockets, will remain suboptimal, highlighting the need for a set of policy responses or measures to bring about more rapid, equitable and sustainable change.

Nevertheless, this possible future represents a marked change in the uncertainty we face, as increased awareness and a marked private-sector interest in emerging opportunities mean that water management is no longer obscured by other short-term gains. In this possible outcome, the impacts on water of various sectoral or interest-based decisions are more readily understood thanks to investments in research and development, and because the possibilities offered by technology are more evident. In this possible future, some segments of the private sector and governments are shouldering a part of the short-term risks by investing in research and development and creating new markets, because the long-term risks are more apparent and the potential benefits are also more clearly understood. However, the long-term risks and uncertainties faced by water users and water-using sectors are still not entirely mitigated. Furthermore, while there is a chance that this spontaneously emerging greener economy has positive impacts on water, there remains uncertainty about continued negative impacts and trade-offs.

9.3.3 Policies that encourage a transition to a sustainable water economy

A third possible future extrapolates on current demographic and technology trends, as well as a set of policy interventions that could be adopted over the next two decades. It presents a picture of a possible future based upon key or important policy decisions regarding financing, poverty reduction, climate change, science, and water governance and overall economic policy being taken.

As highlighted in Section 9.2.2, a legally binding international agreement to combat climate change could be in place by 2040, along with significant financing for awareness-raising and adaptation in low-income countries. Because most climate change impacts are felt through water, this would have positive repercussions on the overall levels of financing for water. This could mean higher levels of investment in water infrastructure, leading to reductions in waste and increases in sustainable mobilization, as well as increased sanitation network coverage. The adoption of a concerted effort to curb greenhouse gas emissions would send a clear signal to the private sector concerning the further development of alternative and renewable energies, confirming a trend explored in the above technology-driven future. Hence, technology development for water extraction and distribution, and reductions in industrial water use (especially for energy), are also expected from the adoption of an optimal climate change regime.

Stronger concerted efforts to reduce poverty would also yield significant benefits for water and sanitation, through an increase in funding for water-related initiatives. As water is often a constraining factor on agricultural productivity and other forms of economic development, investment in water management and conservation, as well as sanitation, is expected to deliver multiplied poverty-reduction benefits. Moreover, debt forgiveness – also among the potentially expected international policy decisions – could free substantial levels of funding for water infrastructure and development.

At the national level, another key policy might be achieved by establishing fair prices for water. This would be contingent on the development of solid property regimes, documented land tenure arrangements, and clearly established water rights and allocation systems. However, if coupled with a growing sense of awareness among local populations and a generally higher level of understanding of water issues, the more likely outcome would be the integration of water issues into development planning, particularly urban planning. Adequate revenues from water management would also allow for the regular maintenance of water infrastructure and reduce contamination and leakages.

> "Debt forgiveness – also among the potentially expected international policy decisions – could free substantial levels of funding for water infrastructure and development."

Other policy changes would include the removal of unsustainable subsidies in agriculture and overall agricultural trade liberalization. Subsidies that encourage inefficient uses of land, water and fertilizers, and create market distortions towards higher water users, would be gradually replaced by flexible, index-based insurance schemes that allow producers to make short-term cropping decisions based on climate variability and extremes, while encouraging intra-seasonal innovation and technological upgrading of cultivation practices. This, coupled with increased spending on agricultural technology, extension and research (as an engine of economic recovery), would lead to significant water efficiency gains in the agriculture sector alone. Models developed recently for the UNEP Green Economy initiative show that trade liberalization tends to reduce water use in water-scarce regions and increase water use in water-abundant regions, meaning that water would be allocated to its most effective use at the global level (Calzadilla et al., 2010). There is, however, a risk that without transparent and equity-based local allocation mechanisms, further liberalization could still create barriers or difficulties of water access for smaller producers.

Another policy shift might be inspired by the recognition that healthy environments provide key services, in particular, water. Hence, governments at the local, subregional and national levels could begin investing in the restoration and rehabilitation of key ecosystem functions. As a result, productivity would increase without jeopardizing key environmental services. This would be greatly facilitated by current technology development trends and increases in awareness, particularly in developed countries. It would also be supported by the increased understanding that healthy ecosystems can help adapt to the effects of climate change while maintaining local livelihoods. As seen in recent studies, water-related services provided by healthy ecosystems, such as mangroves, forests and wetlands, compare favourably with those provided by man-made structures (such as treatment plants), which usually come with much higher costs (see TEEB, 2010; World Bank, 2010), shorter life-spans, and are potentially less resistant to anticipated climate changes.

Increased awareness among the global and national population, coupled with increased access to information and increased inclusiveness and participation of stakeholders everywhere, could also lead to shifts in water governance within and between countries. With recognition of the fact that water is best managed at local levels, water-basin institutions and decentralized authorities would be given increased power and resources to effectively manage water within countries. This would promote local and climate-responsive allocation of water among users, facilitated by well-regulated pricing and, potentially, innovative water rights trading mechanisms. It would ensure that basic water needs are met, as well as needs for environmental purposes, while promoting the most efficient uses of water. For shared basins, transparent processes for allocation and distribution could emerge, provided other market distortions are removed and trade is further liberalized as mentioned above.

A deeper evolution in values may be required, including a decline in consumerism and conscious efforts to reduce energy consumption at the individual and local level, specifically in developed countries. This may also require a softening of aspirations to food sovereignty (i.e. production of all food locally regardless of impacts on water) to allow for the emergence of fairer international trading systems. While water has been recognized as a human right, mentalities may need to evolve to allow for equitable water prices to emerge.

Communities and countries would be better prepared for uncertainties and more adept at managing long-term risks to water with increased information, participation and dialogue among water users, and a longer-term view towards (and acceptance of) holistic approaches. This outcome represents the product of concerted thinking and action based on potential risks and trade-offs. Uncertainties would be reduced due to the increase in information and knowledge, and the adoption of clear policies would provide signals to markets, further reducing risks. In this future, each segment of society shoulders a part of the short-term risks involved in changing policies or practices and developing new products and markets, allowing for a reduction of the global long-term risks.

9.4 Water futures for better decision-making

These exercises in future thinking provide a cursory view of potential futures and an illustration of the interconnections between the various drivers. They illustrate the possible impacts of a set of strong policies and choices that may appear difficult (or risky) today, but are most likely to yield rapid economic and livelihood benefits at all levels and reduce long-term risks and uncertainties.

However, more concrete, rational and scientific modelling of water futures is necessary to better calibrate and explore these possible futures, including the development of regional and global water scenarios. Lack of knowledge is one of the key limitations to adopting some of the measures noted above. Targeted and relevant knowledge is necessary to make informed 'no-regrets' policy decisions, whether at the international, national or local level. Knowledge reduces uncertainties and makes risks more manageable at the individual, community and international level.

This includes science-based and consensus-based measures of the water footprint of various products; measures of water-use efficiency for energy supply technology, basic appliances and crops; downscaled climate and hydrological models that would allow for basin-based allocation decision-making; and economics-based modelling that would provide financial information on the rates of return of various policy measures and investments, including infrastructure, ecosystem rehabilitation or diversification – as well as information on the long-term costs of inaction. The comprehensive and rigorous water scenarios being developed as part of WWAP's World Water Scenarios Project, should provide a stronger indication of policy pathways towards (or avoidance of) determined water futures. The development of water scenarios appears ever more necessary in the face of the risks and uncertainties involved in continuing with the business-as-usual modes of water management.

Notes

1 A significant number of scenarios related to water at the global and other geographic scales were identified and examined to determine drivers that should be reviewed in the WWAP scenarios project. Through this review, ten drivers were identified for in-depth research by graduate-level researchers, to examine possible future developments in each of the domains while also seeking to identify inter–linkages with some of the other selected drivers. See the two WWAP 'Global Water Futures 2050' publications *Five Stylized Scenarios* (G. Gallopín) and *The Dynamics of Global Water Futures: Driving Forces 2011–2050* (C. E. Cosgrove and W. J. Cosgrove).

2 The occurrence of droughts is determined largely by changes in sea surface temperatures, especially in the tropics, through changes in atmospheric circulation and precipitation. Over the past three decades, droughts have become more widespread, intense and persistent due to decreased precipitation over land and rising temperatures, resulting in enhanced evapotranspiration and drying.

3 Based on the United Nations Population Division's quinquennial estimates and projections. World Population Prospects, 2006 revision, and the UN Common Database code 13600.

4 For more information see the Fund for Peace website http://www.fundforpeace.org

5 Stochastic analysis is defined as having a probability distribution, usually with finite variance.

6 A project of the World Water Assessment Programme (WWAP) partially funded via UN-Water.

7 National Research Council (2010) and 2030 Water Resources Group (2009) as cited in UNEP (2011) (GER 4).

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CHAPTER 10

Unvalued water leads to an uncertain future

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Author James Winpenny

The policies that shape water governance are commonly formulated by politicians and officials in planning, economic, finance and water-using departments. As such, national economic and financial considerations play a highly influential role. The case for investment in water and for reforming its development and management is also often framed by others in social, ethical, equity or public health terms. As a consequence, the real importance of reform is not always apparent in public decisions. In the face of rapid change and uncertainty there is a risk that this situation will continue or worsen, creating even greater challenges. It is vital therefore that the case for reform be adequately stated in economic terms. This chapter sets out the elements of such an economic case, starting with the overall benefits of water to an economy, and proceeding to consider the value of water in the various parts of its cycle. These benefits and values can be used to inform policies for the allocation and use of water in situations of growing resource pressures, uncertainties and associated risks.

10.1 The political economy of investing in water: Stating the benefits

Investing in water has various economic benefits. In particular, it promotes the growth of national income by providing:

- Security against fluctuations in the availability of water (mitigating both floods and droughts) and promotion of long-term climate resilience.
- A growth catalyst by opening up new types of economic activity, which were not previously feasible.
- Ongoing benefits in terms of added value and welfare for users throughout the hydrological cycle. These users include economically productive sectors such as agriculture, industry, hydropower, navigation, recreation and tourism, and households. Water also constitutes a vital input to ecosystems and all aquatic habitats, which in turn provide essential life support in addition to services with an economic value.

The following three sections examine these benefits in turn.

10.1.1 A buffer against climatic fluctuations and a key to climate resilience

There is no universally accepted definition of water security; the term can mean different things in different contexts. In general, it reflects a country's ability to function productively in the face of water vulnerability. This has been expressed (e.g. Grey and Sadoff, 2008) as the need for all societies to have a *minimum platform* of investment in water institutions and infrastructure as a basis for water security. Below this minimum, societies are too vulnerable to water shocks and unreliable water supply for production or human livelihoods: 'social fabric is significantly affected and economic growth cannot be reliably and predictably managed' (Grey and Sadoff, 2008,, p. 7). Once the minimum platform has been put in place, basic needs are satisfied and further water development can stimulate economic growth.

Many countries where this concept is most relevant are regularly devastated by climatic extremes, fail to meet the basic household needs of their populations, and cannot offer reliable water services to their farmers and industries. In such economies investment in agriculture is discouraged, while an unreliable water supply is also a deterrent to the development of industry and services (AICD, 2010). A greater ability to counteract climatic variability can avoid the worst costs of droughts and flooding. In Kenya losses from flooding from El Niño in 1997-98 and drought from La Niña in 1998-2000 ranged from 10-16% of GDP during those years. Growth of GDP in Mozambique was reduced by 1% annually due to water shocks. In Zambia hydrological variability is estimated to lower agricultural growth by 1% each year. In Tanzania the impact of the 2006 drought on agriculture caused losses equivalent to 1% of GDP ([McKinsey, 2009)]. Reducing the damaging impact of this hydrological variability would have major benefits for the macroeconomy (AICD, 2010).

The strong likelihood of climate change is an additional justification for implementing projects to strengthen water security. However, many such projects are justifiable even without this scenario. *No regret and low regret* projects generate net social and/or economic benefit irrespective of the impacts and consequences of climate change. Many of these projects would enable an economy to better cope with existing climatic variability, irrespective of future changes.

10.1.2 Water infrastructure as a catalyst for economic growth

The harnessing and development of water resources has been a fundamental driver of economic growth in many countries and periods throughout history. For example, it constituted the major factor in the development of the western United States of America throughout much of the twentieth century, and galvanized the recovery of the Tennessee Valley region from the Great Depression of the 1930s (Delli Priscoli, 2008). The role of water resources development in economic growth in Arizona (USA), Korea and Turkey is covered extensively in Mays (2006).

The construction of large dams has become controversial. It is therefore important to fully assess the alternatives and to be aware of, and properly manage, their social and environmental impacts (World Commission on Dams, 2009). Nevertheless, investment in large dams in certain regions (e.g. the Aswan, Kariba and Volta dams in Africa) has provided a major stimulus for the development and diversification of the host economies (Granit and Lindstrom, 2009). Subject to the above-mentioned qualifications, climate change reinforces the existing case for providing greater water storage in Africa and elsewhere.

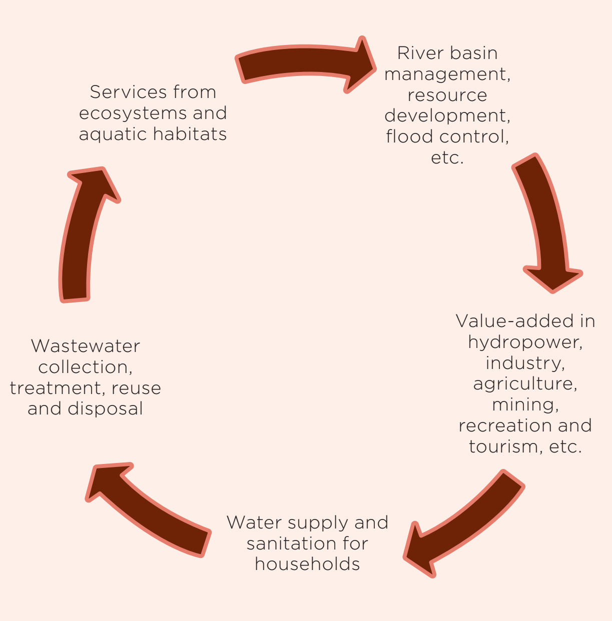
10.1.3 The whole-cycle benefits of water

Much of the water resulting from rainfall and other precipitation is stored in lakes, aquifers and so on for multiple uses, after which it is returned to rivers, lakes or groundwater for further use.[1] Although water is often misleadingly referred to as a sector, it is actually a ubiquitous medium, and one that creates benefits at each part of its hydrological cycle (Figure 10.1). The many facets of water can also be viewed as a *value chain* (OECD, 2010).

The development and management of watersheds and catchments spans a range of activities, both 'hard' and 'soft'. The spectrum varies from major multi-purpose storage schemes to activities entailed in the protection and enhancement of watershed and river basin functions including afforestation, catchment management, land use controls, and so on. Many of these activities are carried out by land users themselves, as in the case of farmers responding to incentives and sanctions. These activities create value for downstream communities through savings in costs that would otherwise be incurred. In New York State, a programme for watershed protection that encourages farmers in the upper catchment area to convert to more environmentally friendly cultivation practices is expected to lead to substantial savings in downstream water treatment for the population of New York City (Salzman, 2005; OECD, 2010). Data from other American cities (Portland Oregon, Portland Maine and Seattle) confirm the significant financial savings from watershed protection, compared with the cost of building new water treatment and filtration systems (Emerton and Bos, 2004). Similar experiences exist in Latin America, as for example in Brazil, Costa Rica, Ecuador and Salvador (Dourojeanni and Jouravlev, 1999; Jouravlev, 2003).

FIGURE 10.1

Benefits from the water cycle



Upstream investment and management can benefit downstream users in other ways, directly and indirectly. Greater regularity of flows of good quality water can save costs of storage, development and treatment for urban waterworks, industrial abstractors, farmers and other water users. The maintenance of minimum river flows creates assimilative capacity for wastewater releases (which would otherwise need pre-treatment) and provides 'flushing' for rivers with a heavy sediment load. In each of these cases, any impairment of the natural river functions due to inadequate management would require costly human interventions to deal with the problems caused.

Water is increasingly a critical factor in decisions regarding the location of economic activities such as industry, mining, power and tourism. Companies working or contemplating investment in water-stressed regions are becoming aware of their 'water footprint' and its impact on local communities, which could pose operational and reputational risks to their business. A growing number of countries will also face increasing difficulties in providing water to their growing water-intensive cities, farms and industries. Investment in measures to bring supply and demand into better alignment can safeguard future development in such cases.

In a study of the water supply-demand balance in four rapidly growing countries and regions – China, India, the state of Sao Paulo in Brazil and South Africa – current trajectories and unchanged policies produce growth projections to 2030 incompatible with water endowments. Achieving the required growth targets will necessitate action to close the potential supply-demand gap for water, combining investments in supply enhancement and measures of demand management (McKinsey, 2009).

The most visible and best-studied aspect of the water cycle concerns household services – the benefits to individual people and their families from receiving clean, safe water and associated sanitation in a reliable fashion or close to where they live. People receiving such services are at less risk of contracting water-borne disease, spend less time fetching water and less money buying it, and have more time and energy available

"The principal benefits of wastewater treatment are avoidance of the costs of pollution and of the use of contaminated water by downstream users, such as other municipalities, industries, farmers and the tourism industry."

for personal washing, cooking and domestic cleaning. Likewise, improved household sanitation provides numerous benefits for public health, as well as less time spent seeking privacy, more dignity and less embarrassment, greater opportunities for female education, and greater pride and communal and personal prestige.[2] Lentini (2010) and Oblitas de Ruiz (2010) provide an exhaustive overview of the many and diverse benefits of water services in a typical developing country setting, and Lentini (2010) also presents a methodology for their monetary estimation.

These potential benefits cannot be fully captured in economic terms, although evidence is becoming available that is suggestive of the size of benefits and their returns on the investment. Empirical studies carried out at the World Health Organization (WHO) and elsewhere show that investments in a range of water supply and sanitation interventions can have high economic benefit-cost ratios. The benefits are typically savings in time spent in household duties, including fetching water and, to a lesser extent, savings in the various costs incurred in illness and medical treatment (Hutton and Haller, 2004).

The following interventions were modelled in the above-mentioned study:

1. The drinking water part of the target to 'halve, by 2015, the proportion of the population without sustainable access to safe drinking water and basic sanitation', with priority given to those already with improved sanitation (UN, 2010, p. 58, Target 7c)
2. The above target for both water and sanitation
3. Access for all to improved water and sanitation
4. Universal disinfection of water at point of use on top of intervention (3)
5. Universal access to regulated, piped water and sewage connections into homes

For each of the 17 WHO regions and for each of the five interventions models, benefit-cost ratios were positive, some spectacularly so[3] (Hutton and Haller, 2004, pp. 35 and 64).

The economic benefits of sanitation include time saved from queuing for public toilets or seeking out secluded spots in the open; increased school attendance, especially for adolescent girls; and gains in national productivity from the greater ease of employing women where proper sanitation facilities are provided. Local standards of sanitation also have an effect on tourist visits to areas concerned (OECD, 2010, p. 33).

In Indonesia, World Bank research estimates that the country lost US$6.3 billion (2.3% of GDP) in 2006 from poor sanitation and hygiene. The result was increased health costs, economic losses, and offsetting costs in other sectors (World Bank, 2008*b*). Corresponding losses in the Philippines as part of the same overall study amounted to US$41.4 billion or 1.5% of GDP (World Bank, 2008*a*).

Investment in safe wastewater collection and treatment, including industrial effluents, can also remove a potential brake on economic activity. It has been estimated that water pollution in South Africa costs the country 1% of its annual national income (Pegram and Schreiner, 2010). The principal benefits of wastewater treatment are avoidance of the costs of pollution and of the use of contaminated water by downstream users, such as other municipalities, industries, farmers and the tourism industry. In serious cases, the pollution of water bodies has caused industries to be closed down and relocated at great cost, or impede access of agricultural and fishery products to international markets.

Water continues to provide benefits after its use by households, industries and others. Growing water stress in many regions is leading to a greater appreciation of the economic value of wastewater. The recycling of municipal wastewater for agriculture, urban landscaping, industrial cooling, groundwater recharge, restoring environmental flows and wetlands, and for further urban consumption is increasing rapidly in water-scarce countries.

An important part of water infrastructure consists of natural systems such as forests, catchments and wetlands that store water, regulate its flow and help to preserve its quality. If these natural systems are destroyed or compromised, their functions have to be replaced by man-made facilities, often at high cost. In one example, the flood attenuation functions of the Muthurajawela Marsh, a peat bog in Sri Lanka, were valued at US$5 million annually, in relation to the mitigative or avertive spending that would be needed if it were lost. The same is true for the Nakivubo Swamp in Uganda, which runs through the capital city Kampala and has a key role in assuring urban water quality. A large amount of untreated household sewage and the effluent of the city's sewage works enters the swamp prior to passing into Lake Victoria, close to the intake of the water works supplying the city with drinking water. The swamp provides natural filtration and purification of the wastewater: the infrastructure required to provide a similar level of wastewater treatment would cost up to US$2 million per year (Emerton and Bos, 2004).

Contrary to the common view that water and irrigation are uneconomic investments, a comparison of the (weighted) average economic rates of return for both water supply and irrigation projects in sub-Saharan Africa shows that they compare favourably in relation to other types of infrastructure (Table 10.1).

10.2 Valuing water

10.2.1 Water's manifold value

The benefits of the water services mentioned above are based on the economic value of water in its various states and uses. Valuing the multiple socio-economic benefits of water is essential to improving the decisions of governments, international organizations, the donor community, civil society and other stakeholders. Conversely, a failure to fully value all the benefits of water in its different uses is a root cause of the political neglect of water and its mismanagement. It leads to insufficient appreciation of the importance of water; suboptimal levels of investment in water infrastructure; and the low priority accorded to water policy in country development programmes, poverty reduction strategies and other policies. Finally, it plays a significant part in the failure to meet international socio-economic objectives.

Valuing water should facilitate water resources and services to be added or compared, or allocated to maximize social welfare. However, not all the benefits of water can be quantified or expressed in monetary terms. There are many limitations to the methods developed to derive the economic value of water in its different uses: some are controversial, have high data requirements, are complex, or require technical and economic skills. Valuation is an eclectic discipline, with different techniques for different uses and policy purposes. But although the production of a comprehensive system of economic values for water is an over-ambitious task, some useful results have been produced in specific local or regional contexts from multi-stakeholder processes involving actors with different subjective valuations.

Such political and technical dialogues can lead to broad agreement, which is useful for setting policies. However, different groups of people value water in different ways and even the same group's perceptions can alter as conditions change. Moss et al. (2003, p. 46) argue that 'the complexity of the interfaces between many different stakeholders and the tendency for water to raise strong emotions frequently leads "value differences" to become "value divides".' These can lead to polarization that blocks dialogue and

TABLE 10.1

Economic rates of return for infrastructure projects in sub-Saharan Africa (%)

Railway rehabilitation	Irrigation	Road rehabilitation	Road upgrades	Road maintenance	Power generation	Water supply
5.1	22.2	24.2	17.0	138.8	18.9	23.3

Source: AICD (2010, p. 71).

prevents reasonable governance solutions. Improved understanding of the value differences can help identify commonalities and interdependencies that may be useful for negotiated agreements.

According to the OECD (2010), the lack of a coherent analysis of investment benefits across the entire value chain of water and sanitation is due to the fragmented markets in which water services are delivered. Although ministries are responsible for setting overall policy direction, investments are made by utilities and agencies operating at a decentralized level, often in an uncoordinated manner. As a result, the benefits (and costs) of a wider range of investments across the full value chain of water management and services do not receive adequate assessment.

10.2.2 Economic values of water in different uses

The Dublin Statement on Water and Sustainable Development (1992) states that 'water has an economic value in all its competing uses and should be recognised as an economic good'. A distinction needs to be made between the value, cost and price of water, which are often very different from each other. The economic value of water is particularly apparent in situations of water scarcity. Water has different economic values in its different uses. It has an economic cost of supply, which also varies in different situations and for different purposes. Water provided to a particular user, in a specific place, at a certain time has an economic benefit, but also entails an economic cost. The relationship between the specific benefit and the specific cost is the basis of the economic justification for supplying that user. Finally, the price of water is a financial or fiscal transaction between the provider and the user, which is often closely controlled by public authorities, and often bears little relation to either its value in specific uses, or its cost of supply.

Allocating water purely on the basis of such economic principles is complicated and difficult to apply in practice (Turner et al., 2004; Winpenny, 1997). However, the basic concept of comparing the costs and benefits of supplying water in specific locations and to specific categories of users is fundamental to water policy, especially in situations of growing stress. This requires an estimation, however approximate, of the value of the water in its various states and uses.

The methods of valuing water are eclectic and depend on the sector concerned, the type of use and the information available (Winpenny et al., 2010). Household consumption is commonly valued using evidence of willingness to pay (WTP) from direct surveys that make use of structured questionnaires or 'choice experiments' survey techniques. This 'stated value' approach can be supplemented and cross-checked by evidence of revealed preference, such as inferring users' preferences from their changes in consumption following a tariff change, or by estimating their actual expenditure.

Irrigation water use can be valued in either of two different ways. The marginal productivity of water (the extra value of output that can be obtained from additional applications of water) can be estimated from changes in yields during crop-water trials. Alternatively, the more common approach (the 'netback' method) is to derive the value of water from farm budget data as the residual after all other costs have been allowed for. This latter method makes the crude assumption that the residual, or unexplained, farm surplus is due entirely to water, rather than to other factors.

Industrial water valuation poses a greater problem. For many industrial (and commercial) enterprises, water constitutes a small part of their total costs. It would therefore be misleading to use the residual method, as for irrigation, and attribute the whole residual surplus to water. Much industrial bulk water is self-supplied from wells and rivers. Many firms recycle water by treating and reusing waste flows. One valuation approach regards the cost of recycling as the upper limit on industrial WTP, because firms would rationally recycle rather than buy in above this level.

The above uses all involve the abstraction of water. However, water also has in-stream values for waste assimilation and dilution, flushing sediment, the functioning of ecological systems, navigation, and various kinds of recreation (water sports, sight-seeing, fishing, rambling, etc.). Various valuation options can be applied to these uses. Often, these natural functions of water (assimilation, dilution, flushing) can be compared with the extra cost of alternatives (dredging, treatment). The value of water for navigation can be imputed from its cost advantage over the next cheapest transport mode (e.g. railways). The value of water for recreation and ecological purposes (the maintenance of low flow regimes and wetlands) is generally estimated by WTP or travel cost[4] surveys.

It is increasingly common to use the *benefit transfer approach* to derive empirical values for these environmental effects. As the term suggests, evidence is transferred from situations where it is available to locations and projects which seem to be broadly comparable.[5]

Hydropower water usage is normally valued according to the cost advantage of hydro over thermal power and other alternative ways of generating electricity. In this, as in other cases, it is important to compare like with like, and to be clear about the basis of the estimate.[6]

There have been a number of comprehensive studies of the economic value of water in different uses, and a number of more selective exercises. The earliest studies use data from the USA, but more recent studies from other regions broadly endorse their results. Table 10.2 indicates the results of a recent comparative US study.

The evidence presented in Turner et al. (2004, p. 91) shows that the value of water for *irrigated agriculture* of many low-value crops (typically food grains and animal fodder) is very low. By the same token, water values can be high for high-value crops (e.g. fruit, vegetables, flowers) where the water is reliable. The same is true for supplementary irrigation taken as insurance against drought. These results are supported by the actual prices paid for water where water markets exist. In short, the value attached to irrigation water depends heavily on how reliable it is and on the type of crop being produced. Values tend to be higher for privately owned groundwater than for publicly supplied surface water schemes.

> "Household water used for truly essential needs such as drinking, cooking and basic hygiene comprises only a minor part of typical daily use; the rest is used for 'lifestyle' or productive purposes."

Household values are relatively high, but this is not a homogeneous category. Household water used for truly essential needs such as drinking, cooking and basic hygiene comprises only a minor part of typical daily use; the rest is used for 'lifestyle' or productive purposes. In affluent regions with a warm climate a high proportion of water is used for outdoor purposes such as watering gardens and lawns, washing cars and filling swimming pools. Households tend to place a higher value on indoor than outdoor uses, though this would not apply where water is used for productive purposes. In some societies, much of the water available to households is used for growing crops and feeding livestock (in other words, it is supplied for *multiple use* purposes). In practice, the valuation of water for

TABLE 10.2

Economic value of water use in the USA: US$ in 1995 prices per acre-foot of water

	Average	Median	Minimum	Maximum	No. of observations
In situ uses					
Waste disposal	3	1	0	12	23
Recreational and habitat	48	5	0	2 642	211
Navigation	146	10	0	483	7
Hydropower	25	21	1	113	57

Note: Acre-foot is the amount of water entailed in covering one acre to a depth of one foot. In metric terms, an acre-foot corresponds to 0.1233 m³ per ha.
Source: Turner et al. (2004, table 9, p. 92).

household use is commonly taken to be equivalent to the average tariff, which usually underestimates the economic cost of supply and ignores the *consumer surplus*[7] involved.

The value of water with regard to its *environmental uses* is not adequately represented in the studies described above, which relate mainly to *use values*, in particular recreation. In fact, recreational values show great variation, depending on the visitation rate, the location of the site, the quality of water and the type of recreation (with fishing and shooting licences attracting high fees in some countries). Failure to account for these benefits in water valuation can result in inefficient water allocation decisions. Valuations of the non-use environmental benefits of water employ a range of techniques and produce a wide spectrum of results, although typical values tend to fall in between agricultural and municipal/household levels (Turner et al., 2004, p. 92).

10.3 Using benefits and values to inform water policies

A sense of the economic value of water in its different states and uses is a necessary part of water management. This is true in routine management of river basins and the operation of multi-purpose storage schemes, where decisions on allocations have to be made in real-time, day-to-day situations. It also applies to seasonal drought responses and even more so to strategic decisions on adaptation to growing water stress and supply-demand imbalances.

In a functioning water market, economic values will establish themselves through trading prices. However, water markets are characterized by various degrees of imperfect competition, externalities, uncertainty, asymmetric information and distributional impacts. These characteristics affect the appropriateness of market prices for use as measures of value (Saliba et al., 1987). As a result, most observed market prices deviate from an ideal measure of willingness to pay, and may serve only as a rough indicator of the marginal value of additions to regional water supply if the additional volume of water made available is small relative to the region's total supply.

A more complete analysis of differential water values and market failures is desirable in decisions to allow for and regulate water trading, for example, when it is in the public interest to allow trading between rights holders. Trading water rights among farmers during Australia's recent eight-year drought greatly mitigated its impact on agriculture in the Murray–Darling Basin. Water transfers from low to higher value purposes meant that a 70% fall in the availability of water only led to a 30% fall in the value of production (Sadoff and Muller, 2009).

Using water values to inform management and allocation policies does not imply that markets should have the last word in such decisions. As is the case with other sectors, the market can be a good servant but a poor master. Public authorities need to intervene to establish regulations designed to prevent transfer of negative externalities, ensure adequate supplies of water and sanitation services to satisfy basic needs, and safeguard public health.

The value of adequate water supplies to the natural environment is another aspect that requires active public intervention. In the Murray–Darling Basin growing aridity is increasing water losses from evaporation, which threatens water-dependent ecosystems, whose needs have to be weighed alongside those of other uses (Young and McColl, 2009).

10.4 Allocating water under conditions of risk and uncertainty

Recognition and acceptance of the economic value of water will add an economic dimension to the social, ethical, public health and equity dimensions of allocating water. The latter dimensions by themselves have failed to generate the required investments in water to meet socio-economic development objectives.

The allocation of scarce water to competing uses lies at the heart of water management. In many parts of the world, increasing pressures on water resources are leading to a shortage of water to satisfy all needs. In general, four interrelated processes drive water stresses: population growth; economic growth; increased demand for food, feed and energy (of which biofuel is one source); and increased climate variability. Choices must be made about how to share, allocate and reallocate the increasingly scarce water – within sectors, from one user group to another and between sectors. Such dilemmas invoke debates about the principles that should guide water allocations, and how access and equity, economic efficiency, sustainability and existing customary norms and values can be reconciled in specific contexts.

Typically, water allocations are the outcome of dialogue between interested stakeholders. Such parties need to build convergence in their 'value perspectives' (Figures 10.2 and 10.3).

Water allocation embraces practices that vary greatly in scale and duration. They include: the grant of water rights or permits to large irrigation schemes expected to last for decades or even indefinitely, while effective and beneficial use continues; hourly allocation schedules between irrigators; short-term reservoir releases to cover peak demands in the electricity grid; and schedules for rationing water between industries, essential services, power generation, farmers and households in the event of drought.

There are four main aspects of a water allocation system:

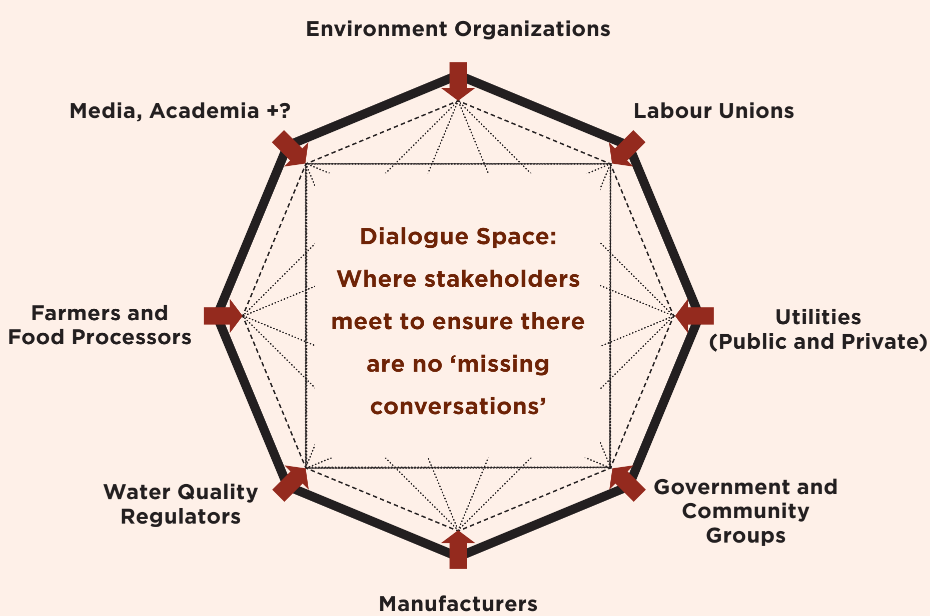
- *Water entitlements* (formal or informal) confer on the holder the right to withdraw water and apply it in a generally recognized beneficial use (Le Quesne et al., 2007). A person's entitlement to withdraw water must be considered legitimate by others.
- *Water allocation* is a process whereby the available water is shared among, and distributed to, legitimate claimants (Le Quesne et al., 2007).
- *Water service delivery (or control)* is the physical act of supplying water to those who are entitled to it in such a manner that they can effectively use it.
- *Water use* is any deliberate application of water to a specified purpose (Perry, 2007).

Water entitlements, allocation, service delivery and use are dynamically linked and constrained by the amount of water that is available at specific times. The use of water creates expectations of similar use in the future. If it is continued over time an entitlement emerges, which may be difficult to ignore or claim back; yet the amount of water available is prone to natural and man-made fluctuations and changes.

The increasingly variable hydrological cycle makes the availability of the resource more uncertain both in time and geographically. Demographic, technological, economic and political futures, along with changing human values, add additional long-term uncertainties. It is crucial to therefore identify

FIGURE 10.2

Parties in the water dialogue space



Source: Adapted from Moss et al. (2003, p. 37).

allocation mechanisms that can effectively and flexibly deal with change, uncertainties and the accompanying risks.

The ability to estimate future surface and groundwater availability at different time scales and the inability to predict future water demands and uses are important factors. Arguably, the largest uncertainty stems from the risk of lack of adaptation on the part of institutions to real issues that need to be addressed, and the possibility of water management organizations taking the wrong decisions.

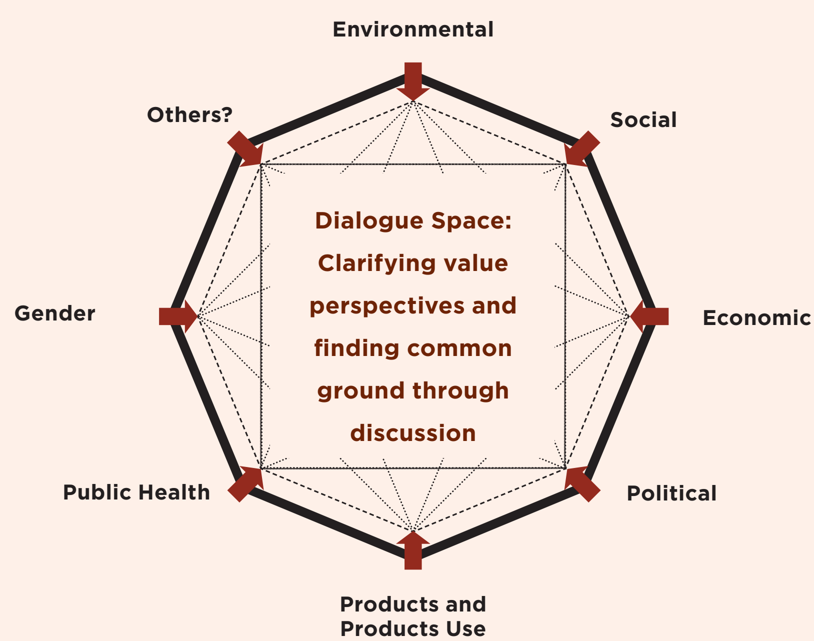
Given these uncertainties, water allocation problems imply four main challenges:

1. How should water be allocated/reallocated in times of shortage and to respond to changes in natural and economic conditions?
2. What solutions are available where rights have been over-allocated and cannot satisfy all holders in times of drought, or where the availability of water from a particular source is subject to long-term decline?
3. How can water institutions evolve to keep pace with and anticipate change?
4. What institutional measures can serve to manage rising tensions that form the source of disputes and conflicts, and how can these tensions be transformed into forms of cooperation?

Effective stakeholder engagement is necessary to make water allocation decisions transparent and fair. Improving the information available to water users is essential but not sufficient to enable them to make the best decisions. Routine stakeholder consultation is not the same as true empowerment, where a community takes control of its water management, leading to more legitimate and cost-effective solutions with better chances of implementation. Fortunately, the experts consulted under the WWAP scenarios project (see Chapter 9) foresee that more information will be made public in the future, and that citizen participation will be more widely practised.

FIGURE 10.3

Value perspectives in the water dialogue space



Source: Adapted from Moss et al. (2003, p. 36).

Notes

1 The exception is consumptive use of water, which evaporates from lakes, reservoirs, trees and crops. (This includes green water, which the WWDR3 [WWAP, 2009, p. 161] defines as 'soil moisture generated from rainfall that infiltrates the soil and is available for uptake by plants and evapotranspiration. Green water is non-productive if evaporated from soil and open water' in the form of rain falling directly onto the land.) Freshwater discharged into the sea, or in a highly contaminated form, is also effectively consumed in the sense that is not available for further beneficial use, except at high cost.

2 In a letter to the Financial Times (7 June, 2010), Jon Lane, Director of the Water Supply and Sanitation Collaborative Council, refers to the fact that more Africans now own mobile phones than toilets. He adds, however, that 'in some countries, a toilet is the new mobile phone – something that shows you've made it'. It is reported that, under the Total Community Sanitation Programme, families in certain communities have decided to categorically reject marriage proposals coming to their daughters from villages where open defecation is practised (Kar, 2003). This exemplifies the recognition of access to sanitation as a sign of health and prosperity.

3 The highest being 191.05.

4 The travel cost valuation method infers the valuation that visitors place on a free amenity from the amount of time and expense they incur in getting to the site.

5 A number of results are reviewed in Turner et al. (2004).

6 If a short-term approach is taken, an assumption is made that capacity is fixed for both alternatives to be compared. In the long term, new investments can be made in either. Marginal and average costs will also differ for both alternatives.

7 The difference between what consumers would be willing to pay, and what they actually have to pay.

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CHAPTER 11

Transforming water management institutions to deal with change

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All individuals, agencies and institutions involved in water resources management are very aware that the impacts of decisions they make may not turn out to be the ones they hoped for. Factors that influence the economic, environmental and social benefits or costs resulting from any management decision are not known with certainty. This uncertainty can result in some degree of vulnerability just as much as it may result in higher levels of reliability or resilience. Water managers and their institutions need to recognize the potential consequences of their decisions in uncertain environments, environments where the uncertainty is changing in uncertain ways.

Vulnerability assessments of water resources systems constitute an important basis for water management under conditions of uncertainty and risk.

Leaders in government, the private sector and civil society make most of the important decisions impacting water. It is therefore imperative that they understand the role of water and incorporate this information into their range of decisions. Important instruments to support decision-making include forecasts and scenarios, and combining a range of forecasts of possible futures allows for more robust decision-making. Water management institutions must be created or transformed to reflect this approach.

11.1 Introduction

Sustainable development under conditions of inherent uncertainty requires a paradigm shift. Key factors include the need for an increasing range of input data and the capacity to adapt to growing pressure on the resource. This will require deliberate efforts to build robustness and resilience into the management structures of water projects as a matter of routine. As shown in Chapter 5, such fundamental changes are likely to occur in the non-structural elements of water management measures. In an inherently complex world, leaders in government, private sector and civil society outside the 'water box' take most of the important decisions impacting water. It is therefore important to develop new ways to provide specialized information to decision-makers in government, as well as to those affected by the decisions they take (Falkenmark, 2007). This requires a formal structuring of relationships between technical specialists, government decision-makers and society as a whole (see Figure 11.3, with explanation later in the chapter) (Hattingh et al., 2007; Turton et al., 2007*a*,*b*).

Recent changes in global climate, financial markets, land use and consumption patterns, have increased the uncertainty surrounding future management of water resources. This uncertainty is inherent to the system itself, and relates to the interconnectedness of various systems – hydrological, financial, social and ecological – as well as a general lack of knowledge concerning how an ecosystem might respond to the new demands being made of it. Some now call for a change in thinking away from separate ecosystems and social systems towards socio-ecological systems (SESs) instead (Burns and Weaver, 2008). In this regard it is accepted that human impact is so significant that economic activities and associated social endeavours are no longer seen as being separate from ecosystems – instead social-ecological systems have co-evolved. This is consistent with the emerging notion of the Anthropocene as a potentially new geological epoch (Zalasiewicz et al., 2008). Rather than planning for one defined future, water management agencies increasingly need to improve their methods of assessment in order to respond to a range of possible futures, all of which are uncertain but present varying degrees of probability. Major engineering issues across all possible futures will include planning, designing and operating sustainable, reliable, resilient and non-vulnerable water resource systems, embedded within an increasingly uncertain set of drivers. The ultimate aim should be to inculcate a multi-disciplinary approach to the development of guidelines and regulations for water resources planning, integrating science, economic decision criteria, and monitoring and evaluation processes, all of which should embrace a range of future realities.

As shown in Chapter 5, water management has traditionally been top-down in orientation. *Adaptive water management*, which can be thought of as the management of water resources under conditions of inherent uncertainty, links this to a bottom-up approach. Contemporary experience increasingly shows that a combination of the two approaches is best suited to the core challenge of dealing with uncertainty and risk. A top-down approach, being more strategic in orientation, can provide an overall picture, offering a general framework within which a water management activity or programme can be developed and implemented. A bottom-up approach, being more operational in orientation, can provide an accurate picture of relevant 'on-the-ground' water issues, needs and uncertainties experienced by a wide range of actors and stakeholders. Enthusiasm and support for addressing water-related issues are often best developed at the local level, as this is closest to the point of actual impact, thereby facilitating acceptance of needed actions, provided that it is adequately positioned and has the capacity to effectively deal with the issues.

Developing and implementing an effective water resources management programme ideally incorporates both ends of this management spectrum, specifically as the emphasis shifts from building infrastructure to building institutions (Figure 11.1). However, the relative importance of each approach will vary under differing social, political, economic and environmental conditions. A major challenge for dealing with inherent uncertainties and risks is the introduction of a more adaptive approach to management, irrespective of whether integrated water resources management (IWRM) is adopted as a framework. Adaptive management is based on specific principles and approaches.

11.1.1 Introducing adaptive management to IWRM

IWRM is a globally accepted management framework for achieving sustainable development (Ashton et al., 2006). IWRM has been defined in many ways and the most widely known definition has it not as a tool but as a process. Furthermore, IWRM is a means, not an end in itself, and the process has been very difficult to implement in developing countries, despite some progress, as described in Chapter 1 (Section 1.3.3).

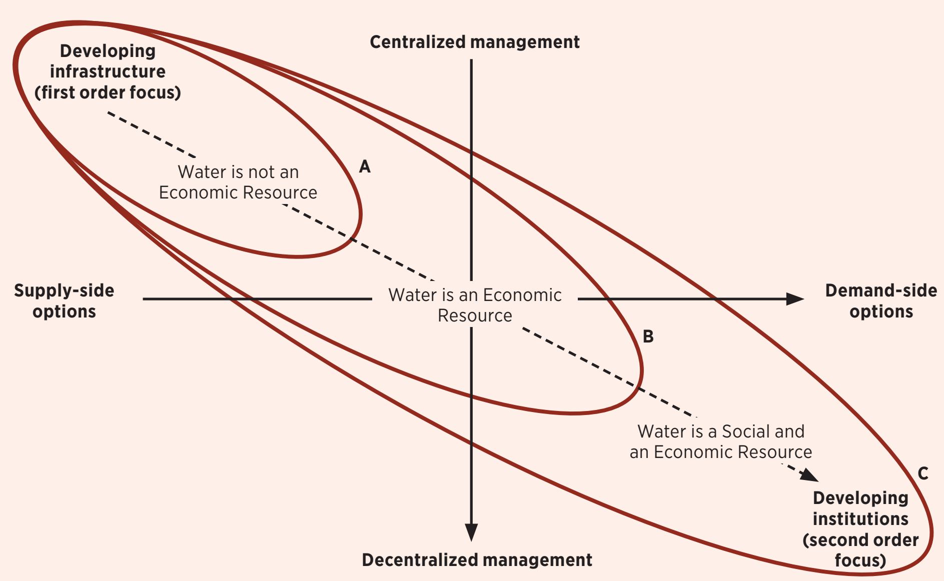
Governance and IWRM are the principal means for resolving competition among multi-sectoral demands on a relatively finite water resources base. Each sector fashions its own set of management principles, rules and incentives that are maximized, often in conflict with one another. Defining social risk tolerance and service reliability is part of a social contract to be determined through a continuing dialogue within each society (Nyambe et al., 2007), whether it be for new drugs, nuclear power plants or water infrastructure. IWRM is contextually shaped through this process to encompass the different dimensions of sustainability (ecological, biophysical, economic, social and institutional), but it is also often path-dependent (see Section 11.4.4). Thus, effective IWRM is knowledge-intensive and needs to be adaptive if it is to continue to respond to exogenous changes over which it generally has little direct control. However, it should also be noted that adaptation can also be identified and adopted without IWRM as the underlying process.

Adaptive management is 'a process that promotes flexible decision-making in the face of uncertainties as outcomes from management actions and other events become better understood' (US National Research Council, 2004). This report describes adaptive management as an approach for keeping up with future changes and making periodic modifications in past decisions in response to those unpredictable changes. It is applicable to situations in which future social, economic, climatic or technological conditions that influence the outcome of any decisions cannot be forecast with certainty.

Absolutely essential for effective adaptive management is a continuing awareness of the changes that are taking place over time, as well as the responses stemming from past decisions. Monitoring, database management and communication are important components of any adaptive management approach. It is an approach that is linked to information about out-of-the-water-box drivers such as economic growth data, population trends and changes in food consumption patterns, mining impacts and demands for energy. Adaptive management is applicable to many aspects of water management, and no less so for responding to flood and drought conditions and their impacts on food production, property damage, and human dislocation and other social impacts. To

FIGURE 11.1

Conceptual model illustrating the general trend of change as water resource managers adapt to include a wider range of drivers and issues



Source: Turton et al. (2007a, fig. 1.1, p. 5, with kind permission of Springer Science+Business Media).

effectively accommodate the 'precautionary principle' (see Section 11.2.3), together with the broader aims of sustainable development, it is necessary to consider the full range of drivers that impact on water infrastructure under a wide range of inherently uncertain supply and demand scenarios. This builds robustness and resilience into water projects by providing flexibility.

11.2 Principles for managing water under risk and uncertainty

In order to meet the goals set by decision-makers, water management must deal with the uncertainty and variability that characterize current changes in the contemporary world. Lempert and Groves (2010) give an indication of the core principles needed to achieve this objective:

- Seek robust projects or strategies, and substantially revise the current economic and optimization decision rules routinely used in water resources management.
- Employ adaptive strategies to achieve robustness; near-term strategies should be explicitly designed to be revised as better information becomes available.
- Use computer-aided processes to engage in interactive exploration of hypotheses, options and possibilities.

These principles are increasingly being advocated by water resource practitioners and academicians, and are manifesting as technological innovations, engineering design changes, multi-objective watershed planning, public participation, regulatory, financial and policy incentives. One example is the emergence of a water accounting framework in Australia (see Chapter 6), designed specifically to integrate reporting across normally disconnected sectors and bureaucracies (AASB, 2011; Godfrey and Chalmers, 2011). Improvements in existing approaches to forecasting are being made using a large number of imperfect but possible future scenarios. These enable analysts and decision-makers to identify a series of near and long-term actions that anticipate a wide range of scenarios, rather than relying exclusively on a single probabilistic forecast of one possible future.

Another key principle is associated with the need to anticipate periods of induced stress brought on by the unanticipated periodic coincidence of high demand and low availability.

Consider some of the options that may help relieve some of this drought stress. In the long run, additional infrastructure can be built to provide added storage capacity, and measures can be taken to reduce leakage in diversion canals and water distribution systems, increase the efficiency of irrigation systems, and provide additional supplies, perhaps through desalination. Alternative sources of energy, such as geothermal, wind and photovoltaic cells, might be developed that use less water than more conventional and more water-consuming alternatives. Short-term options might include demand management measures that reduce human water consumption and increase water reuse.

11.2.1 Diversification as a core principle of adaptive water management

The objective of adaptive water resource management is to enhance resilience by improving the capacity to react appropriately to unanticipated events. These principles, most notably under the broad banner of resilience theory (Burns and Weaver, 2008), are derived from ecosystem theory (Holling, 1973), which argues that diverse systems can better cope with extreme events. An example is the application of portfolio theory, in which investments are made in products of widely differing risk profiles, thereby reducing the overall risk of the total portfolio. Several steps can be taken to diversify water management decisions and investments. For example, in a semi-arid agricultural area that is largely dependent on rainwater, the challenge is to develop new drought mitigation measures, such as increased storage capacity of surface water, increased groundwater capacity, irrigation schemes for local farming communities, satellite technology for precision farming, and new drought-resistant seeds. Water managers would need to advise decision-makers on the policy frameworks necessary to promote such measures, including water pricing policies, subsidies or other financial incentive mechanisms.

11.2.2 Assessing vulnerability

Hashimoto et al. (1982) introduced a taxonomy capable of embracing the risk and uncertainty inherent in water management performance evaluation. They use simple principles that represent a set of descriptors to characterize the key components of the more traditional engineering reliability analysis. In essence they focus on the sensitivity of parameters and decision variables to considerations of uncertainty, including some aspects of strategic uncertainty. These key principles are (Hashimoto, 1982):

- *Reliability*: probability of successful outcomes
- *Robustness*: the satisfactory performance of a system under a range of scenarios
- *Resilience*: how quickly a system recovers from failure (floods, droughts, pollution spills)
- *Vulnerability*: how severe the consequences of failure may be

These five principles expand the key components of more traditional engineering reliability analysis, by focusing on the sensitivity of parameters and decision variables to conditions of uncertainty. Increasing attention is being paid to reducing the structural vulnerability of hydraulic systems by enhancing system resilience as a matter of design. The main question is how to evaluate such strategies? Traditionally, this has been done through risk management on the basis of historical data and statistical analysis, but it is now apparent that past experiences are incapable of predicting future realities, because of the growth of non-linear complexity (Turton, 2007). Strategies are now being selected, for example, using cost–benefit-based risk analysis. The *choice of the discount rate* in economic analysis is an important determinant of the economic viability of a water project, and the level of discount rate appropriate for projects with very long lives, or with strong social or environmental benefits, is the subject of lively debate in engineering circles. The same is true for the level of *acceptable risk* or uncertainty, even if the latter cannot be fully quantified. Supplementary decision-support tools are required when risks cannot be quantified or isolated, as is the case when the many factors described in Chapter 9 interact.

11.2.3 The precautionary principle

The precautionary principle states that if the impacts resulting from an action or policy may cause harm to people or the environment, in the absence of scientific consensus on a probable outcome, the burden of proof that an action or policy is not harmful falls on those taking the action. This implies that decision-makers have a social responsibility to err on the side of caution by protecting the public and the environment from exposure to harm, where a plausible risk has been identified. This is increasingly evident in corporate governance structures found within complex economies, in particular companies listed on various international stock exchanges. These constraints can only be relaxed if subsequent scientific findings emerge providing sound evidence that no harm will occur.

11.2.4 Meeting information needs for management under uncertainty and risk

Reducing the risks associated with water resource management, under conditions of inherent uncertainty, requires a broader set of information inputs. Hydrological data has been often collected for specific purposes, such as the use and design of hydroelectricity schemes, water supply systems and water treatment plants. However, the need for adaptive IWRM places a greater burden on the suppliers of information. The movement of water in time and space is in constant flux, but it is generally managed as if it were a static resource. This approach was possible in the past as demands on the resource were less complex (Turton, 2008, 2010). Today, the web of water dependencies is becoming increasingly complex and the lack

BOX 11.1

Mine closure in South Africa as an example of growing complexity

The city of Johannesburg in South Africa is unusual in the sense that it lacks a river, lake or seashore. Instead, it straddles a continental watershed divide and exists only because of the vast gold resources that lie beneath the city (Turton et al., 2006). These gold-bearing ore bodies consist of pyrite rich in sulphides and are overlain by a massive karst system (Buchanan, 2010). However, the cessation of mining activities is causing the resultant void to fill with highly acidic water, causing some anguish to property owners (Coetzee et al., 2002, 2006). This is driving a degree of uncertainty and constitutes a classic example of the growing complexity confronting water resource managers.

A central issue is calculating the rate of rising water in the void. This requires direct access in order to monitor the water level, however, the companies that control the shafts do not want the data to be made public as they seek to limit their liabilities (Adler et al., 2007). This provides a good example of the need for new types of data previously considered irrelevant to water resource management, as the mine water flows into the headwaters of two major river basins, the Orange and Limpopo, both of which sustain vast socio-economic interests in at least five different downstream countries (Botswana, Mozambique, Namibia, South Africa and Zimbabwe). One of the water resource management challenges is, therefore, establishing how to manage mine closure in situations where limited legislation exists and the absence of cross-sectoral institutional linkages inhibits the flow of needed data (Strachan et al., 2008; van Tonder and Coetzee, 2008).

of accurate information poses a growing challenge for decision-makers, in particular regarding the range of management options including water conservation and demand management strategies. A growing problem is the retention and manipulation of data by commercial entities inaccessible to the public or regulator (Box 11.1). Information may be available in existing government agencies and/or water data sources, but it may also be necessary to initiate monitoring efforts directed to obtaining such data, where it does not currently exist. Monitoring requires extensive instrumentation and transmission capabilities, and demands human capacity; it is also expensive to operate on a sustainable basis. As such, there is mounting pressure in this specific arena (Chapter 6).

11.3 Approaches for managing water under risk and uncertainty

It is useful to differentiate between the vulnerability of a water resources system and societal susceptibility to economic disruptions and dislocation. The vulnerability of a water resources system is a function of the hydrological sensitivity and relative performance of a water management system. The vulnerability of the SES is a function of the sensitivity of the water infrastructure and the resilience of the SES. The two are intimately linked; however, the latter is increasingly manifesting as greater population pressure is placed on a relatively stressed water resource system. The result is a general loss of resilience and a reduction in the margin of error possible before catastrophic failure occurs. This can best be thought of as a general propensity towards vulnerability as greater reliance is placed on an increasingly stressed resource, both as a source and as a sink.

The motivating reasons for making many water management decisions are economic, environmental and social drivers that are not controlled by water managers. Similarly the effectiveness of any water management decisions made is largely determined by these 'outside-the-water-box' drivers. Just how vulnerable any decision-making organization may be given the uncertainties of changing drivers needs to be considered when decisions are made. The question to ask when recommending or making decisions regarding water use or water management, especially long-term decisions, is Will a particular decision or development policy be considered a wise or beneficial one, say, 50 years from now? Does it truly fit in to an integrated water resources plan or policy?

It is not easy for water management institutions to adopt an integrated planning and management strategy. Many existing rules and regulations may limit the scope of responsibilities or decisions any given institution can make. Hence one question to ask to check on the degree of integration obtained by some decision by some institution is who is responsible for implementing integrated plans and policies (Box 11.2). Who is responsible for making sure all possible outcomes, and drivers, and affected stakeholders, have been considered in the decision-making process? Who is responsible for looking into the future and judging whether or not some decision will be judged as important for future sustainability? Having answers to these questions is a measure of the extent to which adaptive IWRM has been implemented.

Regularly reviewing these questions will enable adaptations to be made before the challenge is too great to be adequately met by existing institutional arrangements and decision-making processes.

BOX 11.2
Climate Vulnerability Index

People's vulnerability to global changes is influenced by the quantity of water available now and in the future, underpinned by a range of social, economic and environmental factors. Collectively, these affect the ability to cope with changing conditions. The Climate Vulnerability Index (CVI) is a composite index approach that captures the essence of this definition of vulnerability. This method helps identify to vulnerability in order to prioritize actions to protect local populations. The CVI combines Global Impact Factors (GIFs) including geospatial variables; resource quantification; and information on the accessibility of water and property rights, the capacity of people and institutions, water utilization and the maintenance of ecological integrity. The index values range from 0 to 100, with high values indicating high vulnerability. By developing a range of future conditions, both in terms of climate and socio-economic scenarios, the change in CVI scores from present values indicate how different GIFs will change under different conditions. The CVI has the potential to involve stakeholders, thereby rendering the outcome legitimate and implementable in the eyes of those affected.

Source: Sullivan and Meigh (2005).

11.3.1 Key elements of an adaptive management approach

Adaptive management approaches are slow to evolve, because of increasing uncertainty of future scenarios on the basis of the historical record, in non-linear systems. Consequently, the major challenges facing water resource managers change at unpredictable rates. Failure to respond adequately thus becomes an increasing risk in its own right. A pragmatic 'proactive adaptive management' approach needs to be adopted, comparable to the 'no regrets' philosophy noted in Chapter 5. An adaptive IWRM approach consists of the following elements:

- Strengthened emergency management and preparedness plans for all projects including enhanced public participation and identification of the conditions under which public emergencies requiring special measures will be declared and the limits of such measures (i.e. power and responsibilities of authorities and users)
- Ability to programme the gradual and measured adoption of measures of adaptation and define the threshold which trigger these measures
- An effective information and communications strategy to convey the messages, establish dialogue with allied sectors, influence other sectors' decision-making and rally public support (Nyambe et al., 2007)
- Strengthened inter-agency collaboration for developing joint procedures and applied research for change adaptation
- Risk-based planning and design of infrastructure to account for a defined range of uncertainties
- A new generation of risk-based design standards for infrastructure responding to extreme events (floods and droughts)
- Increased inspections, oversight and regulation of infrastructure during operation, maintenance and life cycle management of aging infrastructure
- Vulnerability assessment of water infrastructure and impact assessment of the socio-economic system in case of failure
- Increased research and development oriented to hydrological change and variability
- Improved forecasting methods
- The process should be reiterative and guided at all stages by common principles

Information and data on water availability and use is inadequate in virtually all countries, irrespective of the state of development. Even where information and data exist, they are often unreliable or fragmented, or may be based on gross estimates. They are usually incompatible both temporally (between periods) and spatially (between countries, water sectors or users, or water basins).

11.3.2 Scenarios as an element of an adaptive management approach

Improvements are being made though an adaptive management approach, involving a range of imperfect forecasts of the future. These rely on many plausible futures, and allow analysts and decision-makers to identify a series of near-term and long-term options that are robust across a wide range of conditions. Rather than relying on a probabilistic forecast of a single future, this approach asks what can be done today to shape a more desirable range of possible futures (Lempert and Groves, 2010; Chapters 8 and 9 of this report.)

There is a need for increasingly sophisticated monitoring systems to source and integrate the necessary data. This adds additional stresses to the overall decision-making process. The need for adaptive management carries with it a fundamental requirement for complex data, hard-wired into feedback loops, specifically for managing the incremental changes needed in the various systems including the means of tracking those changes (Stakhiv and Pietrowsky, 2009). In effect this creates institutional learning as core problems are redefined and new responses are generated through the modified decision-making processes.

11.3.3 Modelling as an element of an adaptive management approach

Systems of locks, dams, levees, irrigation canals and conveyance tunnels were built worldwide before the era of sophisticated modelling and risk and reliability analysis, or the existence of adequate databases for determining risk and uncertainty associated with hydrological variability. Yet those structures still stand and have performed effectively through a wide range of unanticipated supply and demand conditions. In short, they have been remarkably robust and resilient. On the other hand, it is not known how the design specifications based on specific climate parameters will perform under a changing climate.

Every profession has its established customs and standards, and certainly engineers responsible for public safety have theirs. These are partly the result of past practice that seems to be successful or at least acceptable by the public, and partly the result of rules and regulations that engineering contractors need to meet or satisfy to meet legal requirements. An example of such safety standards is the widely used 100-year floodplain that delineates what is susceptible to flooding and what is safe. This is clearly arbitrary and often does not reflect the actual risks of damage involved. Another example is the level of levee protection in the Netherlands, where the range is protecting from a 1,250-year return flow to a 10,000-year coastal storm. Much depends on what the public is willing to pay to be 'safe'.

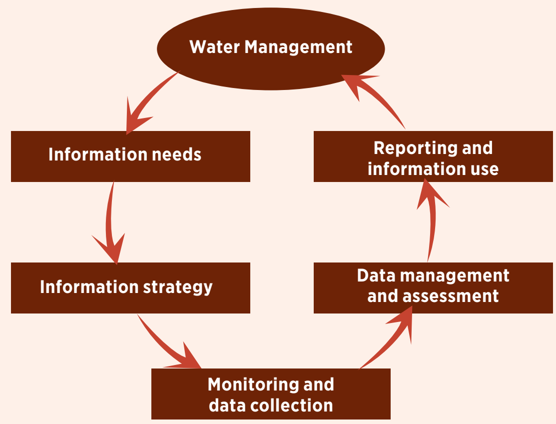
Modelling can help to identify the type and accuracy of data required for decisions being considered. But although the data obtained from current monitoring programmes are intended to be of value to future managers, it is difficult to predict the exact data and precision those future managers may require. The first stage in designing a monitoring system is therefore to define the information needed for the kinds of decisions being made. The information needed determines the attributes to be measured, the types of data to be collected, and the kinds of analyses to be applied.

> Although hydro-climatologic information about frequencies, magnitude, duration and incidence of precipitation and runoff events are the basic inputs into most water management decisions, they are but precursors to more fundamental economic, environmental and socio-economic information and objectives that typically dominate most water management decisions. In fact, it is the non-hydrological information that directs and constrains the basic decision rules that societies use to choose from a range of options that can be employed for any given water management problem. Land-use regulations, economic priorities, trade policies, benefit-cost criteria and even the choice of a discount rate used in deciding the present value of future streams of benefits and costs, are more prominent as decision factors than most hydrologic information. (Stakhiv, 2010, p. 22)

Frequency of measurement and the density of monitoring sites are dependent on the variability of an attribute or parameter's value over time and/or space. Once the monitoring network design has been defined, it is important to specify data collection, storage and analysis procedures, along with plans for reporting and disseminating the results. This is included in the monitoring strategy. These are subject to change and enhancement over time, reflecting changes in knowledge or goals, improvements in methods and instrumentation, and budgets. Actions taken to manage the system more effectively on the basis of monitoring data will lead to changes in information needs. As these change, the monitoring plan is revised accordingly (Figure 11.2) (UNECE, 2006). This approach supports the development of adaptive monitoring programmes that evolve iteratively as new information emerges and research questions change (Lindenmayer and Likens, 2009). This is an inherent property of institutional learning and is an indicator of appropriate adaptive change.

FIGURE 11.2

Monitoring and assessment cycle



Source: UNECE (2006, fig. 3, p. 16).

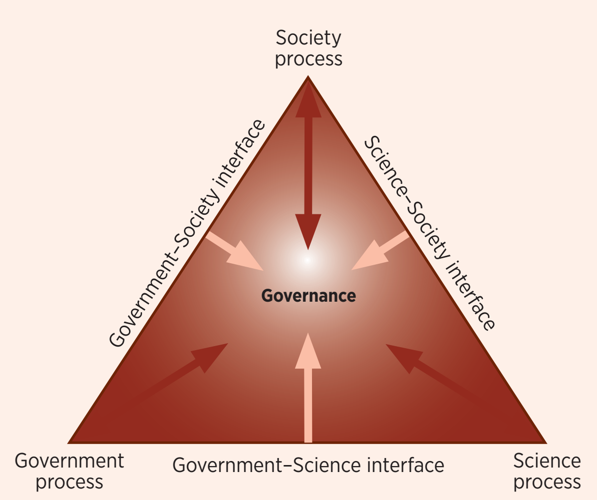
11.3.4 Decision-making that embraces uncertainty and risk

Adaptive IWRM is a sensible and pragmatic approach for modern water managers. It is an extension to IWRM in that it is designed to address the increasing uncertainty inherent to our modern socio-ecological systems (Burns and Weaver, 2008). The natural environment can be considered as 'infrastructure' because it supplies many of the same services as man-made infrastructure. Wetlands assimilate many organic wastes in the same manner as wastewater treatment plants. Soil moisture and groundwater represent significant sources of potential strategic storage. Increased research and monitoring regarding ecosystem water needs helps to optimize use of the natural environment in an infrastructural context.

Water conservation and demand management is an important element of enhanced resource management when set against a backdrop of adaptive IWRM. This requires making trade-offs between various types of water usages to encourage engagement and flexibility. Water management tools for addressing future demands include institutional reforms and policy changes that support demand management and more efficient water use, including the use of appropriate technologies. Appreciation of this approach to managing water resources is important as it embraces behavioural changes and economic and other incentives (Brooks et al., 2009). To be most effective this requires increased public awareness efforts and greater public participation. There is a need for enhanced analytical tools and models yielding results that are credible, understandable and communicable to a broad band of non-technical stakeholders, including the public, the media and political role-players, such as that envisaged by the trialogue approach shown in Figure 11.3 (Ashton et al., 2006; Hattingh et al., 2007; Turton et al., 2007*a*, 2007*b*). Such a multi-disciplinary approach involves stakeholders, psychologists, economists, hydrologists, water resources managers and political scientists, among others, and is increasingly a requirement for deriving optimal infrastructure designs and water-use policies.

FIGURE 11.3

The Trialogue Model with structured interfaces between the three main actor clusters of government, society and science is conducive to adaptive IWRM



Source: Hattingh et al. (2007, fig. 1, © CSIR 2007).

The inability to meet water supply demands and protect people and property against floods and droughts is a significant threat to all countries, but is felt most notably by developing states unable to build the infrastructure needed to reduce the adverse impacts of such events. The reality is that water management systems are not designed to satisfy all demands, given the full range of possible expected extreme events under what is understood to be contemporary hydrological variability. They are designed to minimize the combination of risks and costs of a wide range of hazards to society. This risk-cost balance is constantly adjusted by societies, which is why many countries have flood and drought infrastructure reliability set at a specified-year return period. Of course, as population density and life styles in urban areas increases, these standards invariably change, and begin to approach the risk-averse standards of countries like the Netherlands and Japan. The setting of new design standards and planning criteria are probably the most important aspects of any adaptation strategy.

Water resource management, which is now co-evolving with principles of adaptive management, has employed a variety of tools, in different combinations, to reduce vulnerability, enhance system resiliency and robustness, and provide reliable delivery of water-related services. 'These tools consist of many technological innovations, engineering design changes, multi-objective watershed planning, public participation, regulatory, financial and policy incentives. However, well-functioning institutions are needed to effectively administer this broad array of complex, dispersed and expensive combinations of management measures. Hence, tackling the central issue of governance is a key aspect of any strategy' (Stakhiv, 2010, p. 23) intending to deal with demand change adaptation, and this is a product of adaptive institutions (Falkenmark, 2007; Nyambe et al., 2007; Priscoli, 2007).

11.4 Institutions for managing risk and uncertainty

Present-day water institutions in general are not equipped to deal with contemporary challenges, such as integrating land and water resource management, working towards synergies, ensuring transparency and accountability, acquiring sufficient capacities and resources, and possessing adaptive capacity. Typical mechanisms to deal with uncertainty include establishing watershed services, reducing transaction costs, creating linkages across sectors, and developing a new leadership style.

Improving institutions entails strengthening institutional capacity, creating learning-oriented institutional processes, tackling institutional deficits, and incorporating informal institutions into water management. This implies fostering the capacity to work outside the water box in a way not yet common in mainstream practice.

Institutional capacity needs to encompass a clear definition of the roles and responsibilities of each authority, particularly in cases of emergencies or slow-onset disasters. Important features of adaptive institutional capacity are: clear decision-making procedures, communication protocols and contingency planning, sustained by regular training and simulation exercises (UNECE, 2009; WWAP, 2009).

Conventional water planning tends to be rigid and water institutions are typically poorly linked to other institutions required for effective governance of the water resource and services (Funke et al., 2007). The collective challenge is to ascertain how to develop adaptive governance frameworks and institutions, in response to growing calls for attention to more resilient institutions and approaches (GWP, 2009). Recent developments in water management focus on improved governance and institutional changes, including changes within formal and informal domains, as well as the shifting boundaries of the public/private divide (Falkenmark, 2007; Priscoli, 2007; Nyambe et al., 2007). While some countries have made significant improvements, the success of institutional reform has been mixed, with many countries still facing governance, financial and capacity shortcomings to implement new institutional structures (Box 11.3).

11.4.1 Creating adaptable and flexible institutions

Recognition that IWRM (see Section 5.1) needs to become more adaptive has brought increased appreciation for multi-sector and multi-disciplinary collaborative efforts towards sustainable development. This provides an opportunity for healthy institutional change. Without institutions capable of accommodating uncertainty, climate and other external changes will impose significant costs on water users and water-dependent communities, ultimately limiting economic growth potential. Identifying the way that endogenous and exogenous features influence management processes enhances adaptive institutional architecture and effectiveness. The key challenges to sustain healthy institutional evolution are as follows.

Integration

This includes the alignment and integration policies within the formal and informal institutions that regulate actions for both land and water. Effective institutions encourage cost-effective conservation measures and efficiency enhancements, like water-demand management practices, while remaining flexible and adaptable enough to accommodate increasingly uncertain climate forecasts. They also need to be robust enough to accommodate changes in water availability by facilitating the reallocation of water supplies, which is an action prone to the generation of instability, if incorrectly managed. When integration cannot be achieved, trade-offs may be necessary and

BOX 11.3

Water quality monitoring in Nigeria

The goal of water-quality monitoring is to obtain information useful for managing water resources. In Nigeria, most of the water used for domestic and industrial purposes is channelled from rivers and groundwater. The majority of the populace obtains water from rivers and shallow wells, and constant water-quality monitoring is a way to check and avert pollution, as well as upgrade standards. This is most practical in cities where high population density and industries result in the discharge of a large amount of waste into water bodies. Water-quality monitoring in Nigeria only involves the monitoring of groundwater levels once a year in each state, and is performed by the state water board using standards established by the Federal Environmental Protection Agency of Nigeria. There is no integrated river water-quality-monitoring scheme. Although the environment is characterized by unfavourable legislative, technical and operational conditions, the principal constraints on water-quality monitoring in Nigeria are institutional barriers: the organizational framework does not function in a way to enable such monitoring. The key issues include inadequate and untimely funding, shortage of requisite personnel, lack of a central coordination body for agency activities, poor maintenance of infrastructure, and lack of response to institutional reform needs. As a result, there are only mild or even no penalties for culprits. Moreover, the lack of information on pollution is a serious hindrance to pollution management. Monitoring is not just a technical issue; it is also an organizational and institutional issue.

Source: Ekiye and Zejiao (2010).

synergies can be sought, to achieve resource optimization and minimize adverse impacts. A key challenge is how to engage unregulated traditional and informal institutional frameworks with formal water supply regimes.

Realizing synergies

Different institutions may take measures that influence each other. For example, the European Union (EU) Common Agricultural Policy (CAP) plays a beneficial role in achieving the goals of the EU Water Framework Directive (WFD). Such synergies are beneficial for at least one of the institutions. Identification of weak or strong links between institutions helps to identify possibilities for synergies (or avoidance of disruption), delineate reform tasks, and set institutional priorities (Wettestad, 2008). Similarly, policies implemented by agencies responsible for mining in water-constrained areas might benefit society at large, but have severe negative impacts on national food security, because of the unintended consequence of unplanned mine closure, such as is the case in South Africa (van Tonder and Coetzee, 2008).

Water integrity and accountability

Transparent processes and access to information are required to discourage corruption, which adversely affects efficient and equitable water allocation and the delivery of water and sanitation services – particularly to poor and vulnerable groups. Corruption is a symptom of a governance crisis that increases transaction costs (Allen, 1999; Lund, 1993) and discourages investments (Earle, 2007). Hence, it affects institutional reform for improved accountability (Marin et al., 2007). In most developing countries, regulators tasked with these specific roles are often weak and are sometimes absent (van Wyk et al., 2007). Water accounting is now starting to emerge in water-constrained countries, like Australia, driven by the need to improve the integrity of reporting on water usage by all stakeholders (AASB, 2011; WWAP-UNSD, 2011).

Capacity development and resources

Adequate financing and appropriate staffing are required for effective and efficient delivery of water services, and the ability and authority to address basic governance issues like integrity and accountability. One emerging example comes from the Mapungubwe area in the Limpopo River Basin, where the government has allocated mining rights without consideration for water constraints and cultural sensitivities in the adjacent UNESCO World Heritage Site. The outcome of a process of vigorous contestation was a new agreement between the mining industry, government and wildlife conservationists, to create a new form of offset trading to meet the requirements of all parties.[1]

Adaptive capacities of institutions to deal with risk and uncertainties

Developments in technology and infrastructure, as well as the availability of financial resources, will be essential to improve water-use efficiency.

An example is found in the new coal fields in the Greater Soutpansberg (portion of the Limpopo River basin), where endemic water scarcity is a fundamental constraint to job creation through mining. One solution under investigation involves the creation of what is known as a special purpose vehicle (SPV) by the DWA, which would facilitate the buy-out of the existing water rights of farmers, along with the negotiation of an off-take agreement with the mining sector. This is an example of adaptive management, where government plays a proactive role in shifting water from an activity with a known low sectoral water efficiency (SWE) ratio (agriculture) to one with a known high SWE (mining).

Generating adequate and sustainable financing

Many water institutions in developing countries are plagued by under-financing and capacity deficits. New funding is required for more effective institutional implementation, but existing funding should be used more efficiently. Most water funding goes to infrastructure development rather than being invested in developing institutions and human capacities. Governments and the private sector must provide better incentives for innovative funding approaches that can enhance institutional implementation, and thus reduce the uncertainties affecting people's livelihoods, as well as access to water resources and services.

Another mechanism is to *reduce free-riding* and transaction costs (Nicol et al., 2001). Water resource institutions determine who can use what water, how, at what time and for how much; they also set management responsibilities, tariffs and collect fees. To keep an institution viable the various members need to contribute financially. Free-riding occurs when legitimate water users take more than their allocated share of water, which can trigger disputes over allocation. Water resources may also be extracted by illegitimate users without legal rights, permits or entitlements to that specific resource, which is especially common and difficult to control in the case of groundwater. For that reason, community-based water supply projects in rural areas have frequently proved untenable, with many communities unable to raise sufficient funds to meet operation and maintenance costs associated with common water resources. The transaction costs for monitoring and policing water users can be so high that it outweighs the benefits, particularly in rural areas where water users can be dispersed over large areas. This may also be the case if community goals of fairness in water allocation and cost-sharing are deficient. Social sanctioning may minimize the number of free-riders (Clark, 1977; Olson, 1965). Social norms can generate punishment for community members who break the rules, and run the risk of social exclusion or disrespect (Breier and Visser, 2006; Ostrom, 1990).

BOX 11.4

Review of water management institutions and reforms in 11 countries

A review of 11 countries – Mexico, Chile, Brazil, Spain, Morocco, Israel, South Africa, Sri Lanka, Australia, China, and India, undertaken by Saleth and Dinar (1999) – suggests that among the 11 countries, only Australia and Chile (and within the United States of America, California and Colorado) are at an advanced (though not ideal) stage of institutional change.

'Some of the recommendations from this study on institutional changes include:

- Attempts to fix isolated parts of water management will influence other dimensions. An integrated approach is best, at the heart of which should be institutional changes aimed at modernizing and strengthening legal, policy and administrative arrangements for the 'whole spectrum of water management.
- Institutional changes taking place everywhere suggest that the opportunity costs of (and net gain from) institutional change are overtaking most transaction costs. But institutional change is not uniform, suggesting that opportunity and transaction costs vary.
- Funding agencies should focus efforts and resources in countries, areas, and subsectors that already have enough critical mass in institution-building to ensure success and lower transaction costs.
- The sequence and pace of reform should reflect realities of scale economies and political pressures from reform constituencies. When possible, political economy should be exploited to quicken reform.'

Source: Saleth and Dinar (1999, from the summary findings).

The raising of capital to overcome some of these constraints has a rich history. The Swayam Shikshan Prayog project in India has facilitated the formation of more than 1,000 women's savings and credit groups, which have mobilized their own capital to provide loans for one another. The Sakhi Samudaya Kosh was established as a non-profit organization in 2006 to provide microcredit for women for agriculture, water and sanitation, as well as insurance to low-income people in disaster areas.[2] The Grameen Bank is another example, which has been shown to be highly effective to the point that it was jointly awarded the Nobel Prize in 2006.[3]

11.4.2 Actions which can improve institutions

Institutional changes within water management occur due to endogenous factors (water scarcity, performance deterioration and financial non-viability) as well as exogenous factors (macro-economic crisis, political reform, natural calamities and technological progress). Together, these raise the opportunity costs of institutional change, reduce the corresponding transaction costs, and create an institutional culture that is conducive to reform. Box 11.4 provides recommendations that can be useful in mobilizing the mutually supportive aspects of these factors for institutional reform.

Institutional water management is most effective when based on collaborative governance. Water management that builds on a joint effort of government, society and technical institutions ensures that measures will be both effective and sustainable (Hattingh et al., 2007; Turton et al., 2007). This entails looking outside the water box and improving disciplinary integration over diverse aspects such as water, agriculture, mining, environment, planning, finance and rural development, on both technical and policy levels. Achieving this will require the building of trust and social capital (Fine, 2001; Ostrom, 1994, 2001) to ensure that a problem-solving process takes place (Timmerman et al., 2010).

Institutional reform needs to be firmly anchored among stakeholders and their leadership. If institutions do not have legitimacy in the eyes of the public, they will not receive support and stakeholders are more likely to retain the *status quo*, or even develop their own informal rules, thereby undermining the integrity of the system. An important mechanism is therefore to improve institutional performance by improving political will and leadership. This remains a challenge for water decision-makers.

> "Transparent processes and access to information are required to discourage corruption, which adversely affects efficient and equitable water allocation and the delivery of water and sanitation services – particularly to poor and vulnerable groups."

The basis of any serious and workable system of dispute resolution is the existence of an independent administrator or judiciary with compulsory jurisdiction over the conflict to adjudicate, should every other means fail. Otherwise the party benefiting from the status quo has no incentive whatsoever to submit to any other means of (voluntary) dispute resolution.

Effective institutional change, and the degree to which this can deal with inherent uncertainty, is closely related to *path dependence*. In its simplest form, path dependence explains how current situations facing water decision-makers for any given circumstance, are generally defined by past decisions, even though the past circumstances may be irrelevant in the present and future. Because of the path dependence of water institutions in general, it is important that water decision-makers intensify their efforts to provide incentives for meaningful institutional change, by adopting the following measures.

Reinforce water institutions: Addressing implementation challenges, such as vested political interests and accountability systems, before any new institutions are put in place, helps to strengthen those institutions. Many countries are plagued by implementation problems driven by a lack of human capacity, information flows and financing. The fundamental governance issues that generate disincentives for enforcement by water institutions, and appropriate institutional set-up, generally remain intractable. Within governance systems characterized by the existence of a patron/client relationship, corruption and vested political interests tend to endure. Changing decision-making practices so that they are transparent and accountable will be more effective than increased capacities and better scientific information under these circumstances.

Create learning-oriented institutional processes: Experience suggests that institutional reform is an iterative learning process, where change is negotiated between different groups. There are no perfect solutions, only solutions that work in a particular context, so the best fit is often more important than the best practice (Baietti et al., 2006).

Fostering dialogue and consensus at the national level is an essential element for success, ensuring the full involvement of all sectors of society.

Address institutional deficits: The institutional set-up in areas responsible for water quality and groundwater management is often very limited. Sustainable management of these areas is likely to become more relevant with changing demographics, socio-economic developments and climate change.

Go beyond formal regulation and incorporate informal institutions into risk and uncertainty analyses: Informal local institutions allocate water resources in many parts of the world, and formal regulatory systems may only have limited influence on such decisions. A major challenge is to reach poor and marginalized social groups that normally depend on informal systems of water allocation and service delivery.

Looking beyond what is traditionally considered water management – going outside the water box – is therefore inevitable. Connecting water management with land management and sectors like agriculture, mining and energy, at the institutional level, will enhance the probability of effective decision-making (Ashton et al., 2006). Realizing this approach is highly demanding on leadership, and overcoming the inertia of traditional approaches and resistance from various actors remains a daunting task. Decision-makers need support in putting these ideas into practice, as well as the courage to withstand criticism, and the willingness to share power with other actors. Previous experience has shown that those who champion policy change often become victims of the very process of change that they successfully initiate (Huitema and Meijerink, 2009).

11.5 Communicating risk and uncertainty

In order to make appropriate decisions to manage particular uncertainties and risks, the uncertainties and risks involved first have to be clearly understood. Events carrying a low probability of risk (e.g. an aeroplane crash or nuclear plant leak) are often feared more than those carrying a higher probability of risk (e.g. being hit by a car while walking or cycling). Without precise information expressed in a clear and concise way, the magnitude of any risk or uncertainty involved in an action is easy to misjudge. Mistakenly attaching excessive risk to events may not only cause unnecessary anxiety, but may also cause individuals to put themselves in the way of harm (Thaler and Johnson, 1990). Uncertain situations have uncertain outcomes and therefore carry a degree of the unknown, which if communicated inadequately can cause exaggerated worry or fear. It is therefore important to supply enough accurate information to give the individual a certain amount of control when faced with uncertainty. This can make managing uncertainty less stressful and, as a result, attain more positive and realistic outcomes.

11.5.1 Media influence

It is all too easy to negatively communicate uncertainty, as can be frequently observed in the media. High levels of uncertainty can give those who aspire to a particular agenda an opportunity to 'spin the facts' and communicate in a deliberately misleading or manipulative way, often causing worry or fear. If the objective is to motivate people into positive action, communicating in this manner, commonly used as a method of control, be it political or otherwise, can be largely counterproductive, generating a climate of fear and feelings of helplessness.

The task of covering an issue in a balanced and responsible way presents an obvious challenge for members of the press and the media in general. This is especially true in situations where statements about uncertainties can be immediately seized upon and interpreted in different and conflicting ways in ongoing public debates.

Uncertainty can also offer crucial opportunities for generating benefits, and it is important to find, where possible, ways of communicating uncertainty that are empowering and constructive and that highlight the possible benefits.

Another area that can cause confusion when communicating uncertainty and risk – and indeed when communicating in general – comprises the numerous different voices or opinions, expert or otherwise, that are put forward. If conflicting arguments or opinions are being expressed by what are considered to be reliable and reputable sources – such as trusted media organizations, experts, government agencies or respected personalities and journalists – the resulting situation rapidly creates confusion in the eyes of the general public.

Individuals or groups may have different reactions to conflicting information: some may choose to accept an opinion that most suits their lifestyle/belief system, some may delve deeper – if they are interested enough – and commit to further research on which to base a more informed opinion. Others may be unable or unwilling to make sense of the conflicting opinions and may be discouraged by the topic altogether: 'you can't believe what you hear'.

In order to face the global changes and challenges that lie ahead, a concerted effort by the water community to communicate in one voice – a strong and collective voice – is a priority, especially if it is to encourage leaders and decision-makers and stakeholders from all walks of life to cooperate and act in the best interests of all. The importance of expressing important information coherently and in a coordinated manner should not be underrated.

11.5.2 Deciphering uncertainty and risk

Specialists and non-specialists alike constantly manage uncertainty and statements of probability. While errors in detail can be made, many people succeed in managing non-technical probabilistic information about the likelihood of events, such as river flows, lake levels, weather events, water shortages, floods and pollution levels. Communicating aspects of uncertainty and risk can be a particular challenge when the nature of the decisions being debated is largely technical. Decision-makers other than water managers, including users, politicians, leaders and the general public, all of whom participate in modern water management decision-making at some level, sometimes have difficulty fully understanding standard technical concepts, such as those concerning a 100-year floodplain or a category 5 hurricane storm surge. Explaining various aspects of the uncertainties and unknowns associated with non-stationary phenomena to the decision-making public becomes even more demanding. The challenge is how to most effectively help the public, stakeholders and decision-makers to understand uncertainties and their impact on possible decisions, thereby enabling them to be better informed as they participate in debates over which decisions are best. One of the aims is therefore to express probabilistic information and expert opinion in transparent non-technical and recognizable terms.

Bridging the gap between scientific research and decision-makers is the key to change. Communication plays a large part in the decision-making process and should not be underestimated.

The extremes and changes currently being experienced are still mostly within the norms of natural historical climate variability. Much of today's existing water resources infrastructure was designed to accommodate order-of-magnitude of variability. Standard engineering practices account for uncertainties by including redundancy (safety factors) in designs. It is also imperative for anyone involved in setting flood and crop insurance rates, defining floodplain zones, and designing levees, reservoirs, storm sewers and highway culverts, for example, to understand these risks and uncertainties and their possible economic, environmental, and social consequences.

Most people prefer certainty to uncertainty. They would much rather be told that it is going to rain today, or that it is not going to rain today, or that their flight will depart on time, than being told that there is a 64% chance of getting wet, and consequently there is a small chance of a flight delay, even if they know that these definitive statements may not be true. If the statements turn out to be false, clearly some trust between the forecaster and the public will be lost. People's responses to uncertainty partly depend on their attitude towards what is uncertain, such as a flood hazard. Those desiring more certainty will not be satisfied, and those who had intended to ignore the hazard may become even less concerned about it because if there is a substantial risk of harm related to some possible event, it is no doubt wise to make sure the public knows what that harm might be, even if the probability of that event and hence the risk might be low.

The same applies to warnings and reassurances. The temptation to suppress uncertainty and express confidence is ever present, but it is best if the temptation is resisted. If over-confidence proves to be misplaced it damages credibility and the ability to communicate effectively. If possible, people should be told what is certain, what is almost but not quite certain, what is probable, what is a gamble, what is possible but unlikely, and what is almost inconceivable. Bounds can be placed on the uncertainty: uncertain risks can be expressed in terms of the range of expert opinions. The greater the uncertainty, the more justified the precautions, precisely because the risk could be more serious.

It should be acknowledged by all those making estimates of, or trying to quantify, risk and uncertainty that these estimates or quantitative measures are themselves uncertain. For example, just how confident is it possible to be that the probability of rain today will be 10%? This higher level of uncertainty just complicates the communication of risks and uncertainties, but it is there, even if it is not known. Those who wish to wait before saying anything about a risk level until they know how confident they are of their risk predictions may never have anything to say.

BOX 11.5

Gender-sensitive dissemination of information: The case of early warning systems in Bangladesh

Men and women access, process, interpret and respond to information in different ways, due to the cultural context and gender division of labour. Statistics from past disasters around the world demonstrate the consequences of gender-neutral early warning systems. In 1991, for example, the death toll from the Bangladesh cyclone was five times higher for women than men, partly because early warning information was transmitted by men to men in public spaces, rarely reaching women directly. Early warning systems that are 'gender neutral' are not effective in reaching women adequately, and thus preparedness is limited and may ultimately cost lives. A gender-sensitive approach enhances early warning systems through: monitoring and warning services; dissemination of information by media that can reach women; and response capability. Women play an important role as first responders in taking appropriate and timely action in response to the warnings.

Source: UNISDR, UNDP and IUCN (2009).

Communicating uncertainty is a good start, but it is not enough. The goal is to communicate what is presently thought, or known, as precisely as possible, and to communicate the level of uncertainty.

An easy way to specify degrees of uncertainty is with numbers. The odds of '1-in-a-million' means it is practically not going to happen; '1-in-100' means it is highly unlikely but could happen; and '1-in-10', although less unlikely, would still surprise most people if it occurred. Similar estimates at the other end of the probability distribution include '9-in-10', '99-in-100', and '999,999-in-a-million'. When '50-50' is used it helps to clarify whether the evidence is generally evenly divided, or that there is no relevant evidence on which to base a judgment. When deciding on the consequences of risk, decisions often largely depend on the context (e.g. what is at stake): an engineer may not take a 1-in-10 risk in engineering design, but may leave an umbrella at home if the likelihood of precipitation is 1-in-10.

Other, longer phrases that can communicate different levels of uncertainty reasonably clearly are as follows (Sandman, 2004):

- 'The weight of evidence suggests that X is likelier than not, but there is still plenty of room for doubt.
- We're almost sure that X is not happening, and are proceeding on that assumption, but are continuing to monitor the situation to allow ourselves to change course should it be mistaken.
- We think it is probably X or Y and would be shocked at anything else; although Z is less likely it remains a possibility.'

11.5.3 Targeted communication

When ideas are expressed (e.g. 'more effectively addressing risks creates benefits and reduces vulnerabilities'), they can often seem intangible. As such, they can be easy to agree with, but difficult to know how to achieve. Effective communication breaks down the global statement/aim into smaller sections to make it more easily understood. Questions can be asked such as 'How can that goal best be attained?' 'What are the practical steps that could be taken to achieve that goal?' 'Who could meaningfully contribute to reaching the goal successfully?' and 'How could they do this?

Separating the audience into target groups and tailoring the communication to each can clarify and strengthen the impact of the message. A target group of high importance is the media, in all its various forms. Many crucial messages are imparted through the media, whether expressed negatively or positively. The media is a powerful communicating force both at local and global levels, and influences opinions – and therefore actions – in a vast array of topics. Typically the media need 'hooks'. Generally the more dramatic the 'hook', the more likely it is that the information will be published or broadcast (e.g. a shocking statistic may make headlines while a competing positive statement about the same topic may not). It is important to strike a balance between attracting the media, while being aware of and taking responsibility for the possible impact of the information fed to them.

In order to motivate a target audience with targeted messages it is important to clearly define each group and understand their motivation. How each group responds to communication and acts upon its message is also likely to be different. What motivates political leaders to act in the face of uncertainty may be different from what motivates teachers or small business owners. As there are multiple angles to information and as the reference point, coding and editing of particular messages are key factors in the analysis of decisions (Kahneman and Tversky, 1979) in order to achieve the desired communication objective the correct angle, key words and language should be chosen carefully and correctly for each target group (see Box 11.5).

Profile questions can be asked to identify what motivates each group. This requires some generalization, and it is important to be certain when correctly identifying the characteristics of a particular group (avoiding stereotypical identifiers). This is particularly pertinent if the target group is *not* the one to which the profiler belongs. A diverse group should therefore carry out this activity to ensure broader social knowledge and awareness. Examples of questions that can be asked of each group are:

- What is their average level of education?
- Which newspapers/magazines do/may they buy?
- What motivates them to make particular purchases/take particular action?
- What do they consider as worrying on a local/global scale?
- What action can they/would they *be likely* to take? What inhibits them from taking this action?
- What do *they/others* consider to be their weaknesses and strengths?

Once the target audiences have been defined and their motivations and desires better understood, it is easier to communicate information effectively. It is not important if the communication material prepared for one target audience is not understood by all target audiences, but it is important that it is understandable to the particular group being addressed. The language used in targeted communication can be stronger and clearer as it does not attempt to 'cover all bases'. The more familiar the language, the easier it is for that specific group to understand. For example, technical information and data may be used in abundance for one target group but greatly modified or used sparingly for another.

To maximise effectiveness in terms of positive action when communicating uncertainty and risk, it may be necessary for each target group to feel reasonably challenged (a percentage of shock factor may be necessary), but not fearful or helpless.

Conclusion

Instead of imparting an impression of impending doom or disaster, uncertainty and risk can instead be communicated through targeted, precise and enabling messages, with communicators bridging the gap between experts (who may be largely technical) and the general public. When communicating through the media or otherwise, it is important to highlight the fact that uncertainty and risk can also bring opportunity and the possibility of positive change.

Knowledge is empowering and forms the basis for making informed and progressive decisions, and information communicated in a clear and targeted way, with one voice, can enable people to better understand, and reach their own conclusions, about the risk involved. This in turn imparts responsibility and encourages action, which is essential for change.

Notes

1 For more information see http://www.savemapungubwe.org.za/media.php

2 For more information see the Swayam Shikshan Prayog Project website http://www.sspindia.org/

3 For more information see http://en.wikipedia.org/wiki/Grameen_Bank

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CHAPTER 12

Investment and financing in water for a more sustainable future

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Investment in water and sanitation is a vital concern for the many households that still lack these services. Water underpins all parts of a modern economy and its productive uses are also essential for poverty reduction. Water development is an integral part of a green economy: it is central to society's adjustment to climate change and is crucial to meeting future concerns for food security across the world.

Increased financing is necessary for all facets of water development, ranging from 'hard' infrastructure to equally important 'soft' items such as management; data collection, analysis and dissemination; regulation and other governance issues. The approach to financing propounded in this chapter is pragmatic and eclectic. It examines efforts to minimize the funding gap through internal efficiency and other measures; improve the generation of revenues from users, government budgets and official development assistance (ODA); and use these flows to leverage repayable finance such as bonds, loans and equity.

The current climate for international finance is difficult. It is therefore important to exploit all available risk-sharing tools. International financing institutions (IFIs) in particular have a key role to play.

12.1 Investing in water for sustainable development

A range of emerging factors are challenging enduring economic development stereotypes. These include the response to climate change, destabilizing fluctuations in commodity prices, concerns for food security, the increased role of public investment in infrastructure in response to the global financial crisis, and the desire of governments to limit their exposure to volatile international financial flows.

The current environmental imprint of infrastructure expansion is significant. It is therefore imperative that ways be found to design, operate and maintain systems that minimize negative environmental externalities at a lower cost than existing investments (Fay and Toman, 2010). Public policies should offer incentives for private sector decisions regarding investment and consumption that reflect the social benefits of environmental sustainability and the costs of various forms of environmental protection. At a global level there is a need to increase environmental research and development (R&D) and encourage the international transfer of cleaner technologies.

The *green economy agenda* is a response to these trends and seeks to reinforce and accelerate the progress of sustainable development.[1] It involves public policy, individual and collective business initiatives and private customer behaviour. The agenda has serious implications for water infrastructure. It increases pressure for more efficient use of resources and reductions in waste and greenhouse gas emissions, both of which aim to shift investment and consumption patterns towards alternatives that deplete less natural resources.

There are 11 key green economy sectors: agriculture, buildings, cities, energy, fisheries, forestry, manufacturing, tourism, transport, waste management and water.[2] The water development agenda overlaps with the green economy agenda in the following areas: pollution control, wastewater collection, treatment and reuse, successive uses of water, water use efficiency, energy efficiency in water and wastewater treatment, distribution and reuse, energy recovery, emission mitigation (capture of methane in wastewater treatment and irrigation), irrigation, and hydropower and management of natural water ecosystems (including wetlands).

A large percentage of these projects target several objectives simultaneously. This can often make financing such projects easier. Water development can thus gain from the economic and financial synergies that stem from the green economy. However, other actions justified by their 'greenness' may pose problems for water management unless they factor in and mitigate their potential impact on water. The promotion of biofuel technologies is an example of this. (For implications of biofuel developed for water resources management and use see Saulino, 2011.) Furthermore, to regard or compartmentalize water as a sector among others is too limiting, in spite of its presence as one of the 11 green economy sectors.

Investment in water infrastructure, in both its physical and natural assets, can be a driver of growth and the key to poverty reduction (Garrido-Lecca, 2010; UNEP, 2010). Although the recent global economic crisis set back investment in water in many countries (Winpenny et al., 2009), the impacts have been varied, and some governments have made determined efforts to compensate through counter-cyclical fiscal measures. Green investment in renewable energy, energy efficiency, more efficient use of materials, clean technology, waste mitigation, and sustainable use and restoration of ecosystems and biodiversity accounts for approximately 20% of the US$2 trillion of economic stimulus packages announced since 2008. Water is one of the beneficiaries of these programmes, although its full importance has not been recognized.

UNCTAD reports that 'there is considerable scope for developing economies in the [following] years and decades to gain from the opportunities that will emerge from the structural change towards renewable sources of energy, climate-friendly technologies, low-carbon equipment and appliances, and more sustainable modes of consumption' (UNCTAD, 2009, p. 168). Entry into these new markets could help developing and transition economies to combine climate change mitigation policies with faster growth and the creation of employment (UNEP, 2008). Developed countries dominate the global market for 'environmental goods', but some developing economies are building their market share based on their natural comparative advantages.

12.1.1 The Millennium Development Goals and sustainable development

Environmental goals cannot be achieved without development and efficiency. Poor people without adequate food, sustenance and water and sanitation will degrade their environment if they must do so to survive – even if it risks their long-term survival. Hence, sustainable development goals cannot be achieved and maintained without sound environmental management. Investment in programmes for poverty reduction is crucial for environmental policy, while investment in maintaining a healthy environment is vital for successful poverty reduction., However, investments remain seriously inadequate in many regions of the developing world to meet the Millennium Development Goals (MDGs).

The UN Millennium Project and the UN Millennium Ecosystem Assessment (MA, 2005; see Section 2.5) highlight the interdependencies between economic development and environmental management for poverty reduction and general well-being. The combination of poverty, vulnerability to drought and crop failure, lack of safe drinking water, and other environmentally related ills result in the deaths of millions of people each year. Over 1 billion people suffer from disease due to a lack of safe water, and are consequently less productive than they could be. The desperate situation of the poor therefore exacts a toll on the economy as well as on their environment and its ecosystem (Box 12.1). Lentini (2010) presents an overview for evaluation of the diverse benefits of water services in a typical developing country setting, especially for low income groups.

Alongside the UN's MDGs for ending poverty, eradicating hunger, achieving universal primary education, improving health, and restoring a healthy environment, the Millennium Ecosystem Assessment (MA) examines the consequences of ecosystem change for human well-being, and analyses options for conserving ecosystems while enhancing their contributions to human society. Environmental degradation is a major barrier to sustainable development and to the achievement of the MDGs. 'The MA examined 24 ecosystem services (the benefits people obtain from ecosystems) and found that productivity of only four had been enhanced over the last 50 years, whereas 15 (including capture fisheries, water purification, natural hazard regulation, and regional climate regulation) had been degraded. More than 70% of the 1.1 billion poor people surviving on less than US$1 per day live in rural areas, where they are directly dependent on ecosystem services.' (Sachs and Reid, p. 1002).

Investing in environmental assets and the management of those assets can help achieve national goals for relief from poverty, hunger and disease. Investments in improved agricultural practices to reduce water

BOX 12.1

Economics of access to improved drinking water and sanitation

Improving access to safe water and basic sanitation could have huge economic returns. World Bank studies in five South-East Asian countries estimate that around 2% of their combined GDPs are lost because of poor sanitation, and in the worst case (Cambodia) this figure rises to over 7% (World Bank, 2008). Economic benefits due to improvements in health include lower health system costs, fewer days lost at work or at school through illness or caring for an ill relative, and convenience time-savings (Hutton et al., 2007). The prevention of sanitation and water-related diseases could save approximately US$7 billion per year in health system costs, and the value of deaths averted, based on discounted future earnings, would add a further US$3.6 billion per year (Hutton et al., 2007). In fact, the World Health Organization (WHO) estimates that the overall economic benefits of halving the proportion of people without sustainable access to improved drinking water and sanitation, by 2015, would outweigh the investment cost by a ratio of 8:1 (Prüss-Üstün and Corvalán, 2006). Despite clear benefits to the development of individual countries' economies and health from increased access to sanitation and drinking water, 'many countries seem to allocate insufficient resources to meet the Millennium Development Goal target for sanitation and drinking water. When compared to other sectors (namely education and health sectors), sanitation and drinking water receive a relatively low priority for both official development assistance (ODA) and domestic allocations' (WHO/UN-Water, 2010, p. 2).

In fact, total aid for all aspects of water fell from 8% to 5% between 1997 and 2008 (WHO/UN-Water, 2010). Moreover, domestic and foreign aid are not necessarily well targeted to where need is greatest (e.g. the poorest and underserved populations). Less than half of the funding from external support agencies for water and sanitation goes to low income countries, and a small proportion of these funds is allocated to the provision of basic services, where it would have the greatest impact on achieving the MDG target (WHO/UN-Water, 2010). Stakeholders must continue to make the economic and development case for increased investment in sanitation and water. Furthermore, research must continue on the appropriate level of resources for sanitation and drinking water, compared to other sectors.

pollution can boost coastal fishing industry. Wetlands protection can help meet needs of rural communities while avoiding costs of expensive flood control infrastructure. (Sachs and Reid, p. 1002).

Conversely, reaching environmental goals requires progress in eradicating poverty. Coherent and bold poverty reduction strategies can ease environmental stresses by slowing population growth and enabling the poor to invest long term in their environment. Periodic environmental/ecosystem assessments would be helpful in this context.[3] 'A global network of respected ecologists, economists, and social scientists working to bring scientific knowledge to decision-makers and to the public can clarify the state of scientific knowledge, help to mobilize needed research', and counter any misinformation published by groups having special interests (Sachs and Reid, p. 1002).

12.2 Funding governance, institutional reform and management

To function properly and sustainably, all aspects of water resources management and water supply-related services must be fully funded. This not only includes the creation and maintenance of physical infrastructure, but also water resource management, environmental protection and pollution abatement measures, and less visible functions such as policy development, research, monitoring, administration, legislation enforcement, provision of public information, control of corruption and of conflicts of interest, and the involvement of public stakeholders (see Chapter 17).

BOX 12.2

Cost of adaptation to climate change for water

A World Bank study (see Chapter 24) has evaluated the impact of adapting the water sector to climate change in developing countries, over the period 2010–2050, based on a socio-economic baseline and two climate change scenarios, created by the Commonwealth Scientific and Industrial Research Organisation (CSIRO) in Australia and the National Centre for Atmospheric Research (NCAR) in the United States of America.

The adaptive costs were defined in terms of hard options including building dams and dykes, and soft options such as the use of early warning systems, community preparedness programmes, watershed management, and urban and rural zoning.

The table below represents average annual water resource adaptations costs, combining riverine flood protection and industrial and municipal raw water supply. According to these estimates, measures to cope with the climate scenarios imply an annual increase in adaptation costs of US$13–17 billion for developing countries as a whole. This represents 3% of their GDPs. Africa is the worst affected region.

Average annual water resource adaptation costs (2010–2050) US$ billions (% GDP)

	Baseline*	CC (net costs)**	
Region		CSIRO**	NCAR
East Asia and Pacific	29.4 (0.06)	2.1 (0.00)	1.0 (0.00)
Europe and Central Asia	15.8 (0.03)	0.3 (0.00)	2.3 (0.00)
Latin America and Caribbean	13.4 (0.03)	3.2 (0.01)	5.5 (0.01)
Middle East and North America	11.9 (0.02)	0.1 (0.00)	-0.3 (0.00)
South Asia	34.9 (0.07)	4.0 (0.01)	-1.4 (0.00)
Sub-Saharan Africa	9.8 (0.02)	7.2 (0.01)	6.2 (0.01)
Total: developing country	115.1 (0.22)	16.9 (0.03)	13.3 (0.03)
Total: non-developing country	56.2 (0.11)	7.4 (0.01)	13.3 (0.01)

** The baseline year is 2050. 'Development baselines were crafted for each sector, essentially establishing a growth path in the absence of climate change that determines sector-level performance indicators ... [using] a consistent set of GDP and population forecasts for 2010-50.' (World Bank 2010a, p. 2)*
*** Figures of 0.00 are positive amounts, rounded to the nearest decimal point; they do not imply zero amounts.*
Note: Discount rate = 0%; negative values refer to net benefits.
Source: World Bank (2010d; 2011). Table data from World Bank (2010e, table 5.4, p. 41).

Adequately funded water governance is essential to reduce uncertainty and manage risks. Generating data for policy-makers and managers (observations, analysis, modelling, scenario-building) helps to inform decision-makers and reduce uncertainty. Effective governance in areas such as environmental controls, groundwater monitoring and abstraction licensing, and monitoring and policing of pollution, can reduce the risk of over-exploitation of water resources and catastrophic surface water pollution and irreversible contamination of aquifers. Some of these governance functions can be self-financed through abstraction and pollution charges.

The same is true of regulation. Both public and private water agencies with operational functions should be subject to oversight from independent regulators with full and timely access to relevant information. Far-sighted service providers recognize the value of objective and transparent regulation in giving their activities the public scrutiny and sanction necessary to confer legitimacy and provide assurance against arbitrary actions for short-term political gain. Many regulators are funded by an earmarked tax on water bills (e.g. England and Wales, and Scotland) (see Chapter 25).

The third edition of the *World Water Development Report* (WWAP, 2009) highlighted the need to transcend the 'silo mentality' often found in water planning, and to take account of the wider implications of water decisions and the impact on water of decisions taken in other economic sectors. This is a central aim of integrated water resources management (IWRM). Among other development agencies, the World Bank aims to use its lending programmes to create capacity for IWRM as a way to overcome the institutional fragmentation which affects water. As part of this approach, the World Bank is working to incorporate the cross-cutting nature of water in its country programming, and integrate water interventions with projects in other sectors. In its water programmes, it intends to make focus on projects linking different components, hitherto funded separately, such as resource management, services, water quality and ecosystems (World Bank, 2010*b*).

Many water governance problems arise at the transboundary level, which is fraught with potential risks and conflicts. Capacity-building and management support for transboundary water institutions require proper funding. This is typically drawn from multilateral and bilateral agencies, local governments and other sources, usually in combination.

12.3 Funding for information

Chapter 6 of this report addresses the neglect and decline of national observation systems, which have caused a loss of vital hydrological data. Investment in the technology needed to upgrade countries' water and water-related information bases can result in good returns. As a result the World Bank and other agencies are targeting these systems for support (World Bank, 2010*b*). Such information is of vital national concern, but also constitutes a *regional and international public good*, albeit one which is 'seriously underfunded, and therefore under-provided' (Winpenny, 2009, p. 8). This is for three main reasons:

> Regional programmes and institutions involve co-operation between two or more neighbouring governments, often themselves poor, and which give transboundary issues a low priority compared to urgent national concerns. The problem is aggravated where neighbouring countries are at war with one another.[4]
>
> The attribution of benefits to the different partner countries is difficult, hence sharing costs is problematic, and hampers setting realistic budgets and funding modalities.[5]
>
> For such reasons both donors and recipients of Official Development Aid (ODA) may view regional public goods as less desirable objects than national programmes. Donors may also prefer supporting international, rather than regional, public goods out of self-interest, since they may perceive greater benefit accruing to themselves from actions of global concern. According to one estimate, only 3 to 4% of ODA goes to regional public goods, although such programmes can give high returns.

This problem is particularly acute in Africa: there are more than 60 transboundary rivers and international river basins cover 60% of the total area of the continent. Practically all African rivers cross several borders: the Nile crosses ten, the Niger nine, the Senegal four and the Zambezi eight. African water security will require the construction of regional and shared infrastructure on a large scale and the coordinated management of shared water infrastructure. Such an effort will require a greatly strengthened information base of regional climatic and hydrological data.

Better hydrological information about river regimes and groundwater reserves is essential for reducing uncertainty and anticipating climatic variability, which has had a heavy cost in many countries. In Kenya, losses from flooding from El Niño in 1997–1998 and drought from La Niña in 1998–2000 ranged from 10 to 16% of GDP during those years. Growth of GDP in Mozambique was reduced by 1% annually due to water shocks. In Zambia, hydrological variability is estimated to lower agricultural growth by 1% each year. Similarly, in Tanzania, the impact of the 2006 drought on agriculture caused losses equivalent to 1% of GDP (McKinsey, 2010). Reducing the damaging impact of this hydrological variability would have major benefits for the macroeconomy (AICD, 2010). Improved weather and flood forecasting is crucial to flood risk management, especially in reducing the impact of floods. Investment in weather forecasting and hydrometeorological services can be highly cost-beneficial.

In water resources management, for instance, there is a real need for better hydrological and meteorological information. The basic data should come from systems (including satellite observations) operated by national public and international agencies. However, in many cases agencies fail to collect or share the data. Private companies can also play a significant role in the generation, interpretation and application of such data for applied economic purposes. In France, a private company, Infoterra, provides satellite data for the analysis of farmland to anticipate the likely impact of climate change. In Germany, a private satellite operator, RapidEye, sells data to insurance companies marketing crop insurance to governments in countries at risk of drought and famine. Likewise, companies active in oil exploration and development offer unrivalled services for the prospection and exploitation of groundwater aquifers (Winpenny, 2010).

12.4 Funding in response to climate change and growing water scarcity

Projections reveal that the annual cost of climate change adaptation in developing countries in the industrial and municipal raw water supply sector would be between US$9.9–US$10.9 billion (net) and US$18.5–$19.3 billion (gross). Costs for riverine flood protection are projected at between US$3.5–$5.9 billion (net) and US$5.2–$7.0 billion (gross)[6] (Box 12.2).

Climate change will mainly be experienced through greater variability of temperatures and hydrological conditions. Adapting to *current* variability is an important first step in many cases. As the IPCC has observed, 'many actions that facilitate adaptation to climate change are undertaken to deal with current extreme events' (Adger et al., 2007, p. 719).

Greater variability around, and changes in, the climatic mean are likely to be compounded by greater *uncertainty* over the boundaries of variation, the possible appearance of new factors, and the presence of thresholds, irreversibilities and tipping points (see Chapter 2). Uncertainty has major implications for decision analysis and criteria (Box 12.3).

A common element of risk management, in view of the residual uncertainty about the impacts of climate change and other forces driving change, is the *no regret* criterion: a policy that would generate net social and/or economic benefit irrespective of what change occurs. Examples include demand management measures; improvements in the efficiency of water distribution; wastewater recycling; early warning systems for floods, droughts, and other extreme weather events; and risk-spreading through insurance schemes.

Although no-regret projects can be justified in financing terms, independent of the risks and uncertainties they face, there are many reasons why they may not happen: lack of project preparation, shortage of capital and credit, and a misalignment of social benefits with financial incentives for sponsors. These factors are seen in water demand-management programmes, for example, in cases where both household and industrial users seem reluctant to take up appliances and technologies that, on paper at least, promise rapid payback. No-regret projects may be attractive in theory, but may still require active promotion. Climate change impacts may lend them the extra benefits and impetus they need to make them a reality.

In comparison, projects justified solely on the basis of expected climate change would only be justifiable if the predictions of climatic and hydrological models proved accurate. Such projects include construction of new storage and supply infrastructure, retrofitting of existing structures, altering operational protocols, and developing new water sources and water transfers. Such climate-justified projects and policies have to be planned and implemented against the backdrop of an uncertain future. The key criteria for these projects are resilience, robustness, flexibility and *intelligence* (the ability to provide services or management over a range of possible conditions). Depending on circumstances, some of these projects may have benefits outside of a climate change scenario. As the IPCC observes, 'adaptation measures are seldom undertaken in response to climate change alone' (Adger et al., 2007, p. 719).

Ensuring the capacity to cope with the greater variability and uncertainty caused by climate change and other change forces (see Chapters 1 and 9) constitute a broad challenge for water infrastructure. The measures required will pose severe tests for governments, public agencies and international research institutes. Their efforts will need to be supplemented by the actions of private, non-governmental bodies of all kinds, who can add value though extra resources, different ways of working, new approaches and innovative products. Adaptation and mitigation projects implemented by public agencies can draw on a range of development funds, including new adaptation funds created for this specific purpose. There are currently over 20 specialized climate change funds accessible to public agencies.[7] Leaving aside those funds specializing in forestry or energy, around a dozen funds are available for adaptation for water, amongst other sectors. Of particular relevance is the funding provided by the Pilot Program for Climate Resilience (PPCR), sponsored by the World Bank and other major IFIs:

> The pilot programs and projects implemented under the PPCR are country-led, and build on National Adaptation Programs of Action (NAPA) and other relevant country studies and strategies. They are strategically aligned with other donor-funded activities to provide financing for projects that will produce experience and knowledge useful to designing scale-up adaptation measures. (CIF, 2011)

Specifically, funding is available through PPCR for technical assistance to assist developing countries in 'integrating climate resilience considerations into national development planning' (CIF, 2011).

BOX 12.3

Implications of climate change uncertainty for decision-making

Greater variability and fundamental uncertainty would have profound implications for decisions about water infrastructure, which typically has a long physical life. These implications are at various levels, and of different kinds:
The *climate risk* of such infrastructure should be assessed, at a sector and/or project level.

Traditional ways of dealing with risk in *cost–benefit analysis* need to be fully exploited: these methods include sensitivity analysis, switching values, and risk-benefit analysis.

Decision rules should be used that take into account the *risk preferences* of the agency concerned (minimax, maximin, minimum regret) (Ben Tal et al., 2009).

These traditional aids to decision-making under uncertainty and risk need to be complemented by the use of *scenario building,* which constructs a series of plausible futures, which could not necessarily have been predicted by extrapolation from current trends. Projects which stand up well on different scenarios are considered to be *robust* (World Bank, 2010*a*).

Project design needs to allow for greater climatic variability, and be resilient in dealing with events that cannot be foreseen as yet. The initial cost of building in resilience (e.g. greater storage, which may not be needed; or forfeiting current economies of scale in favour of greater freedom of manoeuvre in future) could be regarded as an insurance premium to avoid future losses in the CC scenario.

Source: Reproduced from Winpenny (2010, pp. 1–2).
Note: Sensitivity analysis measures the impact on a project's rate of return of a change in a specific variable. Switching values are the change in a specific variable required to reduce the rate of return to zero. Risk-benefit analysis compares the risk of action (= its cost) with the benefit of action (= avoided loss).
Minimax = minimizing the maximum expected loss; maximin = maximizing the minimum likely outcome; minimum regret = minimizing the difference between the worst possible outcome and others.

There is a risk that these climate change funds might add to the administrative burdens placed on recipients (Porter et al., 2008). Such funds can be useful sources of money for pilot projects (e.g. the PPCR), but at a country level there is a strong case for 'mainstreaming' adaptation as much as possible, rather than consigning it to a marginal part of the public investment programme, requiring its own procedures and criteria.

Much of the adaptation and mitigation effort, however, will fall to private companies, farmers and households, as well as subsovereign agencies that cannot access these development funds. For them, commercial financial sources are critical. Microfinance is particularly suitable for financing the improvement of irrigation efficiency for small farmers. Certain forms of contract can also be funded by quasi-equity, in which rewards depend on the successful achievement of project aims, for example, performance-related contracts for water leakage reduction.

12.5 Funding diversification and demand management

Diversifying the sources of water by increasing the use of technologies, such as desalination and reclaimed water and promoting self-supply by users (farmers, households and companies) can reduce and distribute risk, compared with relying on a few sources that are dependent on the same hydrological system. Some of these are easier to finance from conventional means than others. Desalination plants and certain projects for the use of reclaimed water, which entail sizeable investment in wastewater treatment plants (WWTPs), lend themselves to public sector or stand-alone commercial ventures funded from equity and commercial finance – typically under a form of concession contract. In Mexico, the Atotonilco WWTP re-uses treated urban wastewater in irrigation. Under the terms of a recent contract, bids were invited under a build-operate-transfer (BOT) structure, with 49% of costs coming from the National Infrastructure Fund and the remainder from the private concessionaire. The Matahuala and El Morro WWTPs have similar aims and financing structures: design-build-operate-transfer (DBOT) and BOT, respectively (GWI, 2009, pp. 51–2).

Dealing with future water deficits will also require action on the demand side. Demand management needs a different approach to financing. In South Africa, current trajectories and policies produce urban,

> "Microfinance is particularly suitable for financing the improvement of irrigation efficiency for small farmers."

agricultural and industrial growth projections to 2030 incompatible with the country's water endowment. In the base case scenario, South Africa faces a gap between projected 2030 demand and current supply equivalent to 17% of demand. Moreover, the impact of climate change might increase the size of this gap. Competition for limited water supplies will intensify in each of the basins feeding the largest cities (Johannesburg, Pretoria, Durban and Cape Town). Household demand is expected to increase as a result of income growth and improved service coverage. The current planning scenario for the Vaal system (Johannesburg, Pretoria and surrounding areas) assumes that demand management will reduce demand increases under a business-as-usual (BAU) scenario by 15% (although that is not yet happening), which will generate substantial investment burdens. Agriculture is not seen as a major growth sector, although its water allocation may need to decrease, implying greater efficiency in its use. Meanwhile, industry, power generation, mining and agriculture – the sectors that will drive the income growth – are all water-intensive.

Closing the projected supply-demand gap for water in 2030 and thereby enabling South Africa's growth potential to be realized can be achieved with a portfolio of different measures: supply-side transfer schemes, new dams and modifications to existing structures, re-engineering of existing irrigation schemes to increase water efficiency, and better use of water in mining and industrial companies. In short, a balance of supply-side and demand management measures are needed. Much of the cost of demand management falls on consumers – households, farmers and industries – and is financed largely by them, though governments can help with subsidies and tax breaks (McKinsey, 2010).

12.6 Generating finance for water infrastructure and services

All countries at every level of development face heavy costs in creating a water infrastructure that is 'fit for purpose', which can address the growing challenges and risks identified throughout this report.

According to a recent World Bank Study (2010*c*), the global financial crisis has negatively impacted progress towards fulfilling the MDGs. The crisis will also potentially magnify the already large investment needs. Using three macroeconomic scenarios to illustrate the risks involved, the report reveals that serious global shortfalls are looming in water development indicators. According to one projection for 2015, 100 million more people will lose access to safe drinking water. A rethinking in financing strategies is therefore required to ensure that improvement in public expenditure efficiency results in additional resources.

The African Infrastructure Country Diagnostic (AICD, 2010) determines the investment needs in infrastructure in sub-Saharan Africa. This tool assists policymakers to set priorities for investment in all infrastructure sectors and provides a baseline for monitoring progress. The AICD estimates that US$22 billion per year (approximately 3.3% of Africa's GDP) is the amount required to attain the MDGs in water and sanitation. These estimates, based on minimum acceptable asset standards, include an annual capital expenditure of US$15 billion and operating expenditures of around US$7 million. These figures do not include the cost of investment in hydropower or irrigation. Similar estimates for Latin America and the Caribbean are available in an IDB study (2010) 'Drinking Water, Sanitation, and the Millennium Development Goals in Latin America and the Caribbean'.

A pragmatic and eclectic approach is required to raise the sums needed. The first step should be to squeeze the financing requirements to a minimum through improvements in efficiency, better collections of revenues due, and adjustments to service levels and technological solutions (AICD, 2010). The second step is to improve the rate of *sustainable cost recovery* by raising tariff revenues, budgetary allocations due from governments and ODA. In this context, the willingness to pay of water users may well be greater than the willingness to charge of politicians. The third step is to use these revenues to attract repayable sources of funds, using available devices for the reduction, mitigation and sharing of water financing risks (Winpenny, 2003; OECD, 2010a among others).

Raising commercial finance for water has become more difficult due to the global financial situation since 2007, which

> has discouraged new private interest in water infrastructure projects, and has also unsettled partners in existing private public partnership (PPP) ventures. Earlier in 2009 the IFC reported that US$200 billion of PSP projects had been postponed or had become 'at risk', 15–20% of which were in water supply and sanitation. The financial climate affected both the supply of risk capital (e.g. equity) and loan capital to finance these concession deals, since liquidity has become scarce, and the problems of international banks have had repercussions on local banks too. Many innovative deals, developed with technical assistance and risk-sharing from donor agencies, are at risk. (Winpenny et al., 2009, p. 18)

The Private Participation in Infrastructure (PPI) database, maintained by the World Bank and the Public-Private Infrastructure Advisory Facility, reported that in 2009 the number of water projects reaching financial or contractual closure had declined by 46% compared with 2008, and that annual investment commitments had fallen by 31% over the same period. In 2009, 35 water projects with private participation were implemented in seven low or middle income countries, involving investment of around US$2 billion. However, three countries (Algeria, China and Jordan) accounted for most of this activity (see Chapter 24).

> Many projects that were close to financial closure when the crisis broke have survived by switching their sources of funding to local public banks or agencies. Even when the financial crisis abates financing terms for PSP deals in water and other sectors are likely to remain harsh, and will call for more 'conservative' project financing structures (i.e. more equity, less debt, more risk mitigation) … These developments are occurring against (and reinforce) a gathering trend towards more selectivity in the choice of markets and type of project by the handful of western multinationals that remain in the market for new international water concessions. (Winpenny et al., 2009, p. 18)

However, these multinationals are increasingly joined by more recent market entrants from Latin America, the Middle East, Southeast and East Asia and elsewhere (Winpenny, 2006).

Public-private partnerships (PPPs) in urban water utilities have had a mixed record in developing countries, with relative success in some (mainly in Chile) and problems in others (e.g. Argentina and Bolivia) (Jouravlev, 2004; Ducci, 2007; Lentini, 2011) and in increasing efficiency than in directly bringing new finance (Marin, 2009). This is particularly relevant as many urban water transmission and distribution systems are highly inefficient in their use of water and energy (AICD, 2010; Kingdom et al., 2006). Improved cost control and better cash flow in utilities will indirectly increase their ability to raise their own finance. This also has implications for energy costs. Water is a large and generally inefficient consumer of energy. This constitutes a sizeable percentage of water delivery cost, even at the subeconomic electricity prices that often apply. The use of more marginal sources as water becomes scarcer will increase the energy requirement for sourcing and treatment (GWI, 2009).

Another potential source of finance would be improving the rate of collection of water bills. In Africa, under-collection is valued at US$0.5 billion annually. Improving the collection rate is an obvious way of increasing water revenues without raising tariffs. Although the better performing water utilities in Africa normally manage collection rates of 80% or more (Mehta et al., 2009), persistent non-payment, especially by public departments and agencies, leaves a big hole in the accounts of water authorities normally be expected to be self-sufficient.

International financial events since 2007 have consolidated the position of national and international public agencies as important sources of finance for water infrastructure. Though many national governments are constrained by their fiscal position, others have benefited from strong commodity prices and have used their fiscal resources to invest in infrastructure, including water (Winpenny et al., 2009). Although the share of water in total ODA has declined since the mid-1990s, the *absolute volume* of ODA has started to rise (Box 12.4). In 2007–2008, the bilateral annual aid commitments of DAC countries to water and sanitation rose to US$5.3 billion. Including concessional outflows of multilateral agencies the total ODA for water and sanitation for that period was US$7.2 billion (OECD-DAC, 2010), compared with US$5.6 billion in 2006.

In addition to ODA, which in the case of water and sanitation is evenly split between grants and soft loans (OECD-DAC, 2010), public international development banks (World Bank, regional development banks, European Investment Bank) offering loans on attractive terms have regained some market share for infrastructure finance during the recent financial crisis, taking advantage of the absence of commercial lenders (e.g. World Bank, 2010*b*). The Asian and Middle Eastern sovereign wealth funds and publicly sponsored companies are an additional and increasingly important source of money for the development of natural resources and infrastructure (ICA, 2007). The above-mentioned public sources of grant and commercial finance are likely to remain important funders of big water infrastructure projects, especially in Africa.

Nearly all the revenues generated by water accrue in local currency (with the exception of transboundary water and power sales, and the indirect benefit to foreign exchange through exports of produce).

BOX 12.4

Increasing aid to water and sanitation: 2002-2008

Aid to water and sanitation has been rising sharply since the 2002-2003 reporting period, from total average commitments of US$ 3.3 billion to US$7.2 billion in 2007-2008 (last reported period and includes DAC member countries' contributions and multilateral agencies' concessional flows). Among DAC members the largest donors for this last reported period were Japan (on average US$1.9 billion per year), Germany (US$771 million) and the USA (US$644 million). Over the period 2003–2008 aid to water and sanitation primarily targeted regions most in need of improved access to water and sanitation: sub-Saharan Africa received 29% of total aid to the sector, and South and Central Asia 18%. Poorest countries classified as 'low income' received 43% of total aid to the sector, two-thirds of which was in the form of grants. Projects for the category defined as 'large systems' are predominant and accounted for 57% of total contributions to the water and sanitation sector in 2007-08. 68% of total ODA for large systems was in the form of loans, and loans also represented 33% of the financing for river development. By contrast, donors relied almost exclusively on ODA grants (90% of total) to finance basic drinking water and sanitation. Grants were also predominant in the subsectors of water resources policy and administrative management, water resources protection and education and training.

Source: OECD (2010b).

This introduces a foreign exchange risk into loans and equity capital raised externally, even on favourable financing terms (e.g. from IFIs). Devaluation has been catastrophic for some high-profile international water concessions[8] needing to service their debt in foreign currency, and is a serious potential risk for all water projects and providers, both private and public. Hedging against devaluation risk is not a practical proposition. The more sustainable long-term solution is to generate more internal revenues from tariffs, and to rely as much as possible on local financial and capital markets, as suggested by experiences in Chile and Brazil (Jouravlev, 2004; Lentini, 2011). A number of donors and IFIs offer risk-sharing products (see Section 12.7) to encourage the growth of local currency finance for water and other infrastructure.[9]

12.7 Mitigating financial and political risks

Many local water utilities are funded with revenues from users or public budgets insufficient to exceed their day-to-day operating costs. As a result, they lack adequate cash flow to borrow money. Such utilities cannot fund long-term investments if they do not receive grant subsidies. However, many that might have adequate cash flows remain unable to finance investments through borrowings, either because lenders perceive them as an unacceptable risk or because their potential rating results in loans with short terms and high interest rates.

Financial markets have a variety of ways of dealing with the risks for lenders and investors discussed in this report. Insurance and guarantees can 'cover political, contractual, regulatory and credit risk from both multilateral and bilateral development agencies. These guarantees have a *development* motive, as opposed to export credit and investment insurance, limited to firms domiciled in the country offering the guarantee, which has a *commercial* aim. There is also a large and active *private* market offering insurance' against political, contractual and credit risks. In addition to these *external* guarantees, *sovereign* guarantees are those 'offered by *national* governments to their own citizens, companies or subsovereign bodies when they borrow or attract direct investment. Certain other instruments have a *quasi-guarantee* status, such as the 'umbrellas of comfort' which IFIs and other agencies erect over other lenders and investors through participations ('B loans') and Municipal Support Agreements' (Winpenny, 2005).[10]

Political risks affect not only lenders and investors. They also impact water utilities which depend on political decisions for setting rules and objectives, fixing tariffs or allocating subsidies. Water utilities can only finance investment through borrowings if their revenues are sufficiently predictable. Many investments are delayed by a failure – often for political reasons – to adjust tariffs to changes in economic conditions. Public subsidies that cannot be anticipated cannot form the basis for borrowing.

Guarantees work in various ways: mitigating specific risks which are the critical sticking points on a project; enhancing securities (e.g. bonds) to take them over a critical threshold of creditworthiness; improving the terms on which borrowers and project sponsors can get access to loans and investment; and giving lenders and investors exposure to previously unfamiliar markets and products (Winpenny, 2005; Matsukawa and Habeck, 2007; OECD, 2010*a*).

Guarantees for investment in water services projects have not been widely adopted, compared with other sectors. Of 124 guarantees issued since 2001 by IFIs, only four were issued for water supply and sanitation projects. This outcome is a mixture of governance and incentive factors affecting both the supply of funds from the originating agencies and the attitudes and practices of borrowers and host governments. Guarantees can mitigate specific risks, but cannot offset other negative project fundamentals often present in water services (Winpenny, 2005; Matsukawa and Habeck, 2007; OECD, 2010*a*). However, they can form a crucial feature of complex strategic infrastructure finance packages, such as the Nam Theun Hydro Project in Lao PDR. The World Bank's Multilateral Investment Guarantee Agency (MIGA) investment guarantees against political and specific regulatory risk have also proved helpful to the financing of water projects (World Bank, 2010*b*).

Pooling mechanisms are another device to reduce perceived risks. Some countries have developed national revolving funds, following the well-established model used in the United States of America. Another example is the decision taken by a group of communities in Colombia in 2010 to form a trust, which issued a US$92 million peso-denominated bond to domestic investors on the Colombian stock exchange. The deal, done under the auspices of Colombia Infrastructure Group LLC, allowed small and medium-sized municipalities access to long-dated funds at competitive rates, with the express purpose of funding local water and wastewater projects (GWI, 2010).

All potential financiers are concerned with managing the reputational risk entailed by certain types of infrastructure projects. The World Bank terms such projects 'high risk-high reward'. The typical IFI response is to develop an extensive set of processes and operational policies to ensure that high risk-high reward (HRHR) projects risks are appropriately addressed and mitigated (World Bank, 2010*b*).

As a general principle, the risk of financial default can be managed by tailoring financial terms to the risk profile and expected cash flow of the project concerned. For large and complex projects it is becoming common to blend different types of finance (commercial loans, concessionary loans, grants, equity) to achieve an acceptable overall mix. A number of international platforms now exist (e.g. the EU-Africa Infrastructure Trust Fund and the EU Neighbourhood Investment Facility) to fund major infrastructure projects on terms appropriate to borrowers' repayment ability and the specific risks in each case.

Another risk management approach is to allow the financial terms to adjust to the outcome of a project. *Convertible loans* can be converted into equity when cash flow would otherwise cause debt-servicing problems. The interest rate on some loans is indexed to the price of the good or service provided by the project, where this is outside the control of the sponsor.

Another outcome-oriented financial device is *output-based aid* (OBA), which is only released to the sponsor when a project is completed and up and running. The sponsor has the assurance that the grant will be forthcoming in due course, enabling commercial finance to be raised, but the clients (local government and international agencies) have the assurance that their funds will not be wasted. There are currently 31 projects with OBA from the World Bank in water supply and sanitation (World Bank, 2010*b*).

Among other innovative funding methods to cope with the heightened risks of water management are index insurance and weather derivatives for farmers (Winpenny, 2010). Other risk mitigation methods include options on water stored in reservoirs and 'contract options' bought by urban water authorities for the use of farmers' water rights in times of drought. All these methods provide insurance against water variability, while avoiding the heavy costs of new infrastructure.

"A precondition of adequate financing for water is a full appreciation of the social and economic purposes that it serves."

A recent review of innovative finance for water notes that commercial funding of all types has suffered from global financial turmoil. Instruments, such as guarantees have been underutilized, and the credibility of complex structured financial products has been weakened. The long-term flow of commercial, including private, finance to water depends on reforms to its governance and operation, and novel forms of finance will remain limited by this constraint. However, there is considerable scope for blending public grant and concessional funds with commercial sources, as noted in the examples above (OECD, 2010*a*).

Conclusion

Water, in its various forms, will need to attract much more finance than it currently receives if it is to overcome its current under-funding, support the future expansion of food production, supply the needs of growing populations including those in the post-2015 MDG targets, and continue performing all the other services it provides to a modern, growing economy. The new impetus to create a green economy offers opportunities, as well as challenges, for the management of water. Climate change sets its own agenda, in addition to and partially overlapping with the above, involving the mitigation of greenhouse gas (GHG) emissions and the adaptation of water infrastructure and services. Water is also central to disaster preparedness, which is likely to increase in importance for any future climate scenario.

One basic reason why water does not receive sufficient funding is that its scope is often viewed too narrowly, whereas in reality it underpins a wide range of economic sectors, all of which would be threatened by water scarcity, pollution or pressures from the other drivers described in this report. Hence, a precondition of adequate financing for water is a full appreciation of the social and economic purposes that it serves.

Even with this, however, the financial climate for water will remain challenging and will call for a pragmatic and eclectic approach to funding. This chapter outlines such an approach, involving a mixture of efficiency measures, review of standards and technological options, improved rates of collection, better cost recovery from water users, more predictable government budgetary allocations and ODA, and the intelligent use of such basic revenues to attract repayable funding sources using the array of risk-sharing devices now available.

Notes

1 A green economy is 'an economy that results in improved human well-being and reduced inequalities over the long term, while not exposing future generations to significant environmental risks and ecological scarcities' (UNEP, 2010, p. 4).

2 For more information see http://www.unep.org/GreenEconomy/Portals/93/documents/Full_GER_screen.pdf

3 Possibly modelled on the UN Millennium Assessment reports, the GEO series, or the OECD's Environmental Outlooks.

4 Control of the desert locust in Sahelian countries has been severely hampered by the decline of regional information and monitoring systems, due in part to civil unrest and armed conflict endemic in border regions in these countries.

5 Birdsall (2006) cites the Southern Africa Power Pool, the Baltic Sea clean up, the control of onchocerciasis in the Sahel, and the control of Chagas disease in Latin America.

6 Gross costs include all costs incurred by adaptation to climate change. Net costs allow for (i.e. deduct from gross) any negative costs (i.e. cost savings) that may arise from climate change. The method used in this study nets out positive and negative cost items for each country, but not across countries within a region (World Bank, 2010c: pp. 3, 54, and elsewhere).

7 For more information see http://www.climatefundsupdate.org/listing

8 Buenos Aires, the original West Manila concession, and Jakarta. The West Manila concession inherited earlier debt owed to the World Bank and Asian Development Bank.

9 For example, the US Development Credit Agency, the Agence Française de Développement, and the GUARANTCO scheme of DFID, SIDA and others.

10 A form of lending used by the European Bank for Reconstruction and Development in which loans to a subsovereign body, such as a local water utility, are made under a formal understanding that the responsible municipality will do everything in its power to enable the utility to continue servicing the debt.

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CHAPTER 13

Responses to risk and uncertainty from a water management perspective

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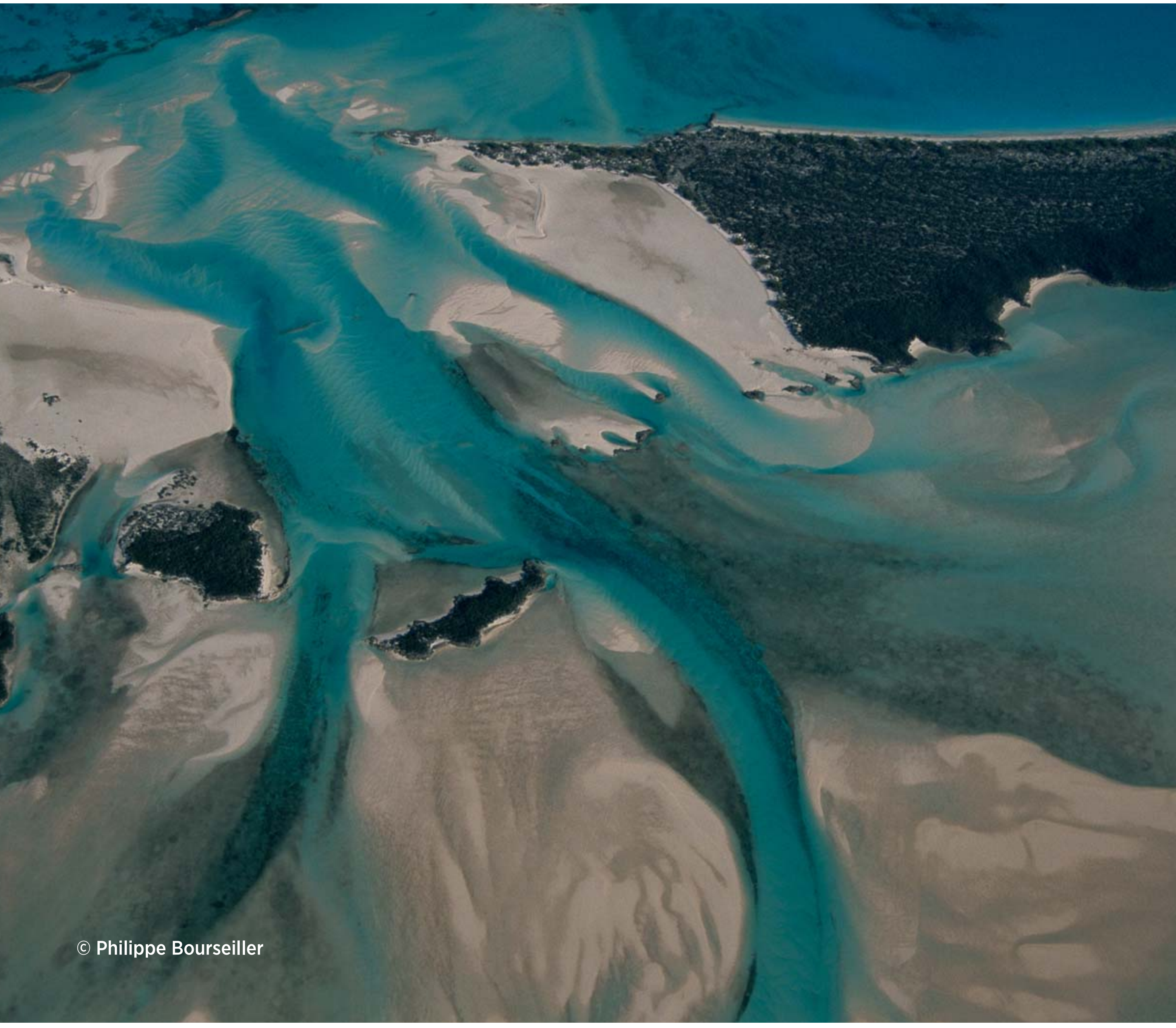

Increasing uncertainty concerning the availability and quality of water resources and their use poses unique challenges for decision-makers (Shaw and Woodward, 2010). Rapid, sometimes unforeseeable changes in external pressures and drivers are the cause of these new and increased uncertainties and associated risks (see Chapters 8 and 9). Managing these risks and taking advantage of any opportunities that arise calls for new kinds of action involving all stakeholders, many of whom have not as yet considered how their decisions and actions affect water.

Water managers employ differing approaches to address the risks and uncertainties surrounding water resources (Chapter 11), relying on the 'rules' set in place by their local and national institutions (Chapters 5 and 11). They have tools and options at their disposal to facilitate the transformation of traditional static planning and management approaches into more adaptive and flexible practices that can increase the resilience of water systems. These include informing the people who make decisions affecting water of the potential benefits and costs of altering allocations to different uses, and the trade-offs among various performance criteria that may need to be made. Although water managers play a significant part in this process, expertise is also required from the social and economic sectors (and from the ultimate beneficiaries).

Water managers operate in differing contexts: some function and adapt to circumstances where governments anticipate water scarcity and variability and adopt precautionary policy instruments; others may have to operate in a context where governments prefer to maintain the status quo in policy development despite changes affecting water resources. Despite the differing contexts, water managers need to review their risk assessment and management practices. Moreover, they need to raise awareness among broader stakeholders of the benefits of responding to uncertainty through risk management – and of the dangers of failing to do so. A shared understanding of the concepts of uncertainty and risk in the context of water resources management, and the allocation and provision of water resources to meet the many uses they need to satisfy, can serve as a basis for further analysis. Collecting and sharing data are another essential element. With these complementary tools in hand, analysis of the impacts of external forces can be broadly inclusive, involving experts from multiple disciplines. Their experiences, both positive and negative, provide options to those who now need to decide how to act. What interventions are water managers willing to make without the assurance that risk and uncertainty will in fact be reduced? Most decision-makers base their choices on some variation of an ex-ante benefit-cost analysis when it comes to water resources (Shaw and Woodward, 2008). However, it is the benefits rather than the costs that are hard to estimate and which make policy-making regarding water so uncertain. As a result, decision-makers may be able to estimate the costs that their interventions will impose, but the advantages of such interventions may remain uncertain.

This chapter illustrates some responses to dealing with uncertainties in the planning, design and operation of water supply and pollution control systems, when attempting to meet changing demands. These responses usually involve the use of various tools to identify and evaluate alternative water resources plans, policies, infrastructure designs and operating rules applicable to different regions of the developed and developing world. These responses and their outcomes illustrate both successes and difficulties in meeting desired water planning and management goals, and demonstrate the relative effectiveness of associated data collection, generation and management schemes in supporting decisions. They also illustrate how technologies have been used to address issues related to adaption to change and dealing with risks and uncertainties.

This chapter also addresses the need to make decisions under increased uncertainty resulting from abrupt changes, discontinuity and unpredictability. While some of these may pose additional risks, others may provide opportunities. Decision-makers can draw on examples of how some uncertainties and risks are being managed – successfully and unsuccessfully – including through adaptation. Finally, this chapter examines the trade-offs that governments are prepared to make in the face of risk and uncertainty. The following sections do not purport to provide an exhaustive inventory of all possible responses to risk and uncertainty implemented by water managers, but rather seek to provide illustrations of various ways in which risks and uncertainties related to water have been reduced or mitigated.

13.1 Reducing uncertainty

One of the most direct ways of reducing uncertainty is to generate new knowledge or understanding of conditions governing water availability and quality in the present and in the future. Data collection, analytical capacity and predictive ability are all required to reduce uncertainty and therefore to facilitate decision-making about allocations, uses, mobilization and treatment. While the risk to water is not reduced, it is better understood.

Given the multiplicity of factors that could potentially affect water directly and indirectly, this exercise is not as straightforward as it may seem; otherwise no country or user would ever have been surprised by a water crisis. The following section provides examples of means by which this uncertainty has been reduced, or the risks better understood.

13.1.1 Monitoring, modelling and forecasting to reduce uncertainty and understand risk

As technology evolves, tools for predicting future water availability become more refined, allowing for the consideration of multiple variables and drivers. Chapter 6 of this report elaborates on various aspects of data and information in water resources, including the challenges that confront water resources management. Regular monitoring and basic data collection serve as a basis for deriving linear trends as well as to develop more complicated models.

A multi-disciplinary approach can be useful to achieving realistic projections, since it integrates the tools and participation of ecologists, engineers, economists, hydrologists, political scientists, psychologists, and water resources managers, among others. Involving parties from these different sectors permits greater insights into how to manage water resources in the face of risk and uncertainty. Given the interconnectedness of water with other sectors, inclusion of different kinds of expertise can help provide some degree of clarity to uncertainty and risk.

It is commonly recognized that solving water resources problems 'requires the integration of technical, economic, environmental, social, and institutional aspects into a coherent analytical and management framework. Since the 1960s, computational frameworks that combine optimization and simulation tools have been used to develop and assess water resources development strategies for decades. While these prior works have produced significant advances in understanding interactions between economic objectives and physical constraints, consideration of the complexity of the systems has been relatively narrow' (Mayer and Muñoz-Hernandez, 2009, p. 1177). Box 13.1 illustrates the use of a less narrow multidisciplinary tool, which provides many benefits, but highlights the challenges that uncertainty and risk can bring, despite comprehensive analyses and modelling.

13.1.2 Adaptive planning in anticipation of fluctuating risks and uncertainties

Adaptive planning and management are sensible and pragmatic approaches that water managers can use under conditions of change, increasing uncertainty and risk. Adaptive management is often employed to decrease uncertainty and optimize decision-making, while ensuring learning from the process. Adaptive planning and management integrates project design, management, monitoring and evaluation for the purposes of testing assumptions, and learning from the outcomes. Essentially, adaptive planning is based on a 'learning by doing approach' (Kato and Ahern, 2008).

BOX 13.1

Integrated Water Resources Optimization Models (IWROMs)

Integrated water resources optimization models (IWROM) are tools that have been developed over the last decade for determining optimal water allocations among competing sectors. IWROMs use optimization methodologies to find the most efficient water allocation strategies from an economic viewpoint, usually while considering the environmental impact of these strategies. Models of economic benefits associated with the consumption of water in various use sectors are derived and assembled in an objective function, including economic benefits associated with the environment. Hydrological simulation models provide values of state variables, which are needed to evaluate the economic benefit models, constrain the physical system, and, in some newer cases, provide state variables for evaluating environmental impacts. The simultaneous evaluation and consideration of allocations across various water sectors, economic benefit models, models of the biophysical system, and economic and environmental impacts constitute the basis of the integrated nature of IWROMs.

IWROMs seek to find water-allocation strategies that occur in an efficient way, by maximizing the economic benefits or by minimizing the costs or number of people affected by such strategies. In addition, IWROMs allow for testing of different future scenarios that could be experienced by a particular region. These scenarios include potential changes in climate, land cover and land use, improvement of infrastructure, population, and consumer preferences. By testing these scenarios, the stakeholders can anticipate the potential environmental or economic consequences related to specific decisions taken in the basin.

IWROMs are particularly useful for regions where competition for water is intense, valuation of water for the various use sectors can be estimated, economic and operational impacts of proposed management alternatives are of interest, and data are available to calibrate supporting models. IWROMs allow for the simulation of and assessment of water resources economic policies and investments in water infrastructure. IWROMs seek to depict coupled human–nature relationships and mimic the impact of driving forces and feedbacks from the environment so they can effectively analyse sustainability. IWROMs support basin-wide decision-making since appropriate biophysical models can reflect spatial heterogeneity in [hydroclimatic] conditions and water uses among different subregions.

[IWROM applications use hydrological simulators and] mathematical methods to solve optimization problems. It is suggested that IWROMs (a) seek to model coupled human–nature relationships and mimic the impact of water resources management strategies on the environment at the basin scale; (b) allow for the simulation and assessment of economic policies and strategies on water resources management; (c) can support basin-wide decision-making; and (d) are particularly useful for water-scarce regions.

[However, as efficient as IWROM may be, uncertainty poses several challenges to its application. For instance,] specifying sources of error and making accurate estimates of uncertainty in the outputs of IWROMs can be very difficult (Jakeman and Letcher, 2003). Sources of error in individual models may be difficult to identify and quantify, as is the case in the hydrological simulators and economic models used in IWROMs, where the lack of data for model calibration and validation is commonly an issue. Because of the breadth and complexity of issues involved in an integrated model, 'the level of uncertainty goes beyond unexplained randomness to a situation where many things are fundamentally unknowable in a traditional, objective, scientific sense' (Rothman and Robinson, 1997, cited in Jakemen, and Letcher, 2003). In addition, it is often that case that the propagation of errors through the IWROM is poorly understood, due to the complexity of feedbacks within the integrated system. Appropriate processes for validating IWROMs have yet to be fully developed; however, in a few cases, researchers have at least attempted to calibrate IWROMs to historical water demands (Cai and Wang, 2006; Draper et al., 2003).

All of these issues indicate that applications of IWROMs must be sensitive to the effects of uncertainty on the model results and more sophisticated approaches may be needed to quantify uncertainty. Furthermore, models tend to be used to investigate scenarios that can be very different from the situation in which the model was calibrated and tested. The validity of the IWROM or component models outside these circumstances may be questionable and the level of uncertainty in predictions may be difficult to quantify. Rational procedures for choosing planning periods in IWROM applications, which have ranged from 10 to 30 years, have not been established. The value of long-term applications of IWROMs is questionable, given the considerable uncertainty in many modelling aspects, especially the prices and costs include in the economics models. Scenario analysis, [as referred to in Chapter 8,] may be used to explore model uncertainties in these cases. However, formulating realistic scenarios may be difficult, considering that temporal trends in many of the phenomena quantified in these scenarios (such as climate, land use and population change) may be non-stationary.

Source: Reproduced from Mayer and Muñoz-Hernandez (2009, pp. 1176, 1187–8, 1191–2).

As Kato and Ahern (2008) note, the key concepts and principles of adaptive management in the literature and application review are: '(1) conceiving management actions as experiments; (2) conducting several plans/experiments at once for fast learning; (3) monitoring being the key; and (4) learning by doing.' Adaptive management is thus a social process as well as a scientific one, where stakeholders play a key role in informing the learning process (Chapters 5 and 11).

Adaptive management embeds uncertainty as a fundamental principle in the management approach. Adaptive management strategies allow decision-makers to alter the direction of projects and programmes due to emerging information gained by the learning-by-doing approach.

There are some challenges to using adaptive management. These include forgoing short-term advantages for long-term objectives, as well as the demands that are placed on stakeholder participation. Stakeholders are expected to maintain their level of engagement over the long-term, which may not be possible (Lockwood et al., 2006). There are circumstances under which adaptive management is seriously compromised and does not work, for example, when monitoring is not fully completed, when monitoring data is not analysed or accurately assessed, or when the results are inconclusive (Moore and McCarthy, 2010). Moreover, if the process does not have participation of key stakeholders, adaptive management will not yield optimal results.

Because decisions made outside the water domain also affect the resource and its use, many perceive an integrated adaptive approach as the most appropriate basis for managing water systems sustainably. Adaptive water management is an extension of integrated water management in that it is designed to address future uncertainties in a comprehensive fashion. The inclusion of feedback mechanisms in response to changing conditions and increased knowledge is critical for revising and updating integrated water management efforts; adaptive modelling considers both human and ecosystem water needs and takes feedback mechanisms into account.

For example, studies carried out in the Netherlands to support long-term water management planning, in the light of uncertainty regarding climate change impacts, focused on three aspects of water management: flood defence, drinking water supply and protection of Rotterdam Harbour. The key point of interest was whether, and for how long, current water management strategies would continue to be effective under different climate change scenarios. To this end, the studies employed the concept of 'adaptation tipping points' (see Chapter 8, Section 8.1.5). If the magnitude of change was such that a current management strategy could no longer meet its objectives, the study assumed that the tipping point had been reached and that an alternative adaptive strategy was needed. Therefore this approach combined both modelling and forecasting elements with those of adaptive management, providing an iterative process to consider the validity of management approaches. Triggers, or tipping points, are an effective way of evaluating various management milestones, and if agreed upon and recognized by stakeholders outside the realm of water management, can provide an effective rallying point for making decisions about water, while including all users.

"Adaptive planning and management integrates project design, management, monitoring and evaluation for the purposes of testing assumptions, and learning from the outcomes."

A similar concept has been applied in many instances under the broader heading of disaster risk management (DRM), where emergency triggers can be considered as the equivalent of 'adaptation tipping points'. Indeed, DRM provides a framework for rapid adaptive management based on a set of agreed management changes that occur under specific

BOX 13.2

Adaptive management: Adaptation tipping points in current Dutch flood management

To ensure safety against flooding, safety levels for all flood defences in the Netherlands must be able to withstand a storm event with a certain frequency, as well as maintain the morphological boundary conditions for dune growth along the coast. Optimization of both sand mining and nourishment must be able to meet ecological requirements. Thus, even in the most extreme sea level-rise-scenario, the existing policy of protecting the sandy coast is not likely to encounter an adaptation tipping point (ATP). Potential ATPs might arise on the social and political level, however. For example, the social acceptability of living behind giant dykes might decline, and increasing spatial claims of ever-larger dykes might provoke changes in governance arrangements.

The Maeslant Barrier is essential to protecting Rotterdam Harbour and its tidal river area against flooding. The dykes in this region are designed to withstand water levels that have a probability of occurrence between 1/10,000 and 1/4000 annually. To meet this safety level, the barrier closes if the water level at the outlet of the waterway exceeds 3 m or exceeds 2.90 m upstream at Dordrecht. The return period of such an event is approximately 10 years. Rising sea level implies that the barrier will close more often. However, closing the Maeslant Barrier hinders navigation to and from Rotterdam Harbour. According to the Rotterdam Port Authority a maximum closing frequency of once per year is acceptable. This is considered an ATP. The closing frequency of the Maeslant Barrier depends on the sea water level, the duration of storm events, and the discharge of the rivers. Another ATP is the maximum sea level rise the barrier has been designed for, which is 50 cm.

The tidal river area is crucial for freshwater provision (drinking water and agriculture) in the southwest of the Netherlands. Rising sea level and reduced river discharge during dry summers lead to extra salinization of groundwater and surface water. An ATP for this sector would occur if sea level rise in combination with lower river drainage were to result in an inability to maintain salt concentrations at a level low enough to maintain key functions. Water allocation has been established in a series of water agreements between national and regional administrations. To meet the requirements, the maximum allowable chloride concentration in the inland water system is 250 mg per L. Under current conditions, the freshwater inlet needs to be closed once between every five and 10 years to protect against saltwater intrusion. However, the frequency and duration of necessary closure of freshwater inlets rapidly increases with rising sea levels and decreasing river discharges.

Source: Kwadijk et al. (2010).

conditions. This is not a new approach, but one that functions with varying degrees of effectiveness depending on the context. The successful operation of a rapid and flexible DRM system requires a number of basic functions such as availability of data, the technical means for monitoring, and rapid response systems, which are not always functional in all countries. In this case, however, uncertainty is not reduced, but mitigated by the adoption of pre-established management responses triggered by specific events. As highlighted in the 2011 Global Assessment Report published by UNISDR, however, DRM frameworks can help to address other 'non-emergency' needs as well, such as planning for hydro-electricity, agriculture and other water needs. DRM need not be a parallel exercise to other risk and uncertainty reduction initiatives in the water domain. 'However, the examples [Box 13.3] indicate that ecosystem-based disaster risk management is an increasingly attractive option for addressing problems as varied as river-basin and urban flooding, drought and wildfires.' (UNISDR, 2011, p. 127)

Another tool used in dealing with disasters from a planning and risk management perspective is catastrophe modelling, as described in Box 13.4.

13.1.3 Proactive management

Another way of dealing with risk and uncertainty in water management is to anticipate the future conditions of a number of key drivers, chief among them demand for water. Analysis of the determinants of water demand can provide useful avenues for reducing some water uncertainties, and many countries have adopted demand management as a mechanism for water allocation, management, conservation and planning. Water demand has been on the rise for a number of years, particularly in urban areas, and projections show continuing growth in demand (Butler and Memon, 2006). The chief influencing factors are the drivers referred to in Chapter 2, including population growth, migration, lifestyle and economic changes, demographic shifts and the impacts of climate change. All of these drivers create conditions of uncertainty and challenges to meet the increasing demand. Demand-side management, as highlighted in Chapter 5, addresses consumptive demand so as to postpone or avoid the need to develop new resources (Butler and Menon, 2006), thereby limiting the uncertainties and risks emerging from unbridled water demand and potential shortages in the future.

BOX 13.3

Risk-addressed examples

River basin flooding

In Hubei Province, China, a wetland restoration programme reconnected lakes to the Yangtze River and rehabilitated 448 km^2 of wetlands with a capacity to store up to 285 million m^3 of floodwater. The local government subsequently reconnected a further eight lakes covering 350 km^2. Sluice gates at the lakes have been re-opened seasonally, and illegal aquaculture facilities have been removed or modified. The local administration has designated lake and marshland areas as nature reserves. In addition to contributing to flood prevention, restored lakes and floodplains have enhanced biodiversity, increased income from fisheries by 20–30% and improved water quality to potable levels (WWF, 2008).

In 2005, the Government of the United Kingdom launched the programme Making Space for Water, an innovative strategy that uses ecosystems instead of costly engineered structures for flood and coastal erosion risk management along river banks and coastlines. The programme, triggered by severe floods in 1998, 2000 and 2005, consists of 25 nationwide pilot projects at the catchment and shoreline scales, and involves collaborative partnerships between local governments and communities. Since April 2003, the Government has invested between US$4.4 and US$7.2 billion as of March 2011. One such project covered an area of approximately 140 km^2 of the Laver and Skell Rivers west of Ripon in North Yorkshire. Activities included planting trees as shelterbelts, establishing vegetative buffer strips along riverbanks, the creation of woodland, fencing off existing woodland from livestock, hedge planting, and creation of retention ponds and wetlands for increased flood storage capacity. These activities reduced surface flow during floods by trapping, retaining or slowing down overland flow and provided other benefits such as protection of wildlife habitats and improved water quality (PEDRR, 2010).

Urban flooding

Urban development replaces vegetated ground that provides a wide range of services, including rainwater storage and filtration, evaporative cooling and shading, and greenhouse gas reduction, with asphalt and concrete, which do not. Although the functions of green spaces in urban areas are easily overlooked, local governments have started reinstating 'green infrastructure' (Gill et al., 2007) as a viable component of urban water management and as a means of combating urban heat. In New York, for example, untreated storm water and sewage regularly flood the streets because the ageing sewerage system is no longer adequate. After heavy rains, overflowing water flows directly into rivers and streams instead of reaching water treatment plants. The US Environmental Protection Agency has estimated that around US$300 billion would need to be invested over the next 20 years to upgrade sewerage infrastructure across the country. In New York City, alone, it is estimated that traditional pipe and tank improvements would cost US$6.8 billion (New York City, 2009). Instead, New York City will invest US$5.3 billion in green infrastructure on roofs, streets and sidewalks. This promises multiple benefits. The new green spaces will absorb more rainwater and reduce the burden on the city's sewage system, air quality is likely to improve, and water and energy costs may fall.

Drought

Two different but almost simultaneous agro-ecological restoration processes that started 30 years ago in southern Niger and the central plateau of Burkina Faso have increased water availability, restored soil fertility and improved agricultural yields in degraded drylands. With very little external support, local farmers experimented with low-cost adaptations of traditional agricultural and agroforestry techniques to solve local problems. Three decades later, hundreds of thousands of farmers have replicated, adapted and benefited from these techniques, transforming the once barren landscape. In Burkina Faso, more than 200,000 ha of dryland have been rehabilitated, producing an additional 80,000 tonnes of food per year. In Niger, more than 200 million on-farm trees have been regenerated, providing 500,000 additional tonnes of food per year, as well as many other goods and services. In addition, women have particularly benefited from improved supply of water, wood fuel and other tree products (Reij et al., 2010).

Aboriginal people in northern Australia have a long history of using fire to manage habitats and food resources. Due to changes in settlement patterns and marginalization, traditional fire management was fragmented over vast areas, leading to an increase in destructive fires in fire-prone savannahs. Traditional fire management practices, such as early dry-season prescribed burning, have been revived and combined with modern knowledge, such as using satellite technology to locate fires.
Aboriginal fire rangers have considerably reduced large-scale fires through fire management across 28,000 km^2 of western Arnhem Land, with subsequent reductions in greenhouse gas emissions of more than 100,000 tonnes of CO_2-equivalent per year. The Darwin Liquefied Natural Gas plant compensates aboriginal communities with approximately AU$1 million (US$1 million) per year for offsetting carbon, generating important income in disadvantaged communities. Additional fire management benefits include protection of biodiversity and indigenous culture (PEDRR, 2010).

Source: Reproduced from UNISDR (2011, p. 129).

For example, demand management is a key element in the United Kingdom government's sustainable development policy. The government has implemented this policy by enacting the Green Deal. This encourages efficient use of water in homes and business through delivering joint energy and water savings; promoting investment by water and sewerage companies of UK£22 billion by 2015; and developing new assets and innovative technologies (EA, 2011).

A water-demand programme was also implemented in South Africa. The objective of the Greater Hermanus Water Conservation Programme was to conserve the natural water resource against increased demand using a comprehensive long-term water conservation programme. It was based on a series of principles including: water-loss management to deal with unaccounted for water such as unmetered and illegal connections and leakage; retro-fit programmes to supply existing homes and buildings with water-saving devices (owners were fined if devices were not installed after a certain period of time); school audits to find out what activities consume the most water and why; assurance of supply with a fixed amount levied every month, forming the basis of the authority's pledge to provide water to every house as long as it is available; escalating block-rate tariffs; water-wise gardening methods; the use of 'grey' water for food production; and the creation of water regulations and building by-laws (WMO, 2001).

BOX 13.4

Catastrophe modelling as a tool for understanding and calculating risk in the insurance industry

Catastrophe modelling is a tool developed by private sector companies, working in the insurance sector, as a 'mechanism to integrate and synthesize all the relevant science, data, engineering knowledge and even behaviour of claimants and insurers in the aftermath of a catastrophe' (Shah, 2008, p. 5). Today, it has evolved into a risk identification and prevention tool. The approach, which combines mapping risk and measuring hazard, came together in a definitive form in the late 1980s.

> While it is generally agreed that a probabilistic approach is the most appropriate method to model the complexity inherent in catastrophes, probabilistic modelling itself is multifaceted. It requires simulating thousands of representative, or stochastic, catastrophic events in time and space; compiling detailed databases of building inventories; estimating physical damage to various types of structures and their contents; translating physical damage to monetary loss; and, finally, summing over entire portfolios of buildings. ... Catastrophe models require substantial amounts of data for model construction and validation. (Grossi and TeHennepe, 2008, p. 7)

Originally intended as tools reserved for the calculation and projections of financial losses within the insurance industry, catastrophe models are increasingly being used by governments and municipalities as a risk management and prevention tool. Catastrophe modelling provides an integrative model whereby eventual losses can be quantified and trade-offs analysed towards the integration of adaptive measures in planning.

Source: The Review (2008).

Although managing water demand is one way of limiting risks associated with increasingly uncertain levels of consumption and potential future shortages, it also poses some unforeseen challenges. For example, water demand management calls for a good understanding of who is making the demands on water and how much they are demanding. This requires considerable knowledge and information, without which policies may target suboptimal sectors or users, thereby having a negligible impact on future risks. Improvements in resource monitoring and databases of water use information are therefore required. In turn, these valuable new resources can be used to produce improved forecasts of water demand, so that planning procedures are able to guarantee water supplies to more people – especially the poorest members of society who are traditionally hardest hit by water shortages (WMO, 2001).

Another challenge is that as policies address the need for demand management, new issues arise regarding recognition of the environment as a user. Traditionally, the environment has been neglected, but with the National Water Act in South Africa, for example, comes the concept of an 'environmental reserve', designed to protect the ecosystems that underpin water resources. The Act also states that it is the duty of the Government 'to assess the needs of the environmental reserve and to make sure that this amount of water, of an appropriate quality, is set aside' (DWA, 1997). This approach has immense impacts on water resources management in South Africa, but raises the difficult question of how much environmental reserve a river or water resource requires (WMO, 2001).

An additional challenge that demand management raises, and which limits its ability to minimize risk and uncertainty, is the necessary participation of various stakeholders at different levels. It requires community buy-in, commitment, monitoring and adherence to the paradigm of demand management. It also requires transparent flows of information, for example, to address unknown users, such as illegal water connections, leakages and other losses, that are not attributable, but which bring an additional layer of uncertainty and risk to the equation.

However, integrating a participatory dimension to demand management can `democratize' the process of determining and prioritizing risks and uncertainties (Baroang et al., 2010). Including various stakeholders can also balance their multiple needs, and inform policy formulations and management responses that respond to them, as illustrated by the example in Box 13.5.

BOX 13.5

Farmer managed groundwater systems in Andhra Pradesh, India

The Andhra Pradesh Farmers Ground Water Management System (APFAMGS) is a community-based project involving over 28,000 men and women farmers in 638 villages across 7 drought-prone districts. The project focuses on developing the capacity of groundwater users in managing their resource in a commonly sustainable way. The project adopted a demand side approach to groundwater management, wherein farmers are made to understand how their groundwater system functions so that they can make informed decisions about their water use. The core concept or belief of APFAMGS is that sustainable management of groundwater is feasible only if users understand its occurrence, cycle and limited availability, and they accept that groundwater conservation through collective decisions is ultimately a safeguard of their own interest. Thus, the burden of control of extraction is transferred to individuals in communities who know the ‘why and how’ and act based on sound information, rather than being enforced by government imposed rules and regulations.

The project emphasizes sustainable use of shared water resources, while promoting capacity development of groundwater users. The demand-side approach to the project allows farmers to manage their water resources, understand how groundwater systems operate, and make informed choices regarding their water use. The underlying premise of APFAMGS is that sustainable management of groundwater is feasible only if users understand its occurrence, cycle and limited availability, as well collective decision-making, which will govern the resource. Extraction is thus practiced by individuals in communities who know the ‘why and how’ of their practices, and base their decisions on sound, collective information, rather than being subject to government laws and regulations.

The project does not offer any financial incentives or subsidies. Rather, the assumption of the project is that access to scientific data and knowledge will enable farmers to make appropriate choices and decisions regarding the use of groundwater resources.

The objective is to equip farmers with the necessary knowledge, data and skills to manage the groundwater resources available to them in a sustainable manner, mainly through controlling demand. The project also facilitates access to information about irrigation water-saving techniques, improved agricultural practices and ways to regulate on-farm demand for water. Unlike most other attempts at centrally based groundwater management, APFAMGS does not seek an agreement from communities to reduce their groundwater use – farmers are free to make crop planting decisions and extract groundwater as they desire, and there is no collective agreement by communities on self-regulation of groundwater use. The project therefore relies solely on the impact of groundwater education to influence individual decisions of thousands of farmers regarding crop selection and irrigated areas in the post-monsoon season.

The project has been successful in that the groundwater supplies have provided a sustainable source of water for the farmers. Even though it is possible, no farmer or group of farmers has depleted the groundwater supply. A number of factors have contributed to the success of this project, two of which are the timely availability of current data on the status of groundwater availability and projected demand, enabling informed planting decisions – a key input to the farmer’s risk management paradigm, and reductions in groundwater overdraft resulting from multiple individual risk-management decisions of farmers. As a result, authoritative leadership is unnecessary for enforcement (GWP, 2008).

Source: APFAMGS (2008); World Bank (2010).

13.2 Reducing exposure to threat and minimizing risks

If the examples in the preceding boxes illustrate various approaches used in attempting to reduce uncertainty, other tools exist that allow for the reduction of risks. The key approach is to analyse the various factors of risks, including the probability of certain events or triggers, and to reduce or eliminate exposure to such risks for water resources and for communities who depend on them.

13.2.1 Investments in infrastructure

New, updated and expanded water resources infrastructure can reduce the risks associated with climate change, hydrological variability and their impacts on water resources and systems. Adding new infrastructure can potentially take advantage of new technology. For example, while in some regions reservoirs are being removed to reduce the risks to ecosystems, including fish, the development of increased water storage capacity, particularly to reduce water scarcity risks and manage floods in other regions, appears inevitable in the light of highly likely water shortages.

There are various types of infrastructure that states can invest in to address the challenge of risk and uncertainty. One response option for reducing the variability and uncertainties of natural stream and river flows is to construct reservoirs designed and operated to redistribute water over time and space in ways that better meet human and environmental needs in comparison to the natural flow regime. Reservoirs are controversial. Many are being planned and built in water scarce or energy deficient areas of the world, while in other areas they are being removed in an effort to restore ecosystems. Dams and reservoirs are essentially risk-avoidance tools, based on a knowledge of current conditions and variability.

For example, the International Water Management Institute (IWMI) predicts that climate change will have dire consequences for feeding an ever-expanding global population, especially in areas of Africa and Asia where millions of farmers rely solely on rainwater for their crops. In Asia, 66% of cropland is rainfed, while 94% of farmland in sub-Saharan Africa relies on rain alone, according to IWMI. These are the regions where water storage infrastructure is least developed and where nearly 500 million people are at risk of food shortages.

IWMI suggests that the solution is to fund a diversity of water storage projects, from small-scale rainwater tanks and larger-scale dams to systems that artificially recharge groundwater aquifers, to improve the soil so it can hold more water. Stored water in times of drought can lead to increased food security. 'Just as modern consumers diversify their financial holdings to reduce risk, smallholder farmers need a wide array of 'water accounts' to provide a buffer against climate change impacts' (McCartney and Smakhtin, 2010; quotation from IWMI, 2010, p. 1).

Small-scale storage projects have delivered some positive results when planned with the participation of both politicians and farmers. For example, small collection basins have boosted maize yields in times of rain or drought in Zimbabwe. In India's Rajasthan State, 10,000 water harvesting structures that help to recharge groundwater now irrigate 34,600 acres (14,000 ha) and feed 70,000 people (Eichenseher, 2010). In India, where there is expected to be a 50% gap between water demand and supply by 2030, decision-makers are starting to fund storage projects because they recognize the long-term economic benefits of a secure supply (IWMI, 2009).

Investing in infrastructure for future risk reduction can also have its trade-offs and unforeseen consequences. For instance, in the case of the Savannah River in the United States of America, the construction of three dams and reservoir systems just 50 years ago has negatively altered the natural flow patterns that support the wildlife, natural communities of the river, its estuary and floodpath. This is of particular concern given that the lower Savannah River watershed supports extremely high species diversity, including the greatest number of native fish species (108) of any river draining into the Atlantic (Hickey and Warner, 2005).
An infrastructure approach thus has to examine all aspects of risk and functions of water. Only at that point can water managers make decisions with the most advantageous trade-off – with the best possible picture of uncertainty and risk.

The example of the Savannah River reveals that positive outcomes ensue when the iterative, consultative approach is used. In 2002, the US Army Corps of Engineers (USACE) and The Nature Conservancy (TNC) launched the Sustainable Rivers Project to restore the river (Hickey and Warner, 2005). The main strategy was to define flow regimes that restored downstream ecosystems processes and services, while continuing to meet other human uses of water such as power generation (provisioning service), recreation (cultural) and flood control (regulatory). The project began in April 2003 with an orientation meeting with more than 50 leading scientists from the Georgia and South Carolina state governments, federal agencies, academic institutions and other non-governmental organizations to define the process. Historical data was used to define the seasonal water flows needed to support the freshwater, floodplain and estuary. It was difficult to get the participants in the flow recommendations workshops to suggest any quantitative flow targets. However, once reminded them that their recommendations were a first approximation that would be refined over time through an adaptive management process, the targets were established. Working with many scientists and agencies can be onerous and time-consuming, but most of these constraints were avoided by giving the most time-consuming activities to one research team. This report became the accepted basic knowledge for other scientists in the project, making it easier to reach consensus during the flow recommendations workshop.

Eventually a flow prescription plan for executing a series of seasonal controlled releases was designed and tested. For five days, USACE released the first

BOX 13.6

Mangrove restoration in Viet Nam

Viet Nam has lost over 80% of its mangroves since the 1950s. The two major causes are the use of defoliating agents during the Vietnam War and the rapid expansion of the aquaculture industry during the early 1980s. Mangrove restoration and rehabilitation has been ongoing since 1991 as a policy response to this loss. The underlying goal of restoration and rehabilitation is to mitigate the impact of sea level rise and coastal storms. Yet with respect to the restoration of mangrove forests, stakeholders have a diverse set of interests and diverging priorities and preferences.

Viet Nam is extremely vulnerable to climate change. Climate change scenarios from different institutions indicate vastly different trends for precipitation, with some projecting decreases and some projecting increases, thus creating climatic uncertainties. Projections also suggest that there will be an increase in frequency and intensity of tropical storms, and that sea level will rise.

Clearly there is a high degree of uncertainty in these climate change projections. However, even in the absence of the changes suggested by these projections, the country's agriculture and water resources are increasingly vulnerable to impacts from saline intrusion and flood inundation. Climate change could result in seawater intrusion into groundwater, which provides valuable freshwater supplies for many coastal areas. Rapid conversion and drainage of wetlands, combined with changes in water flows connected to upstream infrastructure developments, may increase the incidence of floods and droughts. Storm surges can also severely damage coastal infrastructure and the dykes and structures that support the rapidly developing aquaculture industry. Tidal mixing associated with floods and storm surges leads to saline concentrations that have a widespread impact on terrestrial and aquatic ecosystem goods and services, in particular native species and species with high economic value.

In contrast to stand-alone measures such as dykes, mangrove restoration and rehabilitation has been promoted as a 'low/no regret measure'. It can be applied as a precautionary approach to climate change adaptation and foster 'win–win' situations by addressing present multi-sectoral vulnerabilities and future risks. In northern Viet Nam the focus of mangrove restoration and rehabilitation is disaster risk mitigation, and thus its protective function is prioritized. Most of the forests in this region are classified as 'protection forests', owned and managed by the government. In the South, mangrove restoration and rehabilitation has in many cases been promoted as a development action to meet multiple objectives. 'Planted production forests' can be privately owned, with the owner having 'all right to use of forestland including development of combined agriculture-fishery-forestry model'. This regional differentiation in function or purpose is perhaps not surprising given that northern Viet Nam lies in the typhoon belt and is thus most exposed to structural damage from storm surges.

The implementation of mangrove restoration and rehabilitation, nested within a no/low-regret action planning process, is more likely than any single objective approach and stand-alone measures to secure a greater set of benefits across stakeholder groups, even in a future characterized by uncertainty (Mangrove Action Project, 2008).

Source: APFAMGS (2008); World Bank (2010).

controlled flood of 450 m^3 per second (cms) of water from the Thurmond Dam, a sizable increase from the existing daily release of 130 cm. Several controlled floods have been conducted from March 2004 to the present time. These controlled releases mimic pre-existing flow conditions before the dams were built. There have been numerous ecological impacts that have been evaluated by various projects – most notably the ability to monitor changes. These include: assessing impacts of controlled floods on the salinity of the estuary, examining the possibility of regenerative benefits to floodplain forest, following the movement of the shortnose sturgeon, and tracking floodplain invertebrates and fish. Such monitoring provides great insights to stakeholders and yields greater information on possibilities of wildlife preservation.

BOX 13.7

Constructed wetlands for wastewater treatment in Bayawan City, Philippines

The ability of wetlands to filter and transform nutrients and other constituents has resulted in the construction and use of artificial wetlands to treat wastewater and acid mine drainage (Hammer, 1989, 1992; Wieder, 1989). Such a wetland was constructed in Bayawan City – the first of its kind in the Philippines. It was designed to protect coastal waters from pollution from domestic wastewater, protect the health of local residents through improved housing with safe sanitation and wastewater treatment facilities, and to demonstrate the use of constructed wetland technology as a pilot for other communities in the Philippines.

The project took place in the south-west of Negros Island, covering a total land of 70,000 ha with a population of about 113,000. The project was located in a peri-urban area of Bayawan, which has been used to resettle families that lived along the coast in informal settlements, and had no access to safe water supply and sanitation facilities. Records from the City Health Office showed a high incidence of morbidity and mortality arising from water-borne diseases in these informal settlements.

Both the village and the constructed wetland are close to the seashore and during the rainy season groundwater rises to ground level. The project involved creating cells built of concrete and concrete blocks with a drainage system positioned at the bottom of each cell. These cells were covered by a separation layer and then a filter layer. The plants used in the filter are a species of locally available reed called ‘tambok’ (*Phragmites karka*). The reeds also act as an odour barrier during the filling process.

The wastewater distribution system is composed of four concrete header tanks and a system of perforated high-density polythene (HDPE) pipes. The system is manually operated comprising the switching on and off of the pump and the emptying of the header tanks into the distribution system. The header tanks are filled two to three times a day. Since coming into operation, the system has been continuously improved. The header tanks were covered to minimize odour during the filling process, and the collection sumps between the two wetland cells and after the second cell were covered to reduce algae growth. In addition, a large storage tank was built for the treated wastewater.

The local water service provider regularly analyses the influent and effluent of the constructed wetland. This analysis includes TDS, pH, BOD, ammonia, nitrate and phosphate, as well as the microbiological parameters *E. coli*). The analysis of the treated wastewater showed very good pollutant removal efficiency (97% removal of BOD).

The treated wastewater was initially used in construction, for concrete production, which reduced construction costs. It is now also used for an organic cut flower and vegetable farming project introduced in the region. Only a basic microbiological analysis on the effluent from the constructed wetlands was conducted. However, since November 2008, more frequent and accurate monitoring has been conducted to analyse for faecal coliforms. The effluent has almost ideal concentrations of nitrate and phosphate to be used for ‘fertigation’ (fertilizer plus irrigation) for the vegetable and cut flower project. The more advanced analysis of total coliform, however, showed that the pathogen concentrations remain too high for unrestricted irrigation, but demonstrated that the total coliforms concentration in the treated effluent is still lower than in virtually all the rivers of Negros Oriental (approximately 10,000 – < 100,000 CFU per 100 mL in rivers). The investment in this constructed wetland infrastructure consequently provides water resources for various economic activities, which would otherwise be compromised, thereby reducing uncertainty (Lipkow and von Münch, 2009).

Source: APFAMGS (2008); World Bank (2010).

13.2.2 Environmental engineering

The natural environment can also be considered as 'infrastructure', as it supplies many of the same services as man-made infrastructure (see Section 8.3). Wetlands, for example, can reduce peak flood flows and assimilate many organic wastes in the same manner as wastewater treatment plants. Humans often ignore ecosystem water needs in allocating water resources, thereby risking the sustainability of life-supporting ecosystem services. Increased research and monitoring regarding ecosystem water requirements will help planners and managers use the natural environment as a component of water resources infrastructure. Infrastructure planning, particularly investing in ecosystems, can also take a no-regrets approach by anticipating greater variability, and planning for sustainability.

Although the uncertainties around natural disasters may be addressed by investing in physical infrastructures, examples exist where strengthening natural ecosystems can mitigate some of the challenges posed by natural variability. The following responses to flood damage reduction illustrate this and demonstrate that strengthened ecosystems can create greater support mechanisms in the face of weather-induced uncertainties and risk. Natural ecosystems are also options for flood damage reduction, as discussed in Section 8.3.

Stakeholders other than the states can carry out investments in the environment. As the following example of India and Brazil demonstrates, community-based management can lead to successful investment in and management of environment resources:

BOX 13.8

Community-based watershed management in India and Brazil

Examples of community-based watershed management systems in countries such as India and Brazil provide evidence for the value of involving women's groups in maintaining and protecting their water sources. In semi-arid areas of Gujarat, India, the Self Employed Women's Association (SEWA) created its Women, Water and Work campaign in 1995 to sustain and protect traditional water sources through water harvesting, watershed management, and repair and maintenance of pipelines and equipment. SEWA's collective action approach for women combines the presence of a strong grassroots institution and the establishment of a technical cadre of women. SEWA's membership has increased greatly due to the success of the water campaign. Women have benefited in terms of increased income, reduced drudgery, improvements in the livelihoods of their families, reduced migration of both women and men, and increased participation in SEWA's other programmes. SEWA is a powerful non-governmental organization (NGO) with the capacity to negotiate in the water management area, previously occupied by men only (Panda, 2007).

In the community of São João D'Aliança in central Brazil, the local Union of Rural Workers in collaboration with University of Brasília (UnB) designed a community water project to stop pollution of the das Brancas River and to rehabilitate original vegetation along the riverbanks. In the women-led initiative, called the 'Water Women' project, each group of women adapted environmentally friendly practices to their daily activities. Community education taught local people not to dump their sewage into the river, and how to plant native species of trees along the riverbanks. As a result, there is a visible absence of waste in the river, a considerable growth of new vegetation of native species on the riverbanks and decreased soil erosion. Women's political participation was strengthened, and public perceptions regarding their leadership capabilities were changed (Souza, 2006).

13.2.3 Mondi Wetlands Programme, South Africa

Water is South Africa's scarcest natural resource, and 55% of South Africa's wetlands to date have been lost due to irresponsible agriculture and forestry, urban development, pollution, dam-building, erosion and fire. Moreover, the majority of South Africans do not have access to drinking water and therefore rely on streams, rivers, marshes and other types of wetlands to supply them with enough water to satisfy their needs. If the current supply and demand rates continue, South Africa's water resources will be fully utilised by 2025 (MWP, n.d.).

Based in Centurion (Gauteng) and Howick (KwaZulu-Natal) in South Africa, the Mondi Wetlands Programme (MWP) is a joint programme of South Africa's two largest NGO conservation organizations, WWF-South Africa and the Wildlife and Environment Society of South Africa (WESSA), together with two corporate sponsors, the Mazda Wildlife Fund and Mondi Ltd. Established in 1991, the MWP is the most successful non-governmental wetland conservation programme in South Africa, and is recognized by its partner organizations as pioneering wetland conservation outside reserves in South Africa.

> "In an environment of uncertainty and risk, policy-makers may be inclined to make decisions that offer the highest utility, which in uncertain circumstances, may be the status quo."

In January 2001, the Mondi Wetlands Project launched a communal wetlands programme to help manage and rehabilitate communally used wetlands. The main objective of the programme has been to promote and facilitate the effective participatory management and sustainable use of wetlands in communal areas. The objective was supported by the following working activities: develop partnerships with government extension services and service providers, and build their capacity in wetland management; identify community-based wetland management problems and issues; develop an understanding of community dynamics and perceptions of wetlands; catalyse, build and support institutions that can help develop the capacity of communities to use their wetlands sustainably; and facilitate rehabilitation of degraded wetlands where feasible.

By including the participation of various stakeholders, including government departments, tribal authorities and NGOs, the programme has had many tangible successes. For example, the Mondi Wetlands Programme has initiated the rehabilitation of degraded wetlands in South Africa, on a multi-million Rand scale; assessed the condition of over 30,300 ha of wetlands and initiated rehabilitation in many of these; started wetland conservation activities in 21 core areas around South African outside declared reserves; trained more than 1,050 people from 60 organizations in wetland assessment and functioning; and promoted education regarding wetlands. Community buy-in and stakeholder participation is ensured by lengthy processes: the manager of the communal wetland programme is tasked with creating wetland awareness of wetland issues in rural tribal areas, building capacity and competence of government extension officers, lobbying decision-makers of various institutions to address wetlands conservation, facilitating the establishment of wetland governance structures, and promoting the implementation of better wetland management practices (Rosenberg and Taylor, 2005).

Wetlands play a crucial role in managing water. They perform 'water purification, storage, recharging of underground aquifers and streamflow regulation. They are of further national importance for their control of erosion, flood attenuation and biodiversity value. Presently, wetlands are one of the most threatened and under-managed habitat types in South Africa and the world today' (WWF South Africa, n.d.). However, it can be difficult to invest in wetland protection, particularly for non-state actors. Wetlands are often perceived as having little or no value compared to the other uses of land and waters (Schuijt, 2002). Part of the dilemma is that wetlands do not provide immediate and visible benefits to risk reduction. However, investments in wetlands provide safeguards against future risk and uncertainty. Africa, one of the two regions facing serious water shortages (UNEP, 2002), needs wetlands for the long-term health, safety and welfare of its many communities (Schuijt, 2002).

However, most African wetlands are under threat. Stakeholders can be a significant part of the problem. The fact is that many stakeholders of wetlands hold divergent interests. As a result, claims are laid against wetlands that do not coincide, and wetland resources are often turned over for exploitation (Schuijt, 2002). This is why the Mondi Wetlands Programme is such a notable success: it has managed to solicit stakeholder support across various social levels. In the face of future risk and uncertainty, this investment in wetlands supports the life cycles of wildlife that depend on it, provides natural filtration of water, secures water sources and moderates the effects of future droughts, floods, climate change and erosion.

Stakeholder participation, although a useful approach to manage risk and uncertainty, can also pose some challenges. There is always a risk that stakeholders will be unwilling or unable to participate in water management processes. Although the latter problem can be resolved through effective capacity-building, this requires additional resources. The willingness of stakeholder participation is more difficult to achieve, and can involve slower processes aimed at changing attitudes and values, and promoting education.

13.3 Living with risks and uncertainties: Trade-offs in water decision-making

To meet human and environmental needs for water, water managers have always dealt with the risks and uncertainties arising in part from natural variability. But new issues have emerged, particularly due to climate and land use changes and the often-conflicting pressures from other external drivers. This introduces additional uncertainties and associated risks, making it difficult to evaluate costs and the impacts that policy changes can have. Future actions can no longer be based exclusively on past conditions, particularly considering emerging global-scale phenomena such as climate change, or rapid migration flows. The increasing speed with which some of water's drivers are changing such as consumption, demographics and technology, and possible discontinuities in some of them, are exacerbating unpredictability. Decision-makers may address the uncertainties that climate change imposes in a myriad of ways; one of these ways is to convert the uncertainty into a risk scenario, in other words, to assume that risk exists and factor the probability into the management or policy approach. This, however, requires an accurate understanding of the trade-offs involved in each policy option.

Australia, as shown below, has employed the precautionary approach in the face of climate change. However, as the example displays, governments may opt for precautionary measures to avoid future risks, but policy decisions can have unforeseen outcomes, which may in fact create new uncertainties.

The Australian government developed the National Plan for Water Security to address public concerns over water resources, particularly relative to increasing droughts and fears over future shortages. The 10-point plan aims to spend US$10 billion over ten years on water resources. In efforts to exercise precautionary measures, the largest portion of funding, US$6 billion, is to be spent on engineering solutions to enhance irrigated agriculture, which has been identified as an area where water usage can be improved. The aim behind this intervention is to create water-savings, which can then underpin environmental sustainability. The Plan also sets up a buy-back process to address the issue of over-allocation of water, which has been identified as a cause for concern and a contributing factor to future water shortages.

There are, however, some unforeseen consequences to this plan. Despite investing in engineered and technological fixes, involving engineers at a greater level in managing water resources than farmers may have other implications. Engineering-based solutions may interfere with farm level decision-making, which may perhaps be less efficient than educative practices developed with farmers over the long run. Moreover, despite the affordability of the buyback system as a mechanism to address water allocation, the withdrawal of water from some irrigation uses and the exit of irrigators will leave those remaining in the industry with an unreasonable financial burden due to the less-intense use of irrigation infrastructure (Crase, 2008).

Another unforeseen consequence is that the focus on irrigation water has led to lapses in the legislation regarding groundwater. Legislative policies have restricted access to surface water with the result that groundwater demand is increasing. This leaves policy-makers playing catch up to rein in excessive surface level extraction, while monitoring and controlling groundwater use (Crase, 2008). Groundwater use could thus increase the creation of new water uncertainties and challenges.

This example is an illustration of a willing government trade-off to reduce future water uncertainty and risk. However, there is no certainty of policy outcome, as is demonstrated by the unforeseen consequences highlighted above. In an environment of uncertainty and risk, policy-makers may be inclined to make decisions that offer the highest utility, which in uncertain circumstances, may be the status quo. As some research demonstrates, decision-makers exhibit a strong status-quo bias in the face of uncertainty – a bias that becomes stronger when faced with more options (Samuelson and Zeckhauser, 1988). Faced with the increasing uncertainties regarding water, business-as-usual water management often indicates a de facto trade-off between the satisfaction of immediate needs and longer-term solutions that would involve the loss of financial or political capital in the short term.

Limited water availability, growing and evolving demands, and competition among increasingly scarce financial and physical resources create difficult trade-offs for decision-makers, who must plan effectively under considerable risk and uncertainty. Countries can take precautionary or status quo approaches towards addressing risk and uncertainty, and these reflect the trade-offs they are willing to make to address risk and uncertainty. Policy changes only occur when the costs of maintaining the status quo exceed the transaction costs of implementing change (Saleth and Dinar, 2004). In this vein, countries can view their transaction costs in different ways: some may see the deterioration of water and environmental resources as negative externalities not costly enough for current policy change, while others may view future water challenges as bearing higher costs which require current policy change for future benefit.

However, not all trade-offs need be negative. There are indeed examples of win–win situations where efforts to address risks and uncertainties in and outside the water realm have led to multiple multi-sectoral benefits, and to benefits for water in the long-term. The example below illustrates how a private sector firm, Dow Chemicals, faced with the rising costs of water as an industrial input, pollution control costs and corporate social responsibility issues, managed its own risks in a manner that was beneficial to all water users.

While this chapter has focused on the management of risks and uncertainties from within the water domain, the following chapter highlights examples of how efforts to manage other growing risks and uncertainties can also result in positive or negative impacts on water. As the web of risks and uncertainties grows more complex and as changes accelerate, it will become important to derive management approaches that help deliver multiple benefits.

BOX 13.9

Ensuring reliable access to water for industrial purposes while providing a key pollution control service

Dow is a company specialized in innovative chemical, plastic and agricultural products and services. Its Terneuzen manufacturing facilities in the Netherlands require a significant amount of freshwater. However, the local water is brackish, requiring freshwater to be transported a distance of ~100 km. Because the freshwater is utilized by both industry and municipalities, Dow needs to reduce potentially major business risks of increased scarcity and increased costs of freshwater.

The objective of the Terneuze project is to provide a long-term, cost-effective, reliable supply of water for the industrial site. Development of the 'household wastewater utilization' project began in early 2005 with implementation occurring in early 2007. Together with regional partners, the utility provider Evides and the regional Water Board, a robust integrated water management system was created. Thanks to this scheme, the Terneuzen site is now taking the local community's treated wastewater, which was previously discharged directly into the river, and reusing it twice – firstly for steam production in manufacturing plants and then again in cooling towers – before releasing it into the atmosphere as vapour.

Since 2007, the site accepts more than 9.9 million litres of municipal household wastewater every day. Dow has been able to cut its freshwater use in half by using the wastewater from the municipality and also through recycling efforts. By managing water in this manner, Dow has also reduced the amount of brackish water required.

Along with significant reductions in the amount of freshwater used by the site, an additional major environmental benefit lies in the fact that the household wastewater can be purified under lower pressure than the salt water that was used in the past. This translates into 65% less energy and 500 tons fewer chemicals to be used per year, and consequently 5,000 tons less CO_2 is discharged annually. As an additional outcome, every litre of water is used three times, instead of once.

The result is a reliable long-term water supply for the site which allows the manufacturing facilities to be cost effective. A key aspect of this project is the partnership between Dow, the water company Evides and the regional Water Board. This partnership allows water to be supplied for the same prices as Dow had paid in the past.

Source: Reproduced from WBCSD (2010).

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CHAPTER 14

Responses to risks and uncertainties from out of the water box

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As seen in the previous chapter, water managers use a number of mechanisms to help reduce the risks and uncertainties they face. Water policy responses can take various forms, from risk avoidance to anticipatory adaptive management. However, in a world where risk and uncertainties prevail in every domain of human life, responses to water challenges must come primarily as part of attempts to address (or in some cases, failure to address) other sectoral risks and uncertainties.

As noted in WWDR3, many of the problems faced within the water sector are caused by decisions made in other sectors, while many of the solutions to water problems can also be found within these sectors. Most decisions, within or outside the water world, involve some form of risk management. Anticipation of future benefits or threats are an integral part of sectoral decisions and business decisions alike. These decisions do not always take water into consideration, but often have an impact on water – and an impact on the types of decisions and reactions that water managers have to choose from.

This chapter seeks to demonstrate how the management of risks and uncertainties outside of the 'water box' can also have benefits for water management.

14.1 Reducing poverty and greening growth and economies

Water is so close to the heart of social and economic development that it is difficult to address one without addressing the other. Yet short-term plans for poverty reduction and economic development are often undertaken without a long-term analysis of potential water trade-offs, creating unsustainable development pathways.

BOX 14.1

Cuba uses organic agriculture for sustainable growth

The Cuban government responded to a food crisis in September 1993 by eliminating the majority of state farms and turning them into basic units of cooperative production. Much of the 80% of all farmland that was once held by the state was turned over to the workers and re-established as worker-owned enterprises. Although peasants did not own the land, they were allowed to rent the land indefinitely and free of charge as long as they continued to meet production quotas for their key crops.

Food crops produced in excess of these quotas could be freely sold at farmers markets, thereby providing a price incentive for farmers to effectively use new organic technologies such as biofertilizers, earthworms, compost and the integration of grazing animals. Farmers also revived traditional techniques such as intercropping and manuring in order to increase production yields.

Public policies also supported urban organic agriculture through the Programa Nacional de Agricultura Urbana (National Programme of Urban Agriculture) in 1994, which was designed to encourage urban farmers to produce diversified, healthy and fresh products. Havanans transformed their vacant lots and backyards into small farms and grazing areas for animals. This resulted in 350,000 new well-paying jobs (out of a total workforce of 5 million), 4 million tonnes of fruits and vegetables produced annually in Havana (up tenfold in a decade) and a city of 2.2 million agriculturally self-sufficient inhabitants.

While ensuring national food security under a trade embargo, Cuba's transition to organic agriculture has also had a positive impact on people's livelihoods by guaranteeing a steady income for a significant proportion of the population. Moreover, the lack of pesticides for agricultural production is likely to have a positive long-term impact on Cubans' well-being since such chemicals are often associated with various negative health implications such as certain forms of cancer.

Source: Reproduced from UNEP (2011); see also Alvarez et al. (2010).

Beyond the provision of water for basic human needs, such as food, drinking and hygiene, many development efforts have an impact on water risks and uncertainties. In most cases, more development means more water use, and more water pollution arises from higher levels of economic growth. For example, intensification of agricultural production is continuously highlighted as the primary engine for growth and poverty reduction in developing and emerging countries alike. While this is true, it has an impact on the availability of water for other uses. Choosing diverse economic growth pathways could therefore help to address risks and uncertainties related to water availability; however, very few countries have the option to do so because the trade-offs and political costs are so high and immediately felt.

Box 14.1 illustrates how one country, Cuba, has elected to maintain agriculture as an engine of poverty reduction, but has adopted policies to promote organic methods and intensify crop production per hectare, this reducing water pollution and creating improved water use efficiency, with a lesser impact on scarce water resources, thereby reducing risks of future water crises and ensuring a sustainable basis for economic development.

In some cases, green growth entails turning a development challenge – for example, lack of access to chemical fertilizer – into a sustainable development opportunity. Following this model, existing water scarcity could provide a basis for technological innovation to help countries leapfrog towards greener economies, while avoiding the common risks faced by other countries. In countries where expensive water-based sanitation systems are out of reach, especially in rural areas, for example, the dissemination of dry toilets or composting toilets can be an effective alternative, ensuring the provision of basic sanitation services without imposing an additional demand or risk on water. Countries equipped with water efficient or dry devices thereby avoid a series of risks related to water, whether disease-related, scarcity-related or financial in nature.

14.2 Responding to climate change: Adaptation and mitigation

Climate change represents one of the greatest uncertainties currently facing human society. At the global level, there may be a high degree of likelihood for certain types of impact such as temperature increases and sea level rise; however, impacts at the local level are far less predictable.

Efforts are, however, underway to develop adaptation pathways referred to as 'no-regrets' approaches. This means that they will provide benefits – developmental or environmental – regardless of the realization of a given climate scenario. In the absence of certainty regarding local impacts, it is important to plan development in a way that allows for a flexible response to various climate scenarios.

There are also various efforts ongoing throughout the world to anticipate and respond to the impacts of climate change on water, particularly since climate impacts are likely to be felt mostly by increasing uncertainties regarding water availability: changes in rainfall patterns, droughts and so on. As seen in the previous chapter, adaptive management provides a useful framework through which to make various decisions, and with the help of increasingly precise models and data, can help to somewhat reduce uncertainties.

Certain efforts to plan for climate change also provide solutions to water risks and uncertainties without specifically intending to do so. In many countries already suffering from low agricultural yields, for example, efforts to promote no-regrets climate adaptation include measures that combine diversification out of agriculture, sustainable technologies for achieving higher yields per inputs, and technology transfer for the promotion of more sustainable input use (such as land, water, fertilizers, labour). This can have multiple beneficial impacts on mitigating water risks and uncertainties, since it provides the means of producing more food, using theoretically less water. In a context where water is likely to become more scarce, investment in

BOX 14.2

Reducing Emissions from Deforestation and Forest Degradation (REDD) with water co-benefits

The UN-REDD Programme is the United Nations Collaborative initiative on Reducing Emissions from Deforestation and Forest Degradation (REDD) in developing countries. The programme takes as its basis the statement of the Intergovernmental Panel on Climate Change (IPCC) that the forestry sector, mainly through deforestation, accounts for about 17% of global greenhouse emissions, making it the second-largest source of emissions after the energy sector. The basic assumption is that 'reduced deforestation and forest degradation can play a significant role in climate change mitigation and adaptation, yield significant sustainable development benefits, and may generate a new financing stream for sustainable forest management in developing countries. If cost-efficient carbon benefits can be achieved through REDD, increases in atmospheric CO_2 concentrations could be slowed, effectively buying much needed time for countries to move to lower emissions technologies.' (FAO/UNDP/UNEP, 2008*b*, p. 1)

It is recognized that properly managed forests provide a number of non-carbon services. They conserve biodiversity, enhance 'soil and water conditions, help ensure sustained supplies of timber and non-timber forest products and help sustain or improve livelihoods and food security for local communities' (FAO/UNDP/UNEP, 2008*a*). However, there may be trade-offs between forests and water, since site-specific land uses will affect water services differently. For example, forests can sometimes reduce annual water flows, effectively creating a new water risk; however, they can also play a role in reducing sedimentation – in this case reducing risks to a hydropower plant or controlling flood risks. Careful site-specific identification of the water risks and co-benefits expected from a REDD initiative, as well as appropriate ranking of various co-benefits, could prove useful tools in devising appropriate REDD programmes to help mitigate climate change as well as water risks and uncertainties.

Ecuador provides an example of such environmental co-benefits through implementation of its REDD strategy, via the Socio Bosque Programme (an incentive-based policy to tackle deforestation). Throughout the Programme, forest landowners and indigenous communities voluntarily commit to conserving their native forests for a period of 20 years. In exchange, they receive a yearly economic incentive. Since September 2008, Socio Bosque has signed conservation agreements that cover more than 400,000 ha, benefiting more than 40,000 people. The specific identification, ranking and monitoring of co-benefits, both social and environmental (including expected water benefits), occurs through the establishment of a system of safeguards, integrated within the monitoring structure of the REDD programme. This helps to ensure that future risks posed by climate change to water provision, quantity or quality, will be reduced, generating additional adaptive benefits for targeted communities.

Source: World Bank (2011).

agricultural development for climate adaptation can also provide a response to water uncertainties.

An example of efforts creating mutually supporting benefits is the interface between forest management and water resources management (Box 14.2).

14.3 Business decisions to reduce risk and uncertainties

Most business decisions are based on an approach to risks and uncertainties. Decisions on investments and modes of production make presumptions about the future. Many decisions that are uniquely motivated by the financial bottom line can also provide effective means of reducing risks and uncertainties related to water.

These can also be encouraged by government policies such as taxation rates, or fiscal incentives for attracting investment and business in a given location, while legal frameworks also go a long way to reducing uncertainties by providing boundaries and defining incentives for the investment context. It is not rare to see tax benefits offered to companies in exchange for the job

BOX 14.3

Restoring water provision in a dry area: Italcementi

The Sitapuram limestone mine is a captive mechanized open-cast mine operated by Zuari Cement Ltd (part of the Italian Italcementi Group). It is located at Dondapadu, in Nalgonda District, in south-eastern India. The area sustains agriculture while two perennial streams flow through the existing mining lease area and eventually into Dondapadu Village. The area has a tropical climate with an average rainfall of 64 cm, and a maximum humidity of 82%. The temperature ranges from 22 to 50ºC.

The company's objective was to reach the base rock (sandstone) after removing limestone, and convert the excavated area into a lake (75–80% of the mining area) using a geo-hydraulic model for the groundwater balance, then develop a recreation site around it. The company also opted to develop a green belt around the lake to maintain the soil and help protect the flora and fauna.

The conversion of the excavated area into a lake included the creation of small ponds and larger water bodies, in addition to regular assessment of water quality and the water table. Catchment drains or garland drains were constructed and connected to pits to arrest silt and sediment flowing out of the mining area. This helped to reduce uncertainty by creating water reserves and decreased the potential pollution from the mining activities.

The quarry has been operational since 1986, and an adjacent green belt was developed in 2000. Bushes were planted on the slope of the pit to retain soil and protect the pit's walls from collapsing. The developed green belt along the boundary of the mining lease area acted as a barrier, protecting the surrounding area from the dust and noise created by mining activities. In 2007, 300 Ganuga plants were planted near the factory's residential complex. The topsoil removed from the first bench of the mines was used to make a bed above the exposed earth of the land, before plantation. Jatropha plants (for bio-diesel) are being grown on 20 acres in and around the mining lease areas. PVC pipelines were laid to provide a permanent water source to the trees from the quarry bench.

The results have been as follows:

- The creation of a large body of water, which has attracted many birds from other areas, including ducks, cranes and hornbills, and sometimes kingfishers if fish have spawned in water reservoirs. This adds to the preservation of the ecological environment. The reservoir also benefits the local communities who often face water scarcity and can use the reservoir for agricultural irrigation and fish cultivation.
- The recharging of the underlying aquifer, which has raised the water table in the surrounding area and increased vegetation.
- Monitoring and management of silt deposition, which prevents overflow of sediments from the mine area into the surroundings and consequent disturbance of local flora and fauna. Some of the mined pits may fill up over a longer period of time.
- The creation of greenery around mine premises, retention of earth due to the plantation of trees and bushes, and reduction of CO_2 levels in the atmosphere.

Source: WBCSD (n.d.).

and wealth creation they can provide in a city, leading them to establish themselves in locations where they may have impacts on water (near water bodies) or where they can more readily use water. For example (as seen in Chapter 9), governments may facilitate land acquisitions by foreign entities for food or other production, because of the wealth it generates for the country, but may be ignorant of the potential impacts these activities could have on their water resources.

The opposite is also true. Governments may choose to attract investments that provide the highest value for water units, although examples of such types of decision remain unfortunately rare. Box 14.3 illustrates how a business decision, initially motivated by profit and the need to access natural resources for production, has helped to reduce risks and uncertainties related to future water scarcity by providing an additional water reserve for communities and the environment.

Tools such as the proper pricing and valuation of water resources (including charges for water abstraction and wastewater discharges, and transferable water rights) can encourage these sorts of decisions by businesses, particularly when water is a key input in production. They can help to highlight trade-offs, costs and benefits/co-benefits that would otherwise not be apparent to business owners. In a government-led example of this, the provincial government of the Northwest Territories in Canada established a comprehensive framework for water planning that includes a vision and strategy, as well as an action plan for achieving water sustainability goals across all sectors. This also includes research into the various values of water, from market value to ecological services provided by watersheds, as well as cultural values (NWT, 2010).

Risk management is an integral part of business, and as noted by the World Economic Forum (2011), is becoming increasingly necessary as the nature of risks and uncertainties themselves evolve, imposing complex and interconnected considerations on businesses and governments alike today. Whereas industry and businesses learn to deal with uncertainties to protect

BOX 14.4

Implicit valuation reduces business and water risks

Rio Tinto Aluminium’s Weipa bauxite-mining operations in Australia have multiple sources of water, each of which has its own associated costs and additional values. The four main sources are:

- Decant water (recycled or reused water) from the tailings dam (where the materials leftover after extracting the mined material are stored. These materials often include muds, leachates, chemical residues, as well as crushed rock).
- Site rainfall runoff captured in ‘slots’ (like small wells) and other small storage sites across the mining lease.
- Shallow aquifers underlying the area.
- The deeper aquifers of the Great Artesian Basin.

Availability of the different sources can vary during the year, particularly the first two. Rio Tinto identified the level of sensitivity of the shallow aquifers and the Great Artesian Basin during normal environmental risk management processes. This has been reinforced by engagement with key stakeholders, including the Great Artesian Basin Coordinating Committee and non-governmental organizations. The latter have focused on the connectivity that can occur between the shallow aquifers and local rivers.

These processes have aided the establishment of a formal hierarchy of sources, directing the operation to source first from tailings dams, then ‘slots’, then the shallow aquifers, and finally the Great Artesian Basin aquifers.

In general, the costs associated with sourcing from tailings dams and slots are less than those arising from operating bore-fields fed by underground aquifers. However, due to the large area of the mining lease, there are situations where it could be both cheaper and more convenient to source from one of the latter.

The establishment of the sourcing hierarchy effectively places an implicit value on the natural sources of water. In the case of the Great Artesian basin, the focus is on the long-term sustainability of the resource, as it has the slowest rate of recharge. The shallow aquifers recharge very quickly due to the climate; their shallow depth, though, can be linked more closely to the river ecosystems.

Source: Reproduced from WBCSD (n.d.).

their investment, governments and communities can apply similar risk management models to protect their own livelihoods, safety and development.

Other factors are also increasingly motivating businesses to take certain types of decisions, in particular related to business or brand image, reputational risk and social responsibility. As noted in a CERES report (2010), license to operate can no longer be taken for granted, as resources become increasingly scarce, and consumers and shareholders demand greater accountability in relation to sustainability and equity standards.

Unfortunately, not all well-intentioned, reputation-based business decisions lead to positive impacts on water. In a recent study, it was noted that 'paper manufactur[ing] … plants that use wastepaper as raw material require more water per ton of paper produced to remove ink, dirt, plastic, and other contaminants from the pulp slurry. Second, reuse of water raises chemical oxygen demand levels in effluent, making wastewater harder to dispose of' (Klop and Wellington, 2008, p. 30). Using recycled material, although 'good' from a public image perspective, can have negative environmental consequences if not undertaken within a full life-cycle overhaul of production processes.

BOX 14.5

Business decision to promote reputational advantage leads to water benefits

Water efficiency has long been an environmental focus at PepsiCo. Through the third quarter of 2010, our global food and beverage businesses reduced water-use intensity by 19.5% versus 2006. And we're on track to achieve our 2015 target for company-owned facilities. Upgrading our facilities with new technologies is one important way we are reaching this goal. For example, our Frito-Lay facility in Casa Grande, Arizona has been equipped with a state-of-the-art water filtration and purification system that can recycle and reuse up to 75% of the water used in production. Similar technology is also being deployed in our Tingalpa facility in Australia, a water-stressed area. …

In 2009, PepsiCo's operations in India achieved positive water balance, enabling us to give back to society more water than we used to manufacture our products. To expand this achievement to other water-distressed areas where we have a presence, we have launched a number of projects. In 2010, for example, we began working with The Nature Conservancy to develop ways to identify areas of high water risk, so we can focus our attention and resources on achieving 'net positive water impact' in the most vulnerable areas where we operate. We have selected watersheds in China, Mexico, Europe, India and the US to pilot the development of a flexible and robust system that allows PepsiCo plants not only to characterize their water risk, but also identify locally relevant restoration initiatives that will improve water availability.

Source: Reproduced from PepsiCo (2011, p. 33).

Box 14.5 illustrates one example of a business decision driven both by the need to address access to key production input and to increase the positive image of the company brand. The PepsiCo 2010 annual report describes various efforts to reduce its environmental footprint, by increasing water-use efficiency and by working with non-governmental organizations (NGOs) (The Nature Conservancy) to implement environmental rehabilitation and conservation efforts.

14.4 Managing sectoral risks to generate benefits to water

In the absence of a comprehensive framework for managing the increasingly complex trade-offs between policy choices, one approach may be to manage sectoral risks in a way that seeks to maximize benefits of water, or that reduces the uncertainties and risks faced by water users. This can reduce the number of variables, drivers and determinants to be considered in a given policy or investment choice, yet help to create win–win situations. The following section provides examples of such win–win situations.

14.4.1 Reducing risks and costs in the transport sector

Building large infrastructure requires a certain degree of forecasting to ensure the viability of investments. Most large-scale projects for transportation now include some mechanism for reducing future uncertainties, particularly as regards climate change, as seen above, but also take into consideration other drivers such as population and consumption patterns.

Box 14.6 illustrates how one company, in an effort to lengthen the durability of its infrastructure investment and reduce maintenance costs, has undertaken measures to reduce damage risks, which have in return had positive impacts on reducing uncertainties regarding future water flows and supply in the surrounding region, with the added benefit of providing developmental and environmental assets.

14.4.2 Reducing health risks includes reducing water risks

Lifestyle choices often have unintended or misunderstood impacts on natural resources. Meat-rich diets, common in developed countries, and on the rise in rapidly emerging countries, are also having an impact on soil, land and water resources.

In a recent article, Capon and Rissel (2010) show the correlation between climate change and chronic disease, with diet as the main factor. Meat-rich diets and low rates of exercise contribute to creating heavy disease burdens and high health costs in many developed countries. There are a number of programmes already underway to promote more active lifestyles and healthier diets, such as the use of public transport. These are noted as having potential for co-benefits in terms of addressing GHG emissions, reducing pollution and promoting healthier lifestyles. They also have significant co-benefits for water, by reducing the use of water consumed as a result of meat consumption, and also by reducing the risk of water pollution from unsustainable or inefficient transport.

In another example, win–win benefits between water and health planning can be found as the world's concern over pandemics and rapidly transmissible animal and human diseases increases. Since water acts as a vector of transmission or as a determining factor in the prevalence of certain transmissible diseases, efforts

BOX 14.6

Autovias's Waterway Program decreased the need for road maintenance while helping to recharge one of Brazil's most important aquifers

Most problems on the planned road occur during the rainy season when water gathers on roads and then runs off, causing erosion and road damage. So Autovias, a company belonging to the Spanish group Obrascon Huarte Lain S.A. (OHL), has developed a project that collects water on the highways' surfaces and directs it towards the Guarani aquifer recharge zone. The company designed the program mainly to protect this vital water resource. Autovias earns no direct income from putting water into the aquifer, but the program helps decrease the need for road maintenance and prevents washouts, thus saving the company money.

Autovias has won a franchise to manage 316.5 km of highways in Brazil's São Paulo State. This involves a number of activities, including infrastructure construction, which often changes the landscape, modifying water dynamics within catchment areas. This can lead to erosion, settling, decreased groundwater infiltration, particularly in aquifer recharge capacity, and direct changes in the local hydrological cycle.

Autovias's environmental commitment to present and future generations is focused on guaranteeing the quality of the hydrological cycle, effectively using and recycling water resources, and developing public awareness of the correct use of water resources.

The Guarani aquifer, the world's largest known aquifer, covers an area of more than 1.2 million km^2 and is under all the highway the company manages. This mega-aquifer extends under Brazil, Paraguay, Uruguay and Argentina. It may contain over 40,000 km^3 of water, which is more than all the water contained in all of the Earth's rivers.

The Waterway Program consists of building rainwater containment dams along the highway grid managed by the company, particularly in the areas of public-supply springs, waterways and headwaters located within the drainage basins of the Sapucaí-Mirim, Pardo and Grande rivers.

Some 520 rainwater containment dams have been built, with an average capacity of 4,000 m^3, making possible a storage capacity of approximately 2 million m^3 of rainwater and rainwater runoff along the toll road network and adjacent areas during the rainy season. The contribution area of the basin extends to approximately 5,200 ha.

These works store rainwater flowing from the highways and adjacent areas; slow the speed of the water, allowing it to recharge the aquifer, and prevent the water table from falling and the ground from eroding and being dislodged along drainage areas.

Source: Reproduced from WBCSD (n.d).

to prevent (or prepare for) global pandemics could generate benefits for managing risks and uncertainties related to water. A World Health Organization (WHO) study revealed that the return on investment from each dollar spent on water and sanitation in developing countries would be between US$5 and US$28 (Hutton and Haller, 2004).

Box 14.7 illustrates how crowd sourcing can provide a tool for reducing risk and uncertainties in various sectors, from crises to pandemics, with side benefits for water management.

14.4.3 Rising risks and uncertainties from the energy sector

A number of international organizations highlight the water-food-energy nexus as illustrating the most difficult choices, risks and uncertainties facing policy-makers today. Examples abound of the various intended or unintended consequences of favouring one pillar over the other (e.g. food security vs. energy security). For example, the International Energy Organization (IEA) predicts that 'at least 5% of global road transport will be powered by biofuel [by 2030] – over 3.2 million barrels per day. However, producing those fuels could consume between 20–100% of the total quantity of water now used worldwide for agriculture' (WEF, 2011, p. 31) if the production processes and technology remain unchanged. Another example is shale gas extraction, which promises access to new reserves of fossil fuels, but is highly water-intensive and may pose a risk to water quality.

A key challenge will therefore be to incorporate the complex interconnections of risks into response

BOX 14.7

Crowd-sourced health information reduces risks and uncertainties for water

In the aftermath of the tsunami in Japan, in 2011, a number of initiatives began gathering information on survivors, radiation levels and rescue efforts. Ushahidi, an international crowd-sourcing platform, helped to establish a site dedicated to mapping danger zones and relocating lost family members. The site enabled anyone with a mobile phone or smartphone to post details of survivors in difficult-to-reach or unsafe areas. This information was then relayed to rescue operations. In turn, the site posted easily accessible information on the nearest emergency services stations, as well as locations of safe water supplies and food stores (Bonner, 2011). Pachube provided another site where real-time radiation readings taken by citizens, combined with official data, were uploaded onto mapping software to provide a tool to help track radiation movements. This also enabled grouped monitoring of tap water quality.

Another application, developed by Google Trends, enabled passive crowd sourcing of health information. Based on a statistical analysis of search words entered in a given location, the service was able to monitor and, in some cases, predict flu outbreaks in the United States of America and Canada with high degrees of accuracy (Google, 2011). Government authorities and water managers could use similar mechanisms to obtain real-time water availability and quality reports. In fact, a number of applications exist today whereby users can upload information on the status of water levels and quality in their area (see CreekWatch).

Berkeley students in India launched the NextDrop project to assist households to predict water availability, providing further proof that crowd sourcing in the health sector can help reduce water uncertainties, including those related to water. 'Information about local piped water deliveries was delivered over cell phones from water utility employees who call an interactive voice response system when they open valves to distribute water. These reports are used to generate real-time water availability updates and notifications 30-60 minutes in advance of water delivery. In addition, NextDrop uses crowd-sourcing to verify the accuracy of utility reports and create a feedback loop, introducing much needed visibility for engineers in the water utility.' (NextDrop, n.d.)

A similar partnership is being entered between Google and UN Habitat in Zanzibar, where partners worked together to establish citizen-based participatory monitoring techniques to support and empower communities in the management of their newly constructed water resources. A system for collection of geo-referenced data, disaggregated by gender and socio-economic group, and supported by information on the health and environmental status was developed. The partnership has also established a system of benchmarking service providers not only to improve service coverage and efficiency, but also to enhance accountability to customers (UN-Habitat, 2010).

Note: For more information on CreekWatch see http://creekwatch.researchlabs.ibm.com/

strategies that are integrated and take into account the many relevant stakeholders.

14.4.4 Win–win reduction of uncertainties through better integrated urban planning

Modelling tools can also help to reduce uncertainties when considering various drivers and policy options.

BOX 14.8

Landscape analysis helps reduce uncertainties within urban planning requirements: The case of Oregon

The development of spatially explicit landscape analyses is a principal activity in research on the relationships between human activities and changes occurring in natural systems. Using geographical information systems and related tools we produced digital and paper representations depicting the past, present, and potential future conditions of a 320 km^2 watershed in western Oregon. These tools were used to identify trends over space and time in human occupancy and natural resources. Based on a set of values and desired future conditions developed by working with citizen groups, digital representations of the alternative future landscapes were evaluated for their effects on water quality and biodiversity using hydrological and ecological effects models. The water quality evaluative model, a non-point pollutant source geographic information system model, simulated storm events based on field data to calculate pollutant loads across the five alternative futures, the present, and the past. The biodiversity evaluative model measured the change in species richness and potential habitat area for breeding species in each alternative future and in the past and compared these data to the present.

Results from the water quality model show increases in the volume of surface water runoff and total suspended solids under the development-oriented futures in catchments undergoing significantly increased residential development or having a high percentage of area in erosive soils on steep slopes. Results from the biodiversity model show that all native species have at least some habitat in all alternative futures. If land use trends in the watershed continue unchanged or become more highly developed, there will be an increased risk to abundance of extant native species. The set of species at risk in the development-oriented futures differs significantly in composition and is placed at risk at a higher rate than in the past, suggesting that the kinds of habitat changes to date differ from those envisioned in the alternative.

Source: Reproduced from Hulse et al. (2000, ©2000 by the Board of Regents of the University of Wisconsin System. Reproduced courtesy of the University of Wisconsin Press.).

Water usually features prominently in urban planning considerations, but the integration of water's various values and uses – and the risks and uncertainties affecting each of these – is rather more recent. Box 14.8 illustrates how a city has undertaken a modelling exercise in order to determine trade-offs, while considering water's various values in the community.

14.5 Mitigating risks and uncertainties

When it is not possible to minimize risks or to reduce uncertainties, it is sometimes possible to minimize the consequences through mechanisms that help share risk burden, or that mitigate the various negative consequences of a given possible outcome. Insurance is of one of the oldest such mechanisms – one that is applicable to all sectors, but that also helps to reduce the impacts of water-related risks. Sharing or redistributing the burden of risk becomes a useful mechanism where the possible consequences of a given risk are heavier for one group as compared to another (for example, the rural poor can withstand less risk than large multinational corporations).

14.5.1 Insurance as a risk minimizing mechanism

There are different ways of sharing risk burden. One such is risk spreading across space (geographic risk spreading), for example, where complementary climate patterns have been identified in different regions. In Africa, for example, a dry season in the eastern region is often associated with a wetter season in the southern region, and vice versa. This observation is linked to the ENSO phenomenon: La Niña events are associated with lower rainfall in eastern Africa and higher rainfall in southern Africa, while during El Niño the reverse pattern is often seen. This could provide a mechanism whereby risks and uncertainties related to precipitation and variability could be shared across borders.

Index-based (or parametric) insurance is also emerging as a potentially powerful tool for risk management in all sectors. This form of insurance is linked to an index or event, such as rainfall, temperature, humidity or crop yields, rather than to the amount of actual loss. Rather than addressing the amount of actual loss, this approach makes the product more attractive and more accessible to developing country clienteles, while remaining a financially viable product for insurance providers.

Box 14.9 illustrates a combination of both mechanisms, where disaster risks and uncertainties are reduced through the application of loss modelling, and where risks are redistributed geographically through pooled purchase of insurance products.

14.5.2 Treaties as a mechanisms for reducing uncertainties

Conflict among natural resource users as well as civil unrest can create pressures on water directly or indirectly. Treaties and agreements have always been mechanisms to reduce uncertainties regarding future safety, provision of services or access to resources. Water treaties or agreements regarding water allocation in shared transboundary basins are multiplying, and are often quoted as having side benefits for reducing other risks, through the establishment of trust-building mechanisms and a certain amount of predictability in stakeholder behaviours.

> "There are different ways of sharing risk burden. One such is risk spreading across space (geographic risk spreading)."

As noted by Dreischova et al. (2001), uncertainties related to water are not always fully recognized in treaty design or in the elaboration of water collaboration mechanisms. The adoption of open-ended strategies, allowing for flexible rule-making within the agreements, indicates a growing understanding of how uncertainties may affect water policy-making. Examples such as the Nile Basin Initiative and the SADC protocol on Shared Watercourse Systems provide mechanisms for managing risks, deciding on allocations and promoting the application of joint norms.

The opposite is also true: agreements and treaties signed for purposes other than water may help reduce risks and uncertainties regarding water, particularly where they provide mutual assurance of the other party's behaviour regarding natural resource use. Peace treaties could be the first mechanism where water risks (at least those that arise from human use) are reduced.

Trade agreements are often cited as having potentially negative consequences, or creating additional risks, for water. The case of the influence of free trade agreements on North American water resources constitutes one such example. Even prior to the signing of the North American Free Trade Agreement (NAFTA), there was debate as to whether or not bulk water exports from water-rich Canada could be pursued or allowed under the current regulatory framework. These fears have heightened since the adoption of NAFTA, specifically 'over whether surface and ground water in its natural state (for example, in lakes and rivers) is

BOX 14.9

The Caribbean Catastrophe Risk Insurance Facility (CCRIF)

The Caribbean Catastrophe Risk Insurance Facility (CCRIF) is based on geographic risk spreading. The CCRIF is designed to limit the impact of extreme weather events such as hurricanes, severe rainfall events and earthquakes. It provides funds when specific events occur, using parametric formulas.

With original funding from the Japanese government, CCRIF has been recapitalized through a multi-donor trust fund and maintained by membership fees paid by the 16 participating governments: Anguilla, Antigua and Barbuda, Bahamas, Barbados, Belize, Bermuda, Cayman Islands, Dominica, Grenada, Haiti, Jamaica, St. Kitts and Nevis, St. Lucia, St. Vincent and the Grenadines, Trinidad and Tobago and Turks and Caicos Islands.

Participating countries pool their country-specific risks into one, diversified insurance portfolio. As natural disaster risks in any given year are randomly distributed among the Caribbean islands, the cost of coverage for the pooled portfolio is less than the sum of premiums that the countries would have to pay individually for the same coverage. In practice, insurance premiums are reduced by almost half.

The CCRIF also uses a catastrophe modelling approach (see Chapter 13) as a means of understanding the scope of potential losses from a given risk, and therefore as a basis for pricing insurance premiums for a given territory.

Source: CCRIF (2011).

subject to NAFTA obligations. Some argue that this is the case. At the same time, however, the governments of Canada, the United States and Mexico have expressly stated that the NAFTA does not apply to water in its natural state' (Johansen, 2002, p. 19).

14.5.3 Addressing water and security concerns through multi-sectoral cooperation

Uncertainties continue to grow, whether related to climate change and resource scarcity or to economic volatility, and security concerns remain at the forefront of policy-making everywhere. In this context, water constitutes a nexus of risk where all these issues mesh, sometimes with dire consequences.

For example, the recent severe drought in East Africa, combined with ongoing conflict in Somalia and Sudan, has resulted in highly volatile conditions where violence and famine are affecting millions of people, already among the poorest in the world. Water scarcity, which has led to crop and livestock failure, has led to migration and increased competition for resources. In a situation where conflict was already rampant and weapons were already available, this has degenerated into widespread humanitarian disaster.

Creating conditions for national and regional security can also generate multiple benefits for water – and become a mechanism for dealing with future water risks and uncertainties. Much has already been said about the potential role of water cooperation in creating the conditions for peace-building across borders, namely by creating conditions of trust, joint objectives and institutions, and gradual achievements that can later translate into broader cooperation.

However the opposite is also true. Cooperation on security issues can help to address water concerns, and thereby help to create conditions for development and growth on all sides. This was recently recognized by the Organization for Security in Central Europe (OSCE), which works to establish regional cooperation frameworks among countries of Central Asia around water (surface and groundwater) management (Box 14.10).

The role of water as a potential factor of stability in war-torn countries or in countries recovering from conflict was also raised in a recent US study on Afghanistan. The study recommended that reconstruction efforts focus on creating institutions with the capacity to withstand and manage shocks and risks, as well as on the need to institute more effective water management systems, both nationally and regionally (US Senate, 2011).

BOX 14.10

Creating cooperative security-based institutions around water in Central Asia

[The OSCE has worked with Kyrgystan and Kazakhstan] in operationalizing the Agreement on Utilization of the Water Facilities of Interstate Use on the Chu and Talas Rivers. As a result, the inter-state Commission was established and the OSCE assisted in … [setting up the Commission and in performing some repair and maintenance works on] multi-purpose water facilities. This framework included mediation to reach consensus between the governments of both countries.

The OSCE also continues to support the Interstate Committee for Water Coordination (ICWC) in Central Asia … with a strong emphasis on regional co-operation, promotion of policies on water management and environmental sustainability in the region. In collaboration with the ICWC, the OSCE is working on seminars to improve the economic mechanisms related to water management and improve environmental conditions to promote co-operation in the region.

Closer interaction between the countries on the sustainable management of water and water related ecosystems is key to ensuring security and development in the region.

Source: Reproduced from OSCE (n.d.).

Conclusion

This chapter highlights how methods used to deal with risks and uncertainties in all areas of socio-economic development can positively or negatively affect water risks and uncertainties, leading to potential restrictions or an increase in the management choices available to water managers. Risk management, whether it takes the form of avoidance, reduction or mitigation, forms an integral part of all policy-making. Moreover, the complexity of the risks and uncertainties now facing society is increasing and accelerating.

Understanding the way choices impact on water can help to shape decisions that maximize benefits in all domains, creating long-term safer and more sustainable pathways for development. This also requires a clear-minded consideration of immediate, mid-term and long-term trade-offs.

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CONCLUSIONS

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This fourth edition of the *World Water Development Report* (WWDR4) report has sought to demonstrate the challenges facing water today and the increasing complexity, uncertainties and risks of tomorrow, as well as to provide avenues for responding to these challenges in the near future. Water is at the centre of the development nexus, and it has far reaching connections with every realm of human life – from the basic concerns of food, health and energy, beyond to industry, trade and the economy. Today most of these sectors face a crisis. New approaches that will provide insight into possible futures – and where responses can set the stage for future prosperity and avoid imminent catastrophe – are called for. The WWDR4 reveals that the path to solving these crises flows through water, and that solving water problems now is necessary to ensuring chances for the future of our planet and the prosperity of its people.

Sadly, not much has changed since the publication of the last WWDR in 2009. Nearly 1 billion people still do not have access to improved sources of drinking water and there are more people without access to tap water in cities today than there were at the end of the 1990s. In addition, 1.4 billion people do not have electricity in their homes, and nearly 1 billion suffer from malnutrition. Although there has been progress in achieving some of the water-related Millennium Development Goals (MDGs) in certain countries and regions, much work remains, particularly to address the special needs of the most vulnerable members of society – women and children – who bear the brunt of poverty worldwide.

Water constraints on sustainable development have created hotspots where multiple challenges mesh and result in a spiral of increasing poverty, uncertainty and instability. This happens in all regions, though the root of the challenges may differ from one region to the next. In Africa there is insufficient investment in water infrastructure and accessibility, compounded by low levels of technical and institutional capacity, over-consumption and pollution, which creates increasing constraints on North African countries' economies. In Asia, growing population and urbanization create challenges for sanitation, and disputes between users as well as high exposure to natural disasters and extreme events exacerbate existing vulnerability, risk and uncertainty. Demand is ever-increasing within some Arab and Western Asian countries that are already facing severe scarcity constraints, and in Latin America and the Caribbean, increased demand fuelled by industry, trade and growing economies is also posing a challenge alongside governance systems that are often inadequate to deal with the pressures.

From a sectoral perspective, pressures on water continue to grow and technological innovation that could provide much needed water savings is still not fully implemented. Agriculture, the largest water user, continues to be practiced in a water-inefficient manner in many countries; in developing countries, this is mostly due to a lack of capacity or political support. Higher per capita rates of energy consumption and rapidly growing energy demand are also exerting increased pressure on water, with water-intensive energy sources still being the chief part of the energy portfolio in the vast majority of countries. Great quantities of freshwater are used for urban sanitation (in cities where sanitation services are available), and demands for freshwater are increasing to meet MDG target 7c. The vast majority of wastewater is returned to the environment without treatment, generating health risks to humans and ecosystems.

As was discussed in Chapter 2, water demand is affected by a number of drivers, and while there is uncertainty about how each of these will evolve in future, it is somewhat certain that demand will increase – the big questions remaining, 'Where?' and 'By how much?' It is also somewhat certain that, all other things remaining equal, if our approaches to management remain the same, and if our development trajectories continue without some interjection that alters their course, water resources will be insufficient to meet all future demands. In fact, in many regions and countries that are facing scarcity today (Chapter 7).

As described throughout Part 2 of this report, the world is changing faster than ever and becoming more and more complex. Uncertainties about water availability and demand are increasing, as are the associated risks to development and well-being of people, societies and the environment. Unless we can generate the awareness and political will to react now, the crises we are experiencing now are likely to escalate and the odds of meeting our developmental goals will degenerate. However, the harsh realities of existing challenges outlined throughout the WWDR4 must not completely overshadow important progress achieved since WWDR3.

There is in fact increasing recognition of the link between water and other aspects of development, as exemplified by the Conference on the Water, Energy and Food Security Nexus (Bonn, November 2011). The increasing recognition can be seen as a positive development for water, especially as some of the most prominent initiatives have been led by actors from the energy and food sector, and may be viewed as increased recognition of water's importance in development. Without fully implemented (and adaptable) plans for integrated water resources management (IWRM), the 'nexus' dialogue creates a pragmatic and substantial opportunity for informed decision-making outside the 'water box'. There have been improvements in IWRM as well: preliminary findings from a 2011 UN-Water global survey to determine progress towards IWRM show a wider adoption of integrated approaches with significant impact on development and water management practices at a country level (Chapter 1). There have also been some advances made under the recent United Nations Framework Convention on Climate Change (UNFCCC) Conferences of the Parties (COPs) (Chapter 1).

Unfortunately, while many stakeholders recognize in theory that water is a fundamental aspect of achieving global goals, many such as the MDGs and other international and national processes continue to treat water concerns as separate from other issues and challenges; as do for example climate change negotiations and the UNCSD 2012 (Rio+20) process. Yet as seen in this report, failure to address water concerns creates untenable risks and uncertainties for all developmental sectors –agriculture, energy, industry, health and livelihoods – with consequences for global trade and economic growth.

Water policy-makers and resource managers are beginning to understand that long-term cross-sectoral action is required to manage the resource appropriately. Policy-makers in other sectors also need to see the benefits of rallying to this position, and they need to participate in an integrated approach to addressing multiple sector challenges, managing inter-related risks and reducing uncertainties. Governments and water managers have a responsibility to work with stakeholders and water users in making decisions about re-allocating water to the most appropriate and equitable uses for achieving national development goals. But, as water-related problems extend beyond national boundaries into all spheres of the global economy, concerned national governments – as it is the national governments that drive the international policy – have a responsibility to bring water issues forward on the international stage, so that common problems can find shared solutions.

As noted in Chapter 5, 'water is a fugitive resource', and its role in the global economy is ubiquitous but difficult to grasp. If we continue to ignore its fundamental roles and values (and to underestimate the value of its many benefits) in everyday decisions, at all levels, we will have exhausted the resource's full potential before we can adopt alternate behaviours. Water managers need to take a pro-active leadership role in educating and informing decision-makers in all sectors about the different values of water, its multiple benefits to development, and about the options that can help maximize co-benefits for human socio-economic well-being through water, thereby effectively minimizing potentially negative trade-offs. These win–win approaches abound, as can be seen from the examples in Chapters 13 and 14, and many tools exist for sectoral management – adaptive management, science-based tools, economic approaches and other policy mechanisms – to help deliver multiple benefits.

Managing water in a context of increasing and increasingly complex uncertainty requires new approaches that function across sectoral and institutional boundaries to create new coalitions among water users and providers. Such management approaches are already underway in many contexts, and many countries have experience to showcase. Transboundary watershed management, multi-disciplinary scenario-based planning, and 'green accounting' mechanisms are currently being implemented in developed as well as developing countries. However, broader improvement will require institutions to evolve into more flexible dialogue-based mechanisms that promote continuous discussion on social goals and targets and that provide support for rapid decision-making on water allocation and management in response to rapidly changing circumstances.

Successful water management will also require an explicit recognition of the economic values of water and its different benefits, as seen in Chapter 10, not only because there is a need to promote investment in water infrastructure and institutions, but because without such investment, water will become the 'ghost in the machine': the current economic model encourages investment based on growth scenarios that themselves are based on implicit assumptions regarding natural resources (chiefly water). Failure to understand the way water underpins today's global and local economy will simply lead to unrealistic predictions about sustainable growth. Recognizing the full value of water and its benefits and ensuring these benefits' equitable distribution as well as operational continuity in water services, can help mitigate future economic risks and uncertainties.

Beyond this recognition, successful water management will also require increased investment by national governments and the international community if we are to achieve national and international development goals. Successful management entails both 'hard' investment in solid and lasting infrastructure to provide water services over the long term – thus reducing risk – and 'soft' investment in capacity, science, data collection and analysis, and information about water, so that uncertainties are continuously reduced. It will also require investment in alternative and innovative forms of water service provision, including the restoration of water services provided by healthy ecosystems, which have thus far been largely ignored as entry points for water management. As seen in Chapters 5, 8 and 11, combining hard and soft approaches helps ensure higher degrees of water availability and quality in a sustainable manner.

The optimization and equitable distribution of water's benefits can only occur if economic policy, industrial planning, urban design, food, energy and trade policies become more water conscious. Trade-offs and co-benefits can become more visible thanks to emerging planning tools such as modelling, risk management, low- and no-regrets planning tools (Chapter 8). This helps reduce uncertainties related to water as well as economic uncertainties and risks, and can contribute to higher rates of economic growth. Public and private sector decision-makers can take advantage of a certain degree of public awareness regarding environmental sustainability to make decisions that would perhaps have been harder to make 20 years ago. This growing awareness indicates a willingness on the part of the public to shoulder part of the short-term risk to reduce longer-term uncertainties (social risk tolerance, Chapter 11).

As a risk-taker, the private sector is often the root of technological innovation. In this regard, the push to achieve financial profit can become a useful impetus for water sustainable futures, if harnessed appropriately, motivating technological progress towards more resource efficiency, less waste, and less pollution. Many businesses are in fact one step ahead of governments, by acting on a recognition that, in the long term, environmental sustainability or water stewardship is a prerequisite to economic sustainability. Indeed, in some cases, large private sector firms have shown an eagerness to respond to the market's appetite for corporate responsibility by investing in ecological stewardship which, in exchange, provides them with efficient and continued access to resources. However, this type of approach is not yet part of the mainstream of private sector decision-making, mainly because public policy is lagging behind, and because there remain financial obstacles to the adoption of 'greener' technologies. In contrast, some of these green approaches, while well-intentioned, can have negative consequences for water, as seen for example in Chapter 13.

Hence it is important for governments to send the right signals and provide the right incentives to private sector decision-makers about the hierarchy of trade-offs, and particularly about the place of water in business decisions. Civil society, environmental NGOs in particular, also has a role to play. Where environmental NGOs were once sometimes seen as a force of opposition, their constructive participation in collaborative decision-making today helps ensure that different concerns and interests are appropriately represented in the spectrum of decisions taken by public and private operators.

Anticipating and proactively adapting to change present unique opportunities to bring into effect beneficial change without taking overstated risks. Recognizing that past experience is no longer the best way to anticipate the future (Chapter 8), we can however anticipate outcomes based on current trends. As seen in Chapter 9, analysis of the evolution of key drivers provides useful insights into what might happen if we do nothing, or what could happen if certain decisions were made today. Seeing the world in terms of possible futures can help guide our course from the present moment. Approaches to climate change adaptation provide us with a useful model for 'no-regrets' development planning, in that the model demonstrates how – within a more or less broad window of uncertainty (or certainty) – decisions can be made that achieve maximum benefits regardless of the situation (Chapter 13). Adaptive management and no-regrets planning can be applied to all sectors provided that public and private institutions are given the flexibility (and legitimacy) for course correction when new information is made available to them. As noted earlier and in Chapters 5 and 11, an adaptive approach to IWRM has become increasingly relevant to water and non-water managers alike.

Parallel to this change in how we plan for the future, we also need to significantly invest in our knowledge and understanding of how systems work. Climate predictions, modelling and scenarios should become essential parts of the public policy tool box. Similar knowledge should evolve about water systems in and of themselves, for example groundwater (Chapter 3), or the role of ecosystems in maintaining and regulating water flows and their ability to sustainably provide a wide range of services (Chapters 4 and 8). This knowledge must become an intrinsic part of everyday decision-making, rather than the exclusive domain of water scientists, and must be communicated effectively to a broader range of direct and indirect water users. Knowledge and technological innovation can play a significant role in reducing risks and uncertainties related to water, and in moving us from a water-intensive to a water-efficient development model. As described in Chapter 6, the absence of systematic data collection in most countries impedes regular reporting on water resources and water use situation and trends. There is consequently a growing interest in and demand for better water data and accounting, which needs to be translated into improved data availability, more structured data acquisition, and better information about water – from which different users can calculate indicators of specific interest to them.

The difficulty faced today is in identifying the trade-offs made in everyday policy-making and business. Each decision made has potentially far reaching consequences on water; for example, the recent decision made by certain governments to move away from nuclear energy could have impacts on water use if it leads to water-intensive energy production (for example, oil sands extraction). Hastily made decisions in reaction to catastrophe or perceived public opinion could leave unwanted legacies if they are not considered from a cross-sectoral, long-term perspective. Identifying the 'end-point' or the most preferred outcome (or future) – expressing a vision of a desired future – can help in identifying the acceptable trade-offs in the short, medium and long terms. Yet there is much room for improvement in terms of applying this sort of visioning exercise – whether for water specifically or for development in general. While the MDGs express this sort of vision, by missing the opportunity to explicitly incorporate the cross-cutting nature of water in the development nexus, they may have taken an overly fragmented approach.

There is therefore a need to replace the old ways of sector-based decision-making with a wider framework that considers the multiple facets of the development nexus, and the multiple risks and uncertainties, costs and benefits or every decision, in light of a long-term goal. In this regard, national governments have a major contribution to make by creating stronger, more collaborative, flexible institutions, by adopting appropriate financing mechanisms to ensure the long-term viability of water services and infrastructure, and by ensuring that water considerations are mainstreamed into everyday policy decisions as well as international governance processes. Water managers have a responsibility to continuously inform these processes and to raise awareness of the centrality of water in the development nexus.

This is why the most recent economic crisis could be seen as an opportunity; it provides an occasion for reflecting on a desired collective future, and it provides a critical glimpse of the interconnections between countries, sectors and policies. Similarly, looking at the future through a water lens also provides the insight needed to make decisions that maximize benefits to people, the environment and the global economy.

The financial, food, fuel and climate crises are, even individually, serious problems, but in combination their effects could be catastrophic for global sustainability. The WWDR4 has sought to provide a new way of looking at our water reality, through the perspective of risk and uncertainty. It has sought to encourage different ways of thinking about the world's collective future by identifying tools and approaches that maximize water's benefits to different developmental sectors and by demonstrating that win–win scenarios are indeed possible. Political and business leaders as well as water managers, water users and ordinary citizens have a unique opportunity to see past immediate challenges and risks and to effect long-term change towards sustainable prosperity for all, through water.

BOXES, TABLES, FIGURES AND MAPS

BOXES

TABLES

FIGURES

MAPS

ABBREVIATIONS AND ACRONYMS

AASB	Auditing and Assurance Standards Board (Australia)
AC	Albufeira Convention (Portugal)
ACCA	Association of Chartered Certified Accountants (UK)
ACCRA	African Climate Change Resilience Alliance
ACMAD	African Centre for Meteorological Applications for Development
ACWUA	Arab Countries Water Utilities Association
ADB	The Asian Development Bank
ADPC	Asian Disaster Preparedness Centre
ADSS	advanced decision support system
AfDB	The African Development Bank
AFED	Arab Forum for Environment and Development
AI	Aridity Index
AICD	Africa Infrastructure Country Diagnostic
AMCOW	African Ministers' Council on Water
AMO	Atlantic Multidecadal Oscillation
AMOC	Atlantic Meridional Overturning Circulation
AMWC	Arab Ministerial Water Council
ANA	National Water Agency (Brazil)
AO	Arctic Oscillation
APFAMGS	Andhra Pradesh Farmers Ground Water Management System
APWF	Asia-Pacific Water Forum
ARH	Administração da Região Hidrográfica (Portugal)
ARPA	Regional Agency for Environmental Protection (Italy)
ASCE	American Society of Civil Engineers
ASEAN	Association of Southeast Asian Nations
ATP	adaptation tipping point
AWB	area water board
AWC	Arab Water Council
AWDR	African Water Development Report
AWF	African Water Facility
AWICH	African Water Information Clearing House
AWM	adaptive water management
AWM	agricultural water management
AWTF	Africa Water Task Force
BAT	best available technique
BAU	business as usual
BEP	best environmental practice
BGR	Federal Institute for Geosciences and Natural Resources (Germany)
BIRDS	Bharati Integrated Rural Development Society
BMAP	basin management action plan
BMWS	barley, maize, wheat and soybean
BOD	biological (or biochemical) oxygen demand
BOT	build-operate-transfer
BRIC(S)	countries: Brazil, Russian Federation, India, China (South Africa)
BSE	bovine spongiform encephalopathy
BSR	business for social responsibility
CAD	Central Apennines District
CADA	Central Apennines District Authority
CADC	Commission for the Application and Development of the Convention (Portugal)
CAMRE	Council of Arab Ministers Responsible for the Environment
CAP	Common Agricultural Policy (EU)
CATIE	Centro Agronómico Tropical de Investigación y Enseñanza (Costa Rica)
CBD	Convention on Biological Diversity
CBO	community-based organization
CBRN	chemical, biological, radiological and nuclear
CBSR	Canadian Business for Social Responsibility
CCAI	International Climate Change Adaptation Initiative
CCRIF	Caribbean Catastrophe Risk Insurance Facility
CD	capacity development
CDA	Chilika Development Authority (India)
CEC	California Energy Commission
CEC	Commission for Environmental Cooperation of North America
CEDARE	Center for Environment and Development for the Arab Region and Europe
CEDAW	Convention on the Elimination of All Forms of Discrimination against Women (UN)
CEH	Centre for Ecology and Hydrology (UK)
CELADE	Latin America and the Caribbean Demographic Centre
CEPMLP	Centre for Energy, Petroleum and Mineral Law and Policy (The University of Dundee)
CHRAJ	Commission for Human Rights and Administrative Justice (Ghana)
CIDA	Canadian International Development Agency
CIF	climate investment fund
CIFOR	Center for International Forestry Research
CILSS	Committee for Drought Control in the Sahel
CIS	Common Implementation Strategy (EU)
CLIMPAG	climate impact on agriculture
CNE	Comisión Nacional de Prevención de Riesgos y Atención de Emergencias (Mexico)
COD	chemical oxygen demand
CONAGUA	National Water Commission (Mexico)
CoP	community-of-practice
COP	Conference of the Parties
CPA	cleaner production assessment
CPWC	Co-operative Programme on Water and Climate (UNESCO-IHE)
CRED	Centre for Research on the Epidemiology of Disasters, Catholic University of Louvain
CRM	climate risk management
CSDRM	climate smart disaster risk management
CSE	Centre for Science and Environment (New Delhi)
CSEC	Supreme Council for Water and Climate (Morocco)
CSIRO	Commonwealth Scientific and Industrial Research Organisation (Australia)
CSR	corporate social responsibility
CVI	Climate Variability Index
CWA	Clean Water Act (USA)

CWPP	Congo Cross-Border Water Pipeline Project
CWSA	Community Water and Sanitation Agency (Ghana)
DAC	Development Assistance Committee (OECD)
DBOT	design-build-operate-transfer
DEWATS	decentralized wastewater treatment systems
DFE	design for environment
DFID	Department for International Development (UK)
DLDD	desertification, land degradation and drought
DO	dissolved oxygen
DOE	US Department of Energy
DPSEEA	driver, pressure, state, exposure, effect and action model (WHO)
DRI	Disaster Risk Index
DRM	disaster risk management
DRR	disaster risk reduction
DWA	Department of Water Affairs (South Africa)
DWAF	Department of Water Affairs and Forestry (South Africa)
EAWAG	Swiss Federal Institute for Aquatic Science and Technology
EC	European Commission
EC-IFAS	Executive Committee of the International Fund for saving the Aral Sea
ECOWAS	Economic Community Of West African States
EDC	endocrine disruptive compound
EEA	European Environment Agency
EHP	Environmental Health Project
EIA	US Energy Information Administration
EMA	environmental management accounting
EMCA	Environment Management and Coordination Act (Kenya)
EMS	environmental management system
ENERGIA	International Network on Gender and Sustainable Energy
ENSO	El Niño-Southern Oscillation
EPA	US Environmental Protection Agency
EPRI	Electric Power Research Institute (USA)
EU	European Union
EUWI	European Water Initiative
EWP	Ecosystem Workforce Program (University of Oregon)
EWRA	Egyptian Water Regulatory Agency
FAO	Food and Agriculture Organization of the United Nations
FIRM	Forum for Integrated Resource Management
FMMP	Flood Mitigation and Management Programme (of the Mekong River)
FO	farmer organization
FONAFIFO	Fondo Nacional de Financiamiento Forestal (Mexico)
FONAG	Water Protection Fund (Ecuador)
FWRA	Florida Water Resources Act
GAR	Global Assessment Report
GAR	groundwater recharge
GAS	Guaraní Aquifer System
GCC	Gulf Cooperation Council
GCF	Green Climate Fund (UNFCCC)
GCM	general circulation model
GDP	Gross Domestic Product
GEF	Global Environment Facility
GEMS	Global Environment Monitoring System
GEO	Global Environment Outlook
GHG	greenhouse gas

GIF	global impact factor
GLAAS	Global Analysis and Assessment of Sanitation and Drinking-Water (WHO/UN-Water)
GLIMS	Global Land Ice Measurements from Space
GLOF	glacial lake outburst flood
GLOWS	Global Water for Sustainability Program
GPOBA	Global Partnership on Output-Based Aid
GPWAR	General Purpose Water Accounting Report
GRACE	Gravity Recovery and Climate Experiment
GTN-H	Global Terrestrial Network for Hydrology
GVEP	Global Village Energy Partnership International
GWC	green water credit
GWCL	Ghana Water Company Limited
GWD	Groundwater Directive (EU)
GWI	Global Water Intelligence
GWP	Global Water Partnership (CACENA, Caucasus and Central Asia; SEA, Southeast Asia)
GWSP	Global Water Systems Project
HAB	harmful algal bloom
HDI	Human Development Index
HEPP	hydroelectric power plant
HIA	Health Impact Assessment
HKJ	The Hashemite Kingdom of Jordan
HRC	Human Rights Council (UN)
HRHR	high risk-high reward
HVBWSHE	Human Values-Based approach to Water, Sanitation and Hygiene promotion
IAHS	International Association of Hydrological Sciences
IBNET	International Benchmarking Network for Water and Sanitation Utilities
IBRD	International Bank for Reconstruction and Development
IBWT	Inter-Basin Water Transfer Project
ICA	Infrastructure Consortium for Africa
ICCPR	International Covenant on Civil and Political Rights
ICE	Instituto Costarricense de Electricidad (Mexico)
ICID	International Commission on Irrigation and Drainage
ICIMOD	International Centre for Integrated Mountain Development
ICLEI	International Council for Local Environmental Initiatives
ICOLD	International Commission on Large Dams
ICPAC	Climate Prediction and Applications Centre (IGAD, Africa)
ICPDR	International Commission for the Protection of the Danube River
ICRAF	World Agroforestry Centre
ICRISAT	International Crops Research Institute for the Semi-Arid Tropics
ICS	information and communication systems
ICT	information communication technology
IDB	The Inter-American Development Bank
IDRC	International Development Research Centre
IDS	Institute of Development Studies (UK)
IEA	International Energy Agency
IEG	Independent Evaluation Group (World Bank)
IFAD	International Fund for Agricultural Development
IFAS	International Fund for Saving the Aral Sea
IFI	international financing institution

IFPRI	International Food Policy Research Institute
IFRC	International Federation of Red Cross and Red Crescent Societies
IGAD	Inter-Governmental Authority on Development
IGRAC	International Groundwater Resources Assessment Centre
IGWA	Interagency Group on Water
IHA	International Hydropower Association
IIA	international investment agreement
IIED	International Institute for Environment and Development
IIRR	International Institute of Rural Reconstruction
IISD	International Institute for Sustainable Development
ILC	International Land Coalition
ILEC	International Lake Environment Committee
ILWRM	integrated land and water resources management
IMR	UN-Water Task Force on Indicators, Monitoring and Reporting
IPCC	Intergovernmental Panel on Climate Change
IRB	Indus River basin
IRI	International Research Institute for Climate and Society
IRS	indoor residual spraying
IRTCES	International Research and Training Center on Erosion and Sedimentation
IRWS	International Recommendations for Water Statistics
ISARM	Internationally Shared Aquifer Resources Management
ISET	Institute for Social and Environmental Transition
ISNAR	International Service for National Agricultural Research
ISO	International Organization for Standardization
ISPRA	Italian National Institute for Environmental Protection and Research
ISRIC	World Soil Information
ISWM	integrated stormwater management
ITCZ	Intertropical Convergence Zone
IUCN	International Union for Conservation of Nature
IUWM	integrated urban water management
IWA	International Water Association
IWLP	International Water Law Project
IWM	integrated water management
IWMI	International Water Management Institute
IWRM	integrated water resources management
IWROM	integrated water resources optimization model
JISAO	Joint Institute for the Study of the Atmosphere and Ocean
JMP	Joint Monitoring Programme for Water Supply and Sanitation (WHO/UNICEF)
JRV	The Jordan Rift Valley
KDP	World Bank-supported Kecamatan Development Project
LAC	Latin America and the Caribbean
LAS	League of Arab States
LBP	Lower Bhavani Project
LCB	Lerma Chapala River basin
LCBC	Lake Chad Basin Commission
LCRBC	Lerma Chapala River Basin Council
LDC	least developed country
LHWP	Lesotho Highlands Water Project
LLDC	land-locked developing country
LLIN	long lasting insecticide-treated mosquito net
LME	large marine ecosystem
LNMC	Libyan National Meteorological Centre
LPI	Living Planet Index
LVBWO	Lake Victoria Basin Water Office
LVWATSANI	Lake Victoria Region Water and Sanitation Initiative
MA	Millennium Ecosystem Assessment
MAP	Mediterranean Action Plan (UNEP)
MAR	managed aquifer recharge
MAWF	Ministry of Agriculture, Water and Forestry
MCED	Ministerial Conference on Environment and Development of the Asia-Pacific
MDB	Murray–Darling basin
MDBA	Murray–Darling Basin Authority
MDG	Millennium Development Goal
MDWPP	Multi-donor Water Partnership Programme
MEA	Millennium Ecosystem Assessment
MEA	multilateral environmental agreement
MEDAWARE	European Commission Euro-Mediterranean Partnership
MIGA	Multilateral Investment Guarantee Agency (World Bank)
MINAET	Ministry of Environment, Energy and Telecommunications (Mexico)
MPM	Marseille Provence Métropole Urban Community
MRB	Mara River basin
MRC	Mekong River Commission for Sustainable Development
MRI	Mortality Risk Index
MTWM	Ministry of Transport and Water Management (Netherlands)
MWI	Ministry of Water and Irrigation (Kenya)
MWP	Mondi Wetlands Programme (South Africa)
MWRWH	Ministry of Water Resources, Works and Housing (Ghana)
NADMO	National Disaster Management Organization (Ghana)
NAFTA	North American Free Trade Agreement
NAO	North Atlantic Oscillation
NAPA	National Adaptation Plan (or Programme) of Action
NAS	National Academy of Sciences
NCAR	National Centre for Atmospheric Research (USA)
NCASI	National Council for Air and Stream Improvement (USA)
NCMH	National Commission on Macroeconomics and Health (India)
NDMA	National Disaster Management Authority (China)
NDMP	National Disaster Management Plan (Ghana)
NEPAD	New Partnership for Africa's Development
NETL	National Energy Technology Laboratory
NFUS	National Farmers Union (Scotland)
NGO	non-governmental organization
NMHS	national meteorological and hydrological service
NOAA	National Oceanic and Atmospheric Administration (USA)
NRC	National Research Council (USA)
NRW	non-revenue water

NWC	National Water Commission (Australia)
NWC	National Water Council (Portugal)
NWI	National Water Initiative (Australia)
NWL	national water law
NWM	Indian National Water Mission
NWP	Nairobi Work Programme
NWP	National Water Policy (Mexico)
NWS	National Water Strategy (Jordan)
NWSC	National Water and Sewerage Corporation (Uganda)
OAU	Organisation of African Unity (now the African Union)
OBA	output-based aid
ODA	official development assistance (or aid)
OECD	Organisation for Economic Co-operation and Development
OKACOM	Okavango River Basin Trans-boundary Management Commission
OLADE	Latin American Energy Organization
OMVS	Organization for the Development of the Senegal River
ONE	Office National de l'Electricité (Morocco)
ONEP	Office National de l'Eau Potable (Morocco)
OSCE	Organization for Security in Central Europe
OSU	Oregon State University
OTA	Optimal Territorial Area (Italy)
PAHO	Pan American Health Organization
PCaC	Programa Campesino a Campesino (Nicaragua)
PCB	polychlorinated biphenyl
PDO	Pacific Decadal Oscillation
PEDDR	Partnership for Environment and Disaster Risk Reduction
PER	public expenditure review
PES	payment for ecosystem services
PGDAC	Piano di Gestione del Distretto dell'Appennino Centrale (Italy)
PID	Provincial Irrigation Department (China)
PIDA	Provincial Irrigation and Drainage Authority (China)
PMEL	Pacific Marine Environmental Laboratory (NOAA, USA)
PNA	Pacific North American Pattern
PNRC	Le Plan National de lutte contre le Réchauffement Climatique (Morocco)
POP	persistent organic pollutant
PoU	point-of-use
PPCPs	pharmaceuticals and personal care products
PPCR	Pilot Program for Climate Resilience
PPI	Private Participation in Infrastructure data-base (World Bank)
PPP	public-private partnership
PPWSA	Phnom Penh Water Supply Authority
PRB	Population Reference Bureau
PRESA	Pro-poor Rewards for Environmental Services in Africa
PRTA	Regional Plan for Water Protection (Italy)
PSI	Pilot Study on Indicators (WWAP)
PUB	prediction of ungauged basins
PURC	Public Utilities Regulatory Commission (Ghana)
PV	solar photovoltaic
PWTOA	Private Water Tanker Owners Association (Ghana)
R&D	research and development
RAED	Arab Network for Environment and Development
RBB	river basin board
RBC	river basin council
RBDA	river basin development authority (Nigeria)
RBDC	river basin district council
RBF	results-based financing
REDD	Reducing Emissions from Deforestation and Forest Degradation initiative (UNFCCC)
RMC	regional member country
RRC	River Restoration Centre (UK)
RWSSI	Rural Water Supply and Sanitation Initiative (AfDB)
SAARC	Comprehensive Framework on Disaster Management (India)
SABEP	Companhia de Saneamento Básico do Estado de São Paulo
SACI	South African Capacity Initiative
SADC	Southern African Development Community
SADC-DMC	SADC Drought Monitoring Centre
SAFE	surgery, antibiotics, facial cleanliness and environmental improvement
SALDRU	Southern Africa Labour and Development Research Unit
SAP	strategic action plan
SAPP	South African Power Pool
SARPN	South African Regional Poverty Network
SAWAF	South Asia Water Forum
SAWUN	Water Utility Network (South Asia)
SBSTA	Subsidiary Body for Scientific and Technological Advice (UNFCCC)
SDWA	Safe Drinking Water Act (USA)
SEE	South-Eastern Europe
SEEAW	UN System of Environmental-Economic Accounting for Water
SEI	Stockholm Environmental Institute
SEM	Société des Eaux de Marseille
SENARA	Servicio Nacional de Aguas Subterráneas, Riego y Avenamiento (Mexico)
SEPA	Scottish Environment Protection Agency
SES	socio-ecological system
SEWA	Self Employed Women's Association (Gujarat, India)
SIDS	small island developing states
SISS	Superintendencia de Servicios Sanitarios (Chile)
SIWI	Stockholm International Water Institute
SIWW	Singapore International Water Week
SJRB	St Johns River basin
SJR-WMD	St Johns River Water Management District
SLM	sustainable land management
SME	small and medium enterprises
SOC	soil organic carbon
SOM	soil organic matter
SOPAC	Pacific Islands Applied Geoscience Commission
SPI	Standardized Precipitation Index
SST	sea surface temperature
SSWM	sustainable sanitation and water management
SWA	Sanitation and Water for All global initiative
SWAP	sector-wide approach to planning
SWAR	surface water runoff
SWE	sectoral water efficiency
SWOT	strengths-weaknesses-opportunities-threats

TAC	Technical Advisory Committee of the Global Water Partnership
TAO	Tropical Atmosphere Ocean project
TARWR	total annual renewable water resources
TDS	total dissolved solids
TEEB	The Economics of Ecosystems and Biodiversity
TEST	transfer of environmentally sound technology
TMDL	total maximum daily load
TNC	The Nature Conservancy
TRB	Tiber River basin
TRB	Tagus River Basin
TRBA	Tiber River Basin Authority
TSG	Techknowledgy Strategic Group (USA)
TWB-MRB	Transboundary Water for Biodiversity and Human Health in the Mara River basin
UFW	unaccounted for water
UN ECOSOC	United Nations Economic and Social Council
UN	United Nations
UN-HABITAT	United Nations Human Settlements Programme
UNAG	National Union of Farmers and Ranchers (Nicaragua)
UNCCD	United Nations Convention to Combat Desertification
UNCSD	United Nations Conference on Sustainable Development
UNCTAD	United Nations Conference on Trade and Development
UNDESA	United Nations Department of Economic and Social Affairs
UNDP	United Nations Development Programme
UNDRO	United Nations Disaster Relief Organization
UNECA	United Nations Economic Commission for Africa
UNECE	United Nations Economic Commission for Europe
UNECLAC	United Nations Economic Commission for Latin America and the Caribbean
UNEP	United Nations Environment Programme
UNEP/GEMS	Global Environment Monitoring System (UNEP)
UNESCAP	United Nations Economic and Social Commission for Asia and the Pacific
UNESCO	United Nations Educational, Scientific and Cultural Organization
UNESCO-IHE	Institute for Water Education
UNESCO-IHP	International Hydrological Programme
UNESCWA	United Nations Economic and Social Commission for Western Asia
UNFCCC	United Nations Framework Convention on Climate Change
UNICEF	United Nations Children's Fund
UNIDO	United Nations Industrial Development Organization
UNISDR	United Nations International Strategy for Disaster Reduction Secretariat
UNOCHA	United Nations Office for the Coordination of Humanitarian Affairs
UNSD	United Nations Statistics Division
UNSGAB	United Nations Secretary General's Advisory Board on Water and Sanitation
UNU	United Nations University
UNU-WIDER	United Nations University World Institute for Development Economics Research
UNWAIS+	UN-Water Activity Information System
UNW-DPAC	UN-Water Decade Programme on Advocacy and Communication
UNW-DPC	UN-Water Decade Programme on Capacity Development
UPA	urban and peri-urban agriculture
USACE	United States Army Corps of Engineers
USAID	United States Agency for International Development
USBR	United States Bureau of Reclamation
USDA	United States Department of Agriculture
USDOE	United States Department of Energy
USEPA	National Service Center for Environmental Publications (USA)
USEPA	United States Environmental Protection Agency
VBD	vector-borne diseases
WACF	Water Accounting Conceptual Framework
WAJ	Water Authority of Jordan
WAPDA	Water and Power Development Authority (China)
WAPP	West African Power Pool
WASH	water, sanitation and hygiene
WaterSHED	Water, Sanitation, and Hygiene Enterprise Development
WBCSD	World Business Council on Sustainable Development
WCD	World Commission on Dams
WDM	water demand management
WEC	World Energy Council
WEF	Water Environment Federation
WEF	World Economic Forum
WESSA	Wildlife and Environment Society of South Africa
WFD	Water Framework Directive (EU)
WFP	United Nations World Food Programme
WFP	Water Financing Program (ADB)
WFPF	Water Financing Partnership Facility
WHA	World Health Assembly
WHO	World Health Organization
WHYCOS	World Hydrological Cycle Observing System (WMO)
WIN	Water Integrity Network
WMO	World Meteorological Organization
WRC	Water Resources Commission (Ghana)
WRI	World Resources Institute
WRMA	Water Resources Management Authority (Kenya)
WSS	water supply and sanitation
WSSCC	Water Supply and Sanitation Collaborative Council
WSSD	World Summit on Sustainable Development
WTP	willingness to pay
WUA	water users association
WWAP	World Water Assessment Programme
WWC	World Water Council
WWDR	World Water Development Report
WWF	World Water Forum
WWF	World Wide Fund for Nature
WWTP	wastewater treatment plant
YRB	Yellow River basin
YRCC	Yellow River Conservancy Commission

GLOSSARY

'Anthropocene' A new geological epoch so named because humans have come to rival nature in their impact on the physics, chemistry and biology of the global environment.

ablation The removal of material from the surface of an object by vaporization, chipping or other erosive processes. Ablation constitutes a key part of glacier mass balance. The ablation zone refers to the low altitude area of a glacier or an ice sheet where there is a net loss in ice mass due to melting, sublimation, evaporation or calving.

abstraction The process of taking water from a source, either temporarily or permanently.

acid rain The precipitation of dilute solutions of strong mineral acids, formed by the mixing in the atmosphere of various industrial pollutants, primarily sulphur dioxide and nitrogen oxides, with naturally occurring oxygen and water vapour.

adaptation Any alteration in the structure, function or behaviour of an organism, an institution or a society as its external environment changes so that it becomes better able to survive, multiply and achieve its goals, as applicable, in its changing environment.

adaptation tipping point The costs, risks and impacts of climate change will increase over time to the point when they challenge the expectations of resource managers and the business community as they make decisions.

adaptive capacity The capacity of a system (e.g. ecological or human social) to adapt if the environment where the system exists is changing.

adaptive decision-making Approaches and techniques for addressing problems over time in response to changing conditions.

adaptive management A type of natural resource management where adjustments are made in response to project monitoring, new information, and changing social conditions that may indicate the need to change a course of action. The aim is to learn about the system and improve system performance over time.

adaptive planning Planning methods that consider adaption to changing and uncertain conditions over time to achieve improved performance, more effective or efficient resource use, increased benefits, reduced costs and so forth.

adaptive strategy Planning or management strategy that can change depending on changing environmental conditions or changing objectives.

adaptive water management Water management policies that can adapt to changing conditions and objectives over time.

advance market commitment A binding contract, typically offered by a government or other financial entity, used to guarantee a viable market if a product is successfully developed.

Aflaj A system of tapping underground water which is led by man-made subterranean channels to villages where it is used for irrigation and domestic purposes.

agriculture Activities related to the growing and production of animals and crops that can take place either given the natural rainfall patterns (rainfed agriculture) or with the application of additional water (irrigation), often from surface or groundwater sources.

agriculture-to-urban water transfer When water supplies that traditionally have been allocated to agriculture activities are allocated to urban areas to help meet their demands.

aquaculture Also known as aquafarming, the farming of aquatic organisms such as fish, crustaceans, molluscs and aquatic plants. Commercial fishing is the harvesting of wild fish.

AQUASTAT The global information system on water and agriculture developed by the Land and Water Division of the Food and Agriculture Organization of the United Nations (FAO).

aquifer A water body occupying pore space in the Earth or rock formations under the surface of the Earth. Fossil aquifers take thousands of years to build – and rebuild (or recharge).

arable cropping The process of growing crops on land that can be ploughed.

Arctic Oscillation (AO) Also known as Northern Annular Mode/Northern Hemisphere Annular Mode (NAM), an index of the dominant pattern of non-seasonal sea-level pressure variations north of 20° latitude, characterized by pressure anomalies of one sign in the Arctic with the opposite anomalies centred 37–45°N.

arid region Characterized by a severe lack of available water, to the extent of hindering or even preventing the growth and development of plant and animal life. There is no universal agreement on the precise boundaries between classes such as 'hyper-arid' or 'semi-arid'.

Aridity Index (AI) A numerical indicator of the degree of dryness of the climate at a given location. A number of AIs have been proposed; these indicators serve to identify, locate or delimit regions that suffer from a deficit of available water, a condition that can severely affect the effective use of the land for such activities as agriculture or stock-farming.

Atlantic Meridional Overturning Circulation (AMOC) Carries warm upper waters into far-northern latitudes and returns cold deep waters southward across the Equator. Its heat transport makes a substantial contribution to the moderate climate of maritime and continental Europe.

Atlantic Multidecadal Oscillation (AMO) Variability of the sea surface temperature in the North Atlantic Ocean.

Backcasting Reverse-forecasting technique which starts with a specific future outcome and then works backwards to identify policies and programmes that will connect to the present conditions. Forecasting is the process of predicting the future based on current trend analysis.

ballast water Fresh or salt water, sometimes containing sediments, held in tanks and cargo holds of ships to increase stability and manoeuvrability during transit. The discharge of water from ballast tanks has been responsible for the introduction of species that cause environmental and economic damage.

basin closure When supply of water falls short of commitments to fulfil demand in terms of water quality and quantity within the basin and at the river mouth, for part or all of the year, basins are said to be closing or closed. Basin closure can be an anthropogenic process.

Bayesian network A graphical model that encodes probabilistic relationships among variables of interest. It can be used to learn causal relationships, and hence predict the consequences of intervention.

behavioural decision theory Theory on how people make judgments and choices, and how the processes of decision might be improved using concepts and tools from psychology, economics, statistics and other disciplines. People's behaviour is based on their perception of what reality is, not on reality itself.

benefit transfer approach Method used to estimate economic values for ecosystem services by transferring available information from studies already completed in another location or context.

biochemical oxygen demand (BOD) The amount of oxygen needed by microorganisms digest the organic material in a unit volume of water at a given temperature and for a given time. It is an index of the degree of organic pollution in water.

biodiversity The variability among living organisms from all sources including terrestrial, marine and other aquatic ecosystems and the ecological complexes of which they are part. The totality of genes, species and ecosystems in a region.

biofuel Organic material – produced by plants, animals or microorganisms – such as sugar cane stalks, leaves or animal dung, that can be burned directly as a heat source or converted into a gaseous or liquid fuel. These fuels can be used for any purposes, but the main use is in the transportation sector.

biomass energy The energy derived from the carbon, hydrogen and oxygen in biomass. Biomass energy is derived from five distinct energy sources: garbage, wood, waste, landfill gases and alcohol fuels.

biome The complex of living communities (including humans) maintained by the climate of a region and characterized by a distinctive type of vegetation, such as tundra, tropical forest, steppe and desert.

black water Wastewater containing faeces.

blue water Natural surface water and groundwater.

bottom billion The almost one billion people who live in the 60 or so impoverished countries that have failed to progress despite international aid and support. Coined by Paul Collier in the 2007 book *Why the Poorest Countries are Failing and What Can Be Done About It.*

bottom-up approach A stakeholder-driven approach to planning and decision-making as opposed to a government top-down approach that dictates to the stakeholders what decisions will be made.

BRIC(S) countries Brazil, Russian Federation, India, China (and South Africa). The WWDR4 uses both terms (BRIC and BRICS) as BRICS is a new development and not all statistics and descriptors have been updated to include South Africa in the group.

brittleness (as a characteristic of a solution) The likelihood of failure should input variable values deviate from those expected and for which the solution was designed.

business-as-usual approach Proceeding as in the past, in the usual prescribed manner without changing any policy or plan.

capacity The ability to perform and accomplish particular tasks. Capacity-building and capacity development usually refers to educational programmes designed to give individuals the knowledge and skills needed to perform given tasks.

carbon credit A generic term for any tradable certificate or permit representing the right to emit one tonne of carbon dioxide or the mass of another greenhouse gas (GHG) with a carbon dioxide equivalent to one tonne of carbon dioxide. Carbon credits and carbon markets are a component of national and international attempts to mitigate the growth in concentrations of GHGs. Carbon trading is an application of an emissions trading approach.

carbon cycle The biogeochemical cycle by which carbon is exchanged among the biosphere, pedosphere, geosphere, hydrosphere and atmosphere of the Earth. It allows for carbon to be recycled and reused throughout the biosphere and all of its organisms.

carbon sequestration Capturing and storing carbon discharges to the atmosphere in carbon sinks (such as oceans, forests or soils) to either mitigate or defer global warming and avoid dangerous climate change.

cash crop Crop grown for sale as opposed to for consumption by those who grew them on the farm (subsistence crop).

catastrophe modelling Development and use of models that predict risks of catastrophic events.

clean energy Sources of energy that do not pollute the environment or discharge greenhouse gases into the atmosphere, such as energy derived from the sun, tides and wind. Hydropower and nuclear energy sources are also often considered clean.

clientelism Term used to describe a political system at the heart of which is an asymmetric relationship between groups of political actors described as patrons and clients.

climate change Climate change refers to any significant change in measures of climate (such as temperature, precipitation or wind) lasting for an extended period (decades or longer). Climate change can result from natural processes or human activities. Mitigation refers to measures that reduce any adverse impacts from climate change. Adaptation refers to measures that are taken to better manage systems as they change due to a changing climate. Forcing is a process that alters the energy balance of the climate system; that is, changes the relative balance between incoming solar radiation and outgoing infrared radiation from Earth.

Climate Vulnerability Index (CVI) A function dependent on climate exposure, resilience and adaptability. The CVI uses water as a focus as it is a key factor of human and ecological well-being.

climate-smart cropping Measures to conserve nutrients, water and biodiversity in ways that increase crop yields.

closed-loop production system An environmentally friendly production system in which any industrial residual output is capable of being recycled to create another product.

command-and-control approach An approach in which a regulatory body or political authority dictates a behaviour or how some goal is to be achieved. In environmental policy, this basically involves the setting of standards to protect or improve environmental quality.

conditional cash transfer (CCT) Programmes that aim to reduce poverty by making welfare programs conditional upon the receivers' actions. The government transfers the money only to persons who meet certain criteria.

conservation agriculture Practices that aim to achieve sustainable and profitable agriculture and subsequently improved livelihoods of farmers through minimal soil disturbance, permanent soil cover and crop rotations.

convertible loan Loan that entitles the lender (or the holder of loan debenture) to convert the loan to common or preferred stock (ordinary or preference shares) at a specified conversion rate and within a specified timeframe.

corporate social responsibility (CSR) A form of corporate self-regulation integrated into a business model. The goal is to embrace responsibility for the company's actions and encourage a positive impact through its activities on the environment, consumers, employees, communities, stakeholders and the public.

corruption Inducement to wrong by improper or unlawful means such as bribery.

cost–benefit–risk analysis Procedure for calculating and evaluating the benefits, costs and risks of a proposed project.

cradle-to-cradle Industrial design and operation paradigm based on the principles and an understanding of the pursuit of value, processes for product and material research and development, and for educating and training. Cradle-to-cradle principles encourage making waste into food and fuel just as nature does; they seek to create systems that are not just efficient but essentially waste free.

crop per drop The amount or value of product over volume or value of water depleted or diverted to produce it.

cross-cutting (issue) Topic of concern to several different sectors or interests that include subjects such as education, finance and budgeting, personnel management and security, trade, technology transfer, consumption and production patterns, science, capacity-building and information.

cryosphere Portions of the Earth's surface where water is in solid form, including sea ice, lake ice, river ice, snow cover, glaciers, ice caps and ice sheets, and frozen ground (which includes permafrost).

decision rules (minimax, maximin) Strategies or policies that minimize the worst that can happen (i.e. minimize the maximum adverse aspect or impact or measure of system performance) or that maximize the least beneficial aspect, impact or measure of system performance.

decision-scaling Identifying what kind of climate changes would cause problems and then turning to the climate models to estimate whether those climate changes are likely.

decision-support tool Tools such as models that inform the process of decision-making. Often these are interactive menu-driven computer-based programmes.

deforestation The removal of forests and forest cover, often for the purpose of agriculture, urban or industrial development.

delta A landform that is formed at the mouth of a river where that river flows into an ocean, sea, estuary, lake, reservoir, flat arid area or another river, from the deposition of the sediment carried by the river as the flow leaves the mouth.

demand hardening As a water user becomes more efficient in the use of water, it becomes more difficult to save increased amounts of water during a shortage or drought.

demand management measure An action that is meant to ensure greater availability of resources to meet the level of requests.

demography The study of the characteristics of human populations, such as size, growth, density, distribution and vital statistics.

desalination Removal of salt and other impurities from sea or brackish surface or groundwater.

desertification Land degradation in arid, semi-arid and dry sub-humid areas resulting from various factors, including climatic variations and human activities.

disaster risk management (DRM) Measures taken to reduce the risks of human suffering and economic losses caused by natural and technological disasters.

disaster risk reduction (DRR) The practice of reducing disaster risks through systematic efforts to analyse and reduce the causal factors of disasters.

discounting Determining the value of some amount of money in an earlier time period taking into account the time value of money. It is the opposite of compounding, and requires the use of an interest rate applicable to the time interval being considered.

dissolved oxygen (DO) The amount or concentration of oxygen in a medium, such as water. The DO deficit from its saturation concentration is a common indicator of the degree of organic pollution in a water body.

diversification The variability or richness of types of species or organisms in ecosystems or types of investments in investment portfolios that decrease the risks of major failures in ecosystems or of large economic losses, as applicable.

driver Force or event outside the system of interest that affect its behaviour or performance directly or indirectly.

drought The naturally occurring phenomenon that exists when precipitation has been significantly below normal recorded levels, causing serious hydrological imbalances that adversely affect land resource production systems.

drought-resilient crop Crop that is able to survive and recover from extended dry periods. Drought-resistant crops typically refer to crops that have been subjected to plant breeding to improve their ability to survive in periods of extended water shortage.

drylands Arid, semi-arid and dry sub-humid areas, other than polar and subpolar regions, in which the ratio of annual precipitation to potential evapotranspiration falls within the range from 0.05 to 0.65.

dry-year option Contractual agreements that provide for voluntary and temporary drought-triggered water transfers.

durable consumption rate Rate of consumption of goods that do not quickly wear out, or more specifically, goods that yield utility over time rather than being completely consumed in one use.

early warning system Technology designed to provide advanced warning of pending hazards or other events.

eco-efficiency water infrastructure guidelines Procedures for designing water infrastructure for the delivery of competitively priced goods and services that satisfy human needs and improve quality of life, while progressively reducing ecological impacts and resource use.

eco-innovation The commercial application of knowledge to elicit direct or indirect ecological improvements.

ecological footprint The biologically productive land and water area that a person or population requires from around the world to produce the resources consumed and to absorb the wastes generated using prevailing technology.

ecosystem A dynamic complex of plant, animal and microorganism communities and their non-living environment interacting as a functional unit.

ecosystem/environmental infrastructure Infrastructure that provides ecosystem services such as water purification, flood control, recreation and climate stabilization.

ecosystem services (and goods and functions) Any aspect of ecosystem structure and function that has an economic, social or cultural value, known or unknown, to its inhabitants.

ecosystem tipping point A threshold at which a relatively small change causes a rapid change in an ecosystem. When the threshold has been passed, the ecosystem may no longer be able to return to its previous state.

effluent The discharge from a wastewater treatment plant, or water user.

El Niño-Southern Oscillation (ENSO) A quasiperiodic complex climate pattern that occurs across the tropical Pacific Ocean roughly every five years, with impacts such as floods and droughts.

energy Primary energy is an energy source found in nature that has not been subjected to any conversion or transformation process. It can be renewable or non-renewable. Secondary energy is derived from primary energy sources; for example, electricity, transformed from such primary sources as coal, oil, natural gas and wind.

energy–climate–water cycle This cycling of water is intimately linked with energy exchanges among the atmosphere, ocean, and land that determine the Earth's climate and cause much of natural climate variability.

environmental flow The core objective of river basin management. Instream or river flows and regime designed to maintain healthy aquatic ecosystems in the stream or river. Waters allocated to environmental flows are not available for withdrawals to off-stream users.

environmental management accounting (EMA) A business tool for creating internal demand in businesses for cleaner and less wasteful production processes.

environmental management system (EMS) Management of an organization's environmental programmes in a comprehensive, systematic, planned and documented manner. An EMS offers a structured way to incorporate environmental considerations into day-to-day operations.

environmental/ecosystem assessment Estimation of the adverse effects that human activities and pollutants have on an ecosystem.

estuary A bay or inlet often at the mouth of a river in which large quantities of freshwater and saltwater mix together.

eutrophication The nutrient enrichment of waters that stimulates an array of symptomatic changes, among which increased production of algae and macrophytes, deterioration of water quality and other changes are considered undesirable and interfere with water users.

evapotranspiration Water released to the atmosphere through evaporation from the ground and water surfaces and from the leaf surface of plants (transpiration).

extraction The process of locating, acquiring, removing and selling any resource.

extreme (hydrological) event Unusual hydrological conditions rarely observed, such as floods, droughts, temperatures, winds and storms.

fit-for-purpose structure A structure that is suitable and good enough to do the job it was designed to do. 'Fit-for-purpose' is one of the principles for quality assurance.

flash flood Flash floods are short-term events, occurring within six hours of the causative event (heavy rain, dam break, levee failure, rapid snowmelt or ice jam) and often within two hours of the start of high intensity rainfall.

floodplain Mostly flat land adjacent to a river, formed by the actions of the river. Floodplains are beneficial for reducing the number and severity of floods.

food security Having, at all times, both physical and economic access to sufficient food to meet dietary needs for a productive and healthy life. Food security is built on food availability, access and use.

food wastage Food wastes are the organic residues generated by the handling, storage, sale, preparation, cooking and serving of food. Food wastage is a symptom of developed countries' consumerism.

fossil fuel, hydrocarbon A broad name given to a variety of fuels found in the Earth. These fuels have the name fossil fuels because they probably formed from the remains of ancient decaying organisms.

free-riding In economics, collective bargaining, psychology and political science, free-riding refers to the behaviour of consuming a resource without paying for it, or paying less than the full cost. It is usually considered to be an economic problem only when it leads to the non-production or under-production of a public good or when it leads to the excessive use of a common property resource.

freshwater Water containing less than 1,000 milligrams per litre of dissolved solids, most often salt. It naturally occurs on the Earth's surface in ice sheets, ice caps, glaciers, bogs, ponds, lakes, rivers and streams, and underground as groundwater in aquifers and underground streams. This term specifically excludes seawater and brackish water although it does include mineral rich waters such as chalybeate springs.

glacier A large persistent body of ice that forms where the accumulation of snow exceeds its ablation (melting and sublimation) over many years, often centuries. Glacial ice is the largest reservoir of freshwater on Earth.

glacier lake outburst flood (GLOF) and outbursts of glacier-dammed lakes (jökulhlaups) As glaciers retreat due to increasing temperatures, glacial lakes start to form and rapidly fill up behind natural moraine or ice dams at the bottom or on top of these glaciers. The ice or sediment bodies that contain the lakes can breach suddenly, leading to a discharge of volumes of water and debris.

global trade in water resources Long-distance transfers of water in direct or indirect (virtual) form, where virtual water is the volume of water that has been used to produce a commodity and that is thus virtually embedded in it.

global warming The rising average temperature of Earth's atmosphere and oceans and its projected continuation.

globalization The increasingly global relationships of culture, people and economic activity.

governance Decisions that grant power, or verify performance. Governance is either a part of management or leadership processes or a separate process. These processes and systems are typically administered by a government. Water governance is the set of formal and informal processes through which decisions related to water management are made.

green economy An economy that results in improved human well-being and social equity while significantly reducing environmental risks and ecological scarcities. Its most distinguishing feature from prior economic regimes is direct valuation of natural capital and ecological services as having economic value.

green infrastructure The collection of 'life support' functions provided by a network of natural ecosystems, with an emphasis on interconnectivity to support long-term sustainability. Examples include clean water and healthy soils, flood protection, as well as the more anthropocentric functions such as recreation and providing shade and shelter in and around towns and cities.

green water The precipitation on land that does not run off or recharge the groundwater but is stored in the soil or temporarily stays on top of the soil or vegetation. Eventually, this part of precipitation evaporates or transpires through plants. Green water can be made productive for crop growth (but not all green water can be taken up by crops, because there will always be evaporation from the soil and because not all periods of the year or areas are suitable for crop growth).

greenhouse gas (GHG) A gas in an atmosphere that absorbs and emits radiation within the thermal infrared range. The primary GHGs in the Earth's atmosphere are water vapour, carbon dioxide, methane, nitrous oxide, and ozone.

grey water Polluted water that results from non-sanitary uses of water (e.g. dishwashing, showers).

Gross Domestic Product (GDP) The market value of all final goods and services produced within a country in a given period. GDP per capita is often considered an indicator of a country's standard of living. It is not to be confused with Gross National Product (GNP), which allocates production based on ownership.

groundwater Aquifer storage changes depending on the water withdrawn (abstracted) and added (recharge) over time. Aquifer storage can act as a buffer, permitting withdrawals during periods of low recharge, as long as the deficit is reduced during periods of relatively high recharge.

hard infrastructure, hard engineering approach Large physical networks necessary for the functioning of a modern industrial nation.

health impact assessment (HIA) A means of assessing the health impacts of policies, plans and projects in diverse economic sectors using quantitative, qualitative and participatory techniques.

household water security The reliable availability of safe water in the home for all domestic purposes. The term has both a quantity and a quality component.

Human Development Index (HDI) A tool developed by the United Nations to measure, track and compare countries' levels of social and economic development based on four criteria: life expectancy at birth, mean years of schooling, expected years of schooling, and gross national income per capita.

human well-being A state of health, happiness and prosperity; of being with others, where human needs are met, where one can act meaningfully to pursue one's goals, and where one enjoys a satisfactory quality of life.

hydroelectricity Electricity generated from a hydropower plant that typically uses water from a storage reservoir to drive turbines that generate the electricity.

hydro-geological dataset Databases containing values of hydrological and geological parameters and variables.

hydrographic network The sum total of water bodies and streams on land (rivers, lakes, swamps and water reservoirs).

hydrological cycle = hydrologic cycle = H_2O cycle = water cycle The circulatory flux of water at or near the Earth's surface.

hydrological record Recorded time series data of hydrological variable values such as streamflows, precipitation, groundwater levels and water quality constituent concentrations, obtained from monitoring.

hydrometeorology A branch of meteorology and hydrology that studies the transfer of water and energy between the land surface and the lower atmosphere.

hydromorphological alteration/modification Human pressure on the natural structure of surface waters such as modification of bank structures, sediment/habitat composition, discharge regime, gradient and slope.

impacts thinking Thinking that has been impacted by external events.

indeterminacy The quality of something being uncertain, or incalculable.

indicator A measure that indicates the state of something else. In ecology, an organism or ecological community so strictly associated with particular environmental conditions that its presence is indicative of the existence of these conditions. In economics, any of a group of statistical values that taken together give an indication of the health of the economy.

institution Interpersonal networks of groups of individuals (informal institutions) that deal with social issues evolve as society develops economically into formal institutions of a market-based economy, such as a structured system of laws imposed by representative forms of governance.

integrated pest management Effective and environmentally sensitive approach to pest management that relies on comprehensive information on the life cycles of pests and their interaction with the environment. This information, in combination with available pest control methods, is used to manage pest damage by the most economical means, and with the least possible hazard to people, property and the environment.

integrated plant nutrition management Use of nutrients in a yield-targeted, site-and soil specific way; understanding the inter-relation of different nutrients; use of combinations of mineral and organic fertilizers; provision of nutrients on a cropping-system/rotation basis; and use of on-farm and off-farm waste through recycling.

integrated urban water management (IUWM) The practice of managing freshwater, wastewater and stormwater as links within the resource management structure, using an urban area as the unit of management.

integrated water resources management (IWRM) A systematic process for the sustainable development, allocation and monitoring of water resource use in the context of social, economic and environmental objectives.

irrigation The science of artificial application of water to the land or soil. In surface irrigation systems, water moves over the land by simple gravity flow in order infiltrate into the soil. In drip irrigation, the water is placed drop by drop near the root zone of the plants. Ground and rainfed sources obtain their water from groundwater and rainfall respectively.

jet stream Relatively strong winds concentrated within a narrow stream in the atmosphere.

knowledge management The branch of management that seeks to improve performance in business by enhancing an organization's capacity to learn, innovate and solve problems.

land and water rights The relationship, whether legally or customarily defined between people, as individuals or groups, with respect to land. In essence a water right is a legal right: to abstract or divert and use a specified quantity of water from a natural source; to impound or store a specified quantity of water in a natural source behind a dam or other hydraulic structure; or to use water in a natural source.

land degradation Reduction or loss of the biological or economic productivity and complexity of land, resulting from processes, including processes arising from human activities and habitation patterns, such as (i) soil erosion caused by wind and/or water; (ii) deterioration of the physical, chemical and biological or economic properties of soil; and (iii) long-term loss of natural vegetation.

land management Process by which the resources of land are put to good effect, from an environmental and an economic perspective.

land subsidence Sinking elevation of the ground surface, which may occur over an aquifer that is slowly draining and decreasing in volume because of pore collapse.

large-scale land acquisition Gaining of tenure rights to large areas of land through purchase, lease, concession or other means.

least developed countries (LDCs) A group of countries that have been identified by the United Nations as 'least developed' in terms of their low gross national income, their weak human assets and their high degree of economic vulnerability.

livelihood A means of support or subsistence.

low-flow appliance An appliance that is designed to reduce water consumption without compromising performance of the appliance.

managed aquifer recharge (MAR) The process of adding a water source such as recycled water to aquifers under controlled conditions for withdrawal at a later date, or of using the water source as a barrier to prevent saltwater or other contaminants from entering the aquifer.

megacity A city that has a population of more than 10 million people and that is often made of two or more urban areas that have grown so much they have become connected.

microfinance The goal of microfinance is to give low-income people an opportunity to become self-sufficient by providing a means of saving money, borrowing small amounts of money through microcredit, and buying micro-insurance for lower valued assets.

Millennium Development Goal (MDG) Goals that aim to improve human well-being by reducing poverty, hunger, child and maternal mortality, ensuring education for all, controlling and managing diseases, tackling gender disparity, ensuring sustainable development, and pursuing global partnerships.

Millennium Ecosystem Assessment Identification of the consequences of ecosystem change for human well-being and the scientific basis for action needed to enhance conservation and sustainable use of those systems.

modular water treatment design Design of pre-fabricated, self-contained and transportable water treatment facilities.

monsoon The seasonal wind of the Indian Ocean and southern Asia, blowing from the southwest in summer and northeast in the winter.

moraine An accumulation of earth and stones carried and finally deposited by a glacier.

multilateral environmental agreement An agreement created by the United Nations between multiple nations that pledge to conduct trade operations in such a way that limits negative environmental impacts.

nexus A connected group or series of interdependent components.

nitrate vulnerable zone Areas of land that drain into nitrate polluted water, or water that could become polluted by nitrates.

non-consumptive production process Production processes that may use but do not consume water. Examples include the water used for hydropower electricity production and that used for cooling of thermoelectric power plants.

nonstationarity, nonstationary probabilities Changing probability distributions or their parameters over time.

no-regrets decision A decision taken by households, communities or institutions that can be justified from economic, social and environmental perspectives regardless of future changes in external conditions.

North Atlantic Oscillation (NAO) The large-scale seesaw in atmospheric mass between the subtropical high and polar low.

official development assistance/aid (ODA) The amount that a nation expends through grants and other development assistance programs calculated as a percent of gross national product.

output-based aid (OBA) Development aid strategies that link the delivery of public services in developing countries to targeted performance-related subsidies.

Pacific Decadal Oscillation (PDO) A pattern of Pacific climate variability that shifts phases on at least an inter-decadal time scale, usually 20 to 30 years.

path dependence Explains how the set of decisions faced for any given circumstance is limited by the decisions made in the past, even though past circumstances may no longer be relevant.

payment for ecosystem/environmental services (PES) The practice of offering incentives to farmers or landowners in exchange for managing their land to provide some sort of ecological service.

peak ecological water The point beyond which the total costs of ecological disruptions and damages exceed the total value provided by human use of that water.

peak renewable water A term applied where flow constraints limit total water availability over time.

percolation rate The rate at which water moves through saturated granular material.

peri-urban slum/area About a third of the world's slum dwellers live in traditional inner cities, but most live on the peripheral edge in peri-urban slums – sprawling, endless slum-suburbs.

photobioreactor (PBR) A device that houses and cultivates algae. It provides a suitable environment for algae growth, supplying light, nutrients, air and heat to the culture, in addition to protecting the culture from contamination.

phreatophytic agriculture A type of agriculture focusing on deep-rooted plants that obtain water from the water table or the layer of soil just above it.

physical flood defence system Levees, weirs, dykes and reservoirs – systems in place to protect areas from flood devastation.

point-of-use (PoU) water treatment/technology A method of water treatment used to improve water quality for an intended use at the point of consumption instead of at a centralized treatment facility.

polluter pays principle In environmental law, the polluter pays principle is enacted to ensure the party responsible for producing pollution is responsible for paying for the damage done to the natural environment.

pollution abatement technology Technology that is designed to reduce the concentration of contaminants in water or on land.

pollutant/pollution Contaminants in a natural environment that cause instability, disorder, harm or discomfort to the ecosystem or reduce the value of environmental media for other uses. Point source pollution is a single identifiable localized source of pollution. Non-point source pollution comes from many diffuse sources – by airborne deposition as well as from rainfall or snowmelt moving over and through the ground. Diffuse source pollution has no specific point of discharge.

portfolio theory Theory of investment which attempts to maximize portfolio expected return for a given amount of portfolio risk, or equivalently minimize risk for a given level of expected return, by carefully choosing the proportion of various assets.

potable/non-potable water Potable water is suitable for human consumption; non-potable water is not.

precautionary principle States that if an action or policy has a suspected risk of causing harm to the public or to the environment, in the absence of scientific consensus that the action or policy is harmful, burden of proof that it is not harmful falls on those taking the action.

protectionist policy, protectionism The economic policy of restraining trade between states through methods such as tariffs on imported goods, restrictive quotas and a variety of other government regulations designed to allow 'fair competition' between imports and goods and services produced domestically.

public–private partnership (PPP) A government service or private business venture which is funded and operated through a partnership of government and one or more private sector companies.

Ramsar convention An intergovernmental treaty that embodies the commitments of its member countries to maintain the ecological character of their Wetlands of International Importance and to plan for the 'wise use' or sustainable use of all of the wetlands in their territories.

recharge Groundwater recharge is a hydrological process where water moves to groundwater. Surface water recharge is a hydrological process where water runs off to surface watercourses.

reclaimed water Former wastewater (sewage) that is treated to remove solids and certain impurities, and is used in landscaping, irrigation, industrial cooling, or to recharge groundwater aquifers. The purpose of these processes is water conservation, rather than discharging the treated water to surface waters such as rivers and oceans.

reservoir rule/guide curve A reservoir release policy specifying releases as a function of existing storage level or volume and time of year, or specifying a target storage value given the time of year and sometimes the inflow as well.

resilience A measure of the ability of a system to recover from an unsatisfactory state.

results-based financing (RBF) Ties the disbursement of subsidies (or aid) to the delivery of actual results. For example, a carbon finance strategy involves mitigation policies and market mechanisms to create an environment that promotes diverse energy sources and incentives for new and cleaner technologies.

retention capacity The capacity to store and hold water, such as in soil.

rights-based approach Use of human rights as a framework to guide the development process.

risk Probability of an undesirable outcome.

risk management The identification, assessment and prioritization of risks followed by coordinated and economical application of resources to minimize, monitor and control the probability or impact of unfortunate events or to maximize the realization of opportunities.

river gauging station Site and facility where the river flow or stage is being measured and recorded.

riverine flood protection Measures taken to protect areas on the floodplain from experiencing a flood, such as flood proofing, levees and upstream reservoir flood storage capacity.

robustness A measure of how well a system, strategy or decision may perform or function given a range of possible inputs, not all of which are predicted.

runoff Surface flow from land areas during and after a storm or precipitation event.

run-of-the-river dam A reservoir that is created by a dam and whose storage volume is maintained at a constant value, so that the inflow equals the outflow less any losses.

rural zoning Land use and development that is restricted to rural uses and activities.

saltwater intrusion The infiltration or flow of saltwater into fresh surface or groundwater bodies.

sanitation The provision of infrastructure, facilities and services for the safe disposal of human urine and faeces. Inadequate sanitation is a major cause of disease worldwide.

scenario An account or synopsis of a projected course of action, event or situation. Scenario development is used in policy planning, organizational development and generally, when organisations wish to test strategies against uncertain future developments.

sectoral water efficiency (SWE) Measure (ratio) of efficiency based on inputs and outputs.

sector-wide approach to planning (SWAP) An approach wherein planning and activity is at the whole of sector level, and the many aspects of a sector are taken into consideration (capacity of personnel, institutional strength, stakeholder consultation, implementation processes, monitoring, financing and so on).

sensitivity analysis The study of how the variation (uncertainty) in the output of a model can be attributed to different variations in the inputs of the model.

sewage administration Administration of wastewater collection and treatment systems typically so that they produce enough revenues to fund their own activities.

sewage, sewerage Domestic wastewater typically collected in sewers or ditches and treated in wastewater treatment plants or discharged as is into water bodies.

smallholder An individual farming on a small area of land, less than the size of a small farm.

snowpack Layers of snow that accumulate in geographic regions and high altitudes where the climate includes cold weather for extended periods during the year.

social learning Observational learning can occur in relation to an actual person demonstrating the desired behaviour – an individual describes the desired behaviour in detail, and instructs the participant in how to engage in the behaviour – through the media, including, movies, television, Internet, literature and radio.

socio-ecological system (SES) A bio-geo-physical unit and its associated social actors and institutions. Socio-ecological systems are complex and adaptive and delimited by spatial or functional boundaries surrounding particular ecosystems and their problem context.

soft infrastructure All the institutions that are required to maintain the economic, health, cultural and social standards of a country, such as the financial system, the education system, the health care system, the system of government, law enforcement, and emergency services.

soft path (approach, measure, infrastructure, policy) The soft path integrates both supply and demand concepts, recognizing that water is a means to satisfy demands for goods and services, and asks how much water, of what quality, is actually required to satisfy those demands efficiently and sustainably.

stakeholder A person, group, organization or system who affects or can be affected by an organization's actions.

stationary hydrology The probabilistic nature of hydrological processes is not changing over time.

stochastic analysis The analysis of random processes that take place over time.

storm surge An offshore rise of water typically associated with a low pressure weather system.

storm track Relatively narrow zones in the Atlantic and Pacific Oceans along which most Atlantic or Pacific extratropical cyclones or hurricanes travel.

supply-side infrastructure Infrastructure designed to provide the supply and quality of water or energy needed to meet the demand.

surface water Water located on the surface of the Earth, such as in streams, rivers, lakes, seas and oceans.

surprise (in a system) System behaviour or performance that is not expected or foreseen.

sustainability, sustainable development The capacity to endure. The long-term maintenance of environmental, economic and social aspects such that the quality of life is improved over time.

sustainable land management (SLM) Managing land for productivity in agriculture and forestry while providing environmental protection and ecosystem services and taking into account demographic growth and increasing pressure in land use.

sustainable water management The use of water that supports the ability of human society to endure and flourish into the indefinite future without undermining the integrity of the hydrological cycle or the ecological systems that depend on it.

TARWR (total actual renewable water resources) The theoretical maximum annual volume of water resources available on a sustainable basis in a country.

technocratic knowledge Any kind of management or administration by specialized experts selected through bureaucratic processes on the basis of specialized knowledge and performance, rather than democratic election.

teleconnections Links among world climate anomalies. Teleconnection pattern refers to a recurring and persistent large-scale pattern of pressure and circulation anomalies that span vast geographical areas.

tipping point The point at which a slow, reversible change becomes irreversible, often with dramatic consequences.

top-down approach An approach to decision-making where an executive, decision-maker or other person or body makes a decision. This approach is disseminated under their authority to lower levels in the hierarchy, who are, to a greater or lesser extent, bound by them.

transboundary basin, aquifer A river basin or groundwater aquifer that spans multiple political entities, separated by boundaries.

trialogue approach Links science, government and society.

unaccounted-for water (UfW) Water that has been produced and is 'lost' before it reaches the customer.

uncertainty Lack of sureness about something. Uncertainty may range from a falling short of certainty to an almost complete lack of conviction or knowledge, especially about an outcome or result.

urban and peri-urban agriculture (UPA) The practice of cultivating, processing and distributing food in, or around, a village, town or city. It can involve animal husbandry, aquaculture, agro-forestry and horticulture.

urbanization The physical growth of urban areas as a result of global change. Urbanization can represent the level of urban relative to overall population, or it can represent the rate at which the urban proportion is increasing.

value chain (agriculture, food) The full range of activities, with maximum generation of value, that are required to bring a product (or a service) from conception through the different phases of production to delivery to final consumers and disposal after use.

virtual (embedded) water The water used in the production of a good or service.

vulnerability Degree to which people, property, resources, systems and cultural, economic, environmental and social activity is susceptible to undesired outcomes, harm, degradation or destruction.

wadi The Arabic term traditionally referring to a valley.

wastewater Any water that has been adversely affected in quality by human influence.

water accounting Keeping track of the water resources in a river basin, indicating where water is going, how it is being used, and how much remains available for further use.

water allocation system Institutional structure for allocating water. The choice of structure is ultimately a compromise between the physical nature of the resource, human reactions to policies, and competing social objectives.

water balance (in industry) A description of the flow of water in and out of an industrial system.

water bank An institutional mechanism used to facilitate the legal transfer and market exchange of various types of surface water, groundwater and water storage entitlements.

'water box' The collection of activities and organizations that assess, develop and manage water resources. This is in contrast to those who make decisions in their respective economic sectors that have impacts on the decisions and options of those within the water box.

water conservation The reduction of the usage of water and recycling of waste water for different purposes such as cleaning, manufacturing and agricultural irrigation.

water conveyance The transport of water from one place to another, such as in a canal, pipeline or aqueduct.

water demand management Measures taken to alter the demand for water, as opposed to supply management measures that attempt to meet the demands.

water development agenda A comprehensive blueprint of action to be taken by organizations and major groups with respect to water development that can impact on human welfare.

water dialogue space A space that allows individuals within multistakeholder groups to resolve real but 'neutral' problems and thereby build trust and mutual respect.

water distribution The percentages of volumes of fresh and saline water, both on and under the surface of the Earth. Alternatively, the transport of water supplies from water treatment plants to particular water users in an urban area.

water diversion The withdrawal and transport of water from one place (i.e. from a natural water body) to another place (of use) typically via a canal or pipeline.

water efficiency The accomplishment of a function, task, process or result with the minimal amount of water feasible. It focuses on reducing waste.

water entitlements The right to obtain water established by apportionment institutions. In some places, water entitlements are granted by the state and constitute an informal contract between the state and licence-holders. In other, water entitlements constitute a formal property right with judicial enforcement. Whether formal or informal, the contractual nature of water entitlements adds to the cost of institutional change.

water footprint The total volume of freshwater used to produce the goods and services consumed by an individual or community or produced by a business. The direct water footprint of a consumer or producer (or a group of consumers or producers) refers to the freshwater consumption and pollution that is associated to the water use by the consumer or producer. It is distinct from the indirect water footprint, which refers to the water consumption and pollution that can be associated with the production of the goods and services consumed by the consumer or the inputs used by the producer. The grey water footprint of a product is an indicator of freshwater pollution that can be associated with the production of a product over its full supply chain. It is the volume of freshwater that is required to assimilate the load of pollutants based on existing ambient water quality standards, calculated as the volume of water that is required to dilute pollutants to such an extent that the quality of the water remains above agreed water quality standards.

water harvesting Activities such as forest condensation, fog harvesting, cloud seeding (the dispersal of substances into the air that serve as cloud condensation or ice nuclei, which alter the microphysical processes within the cloud) and direct collection of rainwater related to the increase and capture of precipitation to supplement water supplies.

water infrastructure Physical and organizational structures needed to provide the water quantities and qualities demanded by various water users.

water market The ability to buy, sell or lease water rights, in whole or in part, from one legal entity to another and which involves an exchange of a monetary value.

water productivity The ratio of goods and services produced over the volume of water required for their production; measures the efficient use of water.

water quality The physical, chemical and biological characteristics of water. It is a measure of the condition of water relative to the requirements of one or more biotic species and or to any human need or purpose.

water reallocation The transfer of water from one use to another.

water reform Measures taken to change current water management practices to provide increased benefits to water users and the environment, typically couched in terms of reducing if not removing inefficiencies, corruption and incompetence.

water renewability The ability of water to be replaced through biological, physical or other natural processes and replenished with the passage of time. Water is renewable through the process of the hydrological cycle.

water resources management The activity of planning, developing, distributing and managing the supply and use of water resources. The development and use of structural and non-structural measures to provide and control natural and human-made water resources systems for beneficial uses.

water security The availability of a reliable and secure access to water over time.

'water sector' Commonly refers to all activities, trade and professional organizations and individuals involved with providing drinking water and wastewater services (including wastewater treatment) to residential, commercial and industrial sectors of the economy.

water service management, delivery, control A water service control system includes an underground water main, at least one water consumer station downstream from the water main, and an underground water delivery channel and valves that control the flow from the water main to the water consumer.

water storage A term used within agriculture to define locations where water is stored for later use.

water stress The symptomatic consequence of water scarcity (physical or economic), which may manifest itself as increasing conflict over sectoral usage, a decline in service levels, crop failure, food insecurity and so forth. It is often measured by the extent of the difference between supply and demand.

water supply and sanitation (WSS) Services typically provided by water utilities to provide the quantities and qualities of water where and when demanded, and to provide the means of wastewater collection, treatment and disposal.

watercourse Any flowing body of water.

water-derived benefit Economic, ecological or social benefit obtained due to the particular use or management of water.

water-related hazard Human health, economic or social hazard resulting due to the excess, shortage or pollution of water.

watershed The area of land where all of the water that is under it or drains off it goes into the same place. Healthy watersheds provide a host of services, including water purification, groundwater and surface flow regulation, erosion control and streambank stabilization.

wetland An area of ground that is saturated with water either permanently or seasonally (swamp, marsh, peatland, shallow lake).

willingness to pay (WTP) The maximum amount a person would be willing to pay, sacrifice or exchange in order to receive a good or to avoid something undesired, such as pollution.

withdrawal The removal of water from some type of source, such as groundwater, for some use by humans. The water that is not consumed is subsequently returned to the environment after use, but the quality of the returned water may not be the same as when it was removed. Withdrawn water can be used (such as for cooling) without being consumed.

yellow water Sanitary wastewater containing only urine.

The purpose of this glossary is to serve as a reference for readers of the United Nations *World Water Development Report* 4. Definitions might differ somewhat from those used in other publications, and they do not represent official definitions of the UN, UN-Water, or contributors to the WWDR4.

The glossary was prepared under the coordination of Daniel P. Loucks, Contributing Lead Author (Part 2).

This glossary draws, sometimes directly, on material available on the following websites:

http://actionaidusa.org http://answers.yahoo.com http://dictionary.cambridge.org http://dictionary.com http://dictionary.reverso.net http://en.wikipedia.org http://encyclopedia2.thefreedictionary.com http://nsidc.org http://orf.od.nih.gov http://science.nasa.gov/earth-science http://thinkquest.org http://waterwiki.net http://wiki.answers.com www.merriam-webster.com www.Africanwater.org www.alcwin.org www.answers.com www.awwa.org www.businessdictionary.com www.cees.iupui.edu www.cglrc.cgiar.org www.cleanenergyprinciples.com www.corix.com www.cpc.noaa.gov www.csiro.au www.dainet.com www.ecosystemvaluation.org www.ecy.wa.gov www.eoearth.org www.epa.gov www.ess.uci.edu www.euroscience.org www.exclusion.net www.fao.org www.fema.gov www.greenfacts.org www.homelandsecuritynewswire.com www.icpdr.org www.investopedia.com www.kmci.org www.ldeo.columbia.edu www.maweb.org www.mbdc.com www.nationsonline.org www.noaa.gov www.nrdc.org www.ofwat.gov www.physicalgeography.net www.ramsar.org www.science20.com www.sswm.info www.thecommonsjournal.org www.thefreedictionary.com www.ucowr.org www.un.org www.unccd.int www.unep.org www.unisdr.org www.usaid.gov www.waterdialogues.org www.webopedia.com www.who.org www.worldbank.org www.wri.org www.wto.org.

It also draws on *Peak Water: Conceptual and Practical Limits to Freshwater Withdrawal and Use* by P. H. Gleick and M. Palaniappan (2010); *The New Slum Dwellers* by M. Davis (2006); the Macmillan Dictionary; and http://www.ce.utexas.edu/prof/mckinney/papers/aral/Aral.pdf.

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WWDR4

The United Nations World Water Assessment Programme (WWAP) is hosted by UNESCO and brings together the work of 28 UN-Water members and partners in the triennial *World Water Development Report* (WWDR).

This flagship report is a comprehensive review that gives an overall picture of the world's freshwater resources. It analyses pressures from decisions that drive demand for water and affect its availability. It offers tools and response options to help leaders in government, the private sector and civil society address current and future challenges. It suggests ways in which institutions can be reformed and their behaviour modified, and explores possible sources of financing for the urgently needed investment in water.

The WWDR4 is a milestone within the WWDR series, reporting directly on regions and highlighting hotspots, and it has been mainstreamed for gender equality. It introduces a thematic approach – 'Managing Water under Uncertainty and Risk' – in the context of a world which is changing faster than ever in often unforeseeable ways, with increasing uncertainties and risks. It highlights that historical experience will no longer be sufficient to approximate the relationship between the quantities of available water and shifting future demands. Like the earlier editions, the WWDR4 also contains country-level case studies describing the progress made in meeting water-related objectives.

The WWDR4 also seeks to show that water has a central role in all aspects of economic development and social welfare, and that concerted action via a collective approach of the water-using sectors is needed to ensure water's many benefits are maximized and shared equitably and that water-related development goals are achieved.

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UN-Water is the United Nations (UN) inter-agency coordination mechanism for all freshwater related issues. It was formally established in 2003 building on a long history of collaboration in the UN family. It currently counts 29 UN Members and 25 other international Partners. UN-Water complements and adds value to existing UN initiatives by facilitating synergies and joint efforts among the implementing agencies. See www.unwater.org

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Knowledge Base

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THE UNITED NATIONS WORLD WATER DEVELOPMENT REPORT 4
VOLUME 2

UN WATER Report

UNESCO
United Nations Educational, Scientific and Cultural Organization

World Water Assessment Programme

UN WATER

Knowledge
Base

THE UNITED NATIONS WORLD WATER
DEVELOPMENT REPORT 4
VOLUME 2

Published in 2012 by the United Nations Educational, Scientific and Cultural Organization
7, place de Fontenoy, 75352 Paris 07 SP, France

ISBN 978-92-3-104235-5
e-book ISBN 978-92-3-001045-4

Original title: The United Nations World Water Development Report 4: *Managing Water under Uncertainty and Risk* (Vol. 1), *Knowledge Base* (Vol. 2) and *Facing the Challenges* (Vol. 3).

Published in 2012 by the United Nations Educational, Scientific and Cultural Organization

UNESCO Publishing: http://publishing.unesco.org/

Suggested citation:
WWAP (World Water Assessment Programme). 2012. *The United Nations World Water Development Report 4: Managing Water under Uncertainty and Risk*. Paris, UNESCO.

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The contents of Volume 2 were contributed by the UN-Water members and partners listed on the title pages of the chapters therein. UNESCO and the United Nations World Water Assessment Programme (WWAP) are not responsible for errors in the content provided or for discrepancies in data and content between contributed chapters.

WWAP provided the opportunity for individuals to be listed as authors and contributors or to be acknowledged in Volume 2. WWAP is not responsible for any omissions in this regard.

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Cover and interior design and typesetting by Phoenix Design Aid A/S, an ISO 14001 (environmental management) and a DS 49001 (corporate social responsibility) certified and approved carbon neutral company.

Printed by Imprimerie Centrale S. A. (Imprim'Vert certified) for UNESCO CLD, Paris.

This publication is printed with vegetable inks on FSC Mixed Sources paper, supporting responsible use of forest reserves. This is a carbon neutral print product. Imprimerie Centrale will contribute funds to a project replanting trees in Panama for this publication.

Printed in Luxembourg

FSC www.fsc.org MIX Paper from responsible sources FSC® C103749

WWDR4 has been published on behalf of the United Nations World Water Assessment Programme (WWAP) with the support of the following organizations:

United Nations Funds and Programmes
United Nations Children's Fund (UNICEF)
United Nations Conference on Trade and Development (UNCTAD)
United Nations Department of Economic and Social Affairs (UNDESA)
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CHAPTER 15

State of the resource: Quantity

UNESCO-IHP

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What is the current state of the world's freshwater resources? What are the most important external drivers and their resulting pressures and impacts on these resources as well as their use and management? This chapter tries to answer these questions. It begins by describing the main issues facing the state of the resource and how these have been changing over recent years. The chapter then outlines the related principal risks, challenges, uncertainties and opportunities. Finally, geographic hotspots of particular concern are identified and examples of how some countries are dealing with the issues and challenges are provided.

15.1 Drivers of variability

15.1.1 The hydrological cycle

It is well known that a mere 2.5% of global water resources is potentially available for human, animal and plant consumption; the remaining 97.5% resides in the oceans. Adding to this limitation is the fact that freshwater is highly uneven in its spatial distribution; thus, it is not uncommon that regions habitable for human settlement find themselves with insufficient freshwater. The movement of freshwater among terrestrial parts of the earth, the oceans and the cryosphere is known as the hydrological cycle, the water cycle or the H_2O cycle.

Evaporation and evapotranspiration account for 30–70% of the losses to temperature in arid climates and groundwater recharge is about 1–30% for these regions (e.g. see table 4.1 in WWAP, 2006). A large part of the world's population lives in semi-arid and arid climates that have about 30% of precipitation available for ready use. The increase in temperature due to global warming will reduce the amount of water available for ready use in the future, and increasing temperatures will also reduce groundwater recharge, further exacerbating the water availability challenge.

Table 15.1 shows the total precipitation and renewable water available for the population in different ecosystems and regions of the world. The world's population has substantially increased while global precipitation has remained largely constant. Precipitation may be significantly reduced in the future in semi-arid and arid regions, which tend to be among the most vulnerable and poorest in the world, due to anthropogenic climate change (IPCC, 2007). Thus, a smaller fraction of global freshwater will have to satisfy an increasing population, as can be seen in Figure 15.1.

Understanding the movement of water and the spatial and temporal variability of water availability are the most important aspects of water resources that need to be understood and incorporated in planning and management for resource sustainability. Large-scale climate forcings (i.e. drivers) orchestrate the spatial and temporal movement of water. The seasonal variation of available water resources is driven by the earth's tilt and its revolution about the sun. This results in wet and dry seasons in the tropics due to the annual movement of the Intertropical Convergence Zone (ITCZ). In the tropics, annual total rainfall may be large but intra-annual variation is also large, posing a challenge to water resources management and economic development (Brown and Lall, 2006). At high latitudes precipitation is more equally distributed, but streamflow may be influenced by the accumulation and melting of snowpack.

15.1.2 El Niño-Southern Oscillation and other oceanic oscillations

The El Niño-Southern Oscillation (ENSO), a coupled ocean-atmospheric phenomenon in the tropical Pacific Ocean, is the dominant driver of global climate at seasonal to interannual time scales. The state of the tropical Pacific triggers 'teleconnection' responses in other parts of the world – especially in Latin America, South and South-East Asia, and Africa.

The Pacific Decadal Oscillation (PDO), the North Atlantic Oscillation (NAO) and the Atlantic Multidecadal Oscillation (AMO) are drivers that operate at longer time scales (interdecadal to century); they are not robust phenomena that can easily be identified, observed and predicted like ENSO. These phenomena impact regional climates in the mid-latitudes, mainly in North America and Europe. Research in understanding these drivers and their teleconnections to regional climate and hydrology is nevertheless emerging.

All of these oscillations are drivers that impact the variability of moisture delivery in space and time around the world. Understanding and diagnosing their teleconnections to regional hydrology is a potentially powerful tool for water resources prediction and simulation, and consequently, for adaptation to climate variability and change.

15.2 Stressors on water resources

The state of water resources is constantly changing as a result of the natural variability of the earth's climate system, and the anthropogenic alteration of that climate system and the land surface through which the hydrological cycle is modulated. The state of water resources is also influenced by human activities that affect demand, such as population growth, economic development and dietary changes, as well as by the need to control the resources, such as is required for settlement in flood plains and drought-prone regions.

15.2.1 Water supply

The greatest stress on water supply comes from the variability of moisture delivery to a river basin, which predominantly reflects variability in climate – a powerful stress on water supply around the world. The consequence of this stress is amplified by socio-economic growth, management policies, land cover and land use changes. The state of water resources is in constant change, the effects of which can be only partially anticipated. Some changes that we can anticipate are described below.

Decrease in mean flow

There is increasing evidence of substantial streamflow reduction in a number of river basins around the world in the coming decades due to global warming. While some regions, such as those in higher latitudes, could see increases in moisture and streamflow, unfortunately, in much of the populated regions of the world there is projected to be a reduction in flow (IPCC, 2007).

Increase in flood potential

The implications of climate change include acceleration of the water cycle, which could lead to an increase in the probability of heavy rainfall and consequently the flooding potential. Extreme rainfall events produce enormous volumes of water that cause loss of life and damage to property. Furthermore, without significant

TABLE 15.1

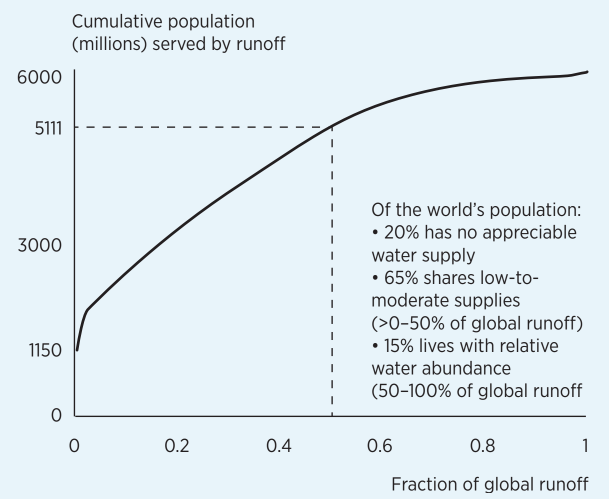
Estimates of renewable water supply, the renewable supply accessible to humans, and the population served by the renewable supply in different ecosystems and regions

System[a] or region	Area	Total precipitation (P_1)	Total renewable water supply, blue water flows (B_1)	Renewable water supply, blue water flows, accessible to humans[b] (B_2)	Population served by renewable resource[c]
Millennium Ecosystem Assessment (MA) System	(million km^2)		(thousand km^3 per year) [% of global runoff]	[% of B_1]	(billion) [% of world population]
Forests	41.6	49.7	22.4 [57]	16.0 [71]	4.62 [76]
Mountains	32.9	25.0	11.0 [28]	8.6 [78]	3.95 [65]
Drylands	61.6	24.7	3.2 [8]	2.8 [88]	1.90 [31]
Cultivated[d]	22.1	20.9	6.3 [16]	6.1 [97]	4.83 [80]
Islands	8.6	12.2	5.9 [15]	5.2 [87]	0.79 [13]
Coastal	7.4	8.4	3.3 [8]	3.0 [91]	1.53 [25]
Inland water	9.7	8.5	3.8 [10]	2.7 [71]	3.98 [66]
Polar	9.3	3.6	1.8 [5]	0.3 [17]	0.01 [0.2]
Urban	0.3	0.22	0.062 [0.2]	0.062 [100]	4.30 [71]
Region					
Asia	20.9	21.6	9.8 [25]	9.3 [95]	2.56 [42]
Former Soviet Union	21.9	9.2	4.0 [10]	1.8 [45]	0.27 [4]
Latin America	20.7	30.6	13.2 [33]	8.7 [66]	0.43 [7]
North Africa/ Middle East	11.8	1.8	0.25 [1]	0.24 [96]	0.22 [4]
Sub-Saharan Africa	24.3	19.9	4.4 [11]	4.1 [93]	0.57 [9]
OECD	33.8	22.4	8.1 [20]	5.6 [69]	0.87 [14]
World Total	**133**	**106**	**39.6 [100]**	**29.7 [75]**	**4.92 [81]**

a Note: double-counting for ecosystems under the MA definitions.
b Potentially available supply without downstream loss.
c Population from Vörösmarty et al. (2000).
d For cultivated systems, estimates are based on cropland extent from Ramankutty and Foley (1999) within this MA reporting unit.
Source: Hassan et al. (2005, table 7.2, p. 173). © Millennium Ecosystem Assessment. Reproduced by permission of Island Press, Washington DC.

FIGURE 15.1

Cumulative distribution of the population with respect to freshwater services, 1995–2000



Source: Hassan et al. (2005, figure 7.7, p. 173). © Millennium Ecosystem Assessment. Reproduced by permission of Island Press, Washington DC.

storage capacity, the flood flows do not relieve periods of water shortage.

Increase in losses

It is widely believed that the mean temperature will increase in almost all parts of the world (IPCC, 2007). Climate models are much more useful in temperature projections than in those for precipitation. The consequences of increasing temperatures on water supply are direct and strong – increased evaporation, transpiration (although this is modulated to some degree by carbon fertilization) and infiltration, all of which greatly increase the losses from incoming moisture, thus severely reducing the amount of water easily available for use. The increase in evaporative demand cannot easily be countered and therefore will impact surface runoff and water availability.

Altered seasonality and timing of flow in snowmelt basins

Many river basins in the mid-latitudes (i.e. snowmelt basins) get their water in the form of snow in the winter, which then melts in the following spring to produce runoff in the rivers that is then stored in reservoirs for water supply. Snow is beneficial from a water supply perspective because it acts a reservoir. Water managers have used the timing of the melt for effective management of reservoir operations to satisfy environmental needs. In a warmer climate it is projected that the snowmelt would occur early due to the advancement of spring and its warmer weather. This early snowmelt would reduce the snow season and increase moisture delivery in the form of rain thus increasing infiltration and evaporative losses during the melt. All of this will place a heavy stress on the amount of water available for use. This is likely to be the case over much of mid-latitude regions, but it will be especially acute in semi-arid and arid regions that depend on mountainous snowmelt.

Decrease or increase in flow due to glacier melt

Few populous places depend entirely on flow from glaciers. The Ganges and Brahmaputra rivers in India receive glacier melt during the winter and spring months (i.e. non-monsoon months) that accounts for 9–12% of their annual flow (see Eriksson et al., 2009, table 2). For India, a country with one billion people, a reduction in flow due to climate change in even one of its vital rivers could pose a serious threat to its water supply. Peru, Chile and Argentina similarly receive a substantial amount of water from glaciers in the Andes. With a warming climate there are two major impacts related to glaciers: (i) reduced snowfall in the lower elevations, resulting in a reduction in the size of the lower elevation glaciers; and (ii) increased losses during the melt season, thereby reducing the amount of flow. Projections indicate a rapid depletion of lower elevation glaciers around the world (IPCC, 2007).

Loss of the groundwater buffer

Groundwater provides a vital buffer against rainfall variability, especially in water stressed parts of the world. Almost all of the shallow groundwater reservoirs are recharged from rainfall, but recharge is greatly impacted by withdrawal, population growth and land cover change. Groundwater also plays a vital role in buffering the variability of surface water resources. With rainfall variability projected to increase in future, the groundwater buffer will become no longer available.

15.2.2 Water demand

The demand for water services involves human use of water for agriculture and industry as well as instream flow requirements for water quality and ecosystems. There is considerable uncertainty surrounding current and future global water demands. This is due in part to (a) the lack of current data describing national consumption patterns, withdrawals and sector usage; (b) large demographic changes, including population growth, economic growth and dietary changes; and (c) our limited understanding of how water demand changes dynamically in response to growing scarcity.

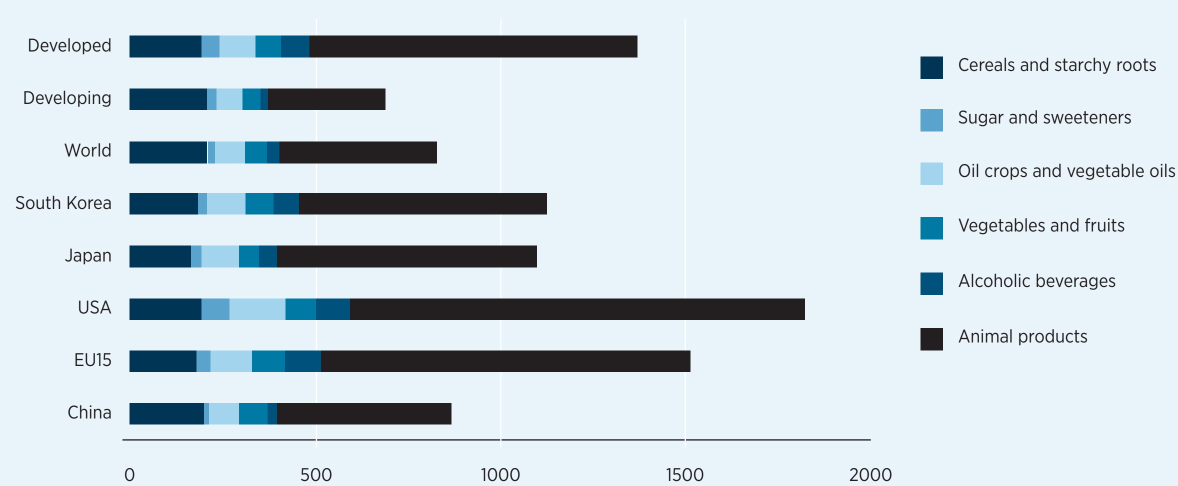
In many parts of the world, water demand is growing due to an increase in population, resulting in an increase in demand for agricultural and industrial products. Economic growth in developing countries often leads to an increase in water demand, for which there are at least two causes. First, direct use of water increases with economic development as access to water and household appliances improve. Second, in many countries a dietary shift occurs along with economic development – a shift from a primarily plant-based diet to one that has a higher proportion of meat. Meat production requires much greater amounts of water; for example, it takes approximately 16,000 L of water to produce 1 kg of beef compared with 3,000 L of water to produce 1 kg of rice (Water Footprint Network, n.d.). In the USA and Europe, the per capita water requirement for food is higher than in other countries, and food consumption is dominated by animal products (Figure 15.2).

Globally, agriculture is the primary water-using sector: more than 70% of water diverted from streams or renewable sources is used for agricultural purposes, and this number is even higher in developing countries. The prevailing climate of a region is an important driver of agricultural water needs, as evapotranspiration rates are sensitive to changes in air temperature, incoming solar radiation, humidity and wind speed. Climate variability plays a large role in agricultural water needs nationally, though globally, weather-driven variability in irrigation is less than 10% (Wisser et al., 2008). The type of crops grown and the land management techniques and irrigation methods used factor strongly into regional agricultural demands. Wisser et al. (2008) noted global irrigation sensitivities to percolation rates in rice paddies: a 50% change in percolation rate creates a 10% change in global irrigation water use; therefore, about 20% of global irrigation water may be percolating from flooded rice paddies.

Countries with the largest per capita water footprints tend to have large gross domestic products (GDPs) and large durable consumption rates (see Margat and Andréassian, 2008). The consumption of durable goods increases the water footprint. The USA has the largest water footprint of any nation, with a large proportion of the per capita water footprint in industrial goods (Figure 15.3); however, the USA ranks third globally in overall water consumption (Figure 15.4). India and China have lower per capita water footprints than the USA but are overall the largest total water consumers (Figure 15.4).

FIGURE 15.2

Per capita water requirements for food (m³ per capita per year)



Source: Liu and Savenije (2008, fig. 5, p. 893).

Despite large water footprints, water demands in developed countries such as the USA have been on a downward trend in the past 20 years. More economically efficient water pricing and the use of water efficient technologies both domestically and in agriculture are the primary causes (Box 15.1).

Other changes in water demand are due to the evolution of human habitation from largely rural to increasingly urban. This shift offers potential advantages in terms of economies of scale for providing domestic water as well as sanitation to people. While this is a potentially helpful trend, the provision of water services in rapidly growing and economically depressed urban areas is a complex challenge that requires continuous effort. Despite domestic water use being a small proportion of total water consumed (10–20%), providing it is becoming increasingly challenging as urban populations expand.

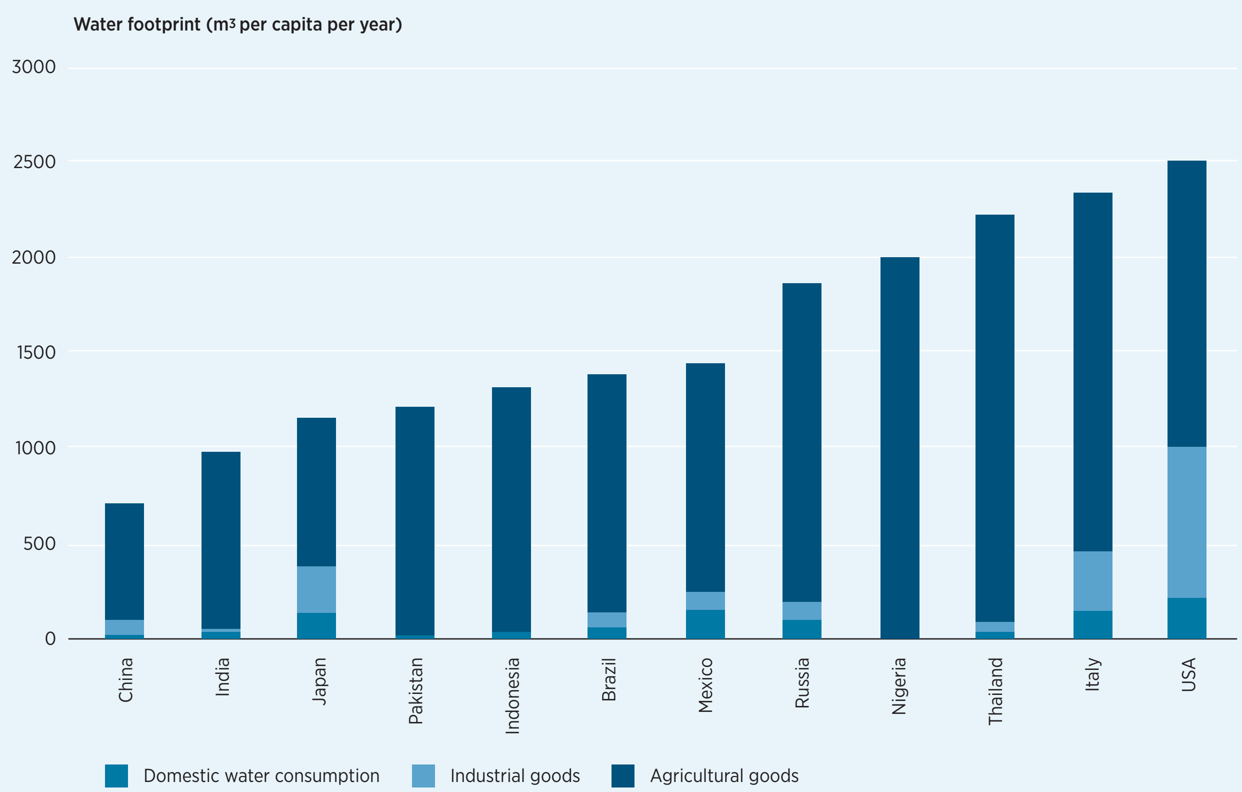
Another major source of water demand is for sustaining flows for ecosystems, called environmental flows. There is growing recognition of the negative impacts on ecosystems of water withdrawals and alteration of flow patterns due to human use of water. Water flows for aquatic ecosystems are now a standard part of water management objectives, and increasingly there is demand for flows that match some measure of the historical flow regime in place of minimum streamflow requirements, which are seen as insufficient.

Inevitably, the varied demand for water resources sets the scene for conflicts over allocation of water services. As the variability of water resources may increase, there is a need for more flexibility in water allocation mechanisms so that demands can be satisfied and shortfalls allocated in the most socially beneficial way. Because environmental benefits are often the most difficult to assign value to, they may be at risk of being left out or underestimated.

Demand for groundwater presents its own set of challenges. As a relatively cheap and reliable water

FIGURE 15.3

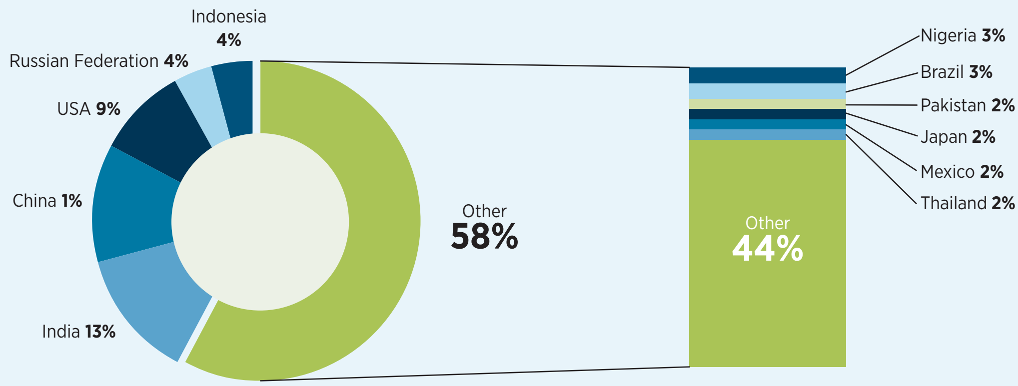
National per capita water footprint and the contribution of different consumption categories for selected countries



Source: Hoekstra and Chapagain (2007, fig. 5). Reproduced by permission from Springer Science+Business Media B.V.

FIGURE 15.4

Contribution of major consumers to the global water footprint



Source: Hoekstra and Chapagain (2007, fig. 4). Reproduced by permission from Springer Science+Business Media B.V.

supply, groundwater has been a boon to farmers throughout the world and a major cause of increasing food security. However, as a common property resource, groundwater is inherently prone to overuse. Many major aquifers around the world are being mined, from the High Plains of North America, to southern India, and the northern plains of China. Groundwater in these regions is being extracted at rates that far exceed recharge and often exceed the economically efficient use rate. Regulation of the common property resource is difficult due to its diffuse nature and the political issues of regulating a resource that is privately accessed.

Finally, there is demand not only for water resources but also protection from hydrological extremes. Societies around the world continue to be negatively impacted by floods and droughts, and the human toll is large. The cumulative impact of hydrological risks has a negative effect on economic development in many countries. Infrastructure and alternatives (structural and non-structural) are needed to reduce these negative impacts. Investment in storage and control structures such as dams is needed in many developing nations. Improved forecasting, early warning systems and insurance mechanisms are all important components of a strategy for addressing flood risk. Water storage at multiple scales, water markets and banks, and insurance are likely components of a strategy for addressing drought.

15.3 Risks and uncertainty in water resources management

15.3.1 Understanding the sources of uncertainty

The key sources of uncertainty related to water resources are those associated with supply, demand and the policy context. The uncertainty of water supply results originally from the natural variability of the earth's climate system and the hydrological cycle, as described earlier. However, anthropogenic influences are introducing new sources of uncertainty. These include the perturbation of the earth's climate due to the emission of greenhouse gases; the large–scale emission of aerosols that influence the physics of precipitation; and changes to the earth's surface through land use development which affect rates of runoff and evapotranspiration. Taken together, natural variability and anthropogenic forcings create a nonstationary climate and hydrological context within which water resources must be managed. This is particularly notable because the current principles for water resources management are based largely on an assumption of hydrological stationarity – the assumption that the future hydrological record can be adequately simulated with the statistics of the historical record.

Uncertainty related to water demand

The uncertainty associated with water demand is largely related to both the difficulty of anticipating demographic change and our limited understanding of how water responds to changing climate and policy conditions. Projections of water demand are

BOX 15.1

Conservation and demand hardening

Demand hardening occurs when long-term conservation practices and efficiency gains reduce the effectiveness of short-term water conservation measures within a given sector of use. Technological advancements and behavioural changes are the primary drivers of increased water use efficiency. Demand hardening increases as water availability becomes either physically or economically limiting.

The concept of 'peak water' (Gleick and Palaniappan, 2010) provides a good description of the demand hardening process. When a region extracts more water from a watershed than is naturally replenished, peak renewable water is said to be reached. Watersheds such as the Colorado River basin and the Yellow River basin are two examples approaching peak water. Ecologically, this can be unsustainable and a more appropriate metric, 'peak ecological water', may be targeted so that environmental and ecological damages are minimized. Basins that reach peak water may also be considered 'closed'; that is, all utilizable water has been allocated. Further allocation of water from the system will result in less water for other sectors or for ecological flows. It has been suggested that the USA has reached peak water, as withdrawals have remained constant or below historical peak water withdrawals reached during the late 1970s.

In response to dwindling water availability, conservation efforts such as indoor fixture retrofit programmes, outdoor watering education campaigns and technology investments have been used to extend existing supplies, thus increasing demand hardening. This by no means suggests the USA is headed for mass water shortages. Many cities in the USA use water metering coupled with water pricing policies as an effective control of outdoor water consumption. But, despite the efficiency gains from metering and pricing schemes, in much of the USA, in addition to other economically developed countries, both municipal and agricultural use remains unmetered. Metering of individual units in multifamily structures is even less common. Additional water savings can be found in the future if cities meter their residents and apply appropriate water pricing.

Gains in fixture efficiency are an important driver of indoor domestic water demands. In the USA, federal regulations made in the early 1990s continue to decrease per capita water consumption as older fixtures are replaced with newer, more efficient fixtures. In Australia, lasting drought across the continent has increased the penetration rate of efficient fixtures in domestic, agricultural and industrial sectors. National initiatives for water re-use and grey-water systems are reducing per capita consumption.

notoriously difficult to get right. Better understanding of the dynamic relationship between water demand and supply and more sophisticated means of modelling changes in demand dynamically are needed.

To model changes in demand, the underlying drivers of demand growth (or decrease) must be understood. The primary factors affecting water demand in much of the developing world are population growth and socio-economic growth. As economies grow, water use increases significantly, which typically leads to increases in water demand. The developing world is projected to have much higher growth in total water demand than the developed world. Increasing demand is projected to occur in agriculture (for irrigation), domestic and industrial sectors – all linked to economic growth. Figure 15.5 shows the global physical and economic water scarcity, the latter of which is a combination of socio-economic growth and water availability. It can be seen that both physical and economic water scarcity occurs together almost entirely in regions with high population growth and situated in the tropics. Economic water scarcity is largely a result of insufficient infrastructure and lack of management capacity.

There is considerable uncertainty in projections of water demand, especially in the projection of socio-economic factors such as population and economic growth. Without accompanying increases in the efficiency of water use, growth in water demand may be unsustainable and ultimately an impediment to continued economic growth.

Uncertainty related to water supply

Climate variations have a significant impact on the water supply and thus are an important source of uncertainty. Climate models project a decrease in precipitation and consequently in streamflow in several regions around the world. Figure 15.6 shows water availability projections for the 2050s from global climate models (taking into account climate variability, precipitation, temperature, topography and socio-economic factors that influence demand). These projections show a reduction in the future due to climate change in tropical regions. While these are projections of surface water availability, which is a major source of water for almost all human activities, the groundwater scenario is likely to be similar or worse as reduced precipitation leads to reduced recharge. With increasing exploitation from socio-economic growth, groundwater will be stressed further. The regions currently under severe stress will face severe to catastrophic stress in the future under these forces.

Projections of water supply due to climate variability come with large uncertainty. A major question that emerges is whether the uncertain climate change projections should be used to make planning and adaptation decisions. While the information used for water planning has always been uncertain, the current rate of potential change and degree of uncertainty associated with it is probably unprecedented. Managing this uncertainty is one of the great water challenges of the century.

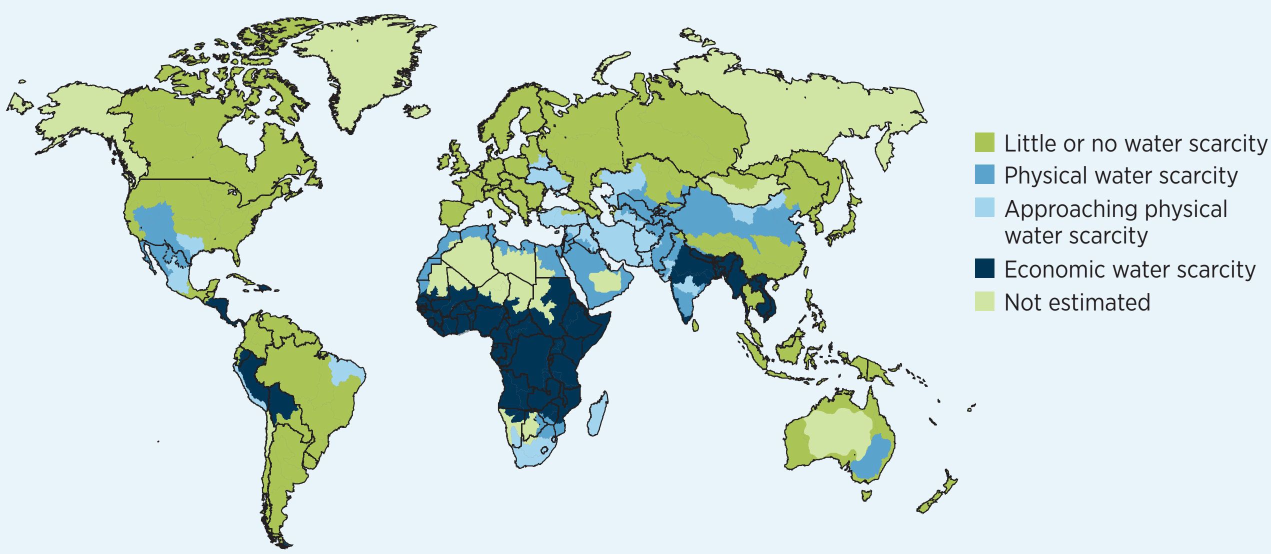
15.3.2 Managing uncertainty and risks

Managing the irreducible uncertainties that affect water supply, demand and the policy context is a significant component of an effective water resources management strategy. Approaches to risk management offer well-developed methodologies for addressing uncertainties associated with hazardous events. There is growing recognition that many uncertainties can offer opportunities in addition to risks (e.g. de Neufville, 2002); for example, unexpectedly high flows may offer opportunities to generate additional water service benefits (such as hydropower) if water managers are prepared to address such an uncertainty.

A general framework for risk management can be described in three steps: hazard characterization, risk assessment and risk mitigation. The first step is to characterize a given event, often considered a hazard, in terms of the impacts or consequences it may have. The next step, risk assessment, involves actual calculation of the risk – defining risk as the product of the probability of an event and the consequences of that event. The final step is the development of a strategy for addressing the risks identified and quantified. Cost–benefit analysis has traditionally been used in the development of such a strategy and the process of risk quantification accommodates a quantitative cost–benefit analysis. However, if there are costs or benefits that are not easily quantified then other multi-objective decision-making methods may be needed.

FIGURE 15.5

Global physical and economic water scarcity



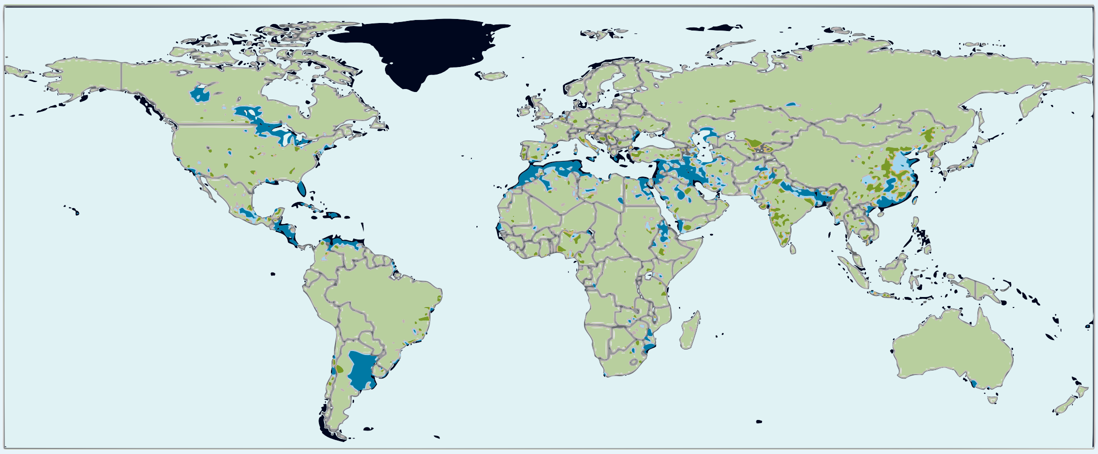
Definitions and indicators

- Little or no water scarcity. Abundant water resources relative to use, with less than 25% of water from rivers withdrawn for human purposes.
- Physical water scarcity (water resources development is approaching or has exceeded sustainable limits). More than 75% of river flows are withdrawn for agriculture, industry, and domestic purposes (accounting for recycling of return flows). This definition – relating water availability to water demand – implies that dry areas are not necessarily water scarce.
- Approaching physical water scarcity. More than 60% of river flows are withdrawn. These basins will experience physical water scarcity in the near future.
- Economic water scarcity (human, institutional, and financial capital limit access to water even though water in nature is available locally to meet human demands). Water resources are abundant relative to water use, with less than 25% of water from rivers withdrawn for human purposes, but malnutrition exists.

Source: Comprehensive Assessment of Water Management in Agriculture (2007, map 2.1, p. 63, © IWMI, http://www.iwmi.cgiar.org/) (from an International Water Management Institute analysis using the Watersim model).

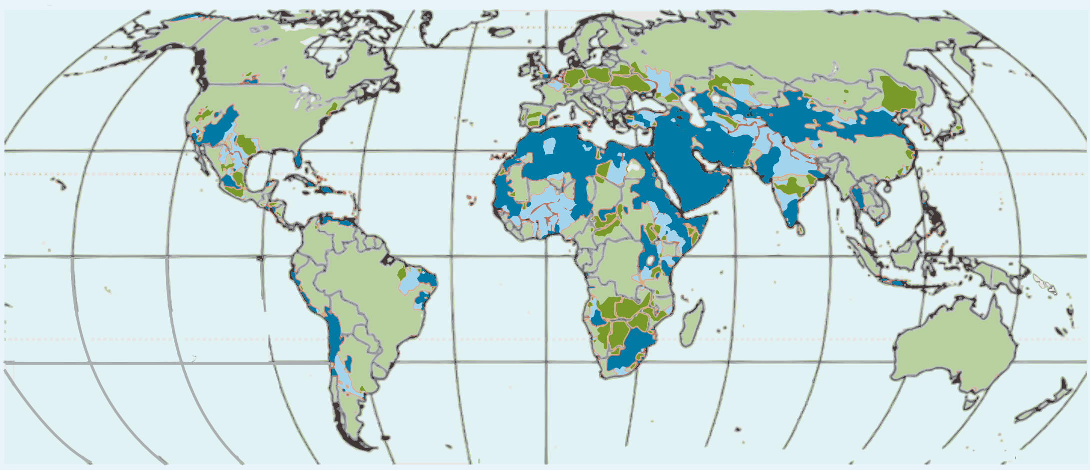
FIGURE 15.6

Projected per capita water availability in 2050



Very Severe Water Stress | Severe Water Stress | Some Water Stress | Adequate Water Supply

2050s



Million litres available per person per year

Less than 0.5 - Extreme stress | 0.5 to >1.0 - High stress

1.0 to >1.7 - Moderate stress | 1.7 and over - No stress | No data

The top panel shows a watershed basis using the most detailed digital basin boundaries available, outputs of precipitation minus evaporation (as a proxy for runoff) from the CCSM3 climate model, and population based on a combination of Global LandScan 2007 current population distribution and downscaled CIESIN country-level growth projections. 'Very severe water stress' indicates that <500 m^3 per person per year of freshwater is projected for the basin; 'severe water stress', 500–1000 m^3 per person per year; 'some water stress', 1000–1700 m^3 per person per year; and 'adequate water supply', >1700 m^3 per person per year. For further details, see http://www.ornl.gov/sci/knowledgediscovery/QDR/water/Glbdetbsn_WA2050_A2p-e_A2pop.png.

The bottom panel was prepared by Martina Floerke and colleagues at the Centre for Environmental Systems Research, University of Kassel, Germany for the BBC using the UK Met Office Hadley Centre generated projections of future temperature and rainfall along with their water resources model, waterGAP (http://www.usf.uni-kassel.de/cesr/).

Both top and bottom projections are for same assumptions of climate change mitigation strategies (A2 scenario; see Nakicenvoic et al., 2000) and aggressive population growth. These indicate there are different ways to make water availability projections (using different models and scenarios). Models are constantly improving, generating new information. Additional research efforts are required to update our knowledge concerning possible future conditions.

Climate risks are particularly relevant to water resources management and their nature warrants some discussion. Some climate risks have a degree of predictability if, for example, they are influenced by a predictable climate phenomenon such as ENSO. Any such predictability should be investigated during the hazard characterization and risk assessment steps of risk management. Climate risks may also be related to climate opportunities and a wider view of climate risk management, such as consequence or uncertainty management, should be embraced. Finally, the advent of anthropogenic climate change and the recognition of the nonstationarity of hydrological records present special challenges to traditional approaches to risk management. The calculation of probabilities associated with climate or hydrological events is confounded by nonstationarity. The historical record is no longer considered representative of the future, and projections from general circulation models (GCM) are not yet able to produce reliable predictions. As a result, methods that depend solely on accurate estimations of probability face large shortcomings.

Given the uncertainties associated with risk estimation, there is a need to consider methods for handling the potential increasing risks. One method is to identify, consider and manage residual risk. Residual risk refers to those risks that are not directly addressed by a risk management strategy. For example, low risk events may not be directly addressed because the cost of addressing them exceeds the benefits of doing so. However, because estimates of low risk events are made with unreliable probability estimates, it is possible that residual risks are actually significant.

Also relevant is the concept of surprise. A surprise is generally understood to be the occurrence of an event that has a low probability relative to other events that could occur. Such events are typically not planned for. Again, because the probability estimation may not be reliable, it is worth considering how such events would be managed if they were to occur, even if nothing is invested in directly managing their occurrence. Doing so would improve the robustness of a particular plan – a robust plan being one that works well enough under a wide range of possible futures rather than just for a best guess estimate of the future. The utility of robustness as a planning criterion reflects the growing awareness of the inability to predict the future (Brown, 2010).

Institutional complexities inhibit flexibility in planning. Large and old institutions in particular tend to have entrenched rules and stakeholders who resist change and science- and knowledge-based decision-making. Developing countries may have a comparative advantage in this regard in that as they are developing institutions they can instil flexibility in them and learn from the drawbacks of matured systems. In the Philippines, progress has been made in improving reservoir performance in the city of Manila due to the willingness of competing water users to consider new approaches to managing drought, including the use of seasonal climate forecasts (Brown et al., 2009). Progress is also possible in mature systems, especially when new information provides an opportunity for reconsideration of past assumptions. The Colorado River water resources management system is a good example. Methods such as Bayesian networks in which all the participants and their probabilistic interactions can be represented and the system performance assessed provide an excellent framework for a participatory solution (Bromley, 2005). The report from the NeWater project (http://www.newater.info) provides an excellent summary of the identification of major sources of uncertainty in integrated water resources management practice (van der Keur et al., 2006).

15.3.3 Emerging opportunities for managing uncertainty

There is a growing list of methodologies available for addressing the new challenges to water resources management. Those described below are in various stages of development but most are still nascent in their practical application. Realizing the full potential of these innovations requires a collaborative effort between the research community and the practicing water management community.

Observations, models and forecasts

The ability to monitor all aspects of the hydrological cycle has never been stronger. Remote sensing, ground-based monitoring and modelling techniques that allow real-time observations and forecasts at multiple time scales are new and potentially important tools to improve water resources management. However, gaps between the production of this information and its use in practice are wide.

Seasonal climate forecasts are increasingly skilful and there are several agencies that provide probabilistic seasonal forecasts for the entire globe. Innovative tools can translate these seasonal forecasts to hydrological and hydroclimate forecasts. For example, researchers have established connections in river basins around the globe between streamflows and large-scale climate forcings, particularly ENSO, PDO and the Pacific North American (PNA) pattern (Grantz et al., 2005; Regonda et al., 2006 and references therein). Using these connections, novel forecast methods have been developed to produce skilful streamflow forecasts at a few months lead time (e.g. Hamlet and Lettenmaier, 1999; Clark et al., 2001; Grantz et al., 2005; Regonda et al., 2006). Additionally, new stochastic simulation techniques (Rajagopalan et al., 2009) can be used to generate ensembles of hydrological scenarios in a water resources system conditional on large-scale seasonal climate forecast. The ensembles can be used in a decision tool to provide estimates of system risks at the seasonal to interannual time scales and thus enable efficient decisions. A good demonstration of these ensemble forecasts can be found in Grantz et al. (2007) and Regonda et al. (2011).

Paleo data

Historical and paleo reconstructed streamflow and climate data can be a valuable resource to quantify historical climate risk. For instance, on the Colorado River, long paleo reconstructions of streamflow indicate a much higher frequency of dry spells and low flows relative to the streamflow in the twentieth century (Figure 15.7). The paleo data provide a more realistic estimate of the drought risk than the historical observational record alone. For example, the recent prolonged drought (2000–2010) on the Colorado River appears to be highly unusual based on the observed data but quite common based on the long paleo reconstruction. There are emerging methods to combine observed and paleo information to obtain robust risk estimates (Prairie et al., 2008).

Decadal-scale patterns of variability

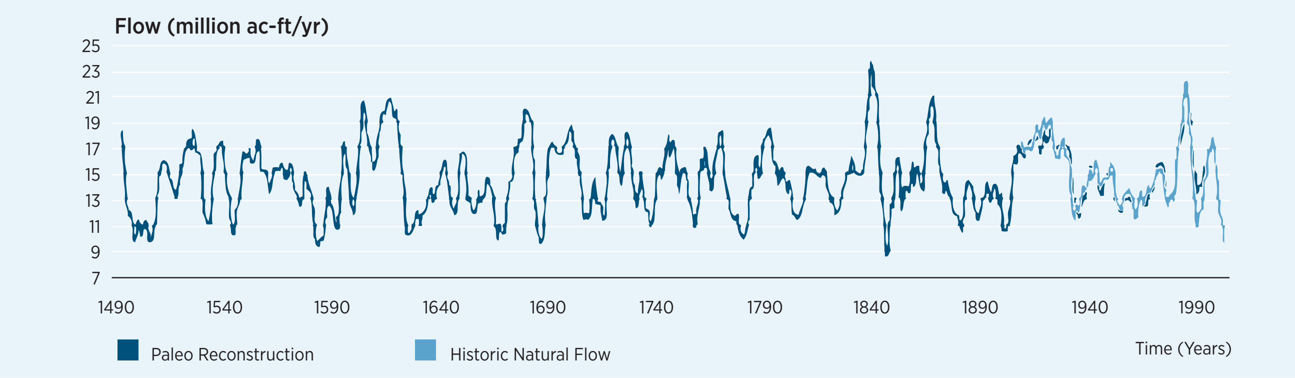
The paleo record affords a long view of hydrological variability that is not possible with the observed hydrological record. Recent and current research based on wavelet-based spectral analysis of paleo data reveals decadal-scale patterns of variability that correlate with large-scale multidecadal climate forcings such as the PDO and AMO described earlier. Better understanding of these modes of variability could enhance water resources management. The existence of decadal-scale variability in the historical hydrological record implies that a water resource system could benefit from flexibility to manage periods of relatively greater and less water availability.

Dynamic operational strategies

Traditional water resources management principles are based on the assumption that the probability distribution for hydrological states is the same every year; that is, the assumption of climatology that the long-term statistics are dominant in every year. For example, reservoir rule curves identify the optimal storage levels at various times of the year that best meet operating objectives, considering the time-varying hydrological conditions. Storage is drawn down before expected periods of high inflows; conservation storage is built up in anticipation of an irrigation season or a period of high hydropower demand. A typical reservoir guide curve is shown in Figure 15.8. Such curves are designed – using the probability distribution of the period of record hydrology – to provide acceptable levels of risk and reliability in meeting operational objectives and avoiding damage or catastrophe.

FIGURE 15.7

Paleo reconstruction of the Colorado River streamflow



Note: One acre-foot is 1,233 m³.
Source: Based on data from Woodhouse et al. (2006) and Prairie and Callejo (2005).

Improved forecasts and understanding of multi-year variability as described above provide a refined understanding of the probability distribution seasonally and annually. A seasonal forecast may indicate a much higher than normal probability of low flows. This could be linked to ENSO or other climate signals and have multi-year effects. Similarly, the ability to forecast extended wet and dry periods may soon be possible as a result of decadal-scale forecasting research (Nowak, 2011). These scientific advances make possible the use of dynamic operational strategies such as reservoir or water system rule curves that change in response to forecasts or observations; flexible water allocation and pricing approaches, such as in response to scarcity; and the use of economic mechanisms to facilitate water exchanges. Adaptive reservoir operations, wherein rule curves are modified to produce more effective management given improved streamflow forecasts, are gaining recognition (e.g. Bayazit et al., 1990; Yao and Georgakakos, 2001).

Adaptive management

Adaptive management is a method used to address the uncertainties associated with climate change, other hydrological change, and our limited ability to correctly anticipate the future in complex water resources systems. The approach was developed in ecology. The general principle of the approach is 'learning by doing' and it emphasises monitoring and the ability to change decisions and update hypotheses on the basis of observations. It can be appropriate in cases where reversible decisions are possible, so that a decision may be changed as climate and socio-economic conditions evolve and a better understanding of the system is achieved. Sankarasubramanian et al. (2009) demonstrate that utility of climate information even of modest accuracy, when coupled with adaptive operations, can benefit water allocation projects with high demand–to–storage ratios as well as systems with multiple uses constraining the allocation process. The ability to ingrain flexibility into a system improves the opportunities for making use of adaptive management principles.

Scenarios-based approach

A common approach to dealing with the implications of climate change is the scenario-based approach. A small number of internally consistent visions of the future are created and plans are evaluated according to how well they perform under these scenarios. Projections from GCM represent internally consistent climate scenarios that are used in the planning process. The GCM projections are converted to hydrological variables through a process that includes bias correction, resolution increases and hydrological modelling, and these variables drive models of the water resources systems. Often, extreme points of the range of GCM projections are chosen to attempt to capture the range of GCM uncertainty, although the true range of climate uncertainty remains unknown. Recent examples of this approach include Traynham et al. (2011), Vano et al. (2010*a*, 2010*b*) and Vicuna et al. (2010). A downside of this approach is that water planners struggle with the very wide range of impacts represented by the scenarios, which often include negligible and severe impacts that are considered equally probable. It is difficult to design a plan that addresses all scenarios: the costs of addressing some scenarios are often exorbitant, and the analysis provides no information as to which is more likely.

Robust decision-making methodologies

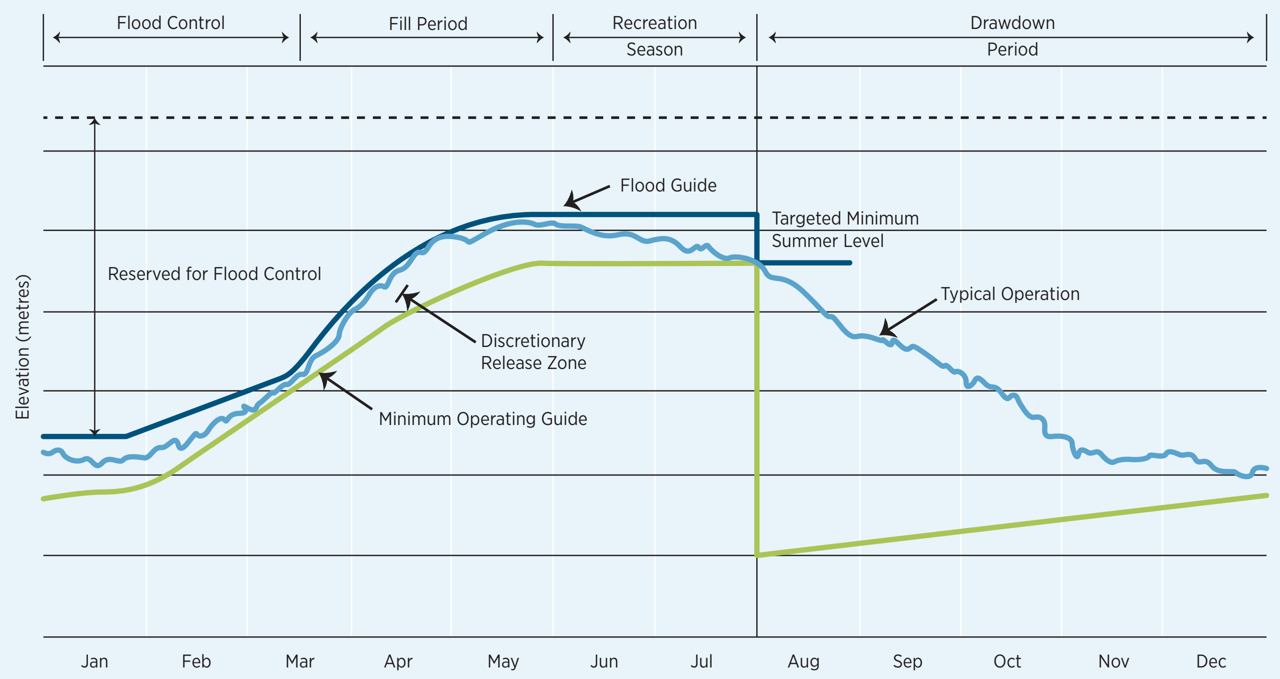
Water resources planners and policy-makers have long understood that most decisions are made under considerable uncertainty related to the future. Nonetheless, anthropogenic climate change raises issues that are different from the typical uncertainty with which water planners are familiar. In particular, assumptions related to the use of the historical hydrological record are jeopardized by the prospect of changing climate. On the one hand, the water planner is informed that 'stationarity is dead' (Milly et al., 2005) and the usual use of the historical record for planning is no longer valid. On the other hand, climate change projections from general circulation models (GCM) are acknowledged to be too uncertain to be used for planning purposes and are associated with significant biases. How are decisions to be made when the future is characterized not only by uncertainty but also by two or more potentially contradictory visions of the hydrological future? A variety of approaches have emerged that attempt to address decision-making under climate uncertainty: see Box 15.2.

Information and communication technology

Advances in information and communication technologies offer great potential for improving the management of water resources. The low cost of these technologies has made them ubiquitous, including widespread use in developing countries. Potential applications include forecast transmittal, early warning systems , and crowd sourcing for data collection and monitoring.

FIGURE 15.8

Example reservoir rule curve showing drawdown for spring floods, filling as the flood season subsides, and maintenance of summer levels for water supply, recreation and hydropower production



Advanced decision support systems

The application of many scientific advances, such as probabilistic forecasting, requires a decision support system in which current and future states of the hydrological system can be modelled, stochastic hydrology that reflects a wide range of assumptions as described above can be generated, and various management and infrastructure alternatives can be evaluated. Decision support tools should support the quantification of risk and reliability and offer the ability to measure performance of a management plan with respect to agreed-upon criteria such as the reliability of supply and the risk of damage to the human or ecological systems. Advanced decision support systems (ADSS) must enable the participatory involvement of a range of scientific, government and management agencies as well as various stakeholders. Such systems have been developed and applied successfully in several basins and are under development in others across the globe.

15.4 Hot spots

15.4.1 India

India faces an unprecedented crisis in the next two decades. Today, major urban areas are unable to provide a reliable and regular water supply. Industrial and energy development face water constraints. Scarcity of water for irrigation is a leading concern of farmers. This can be seen in agricultural water stress maps (Columbia Water Center, n.d.). Of particular concern is that the water stress dramatically increases with multi-year drought. This threatens the country's food and water security. Mighty rivers, such as the Ganges, are significantly depleted over much of the year, and highly polluted over much of their course. Life (biodiversity) abundant in India until as recently as the 1990s is now seriously threatened. Aquifers, the resource of choice due to subsidized energy for pumping, present variable stock and quality. Not surprisingly, aquifer depletion and inefficient water use are now endemic. Uncertainty as to what climate change portends for the water supply is a concern, but the needs for food of a growing population will likely determine the shape of the water crisis in the country. The dramatic natural climate variability (seasonal to interannual to decadal to century scale) and its spatial manifestation as floods and droughts across India poses a serious threat in this context as water stores that could normally buffer against such variations are exhausted and no infrastructure or multi-scale coordinated planning efforts are implemented.

The World Bank warns of a turbulent water future for India absent dramatic coordinated government investments in water infrastructure, governance and agricultural productivity (Briscoe, 2005). The International Water Management Institute (IWMI) talks of taming the anarchy of uncontrolled groundwater exploitation by the population as a whole, and proposes investments in groundwater recharge among policy reforms (Shah, 2008).

Despite these warnings, rather limited in-depth analyses and projections of the water resources of the country, sectoral and ecological demands, and potential solutions exist. Controlled access to the detailed data needed to reconstruct the past and project the future and a lack of institutional support for interdisciplinary research into long-range water resources planning and management are key factors contributing to the situation. Non-government organizations are active lobbyists and implementers of local solutions (e.g. rainwater harvesting, well provision, water treatment, sanitation training and water data provision) but typically do not come close to meeting the needs of a national, state and local strategic analysis.

15.4.2 Western USA

Western USA is mountainous, predominantly semi-arid and receives its water supply from snowmelt. Its population steadily increased during the latter half of the twentieth century. The large population centres are in the south-west desert, while their water is supplied by the Colorado River, which originates in the higher elevations of the Rocky Mountains far to the north. The water in the river is divided among seven basin states and two countries (USA and Mexico); thus, water management is highly contentious.

BOX 15.2

Decision-making under climate uncertainty

An emerging approach to planning under climate uncertainty focuses on providing the specific information needed to inform a decision process. These decision-based approaches typically apply decision analytics to the planning process to identify the conditions that favour a particular decision over another.

The first approach is known as identifying and implementing **'no regrets' decisions**. The idea is that there are decisions that will work well regardless of the degree of climate change or its attributes. The decision pays off for the historical record and for the anticipated climate change. Decisions such as this that are essentially insensitive to future climate are straightforward to make – the challenge is identifying them. Based on the degree to which water managers continue to struggle with the implications of climate change, no regrets decisions that adequately address these climate concerns are rare.

Robust decision-making is a decision-based approach that uses GCM projections as scenario generators that incorporate a variety of decision inputs. (Lempert et al., 2006) and addresses 'deep uncertainty' by favouring management plans that perform well over a range of possible future conditions (Brekke et al., 2009). It uses clustering techniques to identify the conditions that favour particular decisions and to assess the robustness of a decision by varying the assumptions that underlie those conditions. The objective is to identify decisions that are superior regardless of the future climate that is assumed.

Decision-scaling uses sensitivity analysis to identify the climate conditions that favour one decision over others (Brown et al., 2010). Information from multiple GCM super ensembles and historical climate analysis is tailored to estimate the relative probability of those conditions compared to the climate conditions favouring alternative decisions. Risk management strategies are then developed to address the implications of low probability outcomes. In all cases, the process begins with the identification of the key climate information that causes a particular decision to be favoured over others. The hope is that the identification of these factors may reveal that they are less uncertain than the spectrum of climate change possibilities as a whole. This allows even uncertain climate change projections to be able to offer valuable information for the planning process.

Adaptive management can be coupled with robust decision-making by continually monitoring the performance of a robust plan. At intervals in the future, if performance decreases, the plan can be modified to improve its performance. The modification would be made with improved knowledge of future possible conditions. An approach that applies decision-scaling to adaptive management is currently being adopted in the plan for the regulation of outflows from Lake Superior (Brown et al., 2011).

The river has extensive storage (almost four times the annual average flow in the river), which is managed by the United States Bureau of Reclamation (USBR), mandated to manage the water resources of the Colorado River basin in the USA and coordinate water delivery obligations with Mexico, under a complicated set of decrees and rules known as the 'law of the river'. The law of the river worked well for much of the twentieth century, when demand was much lower than supply. But a 'perfect storm' comprising economic growth, increasing population and increasing water demands, coupled with severe sustained drought in the recent decade, is stressing the physical system and the agreements. Paleo reconstructions of streamflow in the basin indicate drier epochs with regular frequency. In fact, they indicate that the twentieth century, when the law of the river was drafted, was one of the wettest. Climate change projections indicate a substantial decrease in annual average streamflow, which will only exacerbate the situation. Many studies (recently Rajagopalan et al., 2009) underscore this and also suggest that flexible and innovative management of the system and collective stakeholder participation can instil effective adaptive management practices that can help mitigate the risk. Studies indicate that the region is likely to experience severe water supply crises in the not-too-distant future if management practices are not modified (USBR, 2005).

15.4.3 West Africa: Niger basin

The Niger River basin is a transboundary basin covering significant portions of nine countries in West Africa. Approximately 100 million people are dependent in some way on the river – for livelihood, trade, transportation and food. The basin is facing complex problems of poverty and low productivity, and it is characterized by severe water constraints, including water-borne diseases and extreme weather events such as floods and droughts. Managing this river system has been challenged by the growing competition for water among urban, industrial, agricultural and ecological users, as well as by the day-to-day, intraseasonal and interannual vagaries of climate variability and climate change. Past interannual variability is large in magnitude compared to any projected climate changes. Within this context, a climate risk assessment of the infrastructure investment plan has been conducted (Brown, 2011).

Due to the great uncertainty of the future climate, a decision-scaling approach was applied that begins with an assessment of the potential impacts of hypothetical climate changes and then utilizes climate information to assess the likelihood of problematic climate changes (Brown, 2011). The resulting analysis indicated that the investment plan was largely well prepared for moderate climate changes or less. Only very large reductions (about 20%) in precipitation would pose significant impacts. The subsequent climate analysis revealed that such changes are not common in climate projections for the region and thus are considered to have a low likelihood. To enhance its preparedness for future climate variability and change, the use of seasonal hydrological forecasts is currently being investigated as an additional adaptation strategy.

15.4.4 East Africa: Nile basin

The Nile, the longest river in the world at about 6700 km, drains about 3 million km^2 and runs through 10 riparian African countries. The Nile comprises two main river systems: the White Nile and the Blue Nile. The White Nile has its source in the Equatorial Lakes Plateau where it originates above Lake Victoria, the second largest freshwater lake in the world, and supports populations and ecosystems of six Eastern Africa nations: Burundi, Rwanda, Tanzania, Kenya, Democratic Republic of the Congo, and Uganda. The Blue Nile originates in the Ethiopian highlands and flows west to meet the White Nile at Khartoum in Sudan. The main Nile flows north from this confluence to the High Aswan Dam in Egypt, then continues north and empties into the Mediterranean Sea through a large delta. The total population of Nile basin countries is about 300 million, and more than half of this population is dependent on the Nile. The river supports particularly large populations in Egypt, Sudan, Ethiopia and Uganda. The population in these countries is expected to increase by about 50% in the next 20 years.

The effects of climate change are not certain, although it is likely that arid countries will become warmer as more water will evaporate. Analysts expect that future stresses will be due in great part to population and development pressures, and will be aggravated by climate change. Egypt, for example, is projected to have in 2025 only about half the per capita water availability that it had in 1990.

15.4.5 Australia

Much of Australia's population is confined to a narrow strip along the coastline, which makes urban water supply a major challenge for the present and an even bigger one for the future, as climate change is projected to lead to a reduction in overall precipitation. While many studies comment on the likely reduction in rainfall across the continent in a warmer climate, it is generally accepted that the future will see an increase in evaporation (Johnson and Sharma, 2010), resulting in a significant reduction in the continent's already low water availability. Australia's farming heartland, the Murray-Darling basin, is likely to see a reduction in water supply to serve the demands for irrigation, urban use and industry along with an increase in the vulnerability of migratory birds visiting freshwater wetlands (Hennessey et al, 2007).

15.4.6 South America

South America is a large continent with a wide range of geomorphological and climatic features, such as the desert lands along the western coasts of Peru and Chile, the Andes Mountains in western South America, and the Amazon forest basin in Peru and Brazil. Thus one finds a variety of water resources problems that are typical of certain regions such as flash flooding in many high-gradient mountain rivers, large-scale floods and inundations in large rivers (e.g. the Parana and Amazon basins), and periods of low flows and droughts in many regions.

During the past few years, the economies of several South American countries have been developing significantly, making them attractive for capital investment and growth. One of the reasons for such unprecedented growth has been the mining industry. For example, many regions in Peru have important mineral stock and have attracted the attention of major mining corporations (Salas et al., 2008). While this has brought employment opportunities for thousands of Peruvian workers and has helped boost the regional and national economy, it has also brought a number of concerns related to the impact of mining operations on water resources and the environment. These impacts include effects on the water quantity and quality of nearby streams, depletion of groundwater levels and water flow from springs, and increased soil erosion. In addition, the mining boom has raised concerns about the vulnerability of inhabitants, livestock, wildlife, vegetation, soil and water to any toxic waste that may result from industrial operations and accidents.

An additional water-related problem that has become relevant in many South American countries in the past decades relates to the accelerated 'deglaciation' of the tropical Andes mountains, – due to, it has been argued, the effects of global warming. For example, Peru has lost at least 22% of its glaciers' surface since 1970, affecting some of the water supply in the Peruvian highlands. The White Cordillera, where 35% of Peruvian glaciers are located, have lost about 190 km^2 of ice surface; for example, the Broggi glacier has retreated about 950 m in the period 1948–2004 and the Pastoruri glacier about 490 m in the period 1980–2005 – the latter glacier has been closed to tourism for safety reasons (PUCP, 2008).

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CHAPTER 16

State of the resource: Quality

UNEP-DHI Centre for Water and Environment

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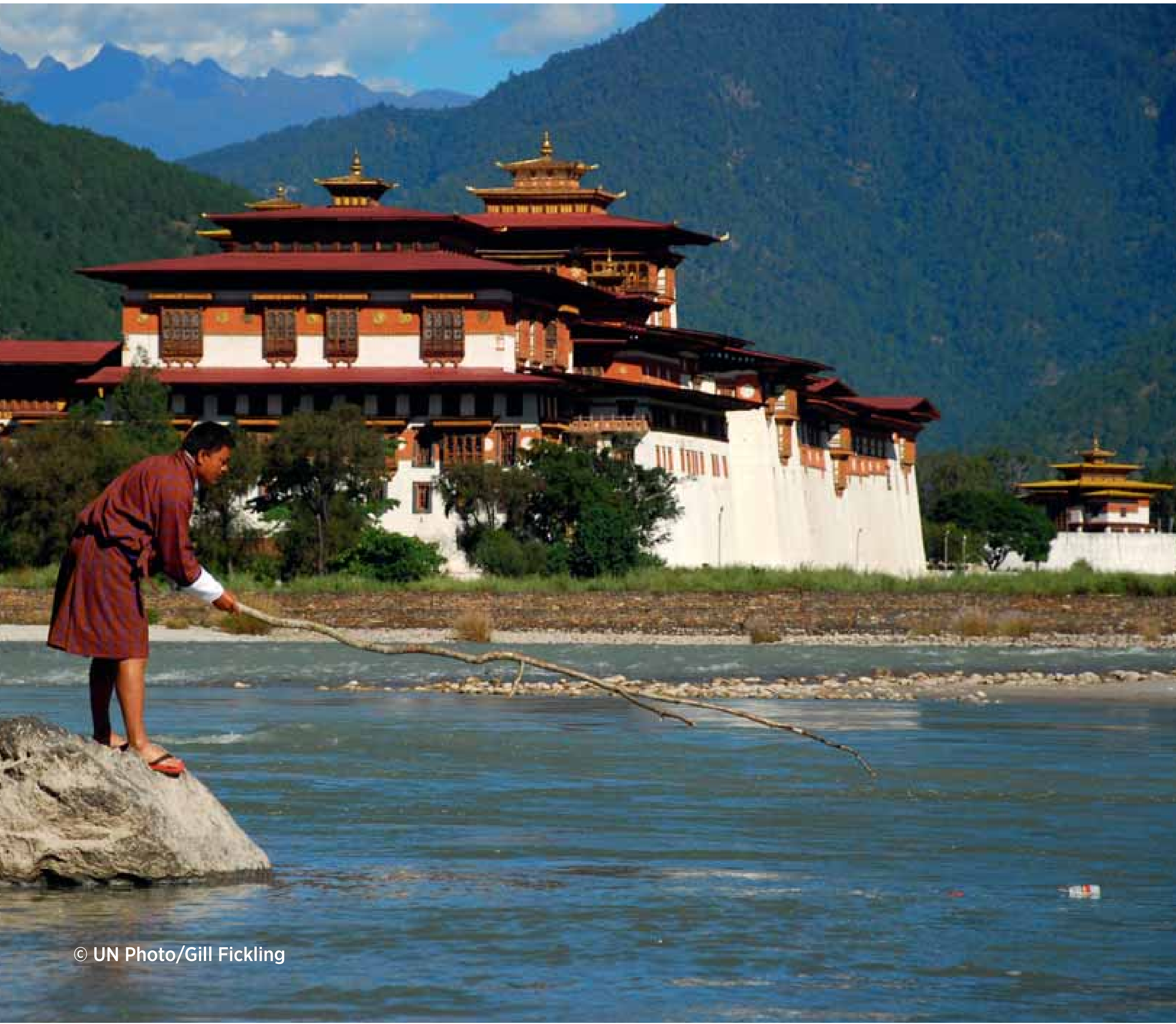


A global water quality assessment framework is needed. While there are many ways to address water quality, from an international to a household scale, there is an urgent lack of water quality data to support decision-making and management processes. An assessment framework should draw on national data sources. The motivation for such a framework is to better understand the state of water quality and its causes; understand recent trends and identify hot spots; test and validate policy and management options; provide a foundation for scenarios that can be used to understand and plan for appropriate future actions; and provide much needed monitoring bench markers.

Water quality is inextricably linked with water quantity as both are key determinants of supply. Water quality degradation is not only a product of external pollutants but is also related to quantity depletion. The problem of water quality can be expected to increase as water scarcity increases. In the past, quality and quantity issues have generally been considered separately. Policy-makers must make a concerted effort to better integrate the two issues. In turn they need the support of the research community who can help to better quantify the problems, as well as the remedial solutions.

Socio-economic development is dependent on water quality. There are well-documented human and ecosystem health risks linked to poor water quality that also threaten socio-economic development. Cost-effective options for collecting, treating and disposing of human waste must still be combined with public education efforts on the environment. Efforts must be directed toward industries using or producing toxic substances. Development of clean technology and substitution processes, combined with cost-efficient treatment options, is a priority. The control of non-point sources of pollution, particularly nutrients leading to eutrophication, is an increasing global challenge. Institutional efforts are also needed to strengthen emergency responses when water sources are threatened or destroyed, and greater attention needs to be given to enforcing existing regulations.

Poor water quality is expensive. The costs of poor water quality can be significant: degradation of ecosystems, health-related costs and their impacts on economic activities, increased treatment costs and reduced property values among others. Conversely, significant savings can be can be made by improving or ensuring that water quality is maintained, such as lives saved, reduced industrial production costs and water treatment costs. More research is needed to better understand and quantify the economic costs and benefits of ecosystem services.

16.1 Introduction

> Safe drinking water and basic sanitation are intrinsic to human survival, well-being and dignity. Without a serious advance in implementing the water and sanitation agenda, there is little prospect of achieving development for all. (United Nations Secretary General Ban Ki-moon, 2008)

Good water quality is an important yet vulnerable development asset, and essential for maintaining ecosystem health. Water quality is inextricably linked with water quantity. Poor quality water that cannot be used for drinking, bathing, industry or agriculture reduces the amount of useable water (UNEP, 2010). Moreover, overuse of water may lead to quality degradation. For example, over-abstraction of groundwater can lead to saline intrusion in coastal areas, or to higher concentrations of naturally occurring toxic compounds (Stellar, 2010), whereas extraction of surface water can lead to high pollutant concentrations during low flow conditions.

The health risks related to drinking water supply and sanitation are generally acknowledged as a priority concern of global significance, as stressed in the above quote by United Nations (UN) Secretary General Ban Ki-moon (2008). Approximately 3.5 million people die each year due to inadequate water supply, sanitation, and hygiene, predominantly in developing countries (WHO, 2008a). Release of toxic wastes from waste dumps and industries is a major threat to the provision of safe water in the developed world.

Ecosystem health has historically been a concern of the richer, more developed countries. However, the increasing recognition of the many benefits of life-sustaining ecosystem goods and services, such as provision of food and fibre, has made ecosystem health and vulnerability an important socio-economic issue, even in the poorest countries.

Poor water quality can lead to significant and varied economic costs, including degradation of ecosystem services; health care; agriculture and industrial production costs; lack of tourism; increased water treatment costs; and reduced property values (UNEP, 2010). For example, the estimated costs of poor-quality water in countries in the Middle East and North Africa range between 0.5 and 2.5% of Gross Domestic Product (GDP) (World Bank, 2007). As the water resources is becoming increasingly scarce in the future, the costs associated with addressing water quality problems is expected to increase and the consequences of not addressing such issues in a timely manner are expected to worsen.

Water quality is a global concern as risks of degradation translate directly into social and economic impacts. Improved management of vulnerability and risk must focus on the unknown and the unexpected in an era of accelerated changes. Given that the world's water quality situation is poorly understood, an important step is to develop a global water quality assessment framework to reduce the information gap and support decision-making and management processes.

16.2 Natural processes combined with social and economic drivers of water quality risks

Water quality conditions are the result of a variety of pressures created by many drivers. A causal chain links drivers to impacts on water quality and further to socio-economic concerns about human and ecosystem health. Identification of these drivers can reduce risks and vulnerabilities through appropriate management.

Drivers are the external causes of changes in water quality. In some instances they may be under the direct control of water managers (like wastewater treatment), although more typically their control is largely beyond the influence of water management. The main drivers may broadly be divided in two separate groups: social and economic. Assessment and consensus on the primary causal chains between drivers, water quality and public concerns are a precondition for developing actions to address them.

Before considering these drivers in detail, it is worth looking at the role of natural processes.

16.2.1 Natural processes

The hydrological cycle is the most important natural process influencing freshwater quality. For example, atmospheric transportation is a natural mechanism that can influence water quality by carrying and depositing atmospheric pollution from one location to another.

Sulphur emissions from fossil fuels can be transported over long distances and precipitate as acid rain. In sensitive lakes and rivers with limited buffer capacity, they may cause acidification on the ecosystems. Sulphur emission control has significantly reduced the issue of acid rain in developed countries, although many power plants still lack proper treatment methods.

Climate processes and associated climate variability and change influence the hydrological cycle. Managing risks associated with climate change is complicated by the challenges of determining the resulting impacts. It is reasonable to expect that the global temperature will rise by more than 2°C, and perhaps by more than 3°C, by the year 2050. The Intergovernmental Panel on Climate Change is predicting major risks for serious impacts, although it emphasizes that there are still major uncertainties in its forecasts (IPCC, 2008).

Many impacts may not manifest themselves for several decades, during which time promising progress could be made. Nevertheless, some issues need immediate attention in regard to risk management, as there are clear indications that climatic events are becoming increasingly erratic and violent. Major floods can destroy safe water supplies and sewage treatment plants, leaving communities with contaminated waters. Heavy rains and floods can increase erosion and sedimentation, while forest fires during droughts can also increase erosion risks.

Droughts and extreme low flows in water systems reduce ecosystem capacity to absorb and process contaminated waters. Estuaries may become affected by increasing saltwater intrusion, as in the Murray-Darling in Australia (Box 16.1), while sea level rise can increase salt intrusion, affecting major urban water supplies, as well as freshwater ecosystem stability and productivity.

BOX 16.1

Risks of salinity intrusion threaten the water supply of Adelaide, Australia

The Murray-Darling Basin (MDB) covers over 1 million km^2, covering four states in Australia, with the city of Adelaide at its mouth. Part of the agreement to manage the basin is to ensure the salinity at Adelaide is less than 800 electrical conductivity (EC) at least 95% of the time. In the 2000s the MDB experienced some of the lowest recorded rainfalls in the last 100 years, reducing river flows and Adelaide's water supply. The drought has highlighted the increased risks of salinity intrusion into the estuary under changing climatic conditions. Response options include ensuring more flow reaches the mouth, but this water is under high demand from upstream users, hence requiring a catchment-wide management approach.

Source: Adamson et al. (2009)

16.2.2 Social drivers

Social drivers have received little attention in water management efforts. Many emerging issues in water quality management are strongly related to social drivers causing waste discharges and associated water quality problems.

Social and political conflicts may jeopardize water management efforts, particularly in transboundary situations. Agreements frequently focus on water quantity, as it is perceived as more important, and generally easier to measure than water quality. Water quality is often neglected in agreements, although considering and improving water quality could benefit all parties (Eleftheriadou and Mylopoulos, 2008).

Community habits, preferences and consumption patterns bring additional social dimensions to uncertainties in water quality management. Cultural habits of waste disposal are difficult to change, not least in manufacturing enterprises and farming practices. Increasing needs for commodities, such as biofuels and meat products in both developed and emerging economies, put new pressures on already-intensive agricultural activities, and may increase nutrient and pesticide contamination. The production and subsequent waste deposition of an increasing number of complex chemical substances also creates new and unexpected impacts.

Population growth is a well-established driver of human wastewater loads. Demographic forecasts are well-developed, but assessment of future migrations, particularly to urban areas, where more than 50% of the world's population already live, is more uncertain. High population density may create critical pollution hot spots. An estimated 2.6 billion people worldwide live without adequate sanitation facilities (WHO and UNICEF, 2010), and the majority of wastewater in developing countries is discharged untreated into receiving water bodies (Corcoran et al., 2010).

Rudimentary control of solid waste dumping can create substantial risks of leakage of toxic chemical to both rivers and groundwater resources. Even where treatment plants exist, inefficient operation and disposal of waste sludge may contaminate soils and groundwater.

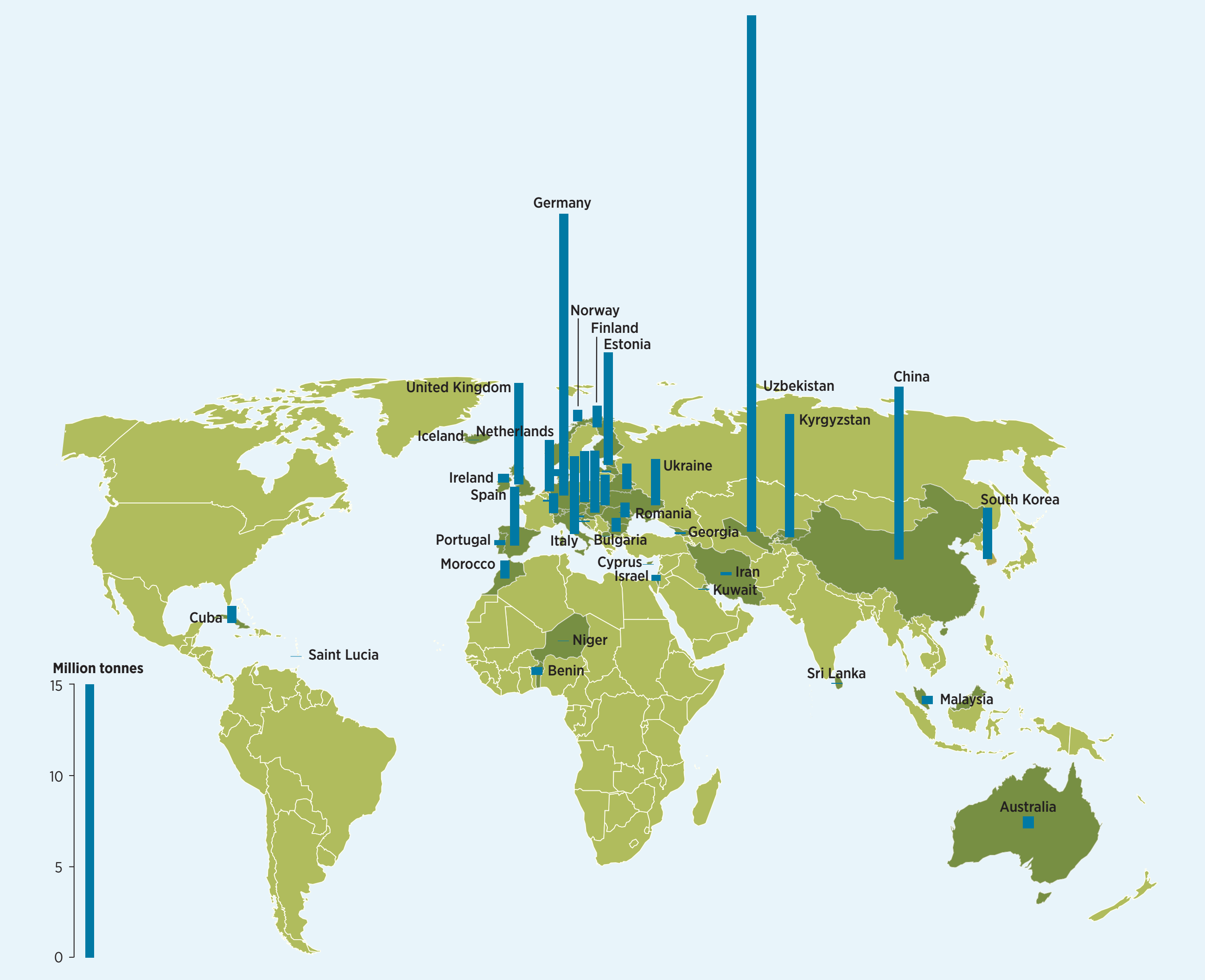
Military conflicts are also drivers that cause migration of millions of people annually, creating increasing risks for developing pollution hot spots and unsustainable pressures on the affected ecosystems.

16.2.3 Economic drivers

The importance of economic drivers is well-established in water management, and several sectors are discussed in separate challenge area reports in this edition of the *World Water Development Report*. The impacts of economic growth on urban settlements, industrial development and food production translate directly into increasing risks and emerging water quality issues. The direct economic drivers are primarily to waste discharges and construction of infrastructure such as barrages, dams and diversions. Agriculture accounts for about 70% of global water use and the potential risk of water quality impacts of agricultural return flows is therefore significant. Agricultural practices cause nutrient contamination, and the sector is the major driver of eutrophication, except in areas with high urban concentrations. Nutrient enrichment has become one of the planet's most widespread water quality problems (WWAP, 2009). Further, pesticide application is estimated to be over two million metric tonnes per year on a global scale (UNEP, 2010). These toxic substances may carry substantial risks to the health and productivity of aquatic ecosystems, although the banning of certain substances and integrated pest management has contributed to reduced risks of pesticide pollution.

FIGURE 16.1

Hazardous waste generation in 2001 as reported by the Parties to the Basel Convention



Source: UNEP/GRID-Arendal (http://maps.grida.no/go/graphic/hazardous_waste_generation_in_2001_as_reported_by_the_parties_to_the_basel_convention, a map by P. Rekacewicz, with source Basel Convention).

Intensive meat production in pig farms and feed lots may also create harmful local water contamination in the form of biological oxygen demand (BOD), ammonia, and nutrients.

Pulp and food processing industries may also create untreated BOD and nutrient rich discharges, potentially leading to oxygen deficits, eutrophication and general ecosystem degradation.

Aquaculture can also be an important source of water pollution. A particular concern is contamination of the natural environment with diseases. Such diseases have seriously degraded large numbers of estuarine ecosystems and destroyed the potential for further aquaculture production.

Industrial development is a key driver behind the risk of hazardous substances contamination. Technological development creates more consumer goods introducing new toxic and hazardous chemicals (Figure 16.1). In the developing world, enforcement of environmental standards is challenging, making it difficult to prevent releases of untreated industrial wastes into freshwater bodies. Globalization has increased the risks of environmental dumping, both in the form of polluting

FIGURE 16.2

Hazardous industrial site, water pollution and mining hot spots in the Balkans

Source: UNEP/GRID-Arendal (http://maps.grida.no/go/graphic/balkans-hazardous-industrial-sites-water-pollution-and-mining-hot-spots, a map by UNEP/DEWA/GRID-Europe).

industries, and as direct exports of chemical wastes from developed or emerging economies to developing countries. Industrial accidents involving dangerous chemicals (not least during natural disasters) also create risks of spills to surface water and groundwater.

Energy production and distribution is a main cause of oil contamination. Hydrocarbons are biodegradable in small concentrations, but major leaks and accidents (including sabotage) create severe contamination risks. Further, shipping of hydrocarbons over the oceans as well as in inland waterways creates also risks of spills. Cooling water releases and bottom water releases from hydropower reservoirs may cause temperature shocks to ecosystems, though can generally be controlled by adequate legislation. Fossil fuel power plants emit large amounts of sulphates, which can contaminate soil and surface water through acid rain. Acid rain was a common problem in industrialized countries in the 1980s, but through legislation on emissions limits and 'cleaning' technology, the situation is vastly improved, though still present. Today, in emerging economies with rapidly expanding fossil fuel power industries, acid rain is increasing. In 2006, one-third of China was affected by acid rain, posing a major threat to soil and food safety (Zijun Li, 2006). While China has implemented programs to reduce sulphate emissions, gains are being offset by increases in nitrogen emissions (Zhao et al., 2009).

A rapidly emerging risk issue is the introduction of biofuels as a climate change mitigation strategy. Aside from the potentially detrimental impacts to food production, this activity involves intensive cultivation practices requiring high use of fertilizers and pesticides. Mining creates contamination risks from hazardous substances and acidification (Figure 16.2). Mine drainage waters can be extremely polluted by salts in the groundwater itself; metals such as lead, copper, arsenic and zinc present in the source rock; sulphur compounds leached from rock; and mercury or other materials used in extraction and processing. The pH of these drainage waters can be highly variable. Some mine drainage is extremely acidic, with a pH of 2–3; other source materials can lead to very alkaline discharges (UNEP, 2010).

Numerous small-scale and primitive mining operations are carried out in developing countries with no or limited control. Artisanal and small-scale mining is practiced in about 50 countries by people living in the poorest and most remote rural areas, with few employment alternatives. An estimated 13 million people are engaged in artisanal and small-scale mining, influencing the livelihood of additional 80–100 million people (Hentschel, 2002). These numbers are likely to increase, caused by higher prices and demands for minerals, both in Organisation for Economic Co-operation and Development (OECD) countries and emerging economies, such as China, India and Brazil.

Forest logging activities are often conducted without efficient erosion control practices jeopardizing both environmental conditions and safe water supplies. This also applies when natural forests are replaced by oil palm plantations for biofuel production.

Tourism generally provides a strong incentive to protect the environment and water quality, because a healthy environment is what attracts its trade. As such, tourism development may become a positive driver, if properly advised and facilitated, but urbanization and lack of proper waste treatment have destroyed recreational assets.

The financial sector is normally not associated with water quality risks. However, the current global financial crisis has had a potentially significant negative impact on private sector investments in clean technology, production safety and wastewater treatment. Despite increased government support to stimulus

BOX 16.2

Financing and cost recovery

Simply maintaining the current percentage of urban population with access to improved sanitation over the next 15 years will require extending access to over 800 million urban residents. However, piped wastewater systems may be too costly to apply on a wide scale, particularly in informal urban settlements, because of infrastructural and geographic cost constraints, as well as the relatively cost prohibitive hook-up expenses for individual households that lack the capacity to pay. As a result, many countries assign a lower priority for sanitation, partly as a result of the high investment costs, and partly because of the lower perceived benefits (individual and societal) of sanitation services, compared to water supply investments. Accordingly, global sanitation investment comprises only 20% of the total invested in the water and sanitation development sector.

Source: Reproduced from USAID (2010).

packages, the crisis has reduced government funds for public mitigation and adaptation responses, such as urban sewage systems and treatment plants (Box 16.2). This particularly applies to international development funding (Committee of African Finance Ministers and Central Bank Governors, 2009 and UNECA, 2009).

16.3 Relationship between water quantity and water quality

Water quality is just as important as water quantity for satisfying basic human and environmental needs, yet it has received far less investment, scientific support and public attention in recent decades, even though the two issues are closely linked (Biswas and Tortajada, 2011).

Poor water quality reduces the amount of water available for drinking, industrial and agricultural purposes (UNEP, 2010) (Box 16.3). The more polluted the water is, the greater the cost of treatment to return it to a useable standard.

Excessive pumping of groundwater can impact the water quality through increased concentrations of naturally occurring compounds that become dangerously high as the amount of water dwindles. In India, fluorosis potentially threatens or directly affects millions of people (Box 16.4). Groundwater quality may also be affected by increasing salinity levels as a result of saltwater intrusion into their coastal aquifers, as observed in Cyprus and the Gaza Strip (Stellar, 2010).

Similarly, overuse of surface water reduces the natural flow and increases the concentration of harmful substances present in the water due to pollution. According to Stellar (2010), 'A marked example of this is the… Rio Grande River, where decreased flows in summer months coincide with large declines in water quality. During the dry season, pathogen concentrations increase by almost 100 times.'

It is important to acknowledge that there is a spectrum of quality–quantity interactions. Some water issues are purely quality related; this refers to water sources that are simply over-polluted as opposed to being overused. Other water quality problems have both quantity and quality components, for example in connection with mining activities.

BOX 16.3

Water quality and quantity impacts of mining in Peru

Peru is Latin America's most water-stressed country. Water draining from the Andean highlands serves as a water tower that supports the downstream population and agricultural activities. Many mining concessions are located in headwater areas in the high Andes, and mining can adversely affect water quality downstream, with impacts potentially lasting for generations.

Source: Bebbington and Williams (2008). Photo: Paulo Tomaz at Wikimedia (http://commons.wikimedia.org/wiki/File:Antamina_Mine_Tailings_Pond.jpg)

16.4 Human health risks related to water quality

Reduction of human health risks are important local, national and global priorities, as expressed in the Millennium Development Goals (MDGs). Waterborne diseases are major global killers, taking millions of lives as a direct result of unsafe drinking water, and inadequate sanitation and hygiene.

Major human health risks from use of unsafe surface and groundwater are related to the presence

BOX 16.4

Reduced water quantity equals reduced water quality: Fluorosis in India

Millions of people in India are threatened or directly affected by fluorosis caused by groundwater that contains excessive natural fluoride levels. India's escalating water stress is forcing people to search for water deeper underground, which is more contaminated with fluoride. Fluorosis is also a problem in countries such as Chile, Ethiopia and Uzbekistan to China, where there are an estimated 1.6 million victims.

Source: Shah and Indu (2008).

TABLE 16.1

Estimated deaths of children under the age of five (8.795 million in total)

68% (5.970 million) of deaths were from infectious diseases			
Pneumonia	18%	1.575 million	1.046–1.874 million [UR]
Diarrhoea	15%	1.336 million	0.822–2.004 million [UR]
Malaria	8%	0.732 million	0.601–0.851 million [UR]
41% (3.575 million) of deaths occurred in neonates			
PTB complications	12%	1.033 million	0.717–1.216 million [UR]
Birth asphyxia	9%	0.814 million	0.563–0.997 million [UR]
Sepsis	6%	0.521 million	0.356–0.735 million [UR]
Pneumonia	4%	0.386 million	0.264–0.545 million [UR]

Note: UR, uncertainty range.
Source: Black et al. (2010).

of pathogenic organisms and toxic substances, from municipal and industrial waste discharges as well as storm-generated non-point-source runoff. In a global context, water contamination with pathogenic substances is acknowledged as the most serious risk factor in relation to human health.

Less attention has been paid to risks of runoff from agricultural lands, where health impacts of fertilizers and pesticides may be transferred to humans through groundwater and surface water. The health impact from livestock waste, particularly from intensive farming, is of continued concern (Corcoran et al., 2010). Risks of human health impacts also arise in the food chains of fish and seafood, as noted in Section 4.1.

16.4.1 Waterborne diseases

Most waterborne diseases are related to contamination from untreated wastewater, or sewage (WSSCC, 2008). Sewage refers to liquid waste from private households as well as wastewater from non-industrial and industrial activities. In many parts of developing countries, sewage is dumped directly into local waterways. Untreated sewage contains waterborne pathogens that can cause serious human illness and even death.

Massive efforts have been made to reduce risks of waterborne contamination by establishing piped drinking water supplies in order to reach the MDGs.

Diarrhoea is typically transmitted by the consumption of food or water contaminated with faecal bacteria from an infected person. Although a global issue, it is most extreme in sub-Saharan Africa and South Asia, killing over 2 million people annually (WHO, 2008). Almost 1.5 million of these deaths are children under the age of five, accounting for 15% of all child deaths under the age of five, second only to pneumonia, and more than HIV/AIDS, measles, and malaria combined (Black et al., 2010) (Table 16.1). Less common waterborne diseases include typhoid, cholera, and hepatitis A. While the number of deaths from these diseases is relatively low, the number of cases (17 million annually for typhoid) put a high burden on communities in developing countries.

Drivers to waterborne diseases are strongly linked to population growth, combined with migration to urban centres with a high population density. Lack of finances limits the possibilities to establish costly sewer and treatment systems to handle urban wastewaters. Natural disasters (floods, storm surges, hurricanes, earthquakes) often destroy safe water supplies, leaving the population with no alternative to using contaminated water for long periods.

Response efforts may first consider public education – hand washing is the most vital component of personal hygiene (Pokhrel, 2007).This effort must be combined with appropriate, cost effective options for collecting, treating and disposing of human wastes. There is an urgent need to create more innovative solutions within the financial capabilities of municipalities in the developing world. Innovative financing of appropriate wastewater infrastructure should incorporate the full life cycle of the plants, and the valuation of non-market dividends from wastewater treatment (such as public amenity and ecosystem services) need to be better understood to enable more comprehensive cost–benefit analyses. Institutional efforts are needed to strengthen emergency responses when safe water supplies are destroyed because of natural disasters and conflicts. This will become particularly important with the emerging climate change threats.

16.4.2 Water quality degradation from toxic substances

Compared to the global importance of human waste contamination, the toxic impacts from hazardous chemicals are often of more local or regional concern. Although the number of fatalities is smaller than for waterborne pathogens, the number of people at risk is substantial (Table 16.2). Further, hazardous chemicals in developing countries are often not noticed before their toxic effects have become evident in the population. Toxic substances in water may originate from natural sources (e.g. arsenic), as well as from human sources (e.g. pesticides).

Inorganic pollutants from industrial processes include the toxic metals such as lead, mercury, and chromium. They are naturally occurring, but become a health issue due to anthropogenic contamination. When present in water, they can cause toxic effects, including damage to the brain, kidney, and lungs. They may damage neural networks and cause blood and brain disorders. Poisoning by trace metals typically arise from consumption of contaminated drinking water or food, such as irrigated crops, fish and seafood.

Arsenic in drinking water can cause human organ failure and cancer. Arsenic poisoning of groundwater from natural sources has been found in many countries and it is estimated that approximately 130 million people have been or are still consuming groundwater with arsenic concentrations above the standard set by the World Health Organization (WHO) (Royal Geographic Society with IBG, 2008) (Figure 16.3).

TABLE 16.2

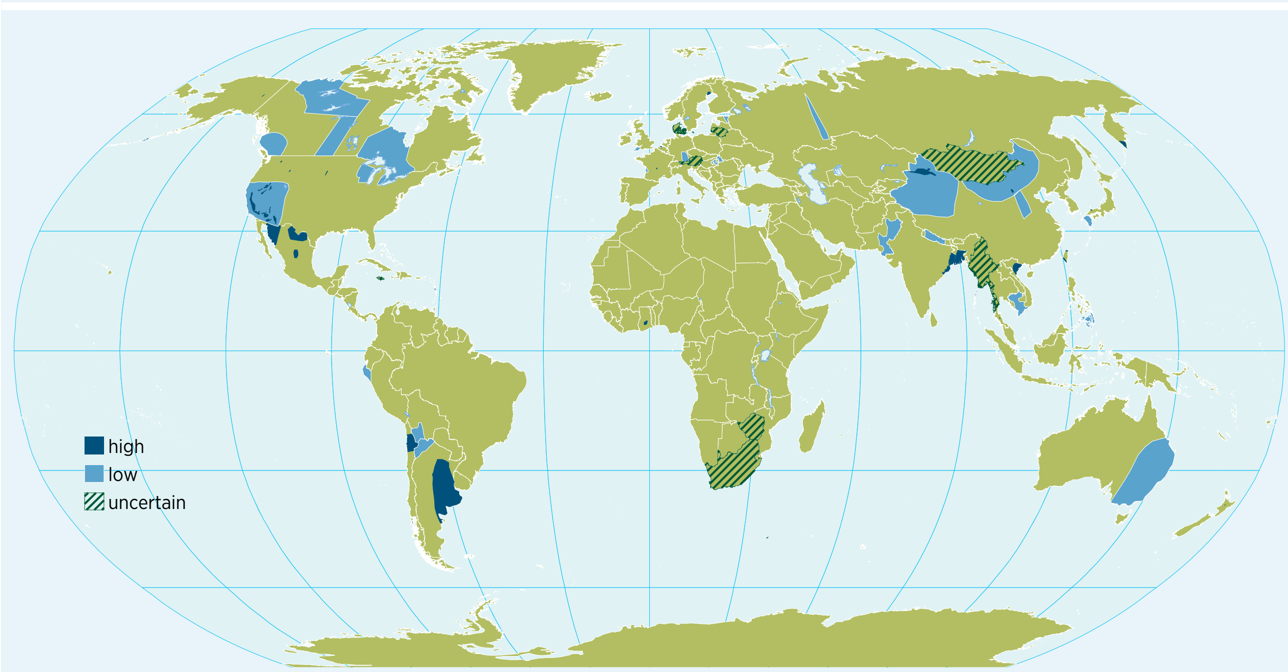
Estimated impacts of toxic pollution

Top six toxic threats:	Estimated population at risk at identified sites (million people)	Estimated global impact (million people)
1. Lead	10	18–22
2. Mercury	8.6	15–19
3. Chromium	7.3	13–17
4. Arsenic	3.7	5–9
5. Pesticides	3.4	5–8
6. Radionuclides	3.3	5–8

Notes: The population estimates are preliminary and based on an ongoing global assessment of polluted sites. The estimated global impact is extrapolated from current site research and assessment coverage.
Source: Blacksmith Institute (2010, p. 7).

FIGURE 16.3

Probability of occurrence of excessively high arsenic concentrations (>0.05 mg per L) in groundwater



Source: Brunt et al. (2004).

Nitrate is a nutrient commonly found in both surface water and groundwater as a result of fertilizer application losses. Although harmless to human health in small concentrations, nitrate may cause harm to infants at levels above 50 mg per L (WHO, 2008). Chloride from seawater intrusions may also render water unsuitable for drinking, though there is currently no guideline value for chloride (WHO, 2008).

Persistent organic pollutants (POPs) are organic compounds resistant to environmental degradation. POPs can remain in the environment for a long time and capable of bioaccumulation in human and animal tissues. POPs exposure can cause death and illness, including disruption of the endocrine, reproductive and immune systems; neurobehavioural disorders, and cancer. POPs include substances such as polychlorinated biphenyls (PCBs), many pesticides (e.g. DDT), as well as certain pharmaceuticals and body care products. PCB use has been banned in the European Union and the United States (USA).

Some of the synthetic chemicals that are found in wastewater containing pesticides and pharmaceuticals are endocrine disruptors (Colborn and vom Saal, 1993) (Box 16.5). The potentially negative effects of these chemicals on humans and human development have been documented, and studies on animals suggest there is cause for concern, even at low doses. Research shows the effects may extend beyond the exposed individual, particularly affecting foetuses of exposed pregnant women and breastfed children (Diamanti-Kandarakis, 2009).

BOX 16.5

Risk of hormonal modifications in ecosystem populations

The effects of endocrine disrupting chemicals (organic chemicals that can mimic natural hormones) on wildlife include the thinning of eggshells in birds, inadequate parental behaviour, and cancerous growths (Carr and Neary, 2008). The feminization of fish and amphibians downstream of wastewater treatment plants, for example, has long been linked to estrogenic pharmaceuticals (Sumpter, 1995), and more recently to pesticides such as atrazine (Hayes et al., 2006). A WHO Global Assessment of the State-of-the-Science of Endocrine Disruptors in 2002 identified the need for better understanding of EDCs and their impacts on humans and ecosystems. However, there is still no global study on the impact of EDCs, partly due to complexities involved in identifying dose–response relationships. While many EDCs have been banned (particularly in Europe and North America), some continue to be used, such as DDT.

Source: UNEP (2010).

Toxic water contamination risks are primarily a function of industrial and agricultural production. Driver uncertainties are related to the particular industrial processes and practices, particularly their waste emissions, including wastewater to solid waste deposits. An important issue is the risk of accidental releases of toxic chemicals, particularly from chemical industries. Intensive agriculture practices (including the Green Revolution) are heavily dependent on pest control, with considerable risk of contaminating both surface water and groundwater. Mining enterprises represent substantial risks for toxic contamination, both from mining waste materials, as well as the mining processes themselves.

Response efforts may primarily be directed toward industries using or producing toxic substances. Development of clean technology and substitution processes, combined with cost efficient treatment options, is a priority component. However, regulations and their efficient enforcement are also needed. Risks of accidental spills must be addressed within the enterprises themselves, but supported by public alarm and response frameworks. Furthermore, handling of solid wastes from production processes must be considered from the perspective of minimizing contamination of waste dumps. Pesticide contamination can be minimized through use of low-impact substances and integrated pest management techniques (UNEP, 2010). Awareness campaigns and extension services on pesticide use are of particular importance. In 1987, the National Union of Farmers and Ranchers (UNAG) in Nicaragua founded the Programa Campesino a Campesino (PCaC), an innovative effort to promote best agricultural practices through peer-to-peer education. Producers from 817 communities are benefitting from the PCaC methodology where the producers share their knowledge and experiences with one another (UNEP, 2010).

16.5 Ecosystem health risks related to water quality

The Millennium Ecosystem Assessment (MA, 2005*a*,*b*) recognized the importance of ecosystem goods and services as an important and multifaceted asset in poverty alleviation, as well as for sustainable economic development. The report changed the focus from simply protecting endangered species to include the livelihoods and income opportunities of the poor dependent on ecosystems for their livelihoods.

16.5.1 Oxygen depletion and fish kills

A healthy aquatic environment maintains a high level of dissolved oxygen (DO), between 80 and 120% saturation. Oxygen demands by microorganisms may deplete the DO to critical levels, causing fish kills and anaerobic conditions in the water column and bottom sediments (Department of Water Affairs and Forestry, 1996). Such conditions can destroy fisheries and seriously harm the ecological structure and the recreational value of the ecosystem (Box 16.6).

Untreated sewage contains high loads of organic material, supporting the growth of microorganisms and increasing their oxygen demand as they decompose the organic matter. Oxygen deficit is related to pollution from human and industrial wastewaters. Therefore, urban centres and industries like pulp producers, abattoirs and pig farms become hot spots for DO deficits in aquatic ecosystems. Figure 16.4 shows the modelled organic loading taking into account different types of sewage treatment only. It shows hot spots in every

BOX 16.6

Bang Pakong pollution destroys valuable ecosystem assets and income opportunities

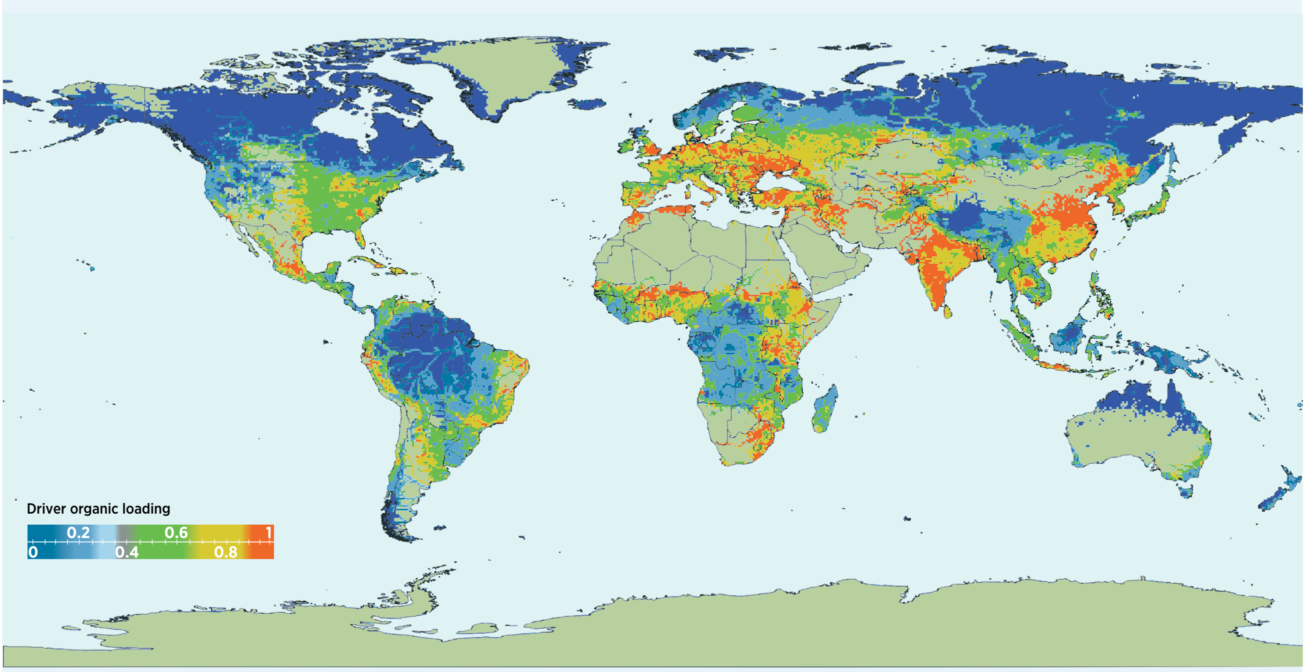
The Bang Pakong estuary has perfect conditions for the river shrimp that is one of Thailand's major delicacies. The estuary is home to endangered species (e.g. the Irawaddy dolphin) and, like many estuaries, plays an important role for both brackish and marine fisheries. However, water quality issues caused by shrimp farming within the estuary are compounded by effluents from catchment activities, including waste water discharges from all sectors. High pollution loads have been reported from different sources: domestic (nearly 6,000 kg BOD per day); industrial (nearly 9,000 kg BOD per day); and agriculture (30,000 kg BOD per day). The development of inland low salinity shrimp farms in the freshwater areas of the basin is an additional pollution threat producing up to 32 million kg BOD per year.

Although several plans have been prepared to address the situation the water quality conditions remain poor. It is recommended to adopt an ecosystems services approach to better realize the benefits of the ecosystem.

Source: UNEP (2008).

FIGURE 16.4

Modelled organic loading based on different types of sewage treatment



Source: Vörösmarty et al. (2010, supp. fig. 2, pp. 3–10.). Reproduced by permission from Macmillan Publishers Ltd.

BOX 16.7

Lake eutrophication in China

Taihu Lake (or Lake Tai) is the third largest freshwater lake in China, providing water to 30 million people. It has a thriving fishing industry and was previously a popular tourist destination. In May 2007 a severe algal bloom and major pollution with cyanobacteria occurred, largely driven by the high levels of industry and development in the catchment, made worse because the lake was at its lowest level in 50 years. The Chinese government called the lake a natural disaster. and banned water providers from implementing price hikes after bottled water rose to six times the normal price. It was reported that the Chinese government had shut down or given notice to over 1,300 factories around the lake by October 2007.

The State Council set a target to clean Taihu Lake by 2012, but in 2010 a fresh pollution outbreak was reported. This highlights the complexities involved in controlling pollution, often with competing political, developmental, commercial, and environmental interests.

Sources: The Economist (2010) and Wikipedia (2011).

region, with particularly large areas affected in central Asia, India, and northern China.

Eutrophication can also cause severe oxygen deficits through the microbial decomposition of dead algal cells.

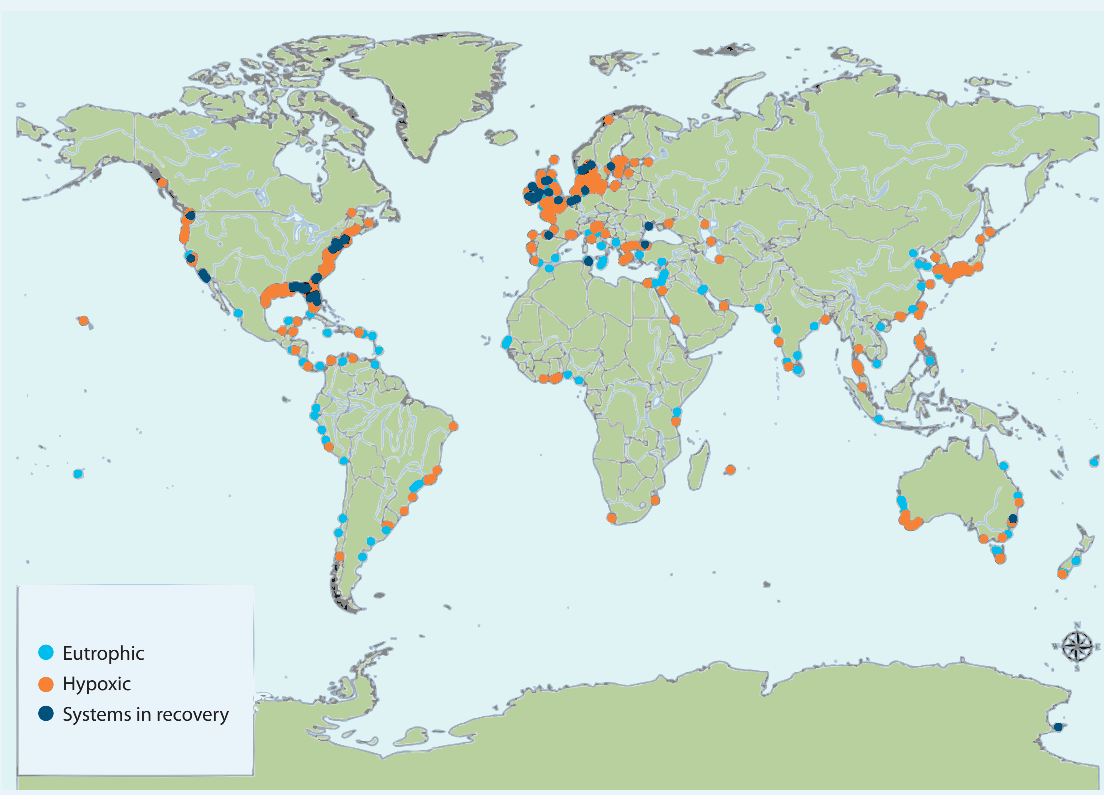
High levels of nutrients like nitrate and phosphate can also destroy the normal biological structures. Often the dominating sources of nutrients are fertilizers, though domestic wastewater also contains nutrients. Agricultural losses are non-point sources, which are difficult to identify, therefore associated with considerable uncertainties and risks (Box 16.7).

Erosion caused by inappropriate land uses (e.g. deforestation) can also become critical sources of nutrients causing eutrophication. As previously noted, an emerging issue is more frequent incidences of forest fires, which may be associated with subsequent erosion.

Unfortunately, there is insufficient data to give a complete overview of eutrophication trends at the global

FIGURE 16.5

World hypoxic and eutrophic coastal areas



Source: Diaz et al. (2010).

level, but it is thought that incidents of eutrophication are becoming more common and more severe. This is supported by Figure 16.5 below, which shows coastal areas suffering from eutrophic and hypoxic (insufficient oxygen) conditions.

Response efforts to urban and industrial point sources are similar to the previously described efforts. Control of non-point sources of nutrients must be conducted in close cooperation with land owners, through extension services and development of appropriate options for reducing contamination risks. The Chesapeake Bay Program, in the USA, which has run for over two decades, has shown that the control of non-point sources is a significant challenge. During this program research demonstrated that atmospheric input was a major contributor to the Bay's declining water quality. Thus, in addition to the watershed, the 'airshed' needs to be considered in an integrated management effort (GWP, 2011).

16.5.2 Ecosystem degradation from hazardous chemicals

Toxic substances that affect humans can also affect ecosystems. Fish kills and changes in biological structures are common impacts of toxic contamination, threatening the livelihood of local communities (Box 16.8).

Metals like mercury, lead and cadmium from industrial and mining wastes are characteristic ecosystem contaminants. Ammonia is a toxic waste product of the metabolism in animals which can lead to fatal poisoning of fish, often with dramatic consequences on local fisheries.

In addition to the direct poisoning of fish, seafood and vegetation, many substances (e.g. mercury, lead, POPs) accumulate in organic tissues, resulting in poisoning if eaten by humans. This bioaccumulation can also lead to toxic chemicals being transported long distances, and must be addressed by quality assurance procedures in the food sector. Irrigation with cadmium contaminated water can accumulate in crops.

Pesticides are by their very definition toxic to ecosystems. Most pesticides are soluble in water, and losses to water resulting from improper use readily translate into threats to both ecosystems and humans. Chemicals such as DDT are toxic to a wide range of animals, in addition to insects, and are highly toxic to aquatic life. Pesticides have particularly serious impacts on fish production in rice fields, an important by-product of traditional paddy systems.

Risk mitigation of toxic contamination of ecosystems is similar to efforts focusing on human health. The drivers are the same, as are many of the response options.

BOX 16.8

The Basel Convention

The Basel Convention was established to address the human health and environmental risks associated with the export of toxic wastes. With the tightening of environmental laws in developed nations in the 1970s, hazardous waste disposal costs increased dramatically. At the same time, globalization of shipping made transboundary movement of wastes more possible, and the trade in hazardous waste, particularly to developing countries, rapidly increased. The convention aims to keep waste as close to the sources as possible, and they can only be exported with prior written notification by the state of export to the states of import and transit. The vast majority of countries have ratified the treaty and it is generally seen as a success, and the Convention Secretariat now works closely with the Rotterdam and Stockholm Conventions. The Convention is legally binding, including reporting national reporting requirements on the movement of hazardous wastes.

Source: OECD (1989).

16.5.3 Ecosystem modifications

Some water quality parameters may appear harmless under normal conditions, but possess significant risks when concentration levels are slightly altered.
This is particularly true for the coastal interface between fresh and marine waters. Minor changes in salinity, temperature or turbidity may catalyse significant risks of changes in the biological structures of estuaries and lagoons providing important livelihoods for coastal communities (Box 16.9).

Salinity is also an important ecological factor. Freshwater species may be evicted with increasing salinity and replaced by brackish or even marine species. Also, many plants are sensitive to salinity – an important issue for irrigation water intakes. The most critical cases of salinity changes occur in the coastal zones, where morphological changes in lagoons and

BOX 16.9

Chilika Lake: slow deterioration and rapid recovery

Chilika Lake is the largest wintering ground for migratory waterfowl on the Indian subcontinent. The highly productive lagoon ecosystem, with its rich fishery resources, sustains the livelihoods of more than 200,000 people. Threats to the lake ecosystem increased through the 1980s from pollution, intensive aquaculture, overfishing, and increased siltation from poor land management. By 1993 the situation became so severe that the lake was put on the Montreux Record (a Ramsar list signifying threats from human activities). In 1992 the State Government set up the Chilika Development Authority (CDA), which facilitated the development of an adaptive integrated management plan with stakeholder participation. Significant national funding supported activities such as catchment conservation, education campaigns, improved socio-economic conditions (e.g. improvement of services), and habitat restoration. Ten years later, Chilika Lake was awarded the Ramsar Wetland Award in recognition of significant improvements. Lessons learned included: (a) danger of unilateral decisions on established rights of stakeholders; (b) vital role of science; (c) importance of coordination and diverse funding; (d) need for long term policies; (e) stakeholder participation can lead to self–initiated good practices; and (f) links between poverty alleviation and ecosystem restoration.

Source: Ghosh and Pattanaik (2006).

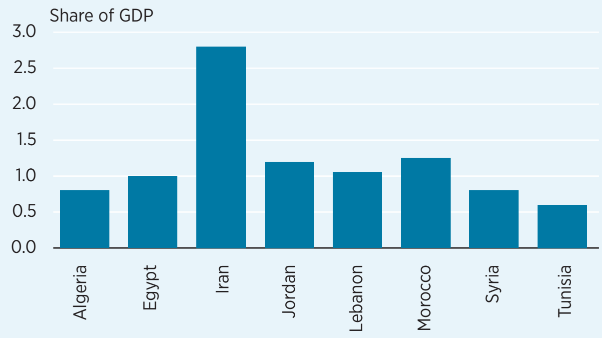
estuaries can cause drastic salinity impacts. Storm surges also may raise salinity in freshwater reservoirs and soil water of low lying agricultural lands.

Many species may be temperature sensitive, particularly during spawning. Therefore, changes in the water temperature may deplete certain species. Increasing water temperature may also compound the impacts of eutrophication. Primary causes of temperature changes are cooling water releases from electricity generation and other industrial activities. However, impacts can be mitigated through legislation and enforcement. Acidity changes may also create changes in the ecosystem structures. Acid rain and acid mining wastewaters have been shown to have adverse impacts on aquatic ecosystems.

Climate change also threatens ecosystems. Sea level rise (or extended droughts) may increase salt water intrusion in estuaries and lagoons, and change the biological structure from freshwater to saltwater species.

FIGURE 16.6

Annual cost of the environmental degradation of water



Source: World Bank (2007, fig. 4.4, p. 109), from various data sources.

A similar effect in relation to invasive species may be caused by temperature changes.

Responses to ecosystem changes depend on an in-depth understanding of the biological processes under transformation. First and foremost, an efficient and targeted monitoring system is needed to detect changes, and if trends are identified, further research must be directed towards understanding the causes.

16.6 Economic costs of poor water quality

Poor water quality may lead to significant economic costs/losses such as reduced ecosystem services; health care; increased agriculture and industrial production costs; lack of tourism; increased water treatment costs; and reduced property values (UNEP, 2010). The estimated costs of poor quality water in countries in the Middle East and North Africa range between 0.5 and 2.5% of GDP (Figure 16.6) (World Bank, 2007). With freshwater resources projected to become increasingly scarce in these and other regions, the costs associated with addressing the resulting problems can be expected to increase.

Increased health has economic benefits to governments and individuals through reduced expenditure on disease treatment and lost time in seeking treatment, and benefits to the agricultural and industrial sectors through improved productivity and fewer expenses associated with employee health care (SIWI, 2005).

Many studies on the health-related costs of poor water quality are in reference to the water and sanitation MDGs, whereby the international community is committed to halving the proportion of people without access to safe water and sanitation by 2015. If this goal is met, it is estimated that 322 million working days per year will be gained, corresponding to nearly US$750 million (SIWI, 2005). Meeting the MDGs on water and sanitation would also result in an annual savings to health sector expenses of US$7 billion. Overall, the total economic benefits of meeting the MDG target have been estimated at US$84 billion (SIWI, 2005). The benefits of wastewater treatment range between US$3–34 for every US$1 invested in sanitation and drinking water (WHO, 2004).

In terms of agriculture, salinized water can reduce crop quality or even destroy it. The use of poor quality water can also have serious consequences on human health. In 2011, several people died from an European *E. coli* outbreak, which was suspected to stem from vegetables that had come into contact with infected water. A strong consumer reaction resulting from a lack of clarity on the source led to thousands of tonnes of vegetables being dumped and an estimated cost to the European Commission of US$300 million to compensate farmers for their losses (Flynn, 2011).

TABLE 16.3

Summary of major risks and their main drivers

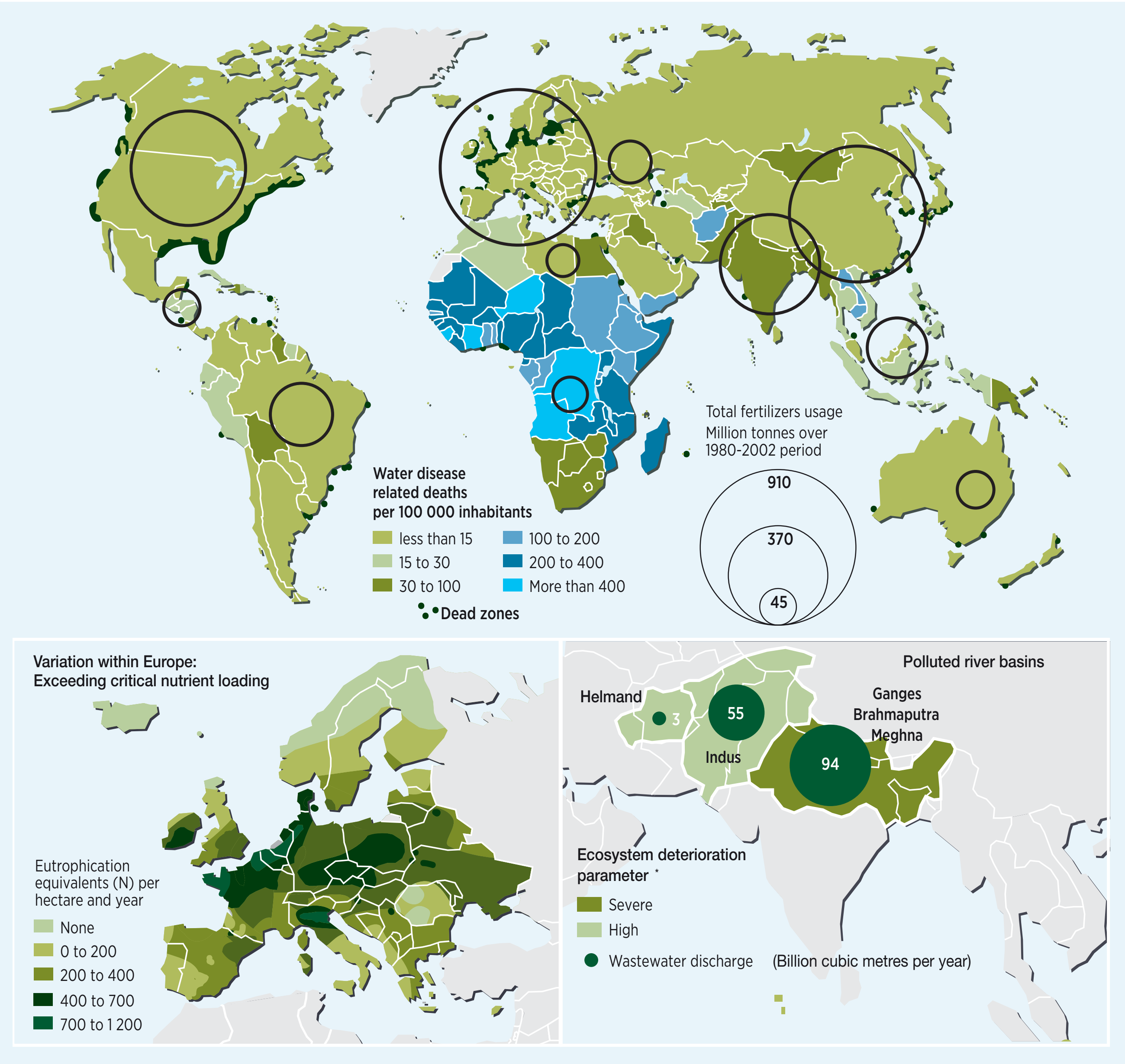
Risk		Main driver			Response option
Human health impact	**Severity**	**Natural process**	**Social**	**Economic**	**Intervention**
Waterborne disease	Millions of fatal cases Increasing waste discharge due to urbanization	Increasing flood disasters damage safe water supply	Urban migration Poverty	Shortage of investment in wastewater treatment	Urban wastewater treatment Low-cost community waste treatment
Toxic contamination	Millions of affected persons Thousands of cases of serious impacts in hot spots Lack of reliable documentation	Saltwater intrusion due to sea level rise and drought	Waste disposal attitudes Poverty	Industrial waste and spills Mining	Industrial waste treatment Clean technology Warning systems Disaster response systems
Ecosystem health impact	**Severity**	**Natural process**	**Social**	**Economic**	**Intervention**
Oxygen deficit and eutrophication	Thousands of km^2 Coastal fisheries decline Recreational value decline	Increasing heat waves and flood erosion events		Intensive agriculture Biofuels Urban wastewater Industrial wastewater	Sustainable agricultural practices Nutrient removal in wastewater
Poisoning	Hundreds of km^2 Fisheries destruction	Increasing flood disasters	Waste disposal attitudes Poverty	Agriculture Urban wastewater Industrial wastewater Mining	Industrial waste treatment Clean technology Integrated pest management
Ecosystem modification	Invasive species increase Invasive pest increase Turbidity increase	Seawater intrusion Heating Erosion after forest fires and floods	Poverty	Agriculture Forestry Urban wastewater Industrial wastewater Hydropower	Sustainable agricultural practices Sustainable forestry Nutrient removal in wastewater

While industrial production is foremost considered to affect water quality it can also be negatively affected by poor water quality. An indication of concern over quality and quantity is the increasing engagement of food and beverage companies, such as Nestlé and Coca Cola, in public discussions on water-related challenges. While no estimates exist on worldwide costs of poor water quality to industry, in 1992, China's industrial sector was estimated to have lost approximately US$1.7 billion as a result of water pollution (SIWI, 2005).

One of the most important services that freshwater ecosystems provide is waste treatment, although more research is required to better quantify this service. Costanza et al., (1997) estimated that the global

FIGURE 16.7

Wastewater: A global problem with differing regional issues



Note: The ecosystem deterioration parameter is defined as the land ratio without vegetation coverage (forest area and wetlands) used to present the contribution of an ecosystem's deterioration to the vulnerability of its water resources.
Source: UNEP/GRID-Arendal http://maps.grida.no/go/graphic/wastewater-a-global-problem-with-differing-regional-issues, a map by UNEP/GRID-Arendal with sources WHO database, data for 2002; FAO database; Babel and Walid, 2008; European Environment Agency, 2009; Diaz et al., 2008).

TABLE 16.4

Countries least likely to express satisfaction with the quality of water in their communities

Risk	
Country	**Satisfied (%)**
Chad	21
Ukraine	26
Nigeria	29
Ethiopia	29
Liberia	30
Russia	30
Tanzania	35
Lebanon	35
Sierra Leone	36
Angola*	38

*Only urban residents interviewed.

Source: Ray (2008).

services provided by lakes and rivers alone were in the region of US$133 billion per year. This figure does not take into consideration wetland biomes, some of which are coastal, which are expected to provide services of far greater value.

People have historically relied on natural processes in freshwater ecosystems to clean agricultural, municipal, and industrial wastes. Often, however, the magnitude and toxicity of these wastes has overwhelmed the capacity and resilience of such ecosystems, degrading water quality locally and regionally. Such degradations manifest themselves in impaired amenity values, declining biodiversity, and diminished ability to provide wastewater treatment and other ecosystem services (Arthington et al., 2009).

16.7 Risks, monitoring and intervention

A summary of global key risk issues, their main drivers and some response options is presented in Table 16.3.

While Table 16.3 is general in scope, it provides a useful overview of the key factors of water quality

TABLE 16.5

Summary of possible water quality interventions by scale

Scale	Education and capacity building	Policy/law/ governance	Financial/ economic	Technology/ infrastructure	Data/monitoring
International/ national	Initiate training and awareness building	Institute integrated approaches Institute pollution prevention	Institute polluter/ beneficiary pays system	Promote best practice and support capacity building	Develop monitoring framework
Watershed	Strategic level for raising awareness on impacts of water quality Establish training for practitioners and develop best practice	Create watershed-based planning units Develop water quality goals	Institute pricing systems Institute cost recovery Create incentives for efficiency	Invest in infrastructure and appropriate technologies	Build regional capacity to collect and process water quality data
Community/ household	Connect individual/ community behaviour to water quality impacts Build capacity to make improvements in sanitation/ wastewater treatment	Amend codes to allow innovative storm water treatment options Promote access to information	Encourage investments	Consider decentralized treatment technologies	Carry out and analyse household/ community surveys

Source: Adapted from UNEP (2010, table 8, p. 73).

risk. However, there is a critical lack of global water quality data upon which to make a robust assessment of trends and geographic hot spots, which means that the world's water quality situation is poorly understood. While there have been advances locally and in some regions, the overall global synthesis of water quality data has deteriorated in recent decades, making it difficult to support international decision making processes. An example of the regional differences is given in Figure 16.7. Although this Figure has been taken from a recent UN publication, much of the data is over ten years old. More up-to-date data is not available at the global scale.

An alternative to quantitative data is qualitative data, an example being the 2008 Gallup Poll on water quality satisfaction. 1000 residents from 145 countries were asked the simple question, 'In the city or area where you live, are you satisfied or dissatisfied with the quality of water?' While it might come as no surprise that the regional median rate of satisfaction was just 48% in sub-Saharan Africa (with a high of 62% in Southern Africa), the global top ten of least satisfied countries contains both Russia and Ukraine (Table 16.4).

While there can be many reasons for a country's ranking, such as the fact that Lebanon was surveyed just after the 2006 conflict with Israel, and that greater comparative emphasis is perhaps given on drinking water quality, the survey provides a simple but interesting snapshot.

Water quality issues also vary with scale, ranging from the international to the community or household level. In 2011, UNEP published its *Policy Brief on Water Quality*, which included a summary table on the possible interventions by scale in the form of education and capacity building; policy, law and governance; financial and economic; technology and infrastructure; and data and monitoring. Table 16.5 provides a summary of possible intervention measures at different scales, including increased capacity for monitoring.

A more substantial body of data on water quality is urgently required. One of the greatest challenges is to create a much needed framework for a global water quality assessment. Some possibilities for the form and value this could have are included in Table 16.5, while the motivation for such a framework would be to:

- better understand the state of water quality and its causes,
- understand recent trends and identify hot spots,
- test and validate policy and management options,
- provide a foundation for scenarios that can be used to understand and plan for appropriate future actions, and
- provide much needed monitoring bench markers (Alcamo, 2011).

The multitude of water quality parameters and uncertainties, and their impacts, makes water resources management a complex and multidimensional issue, particularly with respect to human activities. Improved management of vulnerability and risks is needed to focus on the unknown and the unexpected in an era of accelerated changes and new uncertainties.

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CHAPTER 17

Human settlements

UN-HABITAT

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The challenge is not to curb urbanization but to seize the opportunities it can provide, giving due consideration to environmental issues.

The very real effects of rapid urbanization and climate change on urban water and sanitation systems must be addressed, and resilience must be built in.

Particular attention must be given to the needs of women and girls.

Sustainable and ecological sanitation systems must be promoted to reduce water consumption as well as pollution; and the loop between water use, wastewater generation and wastewater treatment must be closed.

The concept of an urban continuum must be given due consideration, and the consequences for system design, institutional setup and investment needs for urban centres must be well recognized.

Planning must anticipate migration and growth so that the provision of water supply and sanitation services is not outpaced by urbanization.

17.1 The changing urban background

In 2008, for the first time ever, more people lived in urban than in rural areas. And this trend in urbanization is set to continue. In 2011, the world population crossed the 7 billion threshold – just 12 years after the 6 billion threshold was reached in 1999. Figure 17.1 shows, region by region, the proportion of total populations that live in urban areas. The graph shows a general upward trend from the 1960s up to the middle of this century.

Existing cities have been expanding rapidly while new ones are also emerging, particularly in Asia and in low income and middle income countries. In 1960, for example, seven of the world's ten largest urban conurbations were in high income, developed countries. But by 2000, just two of the ten largest were in developed countries and six were in Asia and Latin America. In 1950, only two cities, New York and Tokyo, had populations of over 10 million. By 2015, it is expected that 23 cities worldwide will have populations of over 10 million – and 19 of these will be in developing countries. In 2000, 22 cities had populations of between 5 million and 10 million; 402 cities had between 1 million and 5 million; and 433 cities were in the 0.5 million to 1 million category (UN-DESA, 2005). Projections show that this urbanization trend is set to continue in lower income and middle income countries (Table 17.1).

In 2005, the more developed regions of the world were host to 29% of the total urban population. But between 2000 and 2030, urban populations are expected to expand by 1.8% globally, and by 2.3% (from 1.9 billion to 3.9 billion) in developing countries (Cohen, 2006). And in developed countries, the urban population is expected to increase only marginally, from 0.9 billion in 2000 to 1 billion in 2030 (Brockerhoff, 2000).

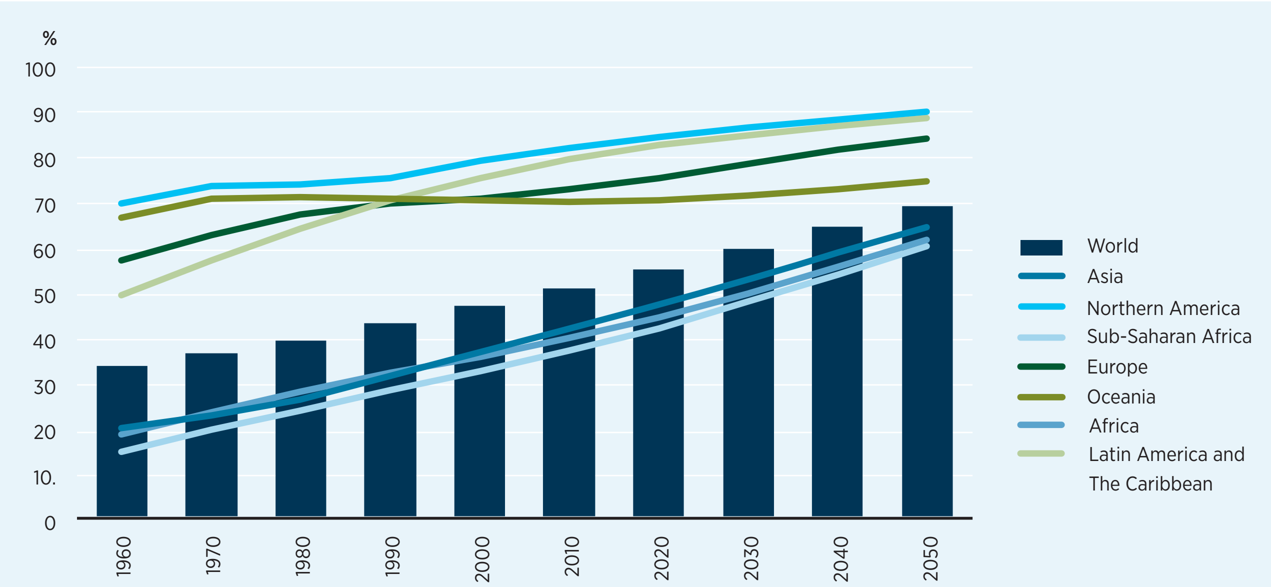
While rapid urbanization, particularly in developing countries, is a major challenge, cities also bring opportunities. They generate wealth, enhance social development, provide employment and serve as incubators of innovation and creativity in an increasingly knowledge-based global economy. As for the challenges associated with urbanization, to a great extent they stem from the failure to match planning with migration and population growth. This failure has severe effects on the provision of basic services such as water supply and sanitation, and results in degraded living environments. The poor, particularly poor women, are the worst affected.

17.1.1 The growing challenge of slums

Rapidly expanding urban spheres exert increasing pressure on the resources, infrastructure and environment on which cities depend. Coupled with failure to plan for migration and demographic growth, this has resulted

FIGURE 17.1

Proportion of world population living in urban areas, 1960–2050



Source: Based on data from UN-DESA (2010).

TABLE 17.1

Ten largest urban conurbations, 1960–2025

By global income distribution

Income classification	Ten largest urban agglomerations								
	1960	1970	1980	1990	2000	2010	2015	2020	2025
High income economies	7	6	5	5	3	2	2	2	2
Lower middle income economies	1		2	2	4	5	5	5	5
Low income economies						1	1	1	1
Upper middle income economies	2	4	3	3	3	2	2	2	2

By geographical region

Region	Ten largest urban agglomerations								
	1960	1970	1980	1990	2000	2010	2015	2020	2025
Countries of the Commonwealth of Independent States	1	1							
Developed regions	7	6	5	4	3	2	2	2	2
Eastern Asia	1			1	1	1	1	1	1
Latin America	1	3	3	3	3	2	2	2	2
Southern Asia			2	2	3	5	5	5	5

Source: Based on data from UN-DESA (2010), '30 largest cities' data at http://esa.un.org/unpd/wup/CD-ROM_2009/WUP2009-F11a-30_Largest_Cities.xls).

in the emergence of slums, and the many problems associated with slums. These typically include poor housing, inadequate access to clean water, poor sanitation, overcrowding and insecure tenure. All these conditions have a serious effect on urban well-being (Sclar et al., 2005). Women are the worst affected. Because of bad planning and inappropriate land use policies, slums are typically located on marginal and dangerous land that is unsuitable for human settlement – locations such as on canal embankments and along railway tracks. For example, shanty towns near Buenos Aires in Argentina are built on flood-prone land, which forces residents to make a tough choice between safety and health on the one hand, and the need for shelter on the other (Davis, 2006).

The overall percentage of urban populations that live in slums is high – nearly one-third of the entire world urban population, according to some estimates (see Figure 17.2 below and Sclar et al., 2005). In some cities, such as Mumbai in India, the situation is worse with nearly 50% living in slums and shanty towns (Stecko and Barber, 2007).

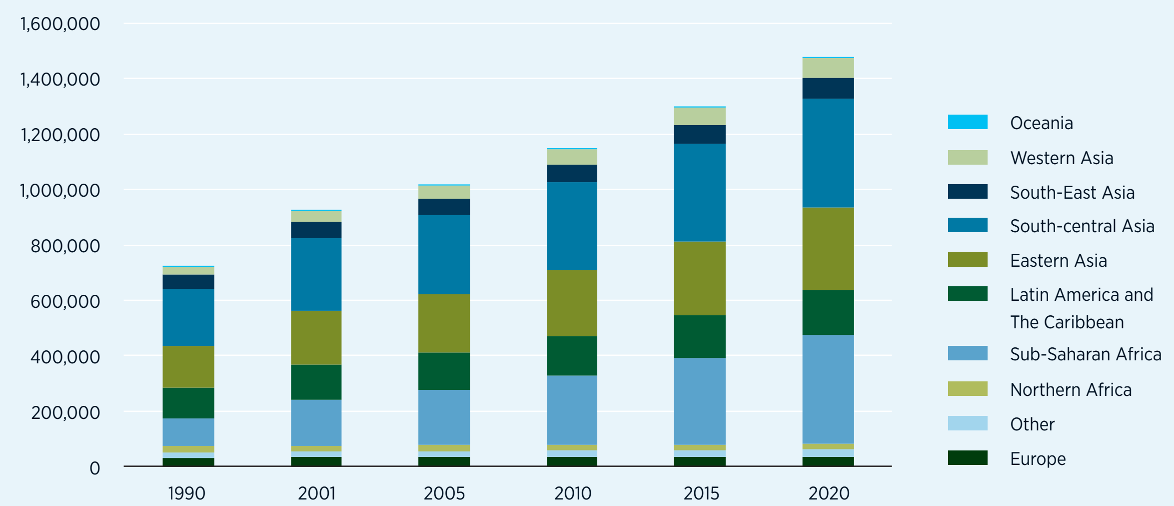
UN-HABITAT's 2008 report, *State of the World Cities 2010/2011*, projected that between 2000 and 2010, 227 million people in the developing world will have moved out of slum conditions. This reflects a remarkable achievement, well beyond the 100 million target set under Millennium Development Goal (MDG) No. 7. During that period, the proportion of urban residents living in slums dropped from 39% to 33% in developing countries. However, as also pointed out in the report, these numbers do not show the whole picture. The number of slum dwellers has actually *increased* considerably during this period and this trend is predicted to continue (UN-HABITAT, 2008). The figure below shows slum population numbers in the world's major regions between 1990 and 2020.

17.1.2 Water and urbanization

Urban centres in low income countries are already facing numerous challenges such as inadequate infrastructure, a lack of basic services such as water and sanitation, and a deteriorating environment caused by pollution. Rapid urbanization and the extraction of resources to meet the demands of growing populations will put enormous stress on water resources in and

FIGURE 17.2

Slum population by region, 1990–2020 (thousands)



Source: Produced by UN-Habitat based on data available at http://ww2.unhabitat.org/programmes/guo/documents/Table4.pdf (published in their State of the World's Cities Report 2001).

around the cities as well as on ecosystems as a whole. Moreover, the expansion of paved and surfaced areas such as roofs, pavements and parking lots, affects the local hydrology and reduces the natural infiltration of water into the ground – which results in higher peak flows during storms.

Although the provision of water and sanitation to urban residents has improved in developing countries, it is not keeping up with the rapid pace of urbanization. According to the WHO/UNICEF Joint Monitoring Programme (JMP) on water and sanitation, the world is on track to meet the MDG on drinking water. This prediction is based on the statistic that 87% of the world population already had access to improved water sources in 2008, compared with only 77% in 1990 (WHO/UNICEF, 2010).

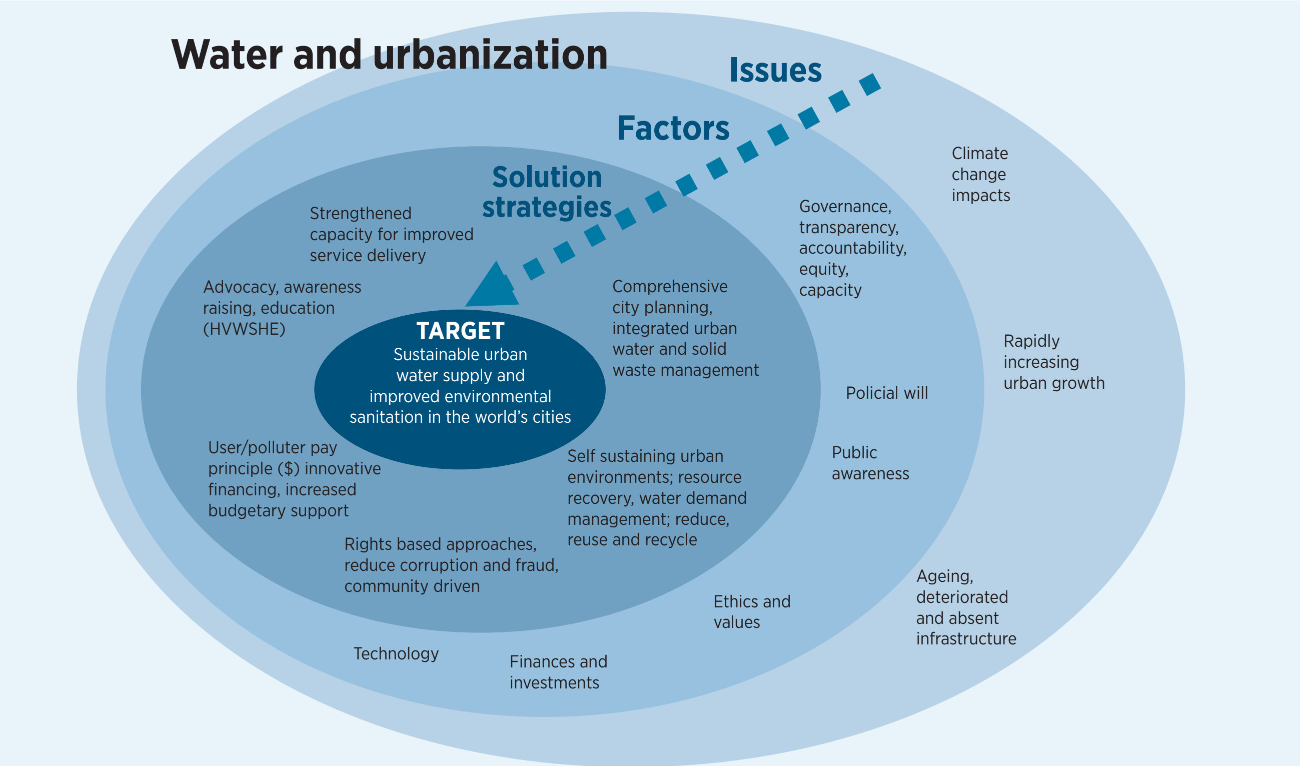
However, the problem is that in urban areas, the increase in access to drinking water has been only a minimal 1% during the same period. But in absolute terms, the number of urban residents with access to improved sources of drinking water has actually decreased. The case of sanitation is similar. Between 1990 and 2008, some 813 million urban residents gained first-time access to improved sanitation facilities, but during the same period, the total urban population grew by over a billion. This means that the total number of urban dwellers who do not have access to improved sanitation actually increased by 276 million in this period (WHO/UNICEF, 2010). As urban populations keep growing, efforts to improve water supply and sanitation in Africa's and Asia's urban areas clearly must be stepped up, particularly for the poor.

Such efforts should come as part of an integrated approach that encompasses the management of upstream catchment areas and river basins, and water-related and sanitation-related infrastructure (including treatment, storage and distribution), as well as conservation of the aquatic environment in the receiving water bodies downstream. As rapid urbanization puts pressure on existing infrastructure and services, and with climate change compounding the adverse impacts on water availability and the frequency of water-related disasters, future links between water and urbanization must be analysed and managed more carefully than ever.

Achieving sustainable water supplies and improved sanitation in the cities of developing countries will require capital investment, improved governance, political will and a new ethic that values all resources and ecosystems. Figure 17.3 depicts the complex interplay between challenges, the variables that can potentially be managed, and some promising strategies that can be adopted by governments and other stakeholders. Although some broad trends, such as the scale and nature of

FIGURE 17.3

Issues and solutions related to water and urbanization



Source: WSS-II, WSIB, UN-HABITAT.

urbanization and the depletion or degradation of water resources, may be discernible, managing uncertainty and risk will be critical.

17.2 Water abstraction

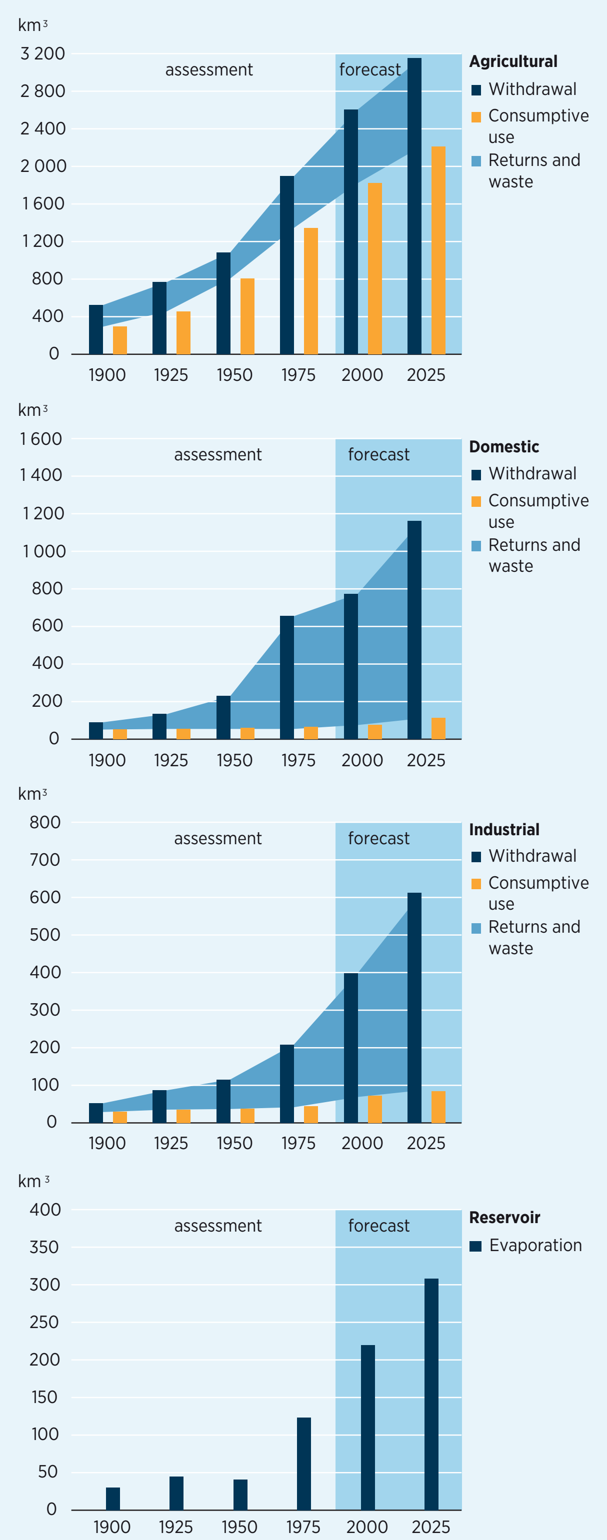
The main sources of water in urban areas are surface water in upstream catchment areas, groundwater in or around the city and rainwater. These water sources, particularly the upstream catchment areas of river basins and groundwater reserves, must be preserved and used wisely to ensure long-term sustainability.

In developing countries, groundwater sources are extremely important for urban centres because they provide a relatively low-cost water supply that is usually of a high quality. However, intensive exploitation of such resources has led to major and widespread falls in aquifer levels. In conurbations such as Bangkok, Manila and the Chinese city of Tianjin, levels have fallen by as much as 20 m to 50 m, and in many others by between 10 m and 20 m. In all these cases, the drop in levels has been accompanied by either land subsidence, a deterioration in groundwater quality or, in some cases, by both. In Mexico City, the aquifer level fell by between 5 m and 10 m between 1986 and 1992, and sections of the city have sunk by 8 m or more over the last 60 years (Foster et al., 1998; Hutton et al. 2008). In coastal areas, over-abstraction results in saltwater intrusion. In Europe, 53 out of 126 groundwater areas show saltwater intrusion. This is mostly in aquifers that are used for public and industrial water supplies (Elimelech, 2006),

Freshwater withdrawals for agriculture exceed withdrawals for other sectors (households, manufacturing, etc.). But withdrawals are expected to rise in all sectors (Fig. 17.4), and cities in developing countries will be most affected. By 2025, water withdrawals are expected to rise by 50% in developing countries as opposed to 18% rises in developed countries. In addition to high agricultural demand, pressure on water resources is compounded by the physical alteration and destruction of habitats caused by urban and industrial developments (UNEP, 2007).

FIGURE 17.4

Changes in global water use, by sector



Source: UNEP/GRID-Arendal (http://maps.grida.no/go/graphic/changes-in-global-water-use-by-sector, by Bounford.com and UNEP/GRID-Arendal with sources UNEP/GRID-Arendal, 2002, based on Shiklomanov and UNESCO 1999).

17.2.1 Discharge of wastewater

In the course of the hydrological cycle, water sustains communities and economies throughout the watershed as it is used in agriculture, in industry and by domestic consumers (Figure 17.4). However, these users do not return the water they extract in its original condition (Corcoran et al., 2010). Across the world, the total sewage, agricultural waste and industrial effluent discharged into waterways amounts to 2 million tonnes every year (Corcoran et al., 2010). Much of this waste comes from urban areas.

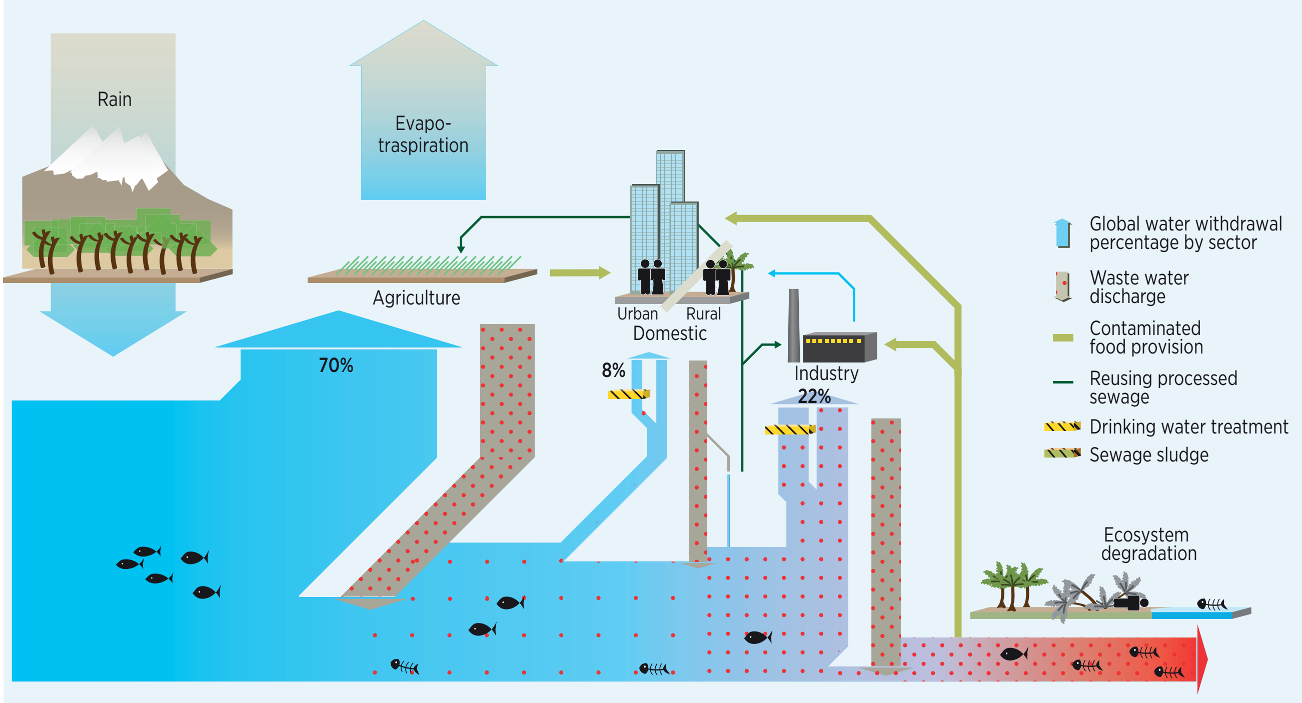
Figure 17.5 depicts the ratio of treated to untreated wastewater discharged into water bodies across ten regions of the world. Urban wastewater poses a particularly serious threat when combined with untreated industrial waste. Treated urban sewage is largely limited to high income countries, while in developing countries about 90% of sewage is discharged without any treatment. In Indonesia, Jakarta's 9 million residents generate 1.3 million m^3 of sewage daily, of which less than 3% is treated. By contrast, Sydney, Australia's largest city, which has a population of over 4 million, treats nearly all its wastewater, some 1.2 million m^3 per day (Corcoran et al., 2010). Point sources such as where sewage is discharged are being controlled more and more, and the concern is now shifting to non-point pollutant loads from storm-generated runoff.

Nutrients in the wastewater discharged from municipal treatment plants and the runoff from cities and farms pose a major health problem. These nutrients have caused an increase in harmful algal blooms in freshwater and coastal systems over the last twenty years (UNEP, 2007). It is estimated that about 245,000 km^2 of marine ecosystems feature 'dead zones' caused by the discharge of untreated wastewater, which has a detrimental effect on fisheries, livelihoods and the food chain. Such discharge merely shifts problems from upstream to downstream areas.

Poor sanitation and inadequate wastewater management in developing countries results in the contamination of freshwater sources, and is a major cause of disease and death, particularly among children. It also holds serious economic and environmental consequences. For instance, World Bank research in South-East Asia found that Cambodia, Indonesia, the Philippines and Vietnam lose an estimated US$9 billion a year because of poor sanitation. This amounts to about 2% of their combined gross domestic product (GDP) (Hutton et al., 2008).

FIGURE 17.5

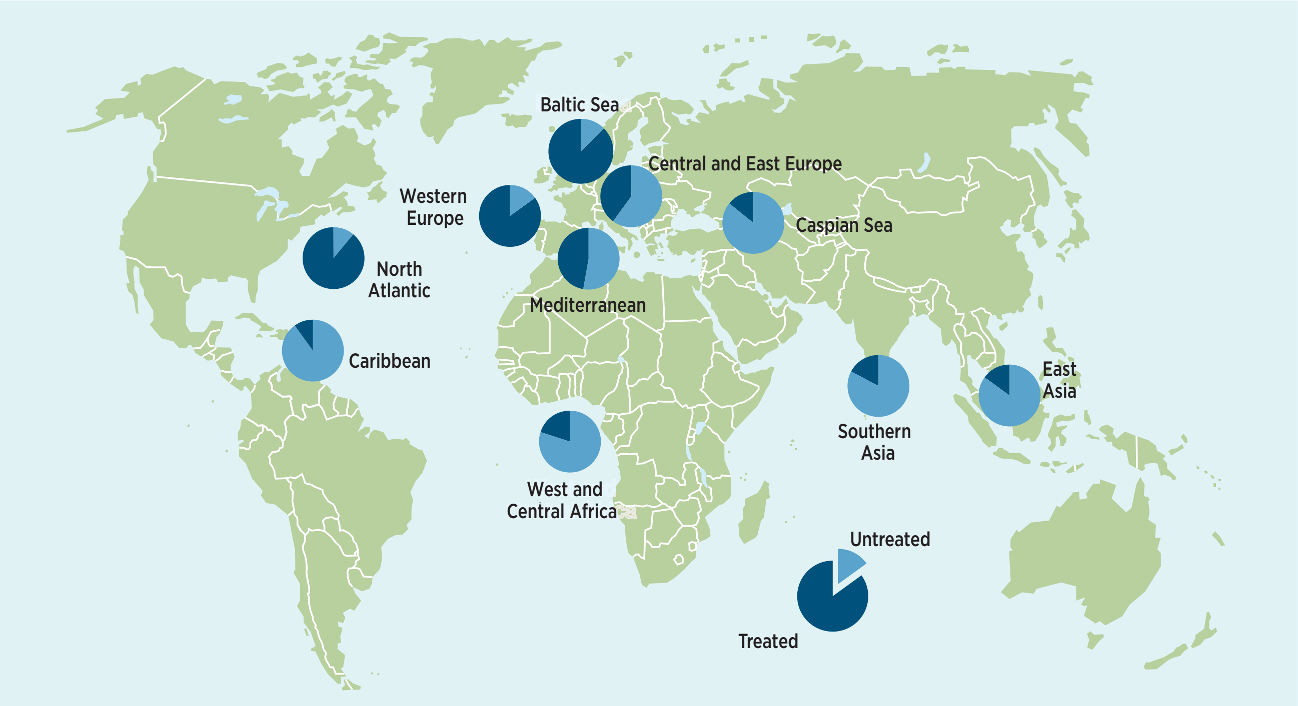
Urban freshwater and wastewater cycle: Water withdrawal and pollutant discharge



Source: UNEP/GRID-Arendal (http://maps.grida.no/go/graphic/freshwater-and-wastewater-cycle-water-withdrawal-and-pollutant-discharge, by UNEP/GRID-Arendal with sources WHO, FAO, UNESCO and IWMI).

FIGURE 17.6

Ratio of treated to untreated wastewater discharged into water bodies (March 2010)



UNEP/GRID-Arendal (http://maps.grida.no/go/graphic/ratio-of-wastewater-treatment1, a map by H. Ahlenius, adapted from a map by H. Ahlenius [http://maps.grida.no/go/graphic/ratio -of-wastewater-treatment, sources UNEP-GPA, 2004]).

Even where extensive sewerage networks and treatment plants are in place, they are all too often unable to adjust to ongoing, rapid urban expansion and the associated massive capital expenditure required. In addition, they often do not have adequate capacity in the areas of planning, design, operations and maintenance. Alternatives such as off-site sanitation and decentralized wastewater treatment systems (DEWATS) are rarely explored, because of a lack of awareness among policy-makers and planners, and poor capacity among utility staff. As a result, extensive sewerage systems often end up with poor, environmentally damaging sanitation services and next to no wastewater treatment.

Even in the face of growing demand, reusing and recycling water remain exceptions. Just as overlooked is the potential for recovering nutrients and energy from wastewater for use in food and fuel production. On top of these two types of technology, it must also be highlighted that other technologies exist that can reduce the amount of water that's required for sanitation – which in turn lowers the amount of wastewater that's returned to the environment untreated (see Box 17.1).

BOX 17.1

Water-saving sanitation methods: Reviewing the options

Sanitation, particularly the use of modern flush toilets, ranks among the major sources of water demand in urban areas. Conventional flushing systems use 10 L to 12 L of water per flush, wasting large amounts of water and polluting water bodies. The main alternatives to conventional toilets include the Sulabh toilet, urine-diverting dry toilets, and waterless urinals, all of which reduce water consumption while improving sanitation standards. Among these, probably the most popular is the Sulabh flush composting toilet developed by Bindeshwar Pathak and his team at Sulabh International in New Delhi. These toilets are very popular in India as well as in other developing countries.

When developing a technology, it is important to keep local culture in mind. The Sulabh toilet was designed to suit the specific needs of people who use water for anal cleansing as well as for flushing. To save water, Sulabh toilets use only 1 L to 1.5 L per flush, as opposed to the 10 L to 12 L used in conventional toilets.

On top of these significant savings, the Sulabh technology also helps to reduce global warming because it prevents greenhouse gas emissions into the atmosphere. And in public toilets where a biogas digester is linked up, the gases are burned when they are used for cooking, lighting and producing energy.

Source: B. Pathak, Sulabh International (personal communication).

17.2.2 Urban water needs and their effects on ecosystems

Human activities have a huge effect on freshwater ecosystems across the world. Freshwater deterioration is particularly acute in cultivated systems, drylands, wetlands and urban areas. However, the effect that urban water requirements have on ecosystems is not fully or systematically researched. Cities are highly diverse, and the effects that their water needs have on ecosystems vary considerably from one to another.

When natural land surfaces are turned into impervious surfaces such as paved streets, parking lots and roofs, the percolation of rainwater and snowmelt into the soil is inhibited. The flow velocity of water over the land is increased, transferring pollutants into receiving water systems Chiramba, 2010). The reclamation of inland and coastal water systems has caused the loss of many coastal and floodplain ecosystems and services. Lost wetlands have resulted in changed flow regimes, with increased flooding in some places together with shrinking wildlife habitats (UNEP, 2007).

Healthy water ecosystems bring multiple benefits to various aspects of urban life. Wetlands provide important natural wastewater treatment functions. For instance, in Xiamen in China, municipal authorities generate revenue by imposing fines on polluters and charging fees for a number of facilities such as using marine areas. Improved wastewater treatment facilities have led to an increase in the quantity of wastewater being discharged – which has also resulted in an increase in Xiamen's revenues. This has allowed the city authorities to spend US$2 billion on sewage treatment systems since the mid-1990s. The result of this has been a huge increase in the proportion of industrial and domestic waste that's being processed. In the mid-1990s, just 20% of industrial wastewater was processed, ten years later, that figure had reached 100%. And the figures for domestic wastewater processing are almost as impressive with an increase from 28% to 85% over the much same period. Today Xiamen attracts immigrants, tourists and real-estate development (Chiramba, 2010).

In Kolkata in India, ponds provide a low cost, natural wastewater reuse and treatment system in a city that lacks conventional treatment plants. This system also provides employment for 17,000 poor fishermen and produces 20 tonnes of fish daily (Newman and Jennings, 2008; UNEP, 2002).

Every year across the world, coastal ecosystems provide an estimated US$25 billion worth of services in the form of food security, shoreline protection, tourism and carbon sequestration (Naber et al., 2008). In Zanzibar, marine ecosystem services account for 30% of GDP, 77% of investment, large amounts of foreign currency and numerous jobs (Lange and Jiddawi, 2009). Caribbean countries depend on coral reefs for tourism, fisheries and shoreline protection. Degradation of these reefs could reduce net benefits by between US$350 million and US$870 million a year. Because conventional urban management is hardly concerned with water resources management, adverse effects are expected to continue before the costs and benefits are fully recognized.

17.3 Climate change and resilient urban water systems

Alongside urbanization, climate change is a second, major, long-term and human-induced factor that affects natural and human systems alike all over the world. It has far-reaching consequences on environmental, economic and social stability (UN-HABITAT, 2011). As with urbanization, the effects of climate change are likely to be felt more sharply in developing than in developed countries.

There are close links between cities and climate change. Cities, where now half of humankind lives, are responsible for up to 70% of greenhouse gas emissions around the world; and urban populations are also vulnerable to the effects of climate change (UN-HABITAT, 2011). Cities also provide the greatest opportunities for combating climate change for two reasons: they are often centres of innovation, and action taken at city level can reach out to a large number of people.

Although vulnerability to the effects of climate change varies from place to place, in developing countries, poor people, particularly poor women, stand out as the most vulnerable. Many poor women live in risk-prone slums, along river banks for example, and their adaptive capacities are minimal (IPCC, 2007).

Water generally acts as a critical link between climate change and its effects on human and physical systems. Rising temperatures will change the hydrological cycle, which, in turn, may alter temporal and spatial rainfall patterns and trigger extreme events such as droughts and floods. Urban water systems are likely to be very vulnerable to the effects of climate change, particularly in developing countries where they are poorly managed and ill-equipped to deal with changed conditions. Therefore, various components of urban water systems such as the protection schemes for catchment areas, water supply systems, wastewater treatment plants and drainage networks must be designed and managed in a climate-sensitive manner.

The direct effects of climate change include the destruction of infrastructure and facilities. This affects, among other things, the regular provision of water supplies, drainage and sewerage systems and solid waste management. If these systems and networks are to become sustainable, they must be more resilient to severe weather events. For instance, the capacity of water drainage or combined sewers must be a direct function of rainfall intensity (as measured in mm/hr).

On the whole, climate change adds to the uncertainty and severity of extreme water-related events. Floods and droughts are becoming increasingly unpredictable and more devastating in many ‘hot spots’ that are also experiencing rapid urbanization. The existing infrastructure is unable to cope, and public health is endangered because of a complex combination of factors such as the dispersal of human excreta during floods, or increased pathogen loads in freshwater supplies caused by rising water temperatures. In the face of the combined challenge of urbanization and climate change, urban water supply and sanitation infrastructure must be made ‘climate proof. What are also needed are processes that can generate optimal water management systems – processes that are robust, adaptable and sustainable under these future global change pressures (Bates et. al, 2008). Such flexible systems would be characterized by their capability to adapt to changing scenarios and associated uncertainties.

These challenges can be addressed with new techniques, including exploratory modelling that combines the best features of traditional quantitative decision analysis with those of narrative, scenario-based planning. Techniques such as risk assessment and ‘real options analysis’ (Zhao and Tseng, 2003) also offer opportunities in this respect. ‘Real options-based decision-making’ recognizes the value of flexibility, including flexibility in examining alternatives and future decision-making, and can be implemented in a flexible way as and when required to cope with uncertainty.

Some cities have begun to develop plans for vulnerability assessments and adaptation. Assisting them in this process are organizations such as UN-HABITAT, the International Council for Local Environmental Initiatives (ICLEI) and the World Mayors Council on Climate Change. Since 2008, UN-HABITAT's Cities and Climate Change Initiative has aimed to enhance the capacity of cities in developing countries to mitigate and adapt to climate change through collaboration between cities, enhanced domestic policy dialogue, risk assessment and designing pilot projects. As part of the Initiative, UN-HABITAT is supporting the preparation of Vulnerability Assessment and Adaptation Plans in 18 cities across Asia and Africa (UN-HABITAT, 2011). These plans are developed in a participatory manor, and this ensures women's involvement in processes that are properly implemented and can be monitored on an ongoing basis. Such an approach is expected to promote designs that are flexible enough to adapt to new, different or changing requirements. It is also very likely to result in 'least regret' solutions in what seems bound to remain an uncertain environment.

17.3.1 Infrastructure that is aging, deteriorated or absent

Most cities in developing countries face an urgent need to provide water and sanitation infrastructure and services to rapidly expanding populations. And many older cities, including cities in developed countries, are also faced with an aging and deteriorated water infrastructure, which is costly to rehabilitate. As well as catering for ever-expanding urban populations, poor populations in particular, these systems must be designed to adapt to and mitigate the challenges posed by global climate change.

Many cities around the world face capital expenditure backlogs for water supply systems that haven't been maintained or upgraded for a very long time. This infrastructure is likely to include source protection, water transmission lines, treatment systems, storage facilities and distribution networks. Much of this infrastructure is over 100 years old, which puts public health at increased risk because leaks, obstructions and malfunctions are more likely as equipment ages. For example, the United Kingdom is served by over 700,000 km of mains and sewer pipes, which require over 35,000 maintenance operations per month (Khatri and Vairavamoorthy, 2007). Similarly, in Kathmandu in Nepal, some of the water pipes are over 100 years old. Here, planning has eluded the expansion of water and sewer networks for many years and about 40% of drinking water is unaccounted for, mainly as a result of leaks. High leakage rates result in increased water demand as well as greater risk of contamination and the spread of waterborne diseases (Vairavamoorthy et al., 2007).

The rehabilitation of urban water systems is becoming increasingly expensive. In Germany, for example, estimates are that over the next 15 years, €12 billion (or US$16 billion) will be required annually – that's €6.5 billion (US$9 billion) for new facilities and €5.5 billion (US$7.5 billion) for operation and maintenance. (Hiessl et al., 2001). In North America, trillions of dollars' worth of infrastructure is failing prematurely and is in need of costly repairs. The US Environmental Protection Agency anticipates a funding gap of over US$500 billion over the next 20 years in water infrastructure investment (USEPA, 2002).

As might be expected, the deterioration of urban water infrastructure is often more severe in cities in the developing world. This is the result of poor construction practices, little or no maintenance and demands that the infrastructure operates at higher capacities than it was designed for. Missing records, or a lack of data on the location and condition of water and wastewater infrastructures, combines with a lack of efficient management to make the problems even more complex (Misiunas, 2005).

17.3.2 Integrated water management and new urban planning

Because water flows in a cycle, no urban water system can be considered in isolation. No one can afford to overlook cities' links with upstream catchments and downstream areas, especially as almost all areas downstream of urban developments are left to cope with urban waste to some extent or another. Even within a given urban area, the various components of the water system – groundwater, water distribution and sewerage networks – typically interact. These interactions must be understood and taken into consideration if water supply and sanitation services are to become effective, efficient and sustainable.

Like its rural counterpart, integrated urban water management (IUWM) is based on a systems approach that looks at the hydrological cycle as a whole from catchment to consumption and treatment. Such a perspective includes any links between the various components within the system. The approach recognizes human as well as ecological demands for water, and sets out to balance environmental, economic, technical and social needs in the short term as well as the long term. In practice, this means that the planning and management of urban water systems must consider water requirements for human health, environmental protection and economic activities as well as for urban design and recreation. This approach demands an integrated and multidisciplinary approach where urban planners work closely with water engineers, landscape architects, economists and social scientists (SWITCH, 2006).

In Kathmandu, Nepal some progress has been made towards an IUWM approach. The Bagmati Action Plan was developed with support from UNEP and UN-HABITAT. The scheme identifies a range of stakeholders and corresponding actions that are needed to prevent the pollution of the Bagmati River, which serves as the city's main water source. The Plan adopts a holistic approach and sets out specific strategies and actions for five different zones within the Kathmandu Valley. The scope of the plan runs from the conservation zone in the upstream catchment area and extends all the way to the downstream zone. Under the Plan, watershed management and conservation is the main goal for upstream areas; sustainable agriculture and eco-tourism are to be promoted in the surrounding rural areas; and decentralized wastewater treatment systems are a priority for peri-urban communities (GoN/NTNC, 2009). Funds to implement the plan come from setting aside a small portion of the registration fees charged on land transactions in the Kathmandu Valley.

As urban population densities increase, the per-capita cost of providing water supply and sanitation services can be reduced (economies of scale) and can make service provision more efficient (economies of scope). This can also reduce the ecological footprint of cities. Those cities in the developing world that aim to improve services to ever-expanding populations should consider a new planning approach, and review existing density regulations, including in peri-urban areas where most of the expansion is taking place. The participation of the poor, particularly poor women, in planning will be critical. The layout of transport networks can significantly impact on growth and density and should be carefully considered, keeping in mind the potential effect on the provision of water supply and sanitation services. New urban legislation can also promote more sustainable service provision. For example, several countries are adopting policies and regulations for the promotion of rainwater harvesting. This simple technique can reduce water stress in any city.

BOX 17.2

Singapore: A model of integrated water management

The Singapore water story is one of political determination, integrated management, continuous innovation and community partnership. In the 1960s after independence, the city-state experienced widespread water shortages cause by rapid demographic expansion and industrialization. Led by the Public Utilities Board (PUB), which is the national water agency, Singapore has turned its inherent water scarcity into growth opportunities. Taking advantage of modern technologies, the PUB has diversified water supplies under the 'Four National Taps' strategy: local catchment, imports, NEWater' (that is, treated and recycled wastewater), and desalination. Today, NEWater can meet 30% of demand, compared with only 10% for desalination. The plan is that by 2060 NEWater should meet 50% of Singapore's water demand and desalination 30%.

PUB also engages the community, encouraging wise water use, advising against the pollution of catchments and waterways, and building a closer relationship with water through leisure and entertainment activities.

Through long-term planning, Singapore has built infrastructure such as the Marina Barrage to serve the 'three-in-one' functions: water storage, flood control and leisure pursuits. The city-state also built the Deep Tunnel Sewerage System to meet Singapore's needs for the collection, treatment and disposal of used water over the next 100 years. The plans to meet water needs for the next 50 years were announced at the 2010 Singapore International Water Week (SIWW).

Through collaboration with the private sector, Singapore has created a vibrant water sector comprising 70 mutually supportive companies. Water has even been identified as one of the city-state's new economic growth engines. The equivalent of US$261 million has been committed over five years to expand the sector through research and development.

Singapore established an annual event (SIWW) and an Institute of Water Policy at the Lee Kuan Yew School of Public Policy with the intent of sharing its experiences, enhancing its capabilities and providing leadership in water governance through research and education.

Source: Public Utilities Board, Singapore.

17.3.3 Resource recovery and water demand management

The current methods of water resources management and the provision of water supply and sanitation are coming under enormous pressure from rapid urbanization. Flush toilets and waterborne sewage systems use large quantities of water, straining already depleted resources. This makes it all the more important to take a critical look into current water use and sanitation practices and to develop strategies and systems that reduce the waste, not just of water, but of other related resources such as organic matter and nutrients as well. In a conventional system, water is abstracted from surface water or groundwater sources, transported to cities, treated and distributed to households and institutions for various uses. After use, the wastewater is collected, treated if possible, and discharged into water bodies. This is a linear system where a large amount of a scarce resource is used once, contaminated and then discharged to pollute the downstream environment. In this process, water is lost – as are many other valuable resources such as organic matter and nutrients. These nutrients are valuable for agriculture, but substitutes such as chemical fertilizers (either mined or manufactured) are applied to the land instead. This may result in further deterioration of both soil and water resources. Overall, this system is unsustainable and leads to overexploitation of water bodies, the contamination of aquatic ecosystems, soil degradation and, ultimately, to food insecurity.

BOX 17.3

Policies and legislation on rainwater harvesting from around the world

- In India, many state governments have made rainwater harvesting mandatory in buildings. In New Delhi, the Ministry of Urban Development and Poverty Alleviation has modified the building by-laws to make rainwater harvesting mandatory in all new buildings built on plots larger than 100 m^2. They grant financial assistance of up to 50% or 100,000 rupees (approximately US$2,000) whichever is less. The State of Tamil Nadu has also made rainwater harvesting mandatory for all public and private buildings.
- In Nepal, the government has enacted policies and guidelines on rainwater harvesting, while cities such as Dharan are providing discounts of up to 30% on building permit fees for houses that install rainwater harvesting systems.
- In Australia, the governments of Victoria, South Australia, Sydney and New South Wales, The Gold Coast and Queensland have taken steps to ensure that energy-efficient and water-efficient measures, including rainwater harvesting, are incorporated into all new houses.
- In Germany, rainwater harvesting is encouraged by the levying of rain taxes on the amount of impervious surface a property has where runoff is directed straight to the storm sewers. So converting impervious paving into porous paved areas or harvesting rainwater from their rooftops makes property owners eligible for a reduction in rain tax.
- In the United States, several states and cities provide incentives for water conservation. Residents of Arizona were offered a one-time tax credit of 25% of the cost of water conservation systems such as grey water and rainwater recycling, up to a maximum of US$1,000. The state has allocated approximately US$250,000 annually to cover these tax credits. Similarly, the residents of San Antonio in Texas can apply for a tax rebate of up to 50% for their rainwater harvesting projects.

Source: CSE (n.d.).

In traditional societies, sanitation systems were built to maximize resource recovery and reuse. In many countries in Asia, Europe, Latin America and Central America, excreta used to be collected and used in the fields as manure, thus closing the loop between resource use and recovery. For instance, in China, farmers have been aware of the benefits of human and animal excreta in crop production for more than 2,500 years. This has enabled Chinese farmers to support higher populations with the crops they produce. Some societies have also recycled excreta as fuel. For example, in Yemen's older cities, including the capital, Sana'a, separate systems for collection of excreta and urine were built into in multi-storey buildings. The faeces was collected, dried and used for fuel (Lüthi et al., 2011).

Sanitation systems built around the concepts of resource recovery and reuse have been around for centuries. However, they began to disappear in the wake of the industrial revolution (and the associated urban expansion) when sewer systems and newly developed chemical fertilizers took over. By the middle of the nineteenth century, industrialized countries turned very gradually to centralized waterborne sanitation with flush toilets connected to sewer systems. Later, large sewage treatment plants were built to meet environmental standards. However, the malfunction of these treatment plants is not infrequent, leading to waste of money and environmental pollution.

Even in industrialized countries, wastewater treatment can remain a challenge for cities. In Europe, EU research found in 2001 that of 540 major cities, only 79 had tertiary sewage treatment and 223 had secondary treatment; 72 featured incomplete primary or secondary treatment, and 168 cities had no (or unspecified) treatment capacity (EU, 2001). In February 2002, the European Commission even took action against France, Greece, Germany, Ireland, Luxembourg, Belgium, Spain and the United Kingdom for alleged failure to implement the EU Urban Water Directive (SEI, 2008). Despite all these failings, the sustainability of these systems has rarely been questioned and they are still considered to be the reference for sanitation.

However, promising new approaches which use waste as a resource – such as ecological sanitation (EcoSan) – are now gaining more popularity. The waste and wastewater from households, for example, can be separated into the following streams and recycled:

- Stormwater, which can be captured and, with minimal treatment, be reused for any purpose ;
- Grey water, or wash water from kitchens and bathrooms, which can be treated and reused for flushing or irrigation;
- Blackwater or faeces, which can be used to produce energy (biogas) or compost;
- Urine or yellow water, which can be reused as liquid fertilizer; and
- Organic waste, which can be composted or used to produce biogas.

In a bid to promote sustainable sanitation systems, the Water Supply and Sanitation Collaborative Council endorsed the 'Bellagio Principles for Sustainable Sanitation' during its Fifth Global Forum in November 2000 (EAWAG, 2005). These principles consider waste as a resource and promote holistic, integrated and decentralized management.

Sustainable options based on these principles include EcoSan, rainwater harvesting and decentralized wastewater treatment systems (DEWATS). These decentralized systems focus on reducing demand for water and preventing water pollution – and they have proved effective in many communities around the world. The time has come to deploy these technologies on a larger scale, particularly in newly urbanizing areas and peri-urban areas in developing countries.

Experience gained from the projects UN-HABITAT has supported over the years proves that Water Demand Management (WDM) for utilities is effective. The method can save or defer massive amounts of capital expenditure on equipment and networks. WDM entails a 'water audit' of the supply system, the identification of areas of excessive consumption or leakage, the rehabilitation of infrastructure, and the deployment of technical and managerial controls. These measures are most effective when combined with public awareness raising and education programmes (McKenzie et al, 2003).

Promotion of sustainable sanitation and holistic water management systems will require knowledge of the water cycle as a whole and how it is affected by human

BOX 17.4

Decentralized and community-based sanitation systems

Large conventional wastewater treatment plants are often expensive to establish and difficult to operate. As a result, many cities in developing countries are unable to set up such plants and operate them properly. Transporting the wastewater through drains is the main cost of urban wastewater management. But decentralized treatment systems that are based on simple yet effective technologies and that have maximum community ownership can serve as an alternative in developing countries.

Since it was developed in the 1990s, the Decentralized Wastewater Treatment Systems (DEWATS) approach has proved to be successful in many communities, particularly in slums, peri-urban settlements and institutions in Asia and Africa. In Indonesia, for example, the Community-Based Sanitation (SANIMAS) programme (which started as a pilot project in six locations in 2003) has now been deployed on a nationwide scale covering more than 420 'clusters' all over the country. Similarly, many slum settlements in Indian cities such as Bangalore and Mumbai also enjoy community-based sanitation facilities. Some of these also generate biogas for cooking and slurry for vegetable gardening.

The DEWATS approach is based on the principles of decentralization of responsibility, simplification of technology and processes, and, where possible, the conservation and recycling of waste energy and nutrients. This modular system combines technical options such as settlers, biogas plants, anaerobic baffle reactors, constructed wetlands and ponds. All options involve community participation.

Source: Gutterer et al. (2009).

activities. In this process, water and urban managers could take advantage of the Sustainable Sanitation and Water Management Toolbox (Box 17.4).

17.4 Water education

It is increasingly recognized that improvements in water management cannot be accomplished by technical or regulatory measures alone. These must be complemented with changes in behaviour and in attitudes to the use of water in society. Following the recommendations of an International Expert Group Meeting held in Johannesburg, South Africa, in May 2001, UN-HABITAT has been promoting the Human Values-Based approach to Water, Sanitation and Hygiene promotion (HVBWSHE). This has included running many HVBWSHE training courses and the publication of the *Facilitators' and Trainers' Guidebook*. In addition to disseminating information on water, sanitation and hygiene, this innovative approach inspires and motivates the public to change its behaviour in favour of the wise and sustainable use of water and sanitation. Experience has shown that a values-based approach has many benefits: it does not add to the current school curriculum because it can easily be mainstreamed into the existing curriculum, and it creates a lasting effect through character development once it is understood, appreciated and practised by children and young adults. This now proven approach has been adopted in several countries in Asia, Africa and Latin America with support from UN-HABITAT and other agencies.

BOX 17.5

The Sustainable Sanitation and Water Management Toolbox

Water resources around the world face increasing pressures from population growth, competing demands from agriculture and industry, and climate uncertainty. However, a number of solutions have been developed to address this challenge, and have been demonstrated to be effective in several parts of the world. Water managers must be aware of these solutions and be able to modify and apply them as necessary to suit their needs. This requires information to be managed effectively so that it is easily available when required. It also requires capacity-building to build confidence in the holistic approach to water resource management that is inherent to the methodology.

The Sustainable Sanitation and Water Management (SSWM) toolbox is a collection of open-source, easy-access and easy-to-use information that is available on line. It allows users to tailor it to their own needs while maintaining a holistic approach. The methodology considers the water system as a whole and focuses on human interactions with various components as water moves in a cycle from source to sea and back. In practice, simple technical and software tools and approaches are proposed for the various problems associated with the effects of human influence on the water cycle. In particular, the methodology links water resources management with sanitation and agriculture.

Source: SSWM Toolbox (n.d.).

17.5 Financing the water sector

Meeting wide ranging human needs as well as looking after the natural environment in a sustainable manner comes at a cost. This is often ignored or underestimated by governments and individuals, which results in dysfunctional water systems and a deterioration of critical services. Sustainable funding is required for water resources management as a whole, including providing water supply and sanitation services, and integrative functions such as policy and legislation development, capacity building, research and good governance.

Achieving the MDG targets for access to drinking water and sanitation will also require significant amounts of capital expenditure, particularly in low income countries and least developed countries. However, the benefits associated with water and sanitation, such as reductions in health costs and increases in the number of productive days, will far outweigh the cost of providing safe water and sanitation. Research has shown that every single dollar invested in drinking water and sanitation can yield a payback of US$7.40 per year. Similarly, achieving the MDG targets would result in an additional 320 million productive days every year as a result of improved health, and a time saving of 20 billion working days (Prüss-Üstün et al., 2008).

In spite of these clear benefits, capital expenditure on drinking water and sanitation has a relatively low priority for official development assistance (ODA) or domestic allocations, compared with other social development sectors such as health and education. Between 1997 and 2008, total international assistance for water-related projects (as measured by the Organisation for Economic Co-operation and Development [OECD]) *decreased* from 8% to 5% of total overseas development aid. Yet during the same period, aid for health projects increased from 7% to 12%. Furthermore, less than half of the investment made in water and sanitation by external support agencies goes to low income countries, and only a small proportion of this goes to providing those basic services which could make major contributions to the achievement of the MDGs (WHO and UN-Water, 2010). Therefore, there is a clear need for aid agencies to make greater investments in water and sanitation, particularly in low income countries where the number of urban poor continues to increase rapidly.

As well as fresh capital expenditure, the water sector also requires funding for the proper operation and maintenance of existing systems. In Nepal, for example, according to government estimates, 80% of the population have access to drinking water from improved sources – which means that, on paper, the country has met its MDG target of 73% water supply coverage. However, government data also show that only 17.9% of the water supply systems in the country are functioning properly; 38.9% need minor repairs, 11.8% need major repairs, 21% need rehabilitation, 9.1% need reconstruction and 1.6% are totally nonfunctional (NMIP and DWSS, 2011). Even in Kathmandu Valley, where coverage is reported to be close to 100%, actual service levels fail to meet half the water demand and the quality of the water supplied is a major concern. Therefore, even if the world is on track to meet the MDG for water supply, the operation and maintenance of water systems will continue to require financing.

17.5.1 Bridging the financing gap

A preliminary assessment by the UN Millennium Project (2005) shows that, taking all the MDGs as a whole, many low income countries, particularly in sub-Saharan Africa, face large financial gaps amounting to 20% to 30% of GDP. This is the case even when domestic resource mobilization is maximized. Consequently, these countries will require substantial external financial support to meet the MDGs, both nationwide and in smaller urban centres. Options for bridging this gap for water supply and sanitation are as follows:

- In the poorest countries, external finance and ODA should be grant based, especially for delivery to those who have no water and sanitation service and who live below the poverty line in small urban centres.
- In all low income countries, and where appropriate, substantial shares of operating costs in urban centres should be met through grants or other instruments like output-based aid.
- In middle income countries, small urban centres where people live below the poverty line may need a variety of instruments, including lifeline tariffs (such as those used in South Africa), output-based loans buttressed by the appropriate forms of external guarantees, and internal transfers to meet the upfront costs of new infrastructure, and ultimately make charges affordable to the poor.
- Domestic resource mobilization should be maximized while ensuring that capital and operating costs are adequately funded, keeping in mind the need to provide the poor, particularly poor women, with sustainable and affordable services.
- Ensure that considerations of affordability are reconciled with the need to generate revenues from those that can afford to pay for services.
- Wherever feasible, trunk infrastructure should be funded by the public sector.

Meanwhile, at national level, strategies must be developed to enable a shift from external to domestic sources of financing, including the private sector. At international level, there should be a shift from sovereign to sub-sovereign lending, and measures such as improved financial and operational management should be put in place to improve affordability, and cost recovery. Measures are also needed to improve the performance and creditworthiness of local authorities and utilities.

All those involved must recognize the urgent need to strengthen those financial mechanisms that reduce overhead costs, and ensure that more targeted funds benefit deprived communities. Such mechanisms should also empower the communities, familiarizing them with the challenges involved, and securing their commitment to the search for common solutions. These financial mechanisms should also build national and international partnerships with appropriate financial institutions, in an effort to leverage capital expenditure.

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CHAPTER 18

Managing water along the livestock value chain

FAO and IFAD

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Acknowledgements Reviewers: Jacob Burke (FAO), David Coates (CBD), Theodor Friedrich (FAO), M. Gopalakrishnan (ICID), Amir Kassam (University of Reading, UK), Willem-Jan Laan (Unilever), Lifeng Li (WWF), Jan Lundqvist (SIWI), David Molden (IWMI), Daniel Renault (FAO), Antonio Rota (IFAD), Pasquale Steduto (FAO), Olaf Thieme (FAO), David Tickner (WWF), Olcay Ünver (WWAP) and Richard Connor (WWAP)

Agriculture is a valid and essential consumer of water. Water is a limited resource, and agriculture already accounts for 70% of water withdrawn by all three sectors (i.e. the agricultural, municipal and industrial), and for 90% of water consumed by these three sectors. Responsible agricultural water management will make a major contribution to future global water security.

Water is the key to food security. Globally there is enough water available for future needs, but access is uneven. Many areas of absolute water scarcity are home to the world's poor. Major changes in policy and management will be needed to make best use of available water resources.

Most least developed countries (LCDs) experience highly variable climates, which add to the uncertainties facing farmers. Climate change will make matters worse. Investment in infrastructure and strong institutions will be essential to introduce measurement and control.

Water has a vital role in all links along the agricultural value chain – from production to transformation, consumption, waste and reuse. The growing demand for water for livestock products highlights this.

We need to be more 'water smart'. We all have a responsibility to use this scarce resource wisely, efficiently, and productively.

18.1 Water: A key role in agriculture

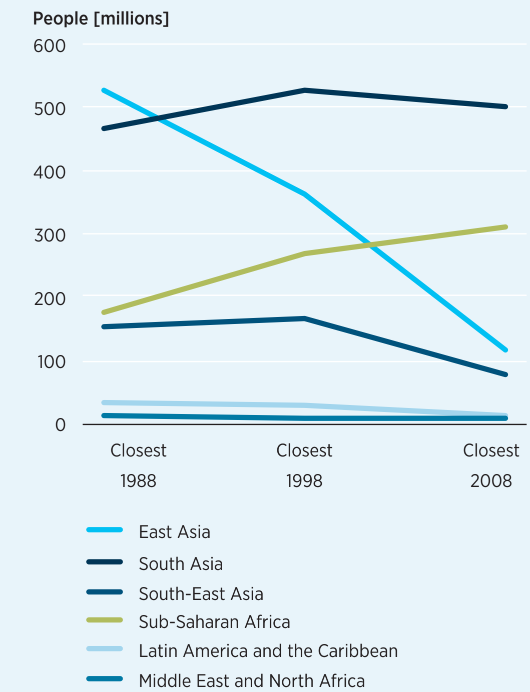
The link between water and food is simple. Crops and livestock need water to grow, and lots of it. Producing 1 kg of rice, for example, requires about 3,500 L of water, 1 kg of beef requires some 15,000 L, and a cup of coffee requires about 140 L (Hoekstra and Chapagain, 2008). The average European diet requires about 3,500 L per person per day, and an additional 2–5 L for drinking and another 145 or so litres for cooking, cleaning, washing, and flushing. Some diets require even more water, for example, a meat-rich diet can require over 5,500 L per person per day. But all this is in stark contrast to the 1.4 billion people living in LDCs in extreme poverty (FAO, 2011e; IFAD, 2011) (Figure 18.1).[1] Despite the historic shift towards urbanization and the fact that urban poverty is increasing rapidly, poverty still largely remains a rural problem. Over 1 billion people rely on agriculture to secure their food and livelihoods on the equivalent of less than 1,000 L of water per person per day.

18.1.1 Water and food security

Food insecurity is a growing concern all over the world. However, there is too little recognition that almost 70% of the world's freshwater withdrawals are already committed to irrigated agriculture (Figure 18.2 and Table 18.1, see Table 18.2 for country groupings) and that more water will be needed as the demand for

FIGURE 18.1

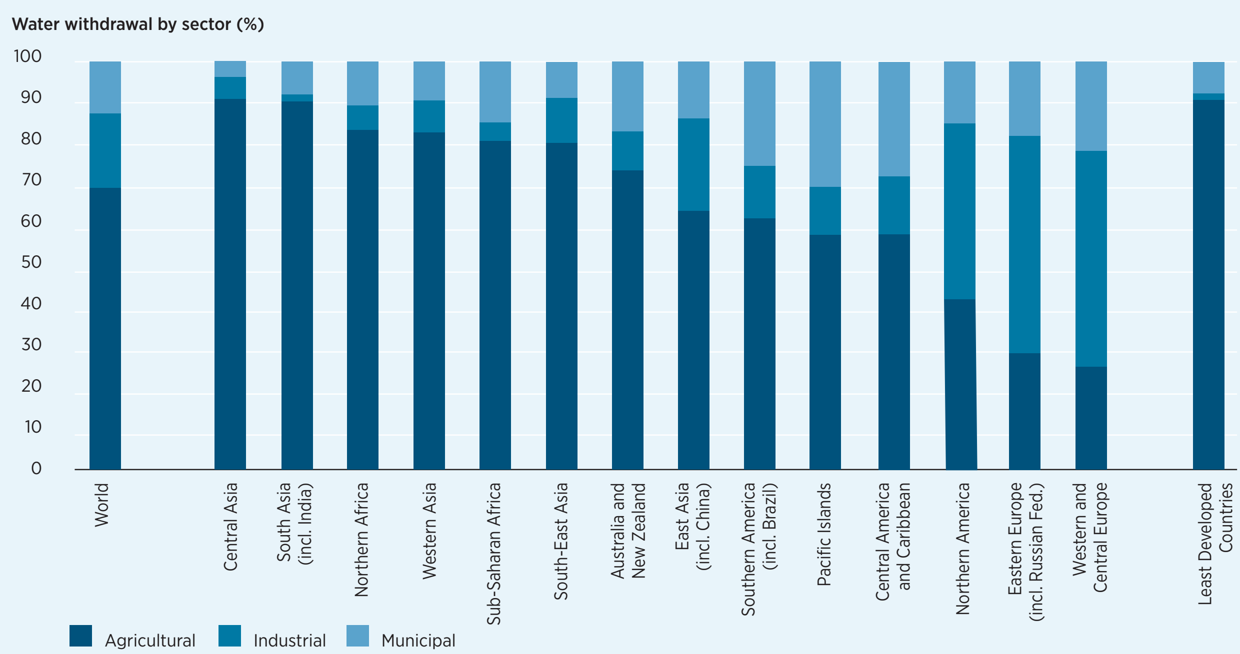
Millions of rural people living in extreme poverty (less than US$1.25 per day) by region



Source: IFAD (2011, fig. 4, p. 49).

FIGURE 18.2

Water withdrawal by sector by region (2005)



Source: FAO (2011c).

food grows. Agricultural water withdrawal accounts for 44% of total water withdrawal in Organization for Economic Co-operation and Development (OECD) countries, but this rises to more than 60% within the eight OECD countries that rely heavily on irrigated agriculture. In the BRIC countries (Brazil, Russian Federation, India and China), agriculture accounts for 74% of water withdrawals, but this ranges from a low 20% in the Russian Federation to 87% in India. In LDCs the figure is more than 90% (FAO, 2011c).

The agricultural sector as a whole has a large water footprint when compared to other sectors, particularly during the production phase (Table 18.3). The booming demand for livestock products in particular is increasing the demand for water at every stage along the livestock value chain, not just during production (see Section 18.5). It is also affecting water quality, which in turn reduces availability.

Although agriculture uses substantial volumes of water, it is time to acknowledge that is also a valid and essential user. In many countries, not just in the LDCs, water availability for agriculture is already limited and uncertain, and this is set to worsen. Several regions are already facing absolute water scarcity, where renewable

TABLE 18.1

Water withdrawal by sector and freshwater withdrawal by region (2005)

Continent	Total withdrawal by sector						Total water withdrawalw*	Total freshwater withdrawal	Freshwater withdrawal as % of IRWR**
	Municipal		Industrial		Agricultural				
Regions	km³/year	%	km³/year	%	km³/year	%	km³/year	km³/year	
Africa	**28**	**12.5**	**11**	**5.1**	**184**	**82.4**	**224**	**224**	**5.7**
Northern Africa	9	10.0	6	6.0	80	84.0	95	95	202.2
Sub-Saharan Africa	19	1.4	6	4.5	105	81.1	129	129	3.3
Americas	**135**	**16.9**	**285**	**35.5**	**381**	**47.6**	**801**	**801**	**4.2**
Northern America	86	14.2	260	43.0	259	42.9	604	604	9.9
Central America and Caribbean	7	27.6	4	14.1	15	58.3	26	26	3.3
Southern America (incl. Brazil)	42	24.8	22	12.6	107	62.6	171	171	1.4
Asia	**227**	**9.0**	**242**	**9.6**	**2 057**	**81.4**	**2 526**	**2 521**	**21.5**
Western Asia	25	9.4	20	7.2	227	83.4	272	269	55.5
Central Asia	6	3.6	8	4.9	150	91.5	164	163	61.8
South Asia (incl. India)	70	7.0	20	2.0	913	91.0	1 004	1 004	56.9
East Asia (incl. China)	93	13.7	149	22.0	436	64.4	677	677	19.9
South-East Asia	33	8.1	46	11.2	330	80.8	409	409	7.1
Europe	**72**	**19.8**	**191**	**52.5**	**101**	**27.7**	**364**	**364**	**5.5**
Western and Central Europe	52	21.0	131	52.5	66	26.6	250	249	11.8
Eastern Europe (incl. Russian Fed.)	20	17.2	60	52.6	35	30.2	115	115	2.6
Oceania	**5**	**16.7**	**3**	**9.5**	**20**	**73.8**	**27**	**27**	**3.1**
Australia and New Zealand	5	16.6	3	9.5	20	73.9	27	27	3.3
Pacific Islands	0.03	29.8	0.01	11.3	0.05	58.9	0.08	0.08	0.1
World	**467**	**11.8**	**732**	**18.6**	**2 743**	**69.9**	**3 942**	**3 936**	**9.3**
Least Developed Countries	**15**	**7.3**	**4**	**1.8**	**186**	**90.9**	**205**	**205**	**4.4**

** Includes use of desalinated water.*
*** IRWR, internal renewable water resources (see Table 18.4).*
Source: FAO (2011c).

TABLE 18.2

Country groupings

Africa	
Northern Africa	Algeria, Egypt, Libya, Morocco, Tunisia
Sub-Saharan Africa	Angola, Benin, Botswana, Burkina Faso, Burundi, Cameroon, Cape Verde, Central African Republic, Chad, Comoros, Congo, Côte d'Ivoire, Democratic Republic of the Congo, Djibouti, Equatorial Guinea, Eritrea, Ethiopia, Gabon, Gambia, Ghana, Guinea, Guinea-Bissau, Kenya, Lesotho, Liberia, Madagascar, Malawi, Mali, Mauritania, Mauritius, Mozambique, Namibia, Niger, Nigeria, Rwanda, Sao Tome and Principe, Senegal, Seychelles, Sierra Leone, Somalia, South Africa, Sudan, Swaziland, Togo, Uganda, United Republic of Tanzania, Zambia, Zimbabwe
Americas	
Northern America	Canada, Mexico, United States of America
Central America and Caribbean	Antigua and Barbuda, Bahamas, Barbados, Belize, Costa Rica, Cuba, Dominica, Dominican Republic, El Salvador, Grenada, Guatemala, Haiti, Honduras, Jamaica, Nicaragua, Panama, Puerto Rico, Saint Kitts and Nevis, Saint Lucia, Saint Vincent and the Grenadines, Trinidad and Tobago
Southern America	Argentina, Bolivia (Plurinational State of), Brazil, Chile, Colombia, Ecuador, French Guiana (France), Guyana, Paraguay, Peru, Suriname, Uruguay, Venezuela (Bolivarian Republic of)
Asia	
Western Asia	Armenia, Azerbaijan, Bahrain, Georgia, Iraq, Islamic Republic of Iran, Israel, Jordan, Kuwait, Lebanon, Occupied Palestinian Territory, Oman, Qatar, Saudi Arabia, Syrian Arab Republic, Turkey, United Arab Emirates, Yemen
Central Asia	Afghanistan, Kazakhstan, Kyrgyzstan, Tajikistan, Turkmenistan, Uzbekistan
South Asia	Bangladesh, Bhutan, India, Maldives, Nepal, Pakistan, Sri Lanka
East Asia	China, Democratic People's Republic of Korea, Japan, Mongolia, Republic of Korea
South-East Asia	Brunei Darussalam, Cambodia, Indonesia, Lao People's Democratic Republic, Malaysia, Myanmar, Papua New Guinea, Philippines, Singapore, Thailand, Timor-Leste, Viet Nam
Europe	
Western and Central Europe	Albania, Andorra, Austria, Belgium, Bosnia and Herzegovina, Bulgaria, Croatia, Cyprus, Czech Republic, Denmark, Faroe Islands, Finland, France, Germany, Greece, Holy See, Hungary, Iceland, Ireland, Italy, Liechtenstein, Luxembourg, Malta, Monaco, Montenegro, Netherlands, Norway, Poland, Portugal, Romania, San Marino, Serbia, Slovakia, Slovenia, Spain, Sweden, Switzerland, The former Yugoslav Republic of Macedonia, United Kingdom
Eastern Europe and Russian Federation	Belarus, Estonia, Latvia, Lithuania, Republic of Moldova, Russian Federation, Ukraine
Oceania	
Australia and New Zealand	Australia, New Zealand
Pacific Islands	Cook Islands, Fiji, Kiribati, Micronesia (Federated States of), Nauru, Niue, Palau, Samoa, Solomon Islands, Tonga, Tuvalu, Vanuatu

Table 18.2 (continued from previous page)

OECD countries	Australia, Austria, Belgium, Canada, Chile, Czech Republic, Denmark, Estonia, Finland, France, Germany, Greece, Hungary, Iceland, Ireland, Israel, Italy, Japan, Luxembourg, Mexico, Netherlands, New Zealand, Norway, Poland, Portugal, Republic of Korea, Slovakia, Slovenia, Spain, Sweden, Switzerland, Turkey, United Kingdom, United States of America
BRIC countries	Brazil, Russian Federation, India, China
Least developed countries (LDCs)	Afghanistan, Angola, Bangladesh, Benin, Bhutan, Burkina Faso, Burundi, Cambodia, Central African Republic, Chad, Comoros, Democratic Republic of the Congo, Djibouti, Equatorial Guinea, Eritrea, Ethiopia, Gambia, Guinea, Guinea-Bissau, Haiti, Kiribati, Lao People's Democratic Republic, Lesotho, Liberia, Madagascar, Malawi, Maldives, Mali, Mauritania, Mozambique, Myanmar, Nepal, Niger, Rwanda, Samoa, Sao Tome and Principe, Senegal, Sierra Leone, Solomon Islands, Somalia, Sudan, Timor-Leste, Togo, Tuvalu, Uganda, United Republic of Tanzania, Vanuatu, Yemen, Zambia

TABLE 18.3

Relative water footprints of various industry sectors

	Raw material production	Suppliers	Direct operations	Product use/end of life
Apparel	💧💧💧	💧		💧
High-tech/ Electronics	💧	💧		💧
Beverage	💧💧	💧	💧	
Food	💧💧💧		💧💧	
Biotech/ Pharma			💧	
Forest products	💧		💧💧	
Metals/Mining	💧💧		💧💧	
Electric power/ Energy	💧💧		💧💧	

Note: Water drops indicate the value chain segments that have relatively high blue, green and grey water footprint intensities. The water footprint is an indicator of water use that looks at both direct and indirect water use of a consumer or producer. The water footprint of an individual, community or business is defined as the total volume of freshwater that is used to produce the goods and services consumed by the individual or community or produced by the business.
Source: Morrison et al. (2009, p. 20).

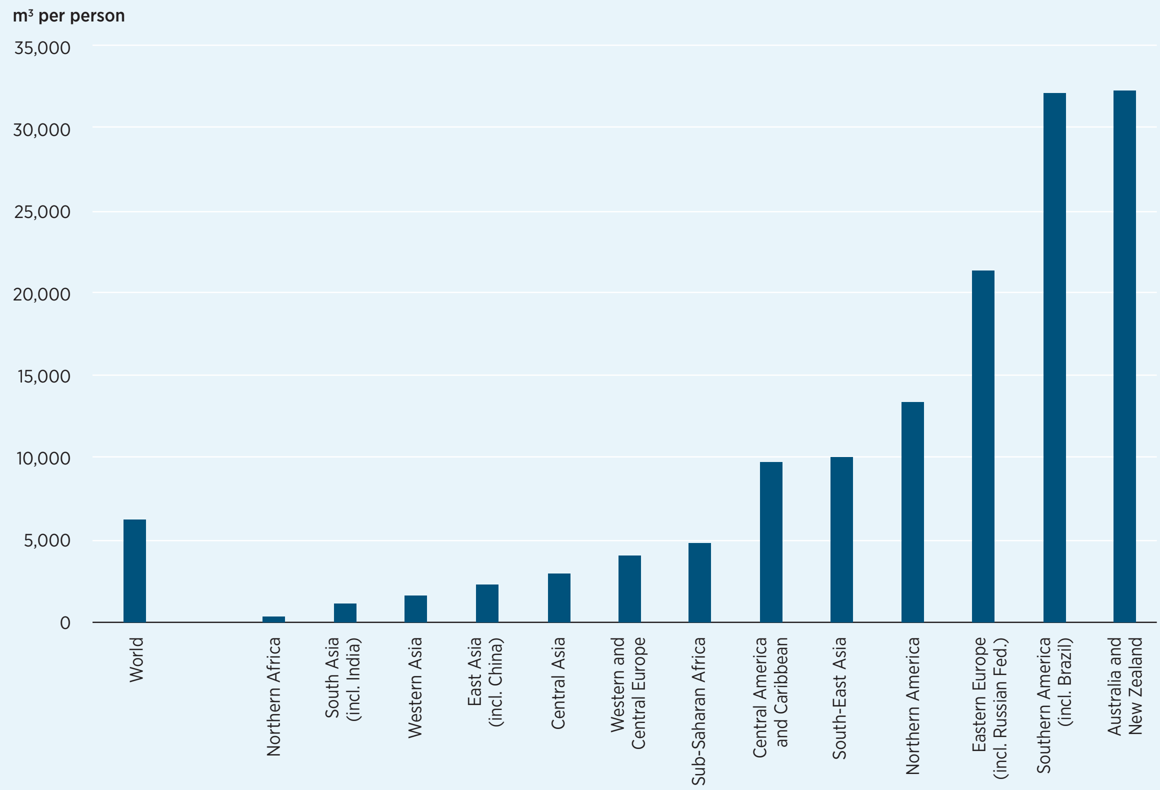
water resources are below 500 m^3 per person per year, or are facing chronic water shortage (500–1,000 m^3) or water stress (1,000–1,700 m^3) (Figure 18.3 and Table 18.4) (FAO, 2011c). By 2030 food demand is predicted to increase by 50% (70% by 2050) (Bruinsma, 2009) and energy demand from hydropower and other renewable energy resources will rise by 60% (WWAP, 2009). These issues are interconnected – increasing agricultural output for example, will substantially increase both water and energy consumption, leading to increased competition for water between the different water using sectors. The main challenge facing the agricultural sector is not so much growing 70% more food in 40 years, but making 70% more food available on the plate. Reducing losses in storage and along the value chain may go a long way towards offsetting the need for more production.

Despite these challenges, there are many reasons for optimism. The world's population has already shown how resilient it can be. The large irrigation schemes built in the late nineteenth and early twentieth centuries in the Indus valley fed many millions of people who would have otherwise starved. In the second half of the twentieth century world food production more than doubled in response to a doubling of the population. Agricultural productivity rose steadily and irrigated agriculture was an important part of this success story. The 'green' revolution in the 1960s and 1970s lifted Asia out of an imminent hunger crisis although the price was heavy in terms of water use, energy consumption and environmental degradation.

In the 1990s the importance of water ecosystem services became better recognized, as did the need for a

FIGURE 18.3

Renewable water resources per person in 2008



Source: FAO (2011c).

balance between water for food, people, industry and the environment. The response to this was a 'green-green' revolution founded on the principles of environmental sustainability (Conway, 1997). This revolution supported the development of 'green infrastructure' such as improving the health of rivers and their catchments to filter pollutants, mitigate floods and droughts, recharge groundwater and maintain fisheries. Technologies that maintain and enhance such services also build resilience into water delivery systems for people and for agriculture.

Although high food prices may not be popular, there are benefits. For poor farmers higher food prices can mean increased farm incomes (provided they actually receive a portion of the price increase) and for others they focus attention on food losses and wastage. In LDCs as much as half of crops produced are lost post-harvest while in OECD countries as much as 40% of food is wasted along the value chain and by consumers. Reducing these high losses would not only reduce the demand to produce more crops at the farm gate by 2050 but also significantly reduce the demand on water resources required to grow them.

Many countries still have a large, untapped endowment of rainfall that can be harnessed using conservation farming practices, and supplementary irrigation has a significant role to play in those areas where there are sufficient water resources.

18.1.2 Agriculture's impact on water

Land use changes as a result of agriculture have produced a wide range of impacts on water quantity and quality (Scanlon et al., 2007). Wetlands in particular have been affected. Poor water quality originating from agricultural pollution is most severe in wetlands in Europe, Latin America and Asia (Figure 18.4). The status of species in freshwater and coastal wetlands has been deteriorating faster than those of other ecosystems (MEA, 2005*a*).

The way that water is managed in agriculture has caused wide-scale changes in ecosystems and

TABLE 18.4

Precipitation and renewable freshwater resources by region

Continent / Regions	Precipitation: Depth (mm/year)	Precipitation: Volume (km^3/year)	Internal renewable freshwater resources: Volume (km^3/year)	% of world's freshwater resources	Per capita in year 2008 (m^3)
Africa	**678**	**20 359**	**3 931**	**9.3**	**4 007**
Northern Africa	96	550	47	0.1	286
Sub-Saharan Africa	815	19 809	3 884	9.2	4 754
Americas	**1 088**	**43 887**	**19 238**	**45.4**	**20 927**
Northern America	637	13 869	6 077	14.4	13 401
Central America and Caribbean	2 012	1 510	781	1.8	9 654
Southern America (incl. Brazil)	1 602	28 507	12 380	29.2	32 165
Asia	**827**	**26 826**	**11 708**	**27.7**	**2 870**
Western Asia	217	1 423	484	1.1	1 632
Central Asia	273	1 270	263	0.6	3 020
South Asia (incl. India)	1 062	4 755	1 765	4.2	1 125
East Asia (incl. China)	634	7 453	3 410	8.1	2 204
South-East Asia	2 405	11 925	5 786	13.7	9 957
Europe	**544**	**12 507**	**6 569**	**15.5**	**9 102**
Western and Central Europe	827	4 045	2 120	5.0	4 123
Eastern Europe (incl. Russian Fed.)	467	8 462	4 449	10.5	21 430
Oceania	**586**	**4 733**	**892**	**2.1**	**33 469**
Australia and New Zealand	574	4 598	819	1.9	32 366
Pacific Islands	2 062	135	73	0.2	54 059
World	**809**	**108 312**	**42 338**	**100.0**	**6 292**

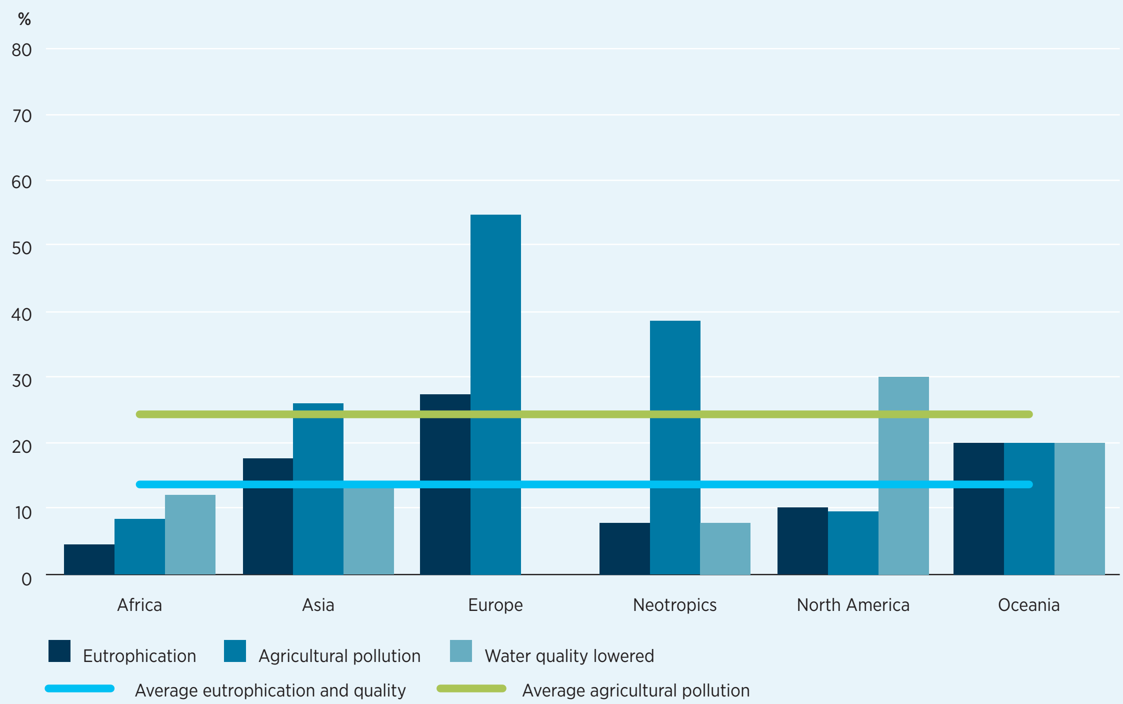
Source: FAO (2011c).

undermined the provision of a wide range of ecosystem services. Water management for agriculture has changed the physical and chemical characteristics of freshwater and coastal wetlands and the quality and quantity of water, as well as direct and indirect biological changes in terrestrial ecosystems. The external cost of the damage to people and ecosystems and clean-up processes from the agricultural sector is significant. In the United States of America (USA) for instance the estimated cost is US$9–20 billion per year (cited in Galloway et al., 2007).

Diffuse pollution from agricultural land continues to be of critical concern throughout many of the world's river basins. Eutrophication from agricultural runoff ranks among the top pollution problems in the USA, Canada, Asia and the Pacific. Australia, India, Pakistan and many parts of the arid Middle East face increasing salinization as a result of poor irrigation practices (MEA, 2005*b*). Nitrate is the most common chemical contaminant in the world's aquifers and mean nitrate levels have increased by about 36% in global waterways since 1990. According to data available in FAO (2011*d*), the USA is currently the country consuming the largest amounts of pesticides, followed by countries in Europe, especially those of Western Europe. In terms of use per unit of cultivated area, Japan is the most intensive user of pesticides. Over-abstraction of renewable groundwater resources and abstraction of fossil groundwater reserves in arid Northern Africa and the Arabian Peninsula, driven primarily by the agricultural sector, is putting irreconcilable pressures on water resources.

FIGURE 18.4

Wetlands water quality state changes by continent



Source: FAO (2008b, p. 50).

In 2005, global conversion of forests (primarily to agricultural land) was estimated to be about 13 million ha per year, and these land cover changes also account for 20% of green house gas (GHG) emissions (Bellarby et al., 2008). South and South-East Asia and Southern and Central America have the highest net carbon flux to the atmosphere (Houghton, 2008). Such land cover changes can increase runoff, increase sediment and nutrient flows, increase floods, reduce groundwater recharge, and reduce biodiversity.

Almost 12% of the global land cover is now under cultivation with cropland covering more than 50% of the land in countries such as India and Bangladesh, and more than 30% in large parts of Europe (Table 18.6) (FAO, 2011*d*).

Between 1961 and 2008, the cultivated area increased by 12%, from 1,368 million ha to 1,527 million ha, and it is all attributable to a net increase in irrigated cropping (Table 18.5).

However, there are also many ways in which agriculture can mitigate these pollution and degradation problems. For example:

- the irrigated area can be expanded somewhat, but it is more important to increase the yield, increase cropping intensities and improve production systems, such as the system of rice intensification;
- the rainfed agriculture area can also be somewhat expanded but again it is more important to increase productivity and improve farming systems using sustainable crop production intensification technologies, such as conservation agriculture, integrated pest management and integrated plant nutrition management;
- reduce post-harvest, transformation, and consumption losses (see Section 18.5).

TABLE 18.5

Net changes in major land use (million ha)

	1961	2008	Net increase
Cultivated land	1 368	1 527	12%
Rainfed	1 229	1 223	–0.5%
Irrigated	139	304	119%

Sources: FAO (2011c, 2011d).

18.2 Managing water resources in agriculture

Do we have enough water (and land) and human capacity to produce the food for a growing population over the next 50 years? The simple answer is 'yes, there is enough' but only if we act now to improve water use in agriculture (Comprehensive Assessment of Water Management in Agriculture, 2007).

Only a small percentage of the world's freshwater is readily available for us to use. Of the 110,000 km^3 of rain falling annually on the earth's surface, 36% ends up in the sea; forestry, grazing lands, fisheries, and biodiversity consume 57%; our towns, cities, and industry consume just 0.1% (110 km^3); while agriculture, including both rainfed and irrigated cropping, consumes 7% (7,130 km^3) (Comprehensive Assessment of Water Management in Agriculture, 2007), of which only 990 km^3 per year is consumed in the OECD countries.

The annual global agricultural water consumption includes crop water consumption for food, fibre and feed production (transpiration) plus evaporation losses from

TABLE 18.6

Population, areas and gross domestic product (GDP) by region

Continent	Population			Area				GDP	
	Total (2008)	Density	% of economically active population active in agriculture	Total area of the country	Total area as % of world area	Cultivated (2008)	Area cultivated per person economically active in agriculture	Per capita (2008)	Value added by agriculture
Regions	1000 inh	inh/km²		1000 ha	%	%	ha	US$/capita	%
Africa	**981 043**	**33**	**54**	**3 004 590**	**22**	**8**	**1.2**	**1 592**	**16**
Northern Africa	163 969	29	24	575 289	4	5	2.0	3 434	11
Sub-Saharan Africa	817 074	34	59	2 429 301	18	9	1.2	1 222	18
Americas	**919 269**	**23**	**10**	**4 032 189**	**30**	**10**	**8.8**	**21 657**	**2**
Northern America	453 480	21	5	2 178 056	16	12	23.1	36 805	1
Central America and Caribbean	80 900	108	24	75 069	1	20	1.9	3 820	7
Southern America (incl. Brazil)	384 889	22	14	1 779 064	13	7	4.9	7 574	7
Asia	**4 079 924**	**126**	**52**	**3 242 111**	**24**	**17**	**0.5**	**3 805**	**8**
Western Asia	296 556	45	21	656 650	5	10	2.9	8 242	6
Central Asia	87 214	19	31	465 513	3	8	3.5	2 272	12
South Asia (incl. India)	1 568 227	350	53	447 884	3	46	0.6	970	18
East Asia (incl. China)	1 546 824	132	56	1 176 232	9	11	0.3	6 413	6
South-East Asia	581 103	117	48	495 832	4	20	0.7	2 481	12
Europe	**721 700**	**31**	**6**	**2 300 705**	**17**	**13**	**12.8**	**29 026**	**2**
Western and Central Europe	514 081	105	5	488 872	4	26	9.7	36 777	2
Eastern Europe (incl. Russian Fed.)	207 619	11	9	1 811 833	14	9	16.8	9 434	5
Oceania	**26 659**	**3**	**7**	**807 440**	**6**	**6**	**45.8**	**41 975**	**4**
Australia and New Zealand	25 304	3	5	800 893	6	6	71.6	45 286	4
Pacific Islands	1 355	21	41	6 547	0	10	1.7	2 847	16
World	**6 728 595**	**50**	**41**	**13 387 035**	**100**	**11**	**1.2**	**8 813**	**4**
Least Developed Countries	**816 782**	**39**	**66**	**2 079 489**	**16**	**8**	**0.7**	**616**	**24**

Source: FAO (2011c, with data from UN Population Division, FAOSTAT and World Bank World Development Indicators).

the soil and from open water associated with agriculture such as rice fields, irrigation canals and reservoirs. Only about 20% of the total 7,130 km³ of agriculture's annual water consumption is 'blue water' – that is water from rivers, streams, lakes and groundwater for irrigation purposes. Although irrigation is only a modest part of agricultural water consumption, it plays a crucial role, accounting for more than 40% of the world's production on less than 20% of the cultivated land.

However, global water resource assessments hide the large differences in water availability across the world. Some regions, such as the more northern latitudes and the wet tropics, have more than enough water, whereas the drier semi-arid and arid regions have too little. Unlike other resources, water cannot be moved across continents in any significant quantities except when it is embedded in food products.

Predicting future water demand for agriculture is fraught with uncertainty. Future demand for water in this sector is in part influenced by demand for food, which in turn depends partly on the number of people needing to be fed, and in part on what and how much they eat. This is complicated by, amongst other factors, uncertainties in seasonal climatic variations, efficiency of agriculture production processes, crop types and yields.

The world population is predicted to grow from 6.9 billion in 2010 to 8.3 billion in 2030 and 9.1 billion in 2050

TABLE 18.7

Pressure on water resources due to irrigation

Continent / Regions	Precipitation (mm)	Renewable water resources (km³)	Water requirement ratio (%)	Irrigation water withdrawal (km³)	Pressure on water resources due to irrigation (%)
Year			**2008**	**2008**	**2008**
Africa	**678**	**3 931**	**48**	**184**	**5**
Northern Africa	96	47	69	80	170
Sub-Saharan Africa	815	3 884	30	105	3
Americas	**1 088**	**19 238**	**41**	**381**	**2**
Northern America	637	6 077	46	259	4
Central America and Caribbean	2 012	781	30	15	2
Southern America	1 602	12 380	28	107	1
Asia	**827**	**11 708**	**45**	**2 057**	**18**
Western Asia	217	484	47	227	47
Central Asia	273	263	48	150	57
South Asia	1 062	1 765	55	913	52
East Asia	634	3 410	37	436	13
South-East Asia	2 405	5 786	19	330	6
Europe	**544**	**6 569**	**48**	**101**	**2**
Western and Central Europe	827	2 120	43	56	3
Eastern Europe (incl. Russian Fed.)	467	4 449	67	35	1
Oceania	**586**	**892**	**41**	**20**	**2**
Australia and New Zealand	574	819	41	20	2
Pacific Islands	2 062	73	-	0.05	-
World	**809**	**42 338**	**44**	**2 743**	**6**

**The water requirement ratio is the ratio between the irrigation requirement and irrigation water withdrawal.*
*** Pressure on water resources due to irrigation is the ratio between irrigation water withdrawal and renewable water resources.*
Sources: Adapted from FAO (2011a) and FAO (2011c).

(DESA, 2009). But these figures hide the fact that the population in some countries, particularly in sub-Saharan Africa and South Asia, will continue to grow while in high income countries the population will decline. By 2050 about 7.5 billion people will be living in low and middle income countries, with 1.5 billion in sub-Saharan Africa and 2.2 billion in South Asia.

Although projections vary considerably based on different scenario assumptions and methodologies, future global agricultural water consumption (including both rainfed and irrigated agriculture) is estimated to increase by about 19% to 8,515 km^3 per year in 2050 (Comprehensive Assessment of Water Management in Agriculture, 2007). The Food and Agriculture Organization of the United Nations (FAO) estimates an 11% increase in irrigation water consumption from 2008 to 2050. This is expected to increase by about 5% the present water withdrawal for irrigation of 2,740 km^3 (Table 18.7). Although this seems a modest increase, much of it will be in regions already suffering water scarcity (FAO, 2011*a*).

In semi-arid environments the amount of rainfall used for cropping is relatively small. Hence in these areas, better use of rainfall is needed by integrating soil and water management – focused on soil fertility, improved rainfall infiltration and water harvesting – to reduce water losses, improve yields and raise the overall water productivity of rainfed systems. The strategy is to get 'more crop per drop'.

Globally, irrigated crop yields are about 2.7 times those of rainfed farming, hence irrigation will continue to

TABLE 18.8

Evolution of area equipped for irrigation, groundwater irrigation and percentage of cultivated land

Continent / Regions	Total area equipped for irrigation (1000 ha)			By groundwater		Total irrigation as % of cultivated land		
				Area	% of total			
Year	1970	1990	2008	2008	2008	1970	1990	2008
Africa	**8 429**	**10 990**	**13 445**	**2 506**	**19**	**4.6**	**5.4**	**5.4**
Northern Africa	4 376	5 131	6 340	2 092	33	18.4	19.2	22.6
Sub-Saharan Africa	4 053	5 859	7 105	414	6	2.6	3.3	3.2
Americas	**26 609**	**38 381**	**44 002**	**21 548**	**49**	**7.2**	**9.9**	**11.1**
Northern America	20 004	27 218	31 826	19 147	60	6.7	9.0	12.6
Central America and Caribbean	932	1 669	1 739	683	39	8.0	12.0	11.5
Southern America (incl. Brazil)	5 673	9 494	10 437	1 717	16	6.3	8.7	8.2
Asia	**116 031**	**168 195**	**222 269**	**80 582**	**36**	**23.3**	**30.3**	**41.0**
Western Asia	11 025	19 802	23 347	10 838	46	17.2	30.0	36.3
Central Asia	7 971	13 366	14 518	1,149	8	15.2	25.9	36.8
South Asia (incl. India)	45 048	66 856	93 140	48 293	52	22.8	32.7	45.6
East Asia (incl. China)	42 894	53 299	68 491	19 331	28	38.5	37.4	51.6
South-East Asia	9 093	14 872	22 773	971	4	12.2	18.8	22.4
Europe	**15 259**	**25 908**	**21 856**	**7 350**	**34**	**4.6**	**8.1**	**7.5**
Western and Central Europe	10 844	17 635	16 221	6 857	42	7.4	12.7	13.0
Eastern Europe (incl. Russian Fed.)	4 415	8 273	5 635	493	9	2.4	4.6	3.4
Oceania	**1 588**	**2 113**	**2 833**	**950**	**34**	**3.5**	**4.1**	**6.2**
Australia and New Zealand	1 587	2 112	2 830	949	34	3.5	4.2	6.3
Pacific Islands	1	1	3	1.00	33	0.2	0.2	0.5
World	**167 916**	**245 587**	**304 405**	**112 936**	**37**	**11.8**	**16.1**	**19.9**

Sources: FAO (2011c), FAO (2011d) and Siebert et al. (2010).

play an important role in food production. The area equipped for irrigation increased from 170 million ha in 1970 to 304 million ha in 2008 (Table 18.8). There is still the potential for expansion, particularly in sub-Saharan Africa and Southern America, in places where there is sufficient water available. Pathways to improve productivity and bridge the yield gap in irrigation are: increasing the quantity, reliability and timing of water services; increasing the beneficial use of water withdrawn for irrigation; and increasing agronomic or economic productivity so that more output is obtained per unit of water consumed (FAO, 2011*a*).

In most LDCs, new institutional structures will be needed which enable governments to centralize responsibilities for water regulation yet decentralize water management responsibility and increase user ownership and participation. Data collection and synthesis for water resources planning will need to be strengthened, and so too will the communication between government departments which have overlapping responsibilities for water management. The need is to try and achieve integrated water resources management (IWRM).

Recognizing the local nature of water management will also be important, as will be the need to significantly increase water productivity and adjust water allocations to meet changing societal habits (FAO, 2009*a*). The effectiveness of existing agricultural water consumption can also be greatly improved by reducing the significant quantities of crops lost in post-harvest stores in LDCs and reducing the large amounts of food waste along the value chain in OECD and BRIC countries.

Virtual water trading may also play an increasing role in the future. This means growing food in water-rich places and exporting it (with the water embedded in its production) to water-scarce countries. This is already happening in the Middle East, although only 15% of the world's farm output in terms of embedded water is traded internationally (Allan, 2011). However, the concept of virtual water as a means of framing economic and trade policy is questioned by some (Wichelns, 2010). One of the main constraints is the low purchasing power in countries facing the largest growth in food demand and this is likely to remain so for the foreseeable future. Evidence from the recent rise in commodity prices suggests that countries are quick to raise export tariffs of staple crops as soon as national food security is threatened.

18.3 Uncertainties and risk management

There are many risks and uncertainties about future water availability for agriculture, and these are greatest in the drought prone low income countries whose GDP is dependent on agriculture. The economic performance in many LDCs is closely linked to rainfall, but there are many other issues that add to the risks and uncertainties created by climate.

18.3.1 A new 'rurality' in least developed countries

Most LDC governments look to their rural communities to produce more agricultural products but those same communities are impoverished, their productivity is low, as is their resource use efficiency. Their burden is made worse by the changing nature of rural life – known as the new 'rurality' (Rauch, 2009). Globalization is transforming the marketplace; new patterns of poverty are emerging as livelihoods adjust; reforms in governance and rural service systems are changing the nature of institutions. All these issues create uncertainty and risk and are likely to have a disproportionate impact on the rural poor and their ability to access and make good use of limited water resources.

18.3.2 Climate change

Agriculture contributes to climate change through its share of GHG emissions, which in turn is affecting the planet's water cycle and adding another layer of uncertainties and risks to food production. Climate change impacts are mainly experienced through the water regime in the form of more severe and frequent droughts and floods, with anticipated effects on the availability of water resources through changes in rainfall distribution, soil moisture, glacier and ice/snow melt, and river and groundwater flows. These climate change-induced hydrological changes are likely to affect both the extent and productivity of irrigated and rainfed agriculture worldwide, hence adaptation strategies will focus on minimizing the overall production risk (FAO, 2011*b*).

Agriculture is the largest contributor to global non-CO_2 GHG emissions (59% in 1990, 57% forecasted for 2020) (US-EPA, 2006). The agricultural sector contributes both directly (methane from cattle enteric fermentation, rice production, etc.) and indirectly (conversion of land to agriculture, fossil fuel use on farms, production of agro-chemicals, etc.) to GHG emissions. The sector directly contributes 14% of global annual GHG emissions and indirectly contributes an additional 4–8% (from forest clearing for rangeland and arable development) (FAO, 2011*b*). The most common GHGs from the agricultural sector – nitrous oxide (N_2O) and methane (CH_4) gases – emanate primarily from agricultural soils (N_2O) and livestock (CH_4 from enteric fermentation, i.e. belching) (Figures 18.5 and 18.6).

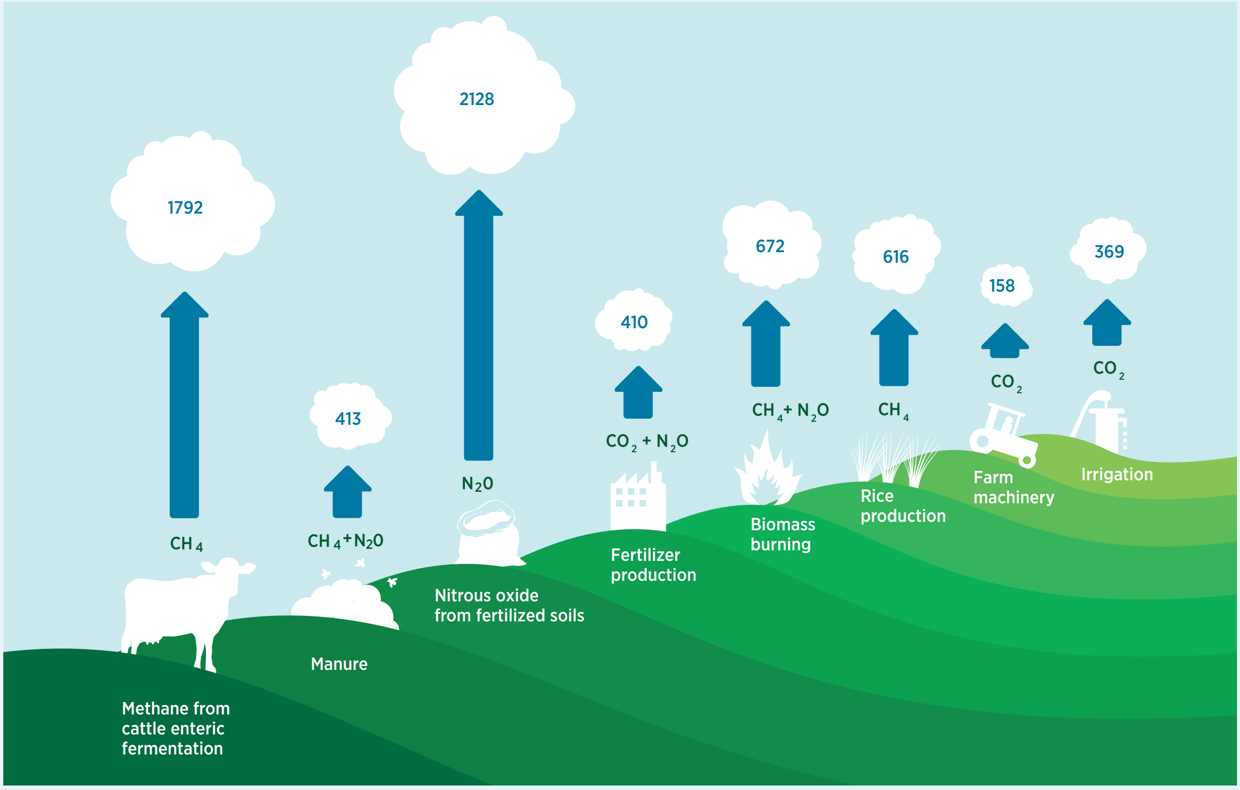
In 1990, the OECD countries, China, the Former Soviet Union countries, Latin America and Africa accounted for more than 80% of N_2O emissions from agricultural soils. By 2020, OECD countries' agricultural soil emissions are expected to decrease and contribute 23% of global emissions (compared to 32% in 1990). Expected increases in crop and livestock production elsewhere portend that Central, South and East Asia's and Eastern Europe's agricultural soil emissions will grow more than 50%, and soil emissions from Africa, Latin America and the Middle East will grow over 100%. Globally, CH_4 emissions from livestock digestion are forecasted to grow, and while most OECD countries' livestock enteric fermentation emissions are expected to decrease somewhat overall (–9%), China, Brazil, India, USA and Pakistan are predicted to be the top emitters in this category by 2020 (US-EPA, 2006).

Agriculture also offers significant mitigation potential which can be realized through a variety of site-specific options spanning from measures and practices aimed at reducing emissions, enhancing removals, and/or avoiding (or displacing) emissions. Estimates suggest that the total biophysical mitigation potential from agriculture could be 5,500–6,000 megatonnes CO_2-equivalent per year which, if fully reached, could offset about 20% of total annual CO_2 emissions (Smith et al., 2008). Specifically, crop and grazing land management, restoring the carbon content of cultivated organic soils and restoring degraded lands provide the most significant mitigation potentials in agriculture, followed by improved water and rice management, land use changes (i.e. conversion of cropland to grassland) and agro-forestry, and improved livestock and manure management (Smith et al., 2007)

In terms of the impacts, floods and droughts are increasing in incidence and severity, and this trend is predicted to continue in the future. Recent evidence

FIGURE 18.5

Sources of agricultural greenhouse gases excluding land use change



Source: Bellarby et al. (2008 fig. 2, p. 7).

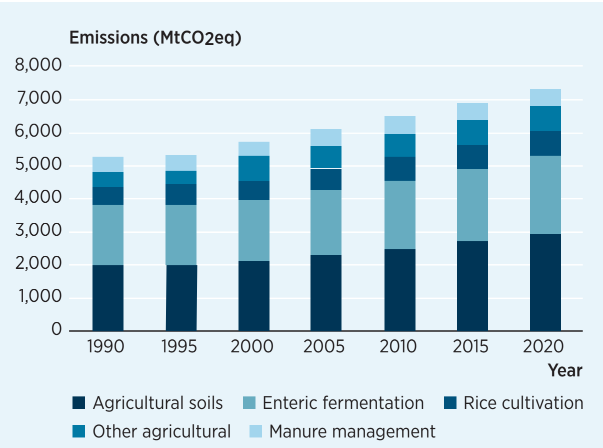
forecasts that the Mediterranean basin and the semi-arid areas of the Americas, Australia, and Southern Africa will experience reductions in river runoff and aquifer recharge, affecting water availability in these already water-stressed regions. In Asia, changes in runoff patterns from snowmelt and high mountain glaciers will affect downstream dependent irrigated lands, as well as the highly populated Asian deltas, from a combination of reduced inflows, increased salinity and rising sea levels. Worldwide, the rising temperatures will increase crop water demand (FAO, 2011b).

Climate change will also affect groundwater and this in turn will affect the vulnerability of women in many countries. Since the burden of collecting water for household purposes often falls on the women, lowering groundwater levels and increasingly depleted water sources result in women having to walk longer and longer distances to fetch water, thus taking away time from agricultural activities and exposing themselves to a variety of dangers (FAO, 2010).

It is predicted that South Asia and Southern Africa will be the most vulnerable to climate change-related food shortages by 2030 (Lobell et al., 2008). Their populations are food insecure because they are highly dependent on growing crops in ecosystems that display high vulnerability and consequences to climate change projections of temperature and precipitation changes.

FIGURE 18.6

Total greenhouse gas emissions from the agricultural sector by source



Source: US-EPA (2006).

As climate variability has a direct impact on crop yields – mainly in terms of precipitation, temperature increases and water availability – adaptive management practices and systems need to build in flexibility which allows for adaptation in the agricultural sector. As a result, climate change research in most OECD countries for instance focuses primarily on examining the implications for agricultural production, such as forecast changes in regional rainfall and water availability, and on analysing the efficiency of farm practices under various climate change scenarios.

For water, options to adapt to the changes are a combination of improved supply management (adapting storage capacity) and demand management – to reduce groundwater overuse, promote more efficient conjunctive use and raise water productivity (FAO, 2011*a*).

18.3.3 Food, economy and energy crises

The food price crisis, followed shortly by the 2009 economic crisis, has had tragic consequences for world hunger. Food prices are significantly higher than they were in 2006. Although the factors which led to this increase in food prices were said to be temporary – such as drought in wheat-producing regions, low food stocks and soaring oil barrel prices that drove up the price of fertilizers – food prices in 2011 had not yet returned to their pre-2006 levels. Poor women shoulder the brunt of economic crises and women with less education tend to increase their work participation more in times of crisis in almost every region of the world (FAO, 2009*b*).

The demand for biofuels has soared in recent years. Substantial amounts of maize in the USA, wheat and rapeseed in the European Union (EU), oil palm in parts of sub-Saharan Africa and South and South-East Asia, and sugar in Brazil, are being raised for ethanol and biodiesel production. In 2007, biofuel production was dominated by the USA, Brazil, and to a lesser extent, the EU. Biomass and waste represented 10% of the world's primary energy demand in 2005, more than nuclear (6%) and hydro (2%) jointly (IEA, 2007).

If a projected bio-energy supply of 6,000–12,000 million tonnes of oil equivalent were to be reached in 2050, this would take up one-fifth of the world's agricultural land (IEA, 2006).[2] Biofuels are also water intensive and can add to the strain on local hydrological systems and GHG emissions. Irrigated biofuels already consume just under 2% of all irrigation water withdrawals (about 44 km^3) (FAO, 2008*a*) (Table 18.9). For instance, it was estimated that 1 litre of ethanol produced in the irrigated south-western part of Nebraska in the USA requires about 415 L of water (Varghese, 2007). In Brazil water pollution associated with biofuel production, the application of fertilizers and agro-chemicals, soil erosion, and sugarcane washing procedures are major concerns.

18.3.4 Land acquisitions and land use changes

Land use is changing because of the rising international phenomenon of land acquisition, which will in turn impact on water use. Since 2007 some OECD and BRIC countries' sovereign funds and investment companies have bought or leased large tracts of farmland across Africa, Latin America and Asia in order to secure their fuel and food requirements. This was triggered by the fuel crisis and the demand for biofuels to replace petroleum-based products.

Although there is still potential to increase the cropped area, some 5–7 million ha (0.6%) of farmland is lost annually because of accelerating land degradation and urbanization, which takes agricultural land out of production and reduces the number of family farms as more people move to the cities. Increasing population means that the amount of cultivated land per person is declining sharply – from 0.4 ha in 1961 to 0.2 ha in 2005.

18.3.5 Policy and governance

Improving productivity of irrigated agriculture and using less water means transferring and adopting newer technologies and adapting equipment and processes to locally appropriate irrigation practices. This requires financial resources, but it also requires good policy and governance, and the links between them need to be given priority. For instance, there have been numerous efforts to link national integrated water resource and water efficiency plans to national development plans in order to access government and donor finance (GWP, 2009).

While there are established tools and instruments to better manage water assets for agriculture, there are many other seemingly unrelated issues that underpin the overall challenges of water governance such as fragile states, corruption, inequitable access to water and land tenure rights. More so, agricultural water allocations sit within increasingly competing social–economic–environmental needs and priorities that drive overall national security and development objectives, and which climate change-induced hydrological changes are set to exacerbate. Various subregional initiatives have sprouted in recent years in a bid to increase high-level political attention (hence investments) to water security issues, such as the African Ministers' Council on Water and the Asia–Pacific Water Forum. Local institutions nonetheless remain the frontline actors and here weak capacity and fragmentation of water-related institutions remain as key concerns in many regions.

18.4 A new era in food and water management?

When water is scarce it is no longer enough to just think about the amount of water we need to grow food (Lundqvist et al., 2008), we must also look at the way water is used along the entire value chain from production to consumption and beyond (Figure 18.7). This is particularly true for the more industrialized countries, and also to some extent in the towns and cities of the BRIC countries, where food increasingly comes from many different sources, often

TABLE 18.9

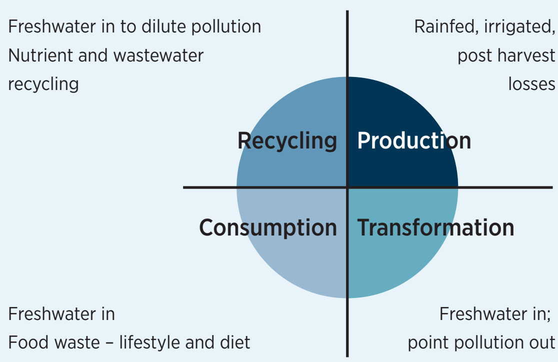
Water requirements for biofuel crops

Crop	Annual obtainable fuel yield	Energy yield	Evapo-transpiration equivalent	Potential crop evapo-transpiration	Rainfed crop evapo-transpiration	Irrigated crop water requirement	
	(L/ha)	*(G/ha)*	*(L/litre fuel)*	*(mm/ha)*	*(mm/ha)*	*(mm/ha)**	*(L/litre fuel)*
Sugar cane	6 000	120	2 000	1 400	1 000	800	1 333
Maize	3 500	70	1 357	550	400	300	857
Oil palm	5 500	193	2 364	1 500	1 300	0	0
Rapeseed	1 200	42	3 333	500	400	0	0

** On the assumption of 50% irrigation efficiency.*
Source: FAO (2008a).

FIGURE 18.7

Water use along the value chain, from production to recycling



BOX 18.1

'It is distressing to note that so much time is being devoted to the culture of the plant, so much money spent on irrigation, fertilization and crop protection measures only to be wasted about a week after harvest' (FAO, 1981).

over long distances, and in some cases from many different countries. Food security is threatened by the potential for waste as agricultural products move along extensive value chains and pass through many hands – farmers, transporters, store keepers, food processors, shopkeepers and consumers – as it travels from field to fork. Food can be wasted at every step along the value chain and this means that the water used to produce it is also wasted. All this is in sharp contrast to the past when most food was produced and consumed locally, which is still the case in most LCDs.

In some countries reducing water use is no longer just about improving water productivity on the farm. Water is used for cleaning, preparing, distributing and consuming food. All these processes pollute the water which then requires recycling prior to discharge or diluting to reduce contamination.

Water management has traditionally been the responsibility of governments, but major international food companies are beginning to realize the importance of water to their businesses, particularly where their value chains are in water-short countries. Although their concern may have more to do with customer perceptions and security of profits, there are potential knock-on benefits for everyone as water is managed with greater care. Initiatives to promote more efficient use of water along the value chain include, for example, the CEO Water Mandate and the Alliance for Water Stewardship.

We are clearly entering a new era of water management in which the links between water and other resources and the socio-economics of poor post-harvest management (Box 18.1) and food waste along the value chain are increasingly recognized.

18.5 Water use along the livestock value chain

The livestock industry, which is growing rapidly, provides a good illustration of the challenges to the water–agriculture–supply chain nexus – how water is used, consumed and polluted along the value chain as animals are produced on the farm, transformed into products, consumed, and the waste products recycled. Livestock products are also an important part of the global trade in food and so the industry also highlights the growing benefits and concerns about water footprints and the 'exporting/importing' of water and pollution as meat and dairy products are shipped from one country to another.

Livestock farming is one of the most important subsectors in agriculture, both socially and economically. It employs over 1.3 billion people across the world. It generates livelihoods for some 1 billion of the world's poorest people. However, livestock farming also contributes to the most serious environmental problems – land degradation, climate change, air pollution, water scarcity and pollution, and loss of biodiversity (FAO, 2006*b*).

The world food economy is being increasingly driven by the shift in diets and food consumption patterns towards livestock products (FAO, 2006*a*). In 2008, about 3,350 million ha were under permanent meadows and pasture – more than twice the area under arable cropping and permanent crops. Livestock provides not just meat but also dairy products, eggs, wool, hides, and so on. The livestock sector is now changing at an unprecedented pace as demand for food derived from animals has boomed in the world's most rapidly growing economies (FAO, 2006*b*). Livestock already contributes 40% of the global value of agricultural output. It is one of the most dynamic parts of the agricultural economy and is driven by population growth, rising affluence, and urbanization.

As the demand for livestock products grows, so too do the concerns about its impact on the environment. The expansion of land for livestock has led to deforestation in some countries (e.g. Brazil) and intensive livestock production (mainly in OECD countries) is already a major source of pollution. Livestock contributes less than 2% of global GDP and yet it produces some 18% of GHGs (FAO, 2006*b*). Hence critics argue that the disbenefits far outweigh the benefits that come from livestock, but others argue that this seriously underestimates the economic and social importance of livestock, particularly in low income countries. Regardless of the balance of these arguments, the increasing demand for livestock seems likely to continue. This means that resource use efficiency in livestock production is now an urgent priority, and this includes the management of water.

18.5.1 How the water flows from field to fork

Considering this global picture of livestock production – including rapid growth, the shift in world livestock output from high income to low income countries, the changing patterns of international trade, and the potential for further growth in the sector – what are the implications for water resources, now and in the future, both in terms of water consumption and the industry's impact on water through pollution?

Livestock production – on the farm

All livestock require water for drinking, cooling and cleaning, but the amount of water required differs according to the animal, the method of rearing and the location. Extensive livestock systems can increase water demand because of the additional effort needed as animals search for feed. Intensive or industrialized systems, however, require additional service water for cooling and cleaning facilities. Globally, the annual drinking water requirement for livestock is about 16 km^3, and servicing requires an additional 6.5 km^3 (FAO, 2006*b*).

The amount of water used to grow feed and fodder is much more significant in volume terms. This amount depends not just on the number and kinds of animals and amount of food they eat but also where the food is grown. It is estimated that livestock consumes about 2,000–3,000 km^3 of water annually – as much as 45% of the global water embedded in food products (Comprehensive Assessment of Water Management in Agriculture, 2007; Zimmer and Renault, 2003) – although these estimates are quite imprecise. Whatever the figure, the amount involved in producing livestock products is substantial. Rainfed grasslands consume most of this water, which is generally thought to be of little environmental value. Some of the more intensively managed grazing lands and cereal and oilseed crops grown for feedstuffs may have alternative agricultural potential but they are mostly located in water abundant areas.

Irrigation water volumes are much smaller but have an important role in producing feed, fodder and grazing for livestock and have a much greater opportunity cost than rainfed cropping.[3] There is no global estimate available but the authors suggest that it could be 13% of agricultural blue water consumption (Table 18.10) – a figure which could rise in the future as the demand for livestock products increases. This figure is based on information available on irrigated feed, fodder crops and pasture for the two main animal groups – monogastrics (pigs and poultry) and ruminants (beef and dairy cows, buffalo).

Pigs and poultry are predominantly reared in intensive and industrially based production systems and rely on concentrated feedstuffs made up of four important crops – barley, maize, wheat and soybean (BMWS). Ruminants are mostly reared in extensive rainfed grazing systems though some rely on irrigated pasture and fodder. In OECD countries

TABLE 18.10

Estimated global annual water consumption of grazing, fodder and feed production for livestock

Item		Net evapotranspiration (km^3 per year)
1	Global water to meet current food demand[a]	7 130
2	Rainfed agriculture[a] (green water) – % of (1)	5 855 (82%)
3	Irrigated agriculture[b] (blue water) – % of (1)	1 275 (18%)
6	Irrigated feed, fodder and grazing[b] – % of (3)	160 (13%)

Sources: [a] CA (2007); [b] FAO (2011c).

an increasing number of dairy cows rely on manufactured compound feed, but the picture of what percentages are irrigated or rainfed is complex. Estimates are based on the FAO's global information system on water and agriculture (AQUASTAT), which can be considered as minimum values due to incompleteness of the information (FAO, 2011c). United States Department of Agriculture (2008) sources suggest that some 16 million ha of permanent fodder and pasture and 16 million ha of annual fodder and feed is irrigated globally, consuming about 160 km^3 of water. Bringing these data together, the global irrigated evapotranspiration for livestock is estimated to be about 13% (Table 18.10 and Figure 18.8).

Transformation

The slaughterhouse is the second largest user of water in the meat processing value chain (after the production phase) and a potentially significant point source of pollution in local ecosystems and communities. The source of water entering dairies and abattoirs depends on the location. The most significant water-related issues with regards to slaughterhouse operations are the use of large amounts of water; large quantities of effluents and emissions of high organic strength liquids into the water; and energy consumption from refrigeration and water heating.

Hygiene standards in OECD countries typically require large quantities of freshwater at the abattoir to be used mainly for watering and washing livestock, cleaning equipment and work areas, and for washing carcasses (Figure 18.9). Food safety and hygiene standards have in fact been tightened in recent years following occurrences of *Salmonella, Listeria*, and the bovine spongiform encephalopathy (BSE, or mad cow disease) crisis. As a consequence, cleaning and sterilization operations using hot water have been intensified, most likely driving up the volume of water consumed at the slaughterhouse in many OECD countries (European Commission, 2005). For example, 46% of water used in an Italian pig slaughterhouse is for cleaning, and 56% of water used at a Danish poultry slaughterhouse killing 25 million birds per year is used for washing carcasses and chilling. Together, cleaning and carcass washing can account for more than 80% of total water use and effluent volumes (European Commission, 2005).

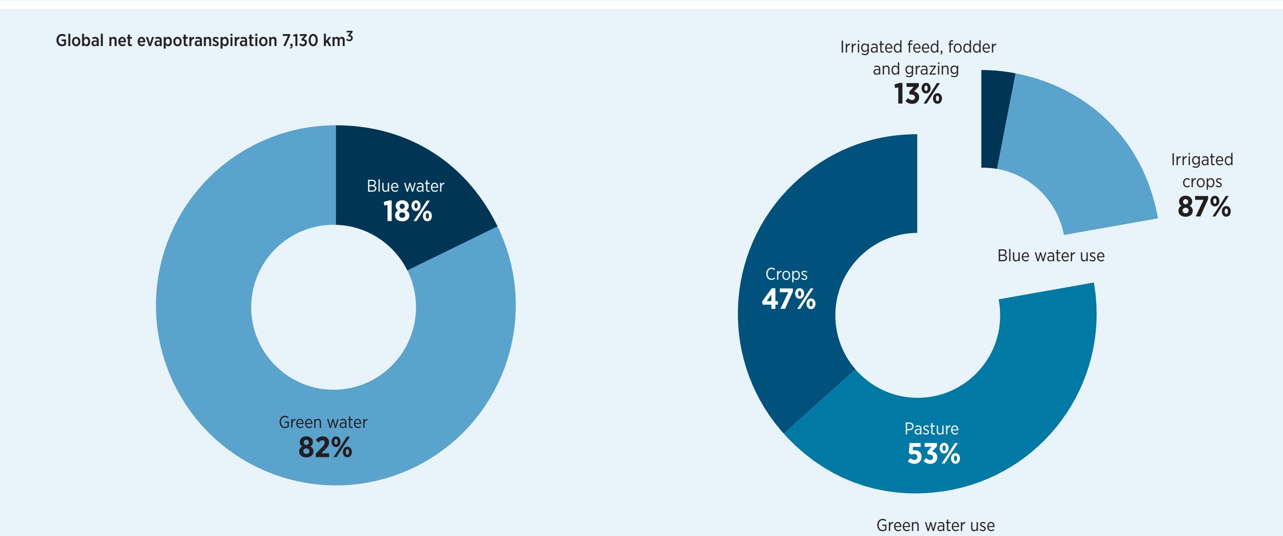
In dairies, food safety and hygiene standards explain that the bulk of water used is for cleaning, sanitizing and pasteurization (Figure 18.10).

Water use also varies according to the type of animals being slaughtered. In Denmark and Norway poultry slaughtering requires the greatest water volumes and generates the highest nutrient loads when compared to slaughtering other animals (Table 18.11).

The floor area of the slaughterhouse also influences water use, as does the size of the animals/birds and slaughter methods, carcass dressing and cooling, and automation.

FIGURE 18.8

Global annual water consumption for livestock grazing, fodder and feed production



Meat processing effluents contain blood, fat, manure, undigested stomach contents and cleaning detergents. Capital and resource intensive wastewater treatment infrastructure is required to treat such effluents which, if left unchecked, will result in high biological oxygen demand (BOD), suppression of sensitive aquatic species, odours, and other problems.

Consumption

Water is used during the consumption[4] stage as food passes through retailers and is packed and prepared for eating by food processing companies and also in the home. This adds to the burden of water pollution as food is washed, cleaned and prepared.

The most serious aspect of food consumption in terms of water use is food wastage. This is particularly the case in industrialized countries where food is wasted because too much perishable food is produced and not sold, products deteriorate in storage, and food is bought and not consumed and hence thrown away. All this adds up to both a significant waste of food and also a significant waste of the water used to produce it (Lundqvist, 2010).

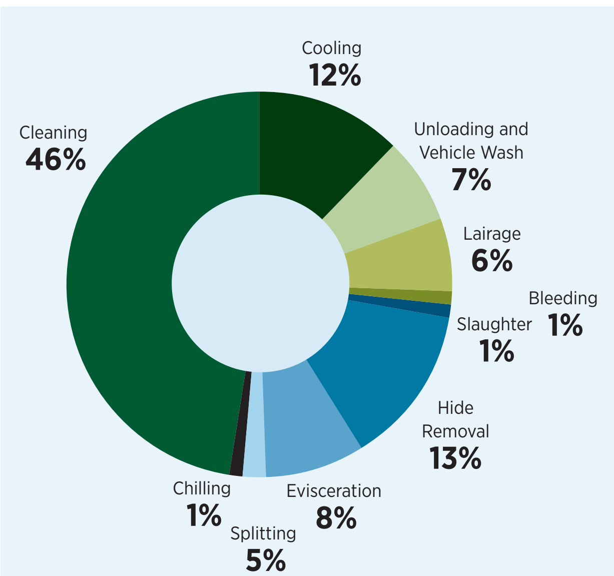
Recycling

Water recycling is needed at every stage of the value chain. At the production stage, the increasing numbers of livestock herds are significant sources of pollution (grey water). Livestock faeces are far more potent in nutrient loadings than human excreta. Asia generates about 35% of global annual livestock excretion of nitrogen (N) and phosphorus (P). Pig waste in Thailand, Viet Nam and Guangdong (China) contributes more to water pollution than domestic wastewater (Table 18.12). In the USA the livestock sector is responsible for about 55% of soil erosion, 32% of nitrogen loads, and 33% of potassium loads into freshwater resources. A further 37% of pesticide use and 50% of the volume of antibiotics used come from the livestock sector (FAO, 2006*b*), and all contribute to water pollution.

The growth in trade of livestock products is further transforming meat production and environmental relationships. Major meat importing countries get the benefit of the land and water use and nitrogen emissions in the meat producing countries. Pig and chicken meat imports into Japan, one of the world's top feed and meat importers, embody the virtual equivalent of 50% of Japan's total arable land. Furthermore, Japan's meat consumption, while annually releasing some 70,000 tonnes of nitrogen domestically, is estimated to leave 220,000 tonnes of nitrogen behind in meat exporting countries (Galloway et al., 2007). Figure 18.11 illustrates Japan's nitrogen flow in the pig and poultry trade and shows that about 1.5 times more nitrogen loss occurs

FIGURE 18.9

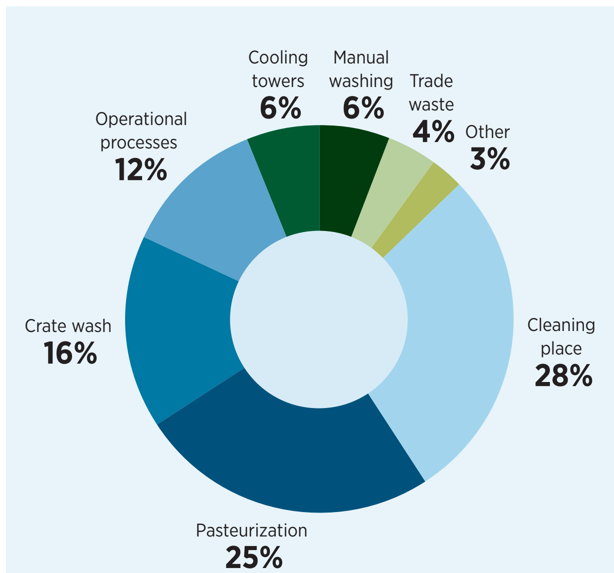
Data for water consumption in a typical Italian pig slaughterhouse



Source: European Commission (2005).

FIGURE 18.10

Typical water use by a market milk processor in Australia



Source: UNEP (2004, p. 20).

TABLE 18.11

Water use and emission data in Danish and Norwegian slaughterhouses

All values per tonne of carcass	Water use, wastewater (L)	BOD emission (kg)	COD emission (kg)	Nitrogen emission (g)	Phosphorus emission (g)	Suspended solids emission (g)
Cattle	1 623–9 000	1.8–28	4–40	172–1 840	24.8–260	11.2–15.9
Pig	1 600–8 300	2.14–10	3.22–10	180–2 100	20–233	0.12–5.1
Sheep	5 556–8 333	8.89		1 556	500	
Poultry	5 070–67 400	2.43–43	4–41.0	560–4 652	26.2–700	48–700

Notes: Biological oxygen demand (BOD) is an indicator of water quality. Chemical oxygen demand (COD) measures the amount of organic pollutants in surface water.
Source: Water-related data extracted from European Commission (2005).

TABLE 18.12

Estimated nitrogen and phosphorous emissions in water systems

Country/Province	Nutrient	Potential load (tonnes)	Percentage contribution to nutrient emissions in water systems		
			Pig waste	*Domestic wastewater*	*Non-point source*
China-Guangdon	N	530 434	72	9	19
	P	219 824	94	1	5
Thailand	N	491 262	14	9	77
	P	52 795	61	16	23
Viet Nam	N	442 022	38	12	50
	P	212 120	92	5	3

Source: FAO (2004).

in the exporting countries (mainly the USA) than at home as a result of its large meat import volumes. Some 36% of the 220,000 tonnes of nitrogen is in the form of virtual nitrogen (nitrogen used in production but not actually embedded in the livestock product). This implies that high meat importing consumers enjoy the benefits of livestock products without paying the environmental costs of nitrogen emissions to local groundwater and surface water and the local atmosphere. In Brazil, 15% of the virtual nitrogen left behind is due to feed and meat exports to China (Galloway et al., 2007).

18.5.2 More ‘protein per drop’

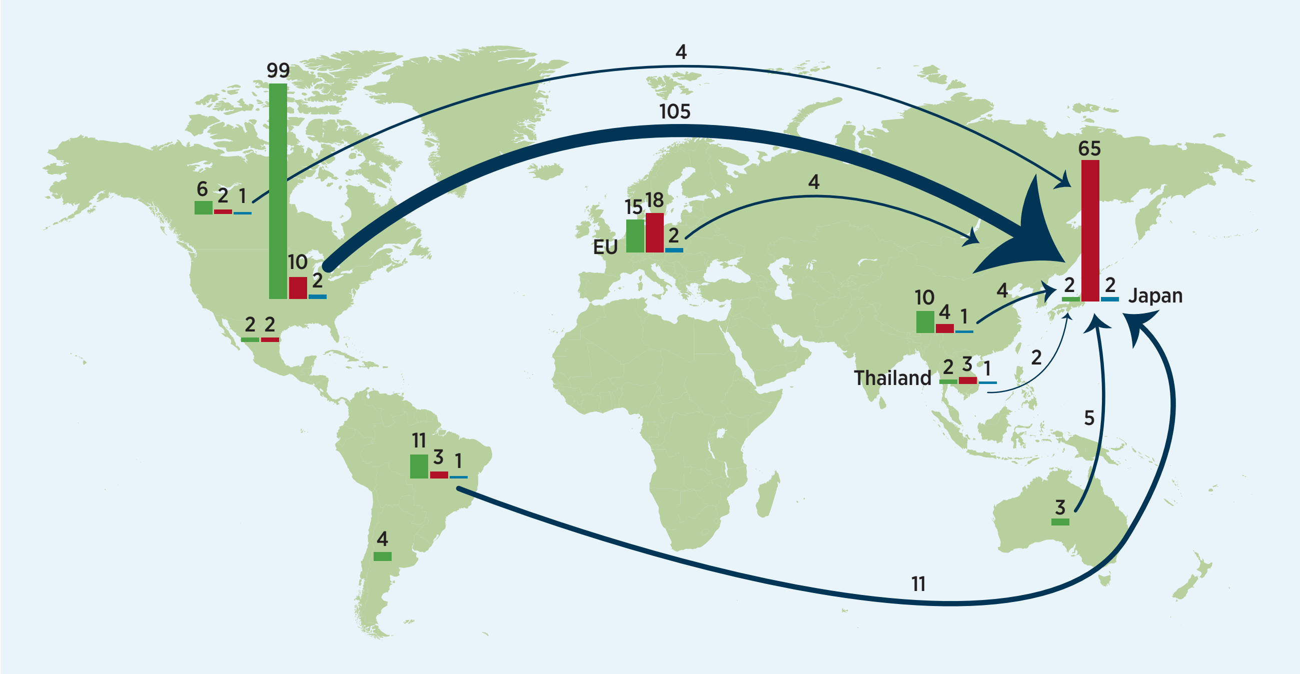
With an expected rise in the demand for animal products and a subsequent increase in pressure on freshwater resources, it is essential to get more protein per drop of water used, particularly for blue water. Some examples of how this can be achieved at each stage of the livestock value chain are outlined below.

- Production: raising water productivity using sustainable crop production intensification techniques for managing soil fertility (increasing crop productivity by incorporating both organic and inorganic plant nutrients which prevent soil degradation and reduces nutrient loss); rainwater harvesting and storage.
- Transformation: adopting cleaner practices that aim to reduce water volumes and capture and treat nutrient-rich effluents; better storage facilities.
- Consumption: increase consumer awareness campaigns to reduce food wastage.
- Recycling: water, nutrient and waste recycling (including cascading systems reusing treated effluents for adapted, safe uses) to close the value chain loops.

Innovative technical responses are only possible within a context of locally-adapted policies, institutions and incentives that promote productive land and water management solutions, along with investments, and the steadfast pursuit of scientific research and development.

FIGURE 18.11

Nitrogen associated with the production of pigs and chickens in Japan



Notes: Bars refer to N left behind in the producing country during different stages of production. Green, feed; red, live animal production; blue, meat processing. Arrows represent transfer of total N embedded in shipped product. Data are annual values in thousands of tonnes, averaged over the years 2000–2002.
Source: Galloway et al. (2007, fig. 2, p. 625), reproduced with permission from the Royal Swedish Academy of Sciences.

18.6 'Water smart' food production

Some experts suggest that if everyone adopted a life style similar to that normally experienced in OECD countries then more than three 'earths' would be needed to satisfy the resource requirements. This is a bold claim but it does make the point that we cannot continue to consume natural resources at the current rate if we wish to use them sustainably for everyone's benefit both now and in the future.

Water will need to be managed so that supply and demand is balanced and shared across sectors and across regions. This may mean reducing the amount of water currently consumed to produce a reasonable and nutritious diet. Improved ratio of crop productivity to water use will be needed as will better ways to manage both green and blue water resources.

18.6.1 The role of technology

In higher income countries, science and technology have long been major drivers of global prosperity. This will undoubtedly continue in the future. Food production will need to be 'greener' and more sustainable so that it does not add to the burden of climate change and ecosystem deterioration. We will need innovative technologies that can improve crop yields and drought tolerance; produce smarter ways of using fertilizer and water; improve crop protection through new pesticides and non-chemical approaches; reduce post-harvest losses; and create more sustainable livestock and marine production. Industrialized countries are well placed to take advantage of these technologies, but they must also take responsibility to ensure that LDCs have opportunities to access them.

18.6.2 Human capacities and institutions as assets

Agricultural development in LDCs is mainly in the hands of smallholders, most of whom are women. Water technologies appropriate to their needs will play a crucial role in meeting the food security challenge. However, in many LDCs, women have only limited access to a wide range of physical assets and lack the skills to deploy them. Multiple water use schemes can provide opportunities for women to extend their influence over water allocation and management.

Most industrialized countries are have the financial resources, as well as the infrastructure, institutions and capacity, to sustain the levels of water security they now enjoy. However, perhaps they should be seeking more sustainable water use per person in the interests of other less industrialized countries. In contrast, LDCs will need to seek ways of increasing water availability per person and whether they can afford to emulate the strategies of the more industrialized countries. There is a balance to be struck between these two contrasting strategies.

Major changes in policy and management will be needed to make best possible use of available water resources. New institutional arrangements are needed which centralize the responsibility for water regulation yet decentralize water management responsibility and increase user ownership and participation. New arrangements are required for safeguarding access to water for poor and disadvantaged groups, particularly women, and ensuring they have long-term land and water security.

18.6.3 A focus on the value chain

Improvements will be needed all along the agricultural value chains. Early gains include opportunities to reduce post-harvest crop losses in LDCs and food wastage in the higher income countries, and hence saving the water embedded in them. In the medium term, innovations in climate-smart cropping are possible. In the longer term, energy-smart conversion of feed and fodder for livestock is also possible. Water recycling at all stages of the value chain will help to secure environmental water requirements when reuse of treated water is not culturally acceptable for other uses.

In the high income countries, the focus will also be on water pollution which 'reduces' freshwater availability. This includes reducing diffuse pollution (in production) and point source pollution (in transformation and consumption).

18.6.4 Managing risk creatively

Reducing vulnerability to drought will require investment in both constructed and 'green' infrastructure to improve water measurement and control and, where appropriate, increase surface water and groundwater storage in constructed reservoirs and in natural storage (both in wetlands and in the soil). Most benefit is expected to come from existing water management technologies and adapting them to new situations. 'Design for management', promoted in the 1980s to ensure infrastructure design took account of who would manage it and how it would be managed, is still highly relevant today and important for future water management.

18.6.5 Virtual water trade

Virtual water may play an increasing role as water-rich countries export water embedded in food to water-short countries that find it increasingly difficult to grow sufficient staple food crops. But the aqua-politics of exporting/importing food versus self-sufficiency will not be easy to resolve; food producing countries may not wish to export crops when food security is threatened; lower income and least developed countries may need to continue over-exploiting water resources to feed their populations.

18.6.6 Implementing 'water smart' production

A twin-track approach is needed that makes best use of available water – demand management options that increase productivity (more 'crop per drop') and supply management that makes more water available through water storage to cope with seasonality and increasingly unpredictable rainfall.

For most LDCs the biggest question, which still remains largely unanswered, is how to do it. Even once appropriate interventions for specific locations and target groups are selected, it is challenging for governments and agencies to successfully intervene in complex and changing agricultural water management (AWM) systems that have specific technical, environmental, socio-economic and institutional issues. The International Fund for Agricultural Development's learning and knowledge on innovations in water and rural poverty (InnoWat) sets out a strategy for this – the development pathway lies somewhere between the paralysis that comes from trying to take account of everything and the folly of focusing in on a single criterion solution.

Major investment in AWM will be needed, and the present-day national priorities in some countries do give cause for serious concern. In 2010, it was estimated that only US$10 billion was invested globally in irrigation systems, a surprisingly low figure given the importance of water for the agricultural sector (in comparison, the global market volume for bottled water in the same year was US$59 billion) (Wild et al., 2010). Surely it is time for the world to wake up to the fact that agriculture is a major, valid, consumer of water and investment is essential for the future of global food and water security. When water is scarce we all have a responsibility to use water wisely, efficiently and productively. Responsible AWM can make a significant contribution to future water security. Agriculture needs to be much more water-smart and must be given the right signals and incentives to make this happen.

Note

1 Least developed countries (LDCs)' is a group of countries which are identified as being particularly vulnerable, with a low income level and a low index of human assets based on nutrition, health and education (UNSD, 2006). A list of LDCs is included in Table 18.2.

2 The International Energy Agency (IEA, 2006) mentions that considering very rapid technological progress, the higher figure could be 26,200 million tonnes of oil equivalent instead of 12,000. However, IEA also indicates that a more realistic assessment based on slower yield improvements would be 6,000–12,000. A mid-range estimate of around 9,500 would require about one-fifth of the world's agricultural land to be dedicated to biomass production.

3 Opportunity cost is the cost of any activity measured in terms of the value of the best alternative that is not chosen (that is foregone).

4 No attempt is made here to closely define the word 'consumption' as food directly eaten by individuals and contributing to their nutritional requirements. Rather it is used here to describe in broad terms, the food purchased from retail outlets which may include both food eaten and food wasted.

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CHAPTER 19

The global nexus of energy and water

UNIDO

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Acknowledgements This chapter includes significant contributions from Carey King, Ashlynn Stillwell and Kelly Twomey. The chapter was coordinated by Igor Volodin and Carolina Gonzalez-Castro.

Energy and water are inter-related; people use energy for water and water for energy.

The energy–water relationship is under strain, introducing cross-sectoral vulnerabilities (i.e. a water constraint can become an energy constraint and an energy constraint can induce a water constraint).

Trends imply that the strain will be exacerbated by:

- growth in total demand for energy and water, driven by population growth,
- growth in per capita demand for energy and water, driven by economic growth,
- global climate change, which will distort the availability of water, and
- policy choices, by which people are selecting more water-intensive energy and more energy-intensive water.

Policy options are available to decision-makers to improve energy and water supplies without compromising either resource.

19.1 Introduction

Energy and water are fundamental ingredients of modern civilization and precious resources. They are key inputs to agricultural systems, factories and buildings, and are necessary to meet human requirements for food, shelter, healthcare and education.

Energy and water are also closely interconnected and under strain. Consequently, the nexus of the two has been the subject of attention by the scientific community, popular media and governing bodies. This nexus manifests itself in society in many ways. For example, water provides electric power, is used for extraction of fuels, and plays a growing role in the irrigation of energy crops to produce biofuels such as ethanol. The thermoelectric sector is one of the largest users of water for cooling. In parallel, the water industry uses power for moving, pumping, treating and heating water. On top of this relationship, the parts of the world with high expected rates for population growth and economic expansion are also often places where water sources are scarce. Combining these trends with projections for more irrigation implies rapid growth for water demands that some localities might satisfy with desalination or wastewater treatment, both of which are very energy-intensive.

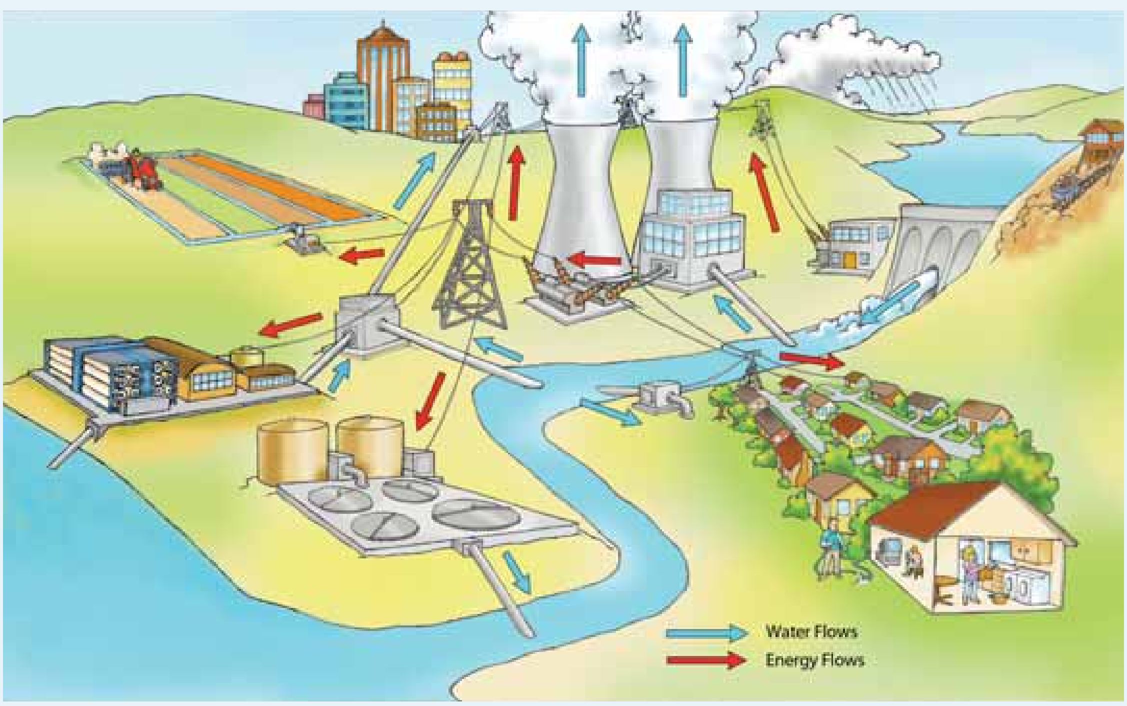
Despite the importance of energy and water, and the close relationship between the two, funding, policymaking and oversight of these resources are performed by different people in separate agencies in many governments. Integrated energy–water policymaking is rare. Energy planners often assume they will have the water they need and water planners assume they will have the energy they need – if one of these assumptions fails, consequences will be dramatic. By bringing scientific and engineering expertise into this vastly understudied problem, this scenario might be avoided.

19.1.1 Energy and water are inter-related

Energy and water are highly interconnected: people use water for energy and energy for water. Figure 19.1 shows some of these interconnections. For example, water is a direct source of energy through hydroelectric dams, which in 2007 provided about 15 per cent of global electricity generation (or approximately 2 per

FIGURE 19.1

The energy–water nexus



Note: Energy flows are shown in red and water flows are shown in blue. As shown in the residential community, electricity and water are both used for different purposes.
Source: Courtesy of EPRI (prepared by EPRI for a US DOE Report to Congress in 2006).

cent of total energy consumption)(IEA, 2009). Water also indirectly enables power generation through cooling thermoelectric power plants (power plants that use heat to generate power), which provide more than 75% of the electricity globally (more than 16,000 TWh) (IEA, 2009). While agriculture is the largest user of water globally, because of the large cooling needs of power plants, the thermoelectric power sector is the largest user of water (for withdrawals) in the United States (USA). In the USA the power sector is responsible for nearly half of all water withdrawals (approximately 800 billion litres per day, when including seawater), ahead of even agriculture (Hutson et al., 2004). Low– and middle– income countries use less water for power plants and more for agriculture, whereas high-income countries are the opposite (WWAP, 2003). In addition, water is used for extractive industries that produce fuels (coal, natural gas, uranium) for the power and transportation sectors.

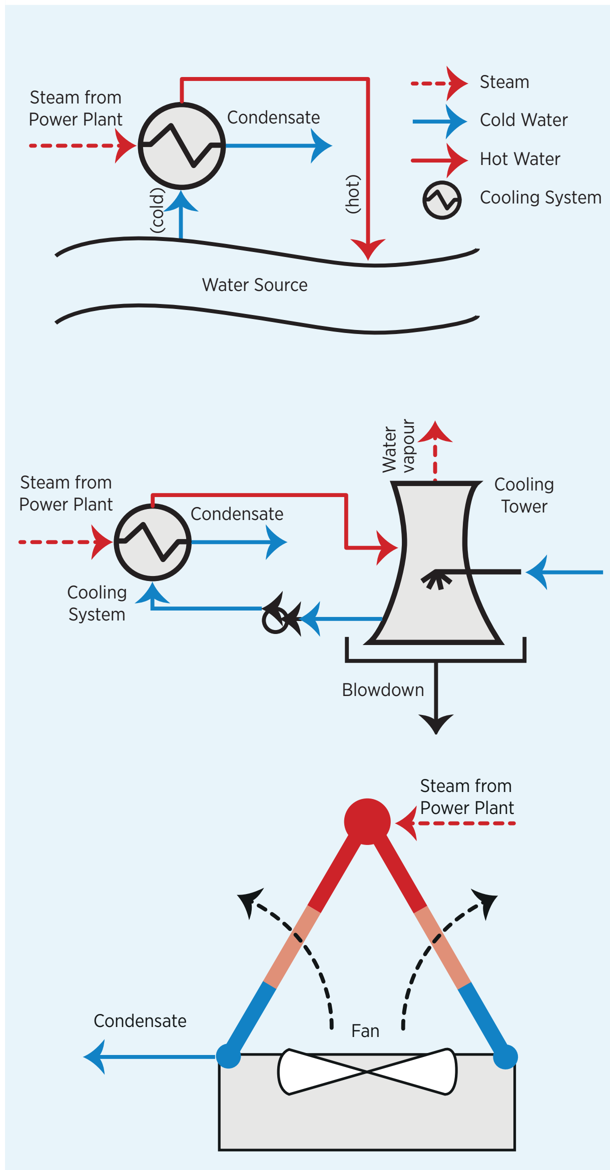
An important feature of water use is the distinction between water *withdrawals* and *consumption*. However, this terminology is not used in a consistent manner from one country to the next. Using the terminology from King et al. (2011), water *withdrawal* refers to the volume of water removed from a water source; this water is not lost, but it cannot be allocated to other users before discharge. *Consumption* refers to the volume of water lost through evaporation, transportation, or any other means by which water is not returned to its native source in liquid form. As consumption is a subset of withdrawal, it is less than or equal to withdrawal, by definition (King et al., 2011).

Nearly all of the water used for power plants is returned to the source (typically a river or cooling pond), though at a different temperature and quality. As a result of these returns, power plants are often responsible for a small portion of national water consumption, despite the large withdrawals. Averaging across the national thermoelectric power sector in the USA[1], over 80 litres of water are withdrawn and 2 litres are consumed for every kilowatt-hour of electricity generated (Webber, 2007). Hydroelectric dams use a significant amount of water consumption for power generation primarily because the increased surface area of manufactured reservoirs beyond the nominal run-of-river accelerates the evaporation rates from river basins (Torcellini et al., 2003). Notably, the estimates for this increased evaporation depend significantly on regional location: hydroelectric reservoirs in the desert south-west of the USA have significant evaporative losses, whereas reservoirs in cooler climates might have negligible losses. Further, whether all the evaporation should be attributed to power generation is not clear, as reservoirs serve multiple purposes, including water storage, flood control, navigation and recreation.

The amount of water withdrawn and consumed by thermal power plants is driven by (a) the type of fuel and power cycle used by a power plant (e.g. fossil fuels

FIGURE 19.2

Power plants typically use three types of cooling: open-loop (top panel), closed-loop (middle) and air-cooling (bottom)



Source: Stillwell (2010), based on CEC (2002).

or nuclear fuels with steam cycles, natural gas with combined cycle) and (b) the cooling method. There are three basic cooling methods: open-loop, closed-loop, and air-cooling (Figure 19.2). For typical values on water withdrawal and consumption by power plants, see Table 19.1, which contains a breakdown by fuel and cooling type.

Open-loop, or once-through, cooling withdraws large volumes of surface water (fresh or saline), for one-time use and returns nearly all the water to the source with little of the overall water consumed due to evaporation (Stillwell et al., 2011). While open-loop cooling is energy efficient and has low infrastructure and operational costs, the discharged water is warmer than ambient water, causing thermal pollution, which can kill fish and harm aquatic ecosystems. Thus, environmental agencies regulate discharge temperatures, taking into account a water body's heat dissipation capacity. Closed-loop cooling requires less water withdrawal because the water is recirculated by cooling towers or evaporation ponds. However, as the cooling is essentially achieved through evaporation, closed-loop cooling causes higher water consumption (Table 19.1). The alternative, air-cooling, does not require water, but instead cools by use of fans that move air over a radiator, similar to that in automobiles. However, power plant efficiency for air-cooling is lower, up-front capital costs are higher and real estate requirements are sometimes larger, often making this option less attractive economically unless water resources are scarce.

Even though power plants return most of the water they withdraw, their need for large amounts of water at the right temperature for cooling subjects them to vulnerabilities. If a severe drought or heat wave reduces the availability of water or restricts its effectiveness for cooling due to heat transfer inhibitions or thermal pollution limits, the fact that the power plant consumes so little water becomes less important than the fact that it needs the water in the first place.

Significant volumes of water are also used for fuels production, such as coal, natural gas, oil, uranium and biofuels. The water requirements for fuels production for coal, natural gas and uranium, while non-trivial, are much smaller than the water requirements for their use within power plants and therefore are considered negligible by comparison. By contrast, the water requirements to produce coal, natural gas and petroleum for transportation applications is significant by comparison (because transport vehicles have no water requirements on-board), and is discussed later in this report.

All forms of energy require water at some stage of their lifecycles, including production, conversion, distribution and use. Each fuel and technology has a slightly different set of requirements.

TABLE 19.1

Water used (withdrawn and/or consumed) varies for different fuels, power cycles (combined and open cycle) and cooling methods (open-loop, closed-loop and air-cooling)

	Closed-Loop (cooling tower)		Open-Loop	
	Withdrawals (L/kWh)	**Consumption (L/kWh)**	**Withdrawals (L/kWh)**	**Consumption (L/kWh)**
Nuclear	3.8	2.6	160.9	1.5
Solar CSP	3.0	3.0	---	---
Coal	1.9	1.9	132.5	1.1
Natural gas (Combined cycle)	0.9	0.7	52.2	0.4
Natural gas (Combustion turbine)	Negligible	Negligible	Negligible	Negligible
Solar PV	Negligible	Negligible	Negligible	Negligible
Wind	Negligible	Negligible	Negligible	Negligible

Source: Adapted from Stillwell (2010c).

Crude oil

Crude oil is the largest primary energy source globally. Its production requires water at drilling, pumping, refinement and treatment. The average water use is estimated to be 1.058 m^3 per GJ (Gerbens-Leenes et al., 2008). Unconventional oil production, which is projected to increase in North, Central and South America until 2035, consumes 2.5–4 times more water (WEC, 2010).

Coal

Coal is the second largest primary energy source globally, and its use is projected to increase by 2035. UNESCO-IHE (Gerbens-Leenes et al., 2008) estimates that approximately 0.164 m^3 per GJ are used in the various processes, significantly more of which is used during underground mining operations than in open pit mining (Gleick et al., 1994).

Natural gas

Significant increases are expected in the production of natural gas by 2035. Water requirements for drilling, extraction and transportation of conventional gas sources are relatively modest, at an estimated 0.109 m^3 per GJ (Gerbens-Leenes et al., 2008). However, shale gas production, which is expected to increase in Asia, Australia and North America (Pacific Energy Summit, 2011), has slightly higher water-intensity than conventional gas because its extraction method, hydraulic fracturing, injects millions of litres of water into each well.

Uranium

Uranium's share of global energy consumption is projected to increase from about 6% to 9% by 2035 (WEC, 2010). UNESCO-IHE estimates modest water requirements of 0.086 m^3 per GJ for uranium mining and processing (Gerbens-Leenes et al., 2008).

Biomass and biofuel

Biomass, including wood, agro fuel, waste and municipal by-products, is an important source of fire and heating in many non-Organisation for Economic Co-operation and Development (OECD) country households (WEC, 2010). Further, bio-feedstocks are increasingly grown commercially to replace fossil fuels in OECD countries, and this trend has raised concerns about crop water requirements. However, water intensity depends on the feedstocks, where and how they are grown, and whether they are first– or second–generation crops (Gerbens-Leenes et al., 2008; WEF, 2009). This variety in production processes makes it impractical to attribute a singular value or even a representative range of water consumption to biofuel production.

Just as significant volumes of water are used for energy, in wealthier nations a significant fraction of energy is used for water, in the form of electricity to heat, treat and move water, sometimes across vast distances (CEC 2005; Cohen et al., 2004; EIA, 2001; Stillwell et al., 2010*a*). Most water systems are comprised of many stages of collection, treatment, conveyance, distribution, end-use preparation, reconditioning and release Twomey and Webber (2011). The energy intensity of water is influenced by source water quality, its proximity to a water treatment facility and end-use, its intended end-use and sanitation level, as well as its conveyance to and treatment at a wastewater treatment facility. Treating water to a quality that is safe for drinking requires significant amounts of energy to pump, treat and distribute water to end-users, who are likely to heat, chill, or pressurize this water to suit their needs. After water is used in industrialized countries, much of it is collected and sent to a wastewater treatment plant where the water is reconditioned so that it can be released back into a water reservoir. In some cases, water is recycled or reclaimed, that is, it is treated to an acceptable standard for use in non-potable applications (e.g. agricultural and landscape irrigation, groundwater recharge, industrial cooling/process water, toilet flushing). Self-supplied water users, such as industrial facilities, power generators and irrigators, typically do not require water for drinking water. However, these users might utilize energy-intensive processes, such as heating, chilling and pressurizing. For the more than 1 billion people who do not have access to piped, clean drinking water, or to water-based sanitation, the availability of abundant energy, especially in the form of electricity, is a critical ingredient to enabling those services.

The energy required to produce, treat and distribute water varies depending on the source (Table 19.2 shows typical figures in the USA). Surface water (e.g. from lakes and rivers) is the easiest and least energy-intensive to treat. However, water conveyance can require anything from between zero (for gravity-fed systems) to as much as 3600 kWh per million litres for long-haul systems (CEC, 2005; Cohen et al., 2004). Groundwater (e.g. from aquifers) requires more energy for pumping water to the surface for treatment and distribution. For example, water collection alone from a depth of 40 m requires 140 kWh per ML, while a depth of 120 m requires approximately 500 kWh per ML, in addition to treatment energy use (EPRI, 2002; USDOE, 2006; Stillwell et al., 2011).

As fresh water supplies become strained, water sources once considered unusable, including brackish groundwater and seawater, are being turned to (Stillwell et al., 2010*b*). While use of these water sources helps mitigate constraints on drinking water supplies, treatment of brackish groundwater and seawater requires use of advanced filtration (e.g. reverse osmosis membranes), specialty materials, and high-pressure pumps for desalting. Overall, treatment of these water sources can require as much as 4400 kWh per ML (EPRI, 2002), or 10–12 times the energy use of standard water treatment. The theoretical minimum energy requirement for desalination using reverse osmosis systems is 680 kWh per ML (Shannon et al., 2008).

Wastewater treatment also requires large amounts of energy (WEF, 1997). High-income countries that have stricter discharge regulations install more energy-intensive treatment technologies. Trickling filter treatment, which uses a biologically active substrate for aerobic treatment, is a reasonably passive system, consuming on average over 250 kWh per ML (EPRI, 2002; Stillwell et al., 2011). Diffused aeration as part of activated sludge processing is a more energy-intensive form of wastewater treatment, requiring 340 kWh per ML due to blowers and gas transfer equipment (EPRI, 2002; Stillwell et al., 2011). More advanced wastewater treatment, using filtration and the option of nitrification, requires 400–500 kWh per ML (EPRI, 2002; Stillwell et al., 2011). In fact, more advanced sludge treatment and processing can consume energy in the range of 30–80% of total wastewater plant energy use (Center for Sustainable Systems, University of Michigan, 2008). Treating wastewater sludge through anaerobic digestion can also produce energy through the creation of methane-rich biogas, a renewable fuel that can be used to generate up to 50% of the treatment plant's electricity needs (Stillwell et al., 2010*b*; Seiger et al., 2005).

Because systems vary significantly between regions in terms of pumping requirements, source quality, prevailing treatment practices (if any), and wastewater collection (if any), it is difficult to assess global energy inputs embedded in the water system. For the USA, where data are available, approximately 10% or more of national energy consumption is required for the entire water system (Figure 19.3) (Twomey and Webber, 2011). These figures are typical for high- income countries. For low- and middle- income countries, where large-scale water systems are rarer, the embedded energy is lower by comparison.

19.1.2 Global strain in the energy–water relationship

The interrelationship of energy and water and the strains placed on both of these resources manifests itself in tough choices at the local level. For example, low water levels in hydroelectric reservoirs can force

TABLE 19.2

Water and wastewater treatment and conveyance requires vast amounts of energy

	Source / treatment type	Energy use (kWh/million L)
Water	Surface water	60
	Groundwater	160
	Brackish groundwater	1,000–2,600
	Seawater	2,600–4,400
Wastewater	Trickling filter	250
	Activated sludge	340
	Advanced treatment without nitrification	400
	Advanced treatment with nitrification	500

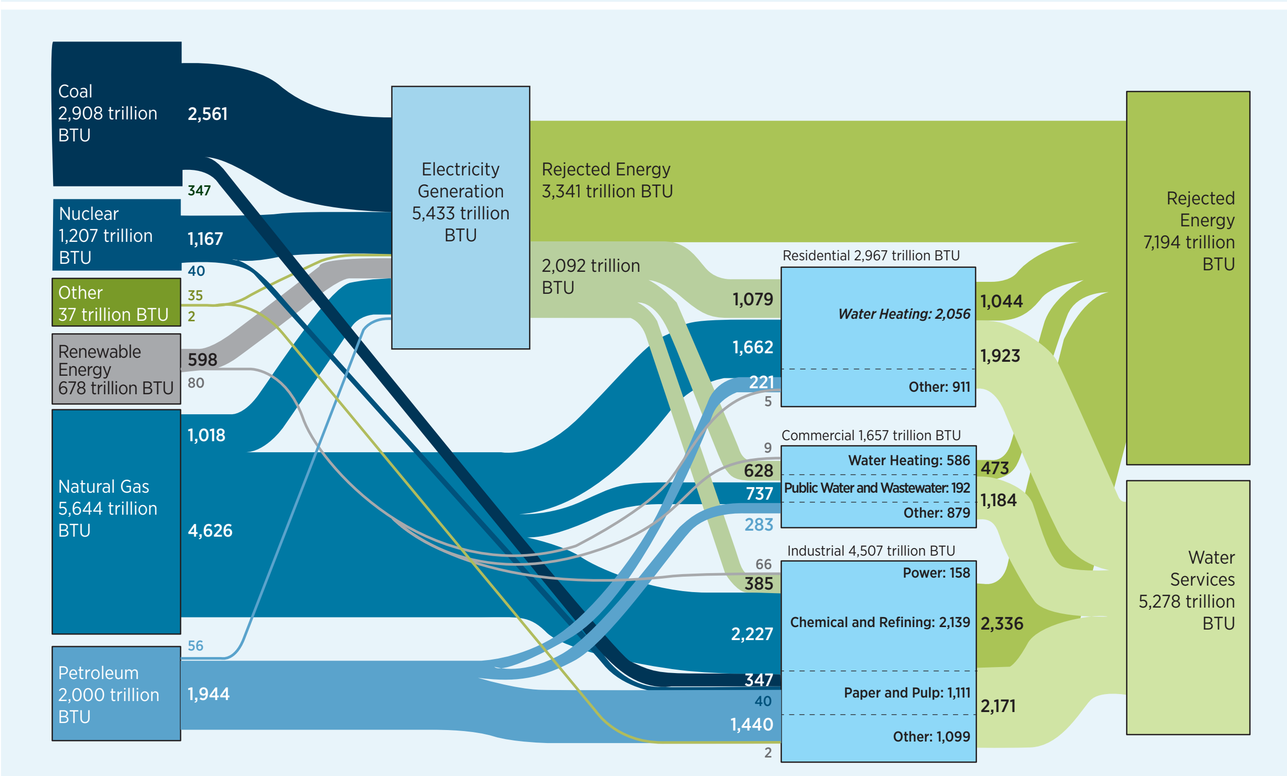
Note: Average US figures for energy used for water production (not including energy used for distribution).
Sources: CEC (2005); EPRI (2002); Stillwell et al. (2010b, 2011); Stillwell (2010c).

power plants to turn off. Though hydroelectric power is attractive, it is least reliable during droughts when the need to use water for other purposes (e.g. for drinking and irrigation) may take precedence over hydroelectricity. For example, without a change in water usage patterns, lakes Mead and Powell along the Colorado River in the USA, which are used for hydroelectric power and municipal supply, are projected to have a 50% chance of running dry by 2021 (Spotts, 2008). Similarly, cities in Uruguay must choose whether they want the water in their reservoirs to be used for drinking or electricity (Proteger, 2008).

The problem is not just limited to hydroelectric reservoirs. As thermoelectric power plants require vast amounts of water, they are vulnerable to droughts or heat waves restricting their output. Heat waves in France in 2003 caused power plants to draw down their output because of limits on rejection temperatures imposed for environmental reasons (Poumadère et al., 2005; Lagadec, 2004). Severe heat and drought killed approximately 15,000 people and created river water temperatures that were too hot for effective power plant cooling. Many nuclear power plants had to operate at much reduced capacity and an environmental exemption was enacted to allow the rejection temperatures of cooling water from power plants to exceed prior limits (Poumadère et al., 2005; Lagadec, 2004). At the same time, 20% of hydropower capacity was not available because of low river levels (Hightower and Pierce, 2008). Just as demand for electricity was spiking for air conditioning in response to the heat, supplies were being cut back. The dilemma has also shown up in other countries where drought has brought nuclear power plants within days of shutting off because the vast amounts of cooling water were at risk from diversion to other priorities, such as municipal use for drinking water.
While water limitations can restrict energy, energy limitations can restrict water. For example, power outages

FIGURE 19.3

Energy flows for the public water supply system in the USA



Notes: Fuels (on the left) are used directly and indirectly through electricity generation for different purposes (on the right). The thickness of the flows is proportional to the amount of energy consumed. About 60% of the total energy consumption is lost as waste heat. Only energy consumption related to the conveyance, treatment, distribution and heating (in the commercial and residential sectors) and public water and wastewater treatment distributed in the US public water supply is included. Self-supplied sectors, including agriculture and industry are not included.
Source: Courtesy of K. M. Twomey and M. E. Webber, University of Texas, Austin, USA.

(due to storms or intentional acts) at water and wastewater treatment plants put the water system at risk of disruptions due to energy shortages. This trade-off is a strategic question for some countries. Saudi Arabia uses much of its own most valuable resources (crude oil and natural gas) to obtain the resources it does not have (freshwater), facing the choice of whether it is better to sell its energy resources at high prices or have enough freshwater to maintain municipal needs (EIA, 2007; IEA, 2005).

19.2 Exacerbation of the strain in the energy–water relationship

Trends imply that the existing strain in the energy–water relationship will be exacerbated by:

- growth in total demand for energy and water, primarily driven by population growth,
- growth in per capita demand for energy and water, primarily driven by economic growth,
- global climate change, which will distort the availability of water in positive and negative ways, depending on the location, and
- policy choices, by which people are selecting more water-intensive energy and more energy-intensive water.

19.2.1 Growth in total demand for energy and water

Though the global fuel mix is diverse, fossil fuels (oil, coal and natural gas) satisfy more than 80% of the world's needs for primary energy resources. Total energy consumption, including traditional biomass, such as wood and dung, was approximately 500 exajoules in 2008. Most projections show an increase in demand for energy, predominantly driven by both population and economic growth. Based on its central scenario (New Policies Scenario), the International Energy Agency (IEA), estimates that world primary energy demand will increase by 36% between 2008 and 2035, or by 1.2% on average per year (IEA, 2010). In 2008 non-OECD countries were responsible for approximately 56% of the energy consumption (IEA, 2010) and are expected to account for 93% of the increase with China accounting for 36%. With fossil fuels accounting for 50 % of the increase from 2008–2035 and with an estimate that the demand for electricity will grow by 76% globally between 2007 and 2030 (IEA, 2009), there will be a complementary significant increase in demand for water.

The United Nations (UN) makes several projections for global population (with low–, medium– and high– growth variants), all showing population growth to at least 2050, at which time population could decrease (UN, 2005; UN, 2006). The IEA assumes for its projections that (a) global population will grow 1% per year on average from 6.4 billion in 2004 to 8.1 billion in 2030 and (b) that economic growth will take place at an average of 3.4% per year over the same period (IEA, 2009). The IEA interprets these trends to yield a growth in global primary energy demand of 70% between 2004 and 2030, without a very significant shift in the basic makeup in the fuel mix, despite policy prioritization for biofuels and other renewable sources. Similarly, this population growth should lead to increases in global water demand (Oki and Kanae, 2006).

19.2.2 Growth in per capita demand for energy and water

As the world population grows, the global demand for energy and water is increasing to meet people's subsistence and lifestyle needs. Added to this, the per capita demand for energy and water is also growing. While the developed world is looking for ways to conserve energy and water, the developing world is rapidly accumulating wealth, bringing about a desire for better transportation, a nicer lifestyle, more meat-intensive diets, and a robust economy. The combined effect is that the demand in developing countries is increasing rapidly for liquid fuels, electricity, and water (for industrial processes, higher-protein diets, and comfort). Consequently, the growth in demand for energy and water is outpacing the growth in population. For a world in which these resources are under strain, accelerating demand could have far-reaching impacts.

Despite population growth estimates of only 19–37% (UN, 2005; UN, 2006) from 2004 to 2030, the IEA projects much greater increases in energy demand, approximately 70% (IEA, 2009), indicating that the annual per capita energy use globally will increase from 1.7 to 2.1 tonnes of oil equivalent. Half of the growth in demand is projected to come from the power sector (IEA, 2009), showing that electricity is a preferred form of energy for those who can afford it. Because of the power sector's water intensity, the new demand for electricity will likely lead to increased demand for water withdrawals. The IEA also considers an alternative policy scenario, for which energy growth is lower than the nominal reference projection for energy growth. Even in this alternative, both absolute and per capita energy demands are expected to increase between

2004 and 2030 (IEA, 2009). Even in the USA, where energy-intensive manufacturing has shrunk over the last few decades, the per capita energy use is projected to increase.

One of the drivers of increasing energy use per capita is the demand for better environmental conditions as people's incomes rise (Dasgupta et al., 2002), a phenomenon that is illustrated with the case of wastewater treatment. Advanced wastewater treatment is more energy-intensive than standard wastewater treatment, so the trend towards higher treatment standards will likely increase the unit energy needs of wastewater treatment for countries moving up in income (Applebaum, 2000). However, the introduction of greater energy efficiency will possibly offset the expected increases in energy intensity for stricter treatment standards, limiting the projected growth in electricity use at treatment plants. The higher per capita energy expenditures for wastewater treatment to achieve stricter environmental standards is a scenario likely to be repeated in analogous ways throughout societies that are achieving affluence; that is, as nations get richer, they will demand more energy.

19.2.3 Intensification of cross-sectoral strain at the nexus of energy and water through global climate change

Water systems are likely to be hit hardest by climate change and will be a leading indicator of temperature changes. The effects are hard to predict, but higher temperatures could induce several consequences, including turning some snowfall into rainfall, moving the snowmelt season earlier (thereby affecting spring water flows), increasing intermittency and intensity of precipitation, affecting water quality and raising the risks of floods and droughts (Oki and Kanae, 2006; Gleick, 2000*a*). In addition, sea level rises could cause contamination of groundwater aquifers with saline water near the coasts, potentially affecting nearly half of the world's population (Oki and Kanae, 2006). These challenges can be fixed with greater energy expenditures for mining deeper water, moving it farther, treating water to make it drinkable, or storing it for longer periods of time. With a typical energy mix over the next few decades, these energy expenditures release greenhouse gases, which intensify the hydrological cycle further, compounding the problem in a positive feedback loop (Figure 19.4).

19.3 Policy choices towards more energy-intensive water and water-intensive energy

On top of the above-mentioned three trends is a policy-driven movement towards more energy-intensive water and water-intensive energy.

19.3.1 Growing energy-intensity of water

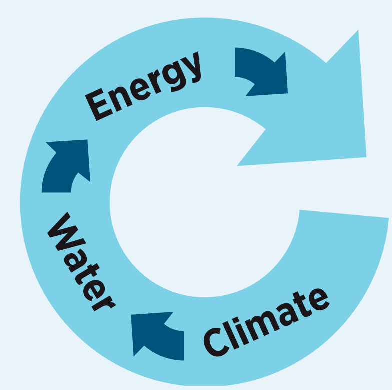
Many high-income societies are moving towards more energy-intensive water because of a push by municipalities for new supplies of water from sources that are farther away and of lower quality, thereby requiring more energy to get them to the required quality and location.

Because of growing environmental concerns, standards for water treatment are becoming stricter as water is expected to be cleaner, and so the amount of energy people spend per litre will increase. Unit electricity consumption for water treatment has increased at a compound rate of 0.8% per year, with no obvious expectation for the trend to stop (Applebaum, 2000). At the same time, in many industrialized societies, water or wastewater infrastructure is aging and will increase unit electricity use due to age-related losses, while other factors (e.g. replacing older equipment with more efficient new equipment and processes, and establishing larger treatment plants with higher energy economies of scale) will decrease unit energy consumption, but not enough to offset the energy needs of higher level treatment (Applebaum, 2000).

Societies are also going to greater lengths to bring freshwater from its sources to dense urban areas. These

FIGURE 19.4

The energy–climate–water cycle creates a self-reinforcing challenge



Source: Image based on suggestion of J. Long at Lawrence Livermore National Laboratory.

efforts include digging to ever-deeper underground reservoirs, or by moving water through massive long-haul projects (Stillwell et al., 2010b). For example, China is implementing the South-North Water Transfer Scheme, which is an order of magnitude larger than California's aqueduct and will move water from three river basins in the wet southern part of China to the dry northern parts (Stone and Jia, 2006). Two of these routes are more than 1000 km long (Stone and Jia, 2006), representing substantial investments in energy for transport. Similarly, in Texas, private investors are proposing a project to move groundwater from the Ogallala Aquifer (one of the world's largest) hundreds of kilometres across the state of Texas to the municipalities in the Dallas–Fort Worth Metroplex (Berfield, 2008).

On 12 April 1961, US President Kennedy said, 'If we could ever competitively – at a cheap rate – get fresh water from salt water that would be in the long-range interest of humanity, and would really dwarf any other scientific accomplishment.' (Gleick, 2000*b*). A few months later, he signed a bill to set the USA on a research course to seek a breakthrough in desalination (Kennedy, 1961). Since that time, global desalination capacity has seen a decades-long steep upward trend (Gleick, 2006). It is unlikely that this trend will end soon given the other trends noted above. While desalination is traditionally associated with the Middle East where energy resources are plentiful but water is scarce, cities in other locations (e.g. London, San Diego, El Paso) are considering desalination plants to get fresh water either from nearby saline aquifers or coasts. The steep market penetration rates for desalination are particularly relevant for the adoption of new membrane-based technologies (NAS, 2008). While membrane-based reverse-osmosis approaches are less energy-intensive than thermal desalination, they require much more energy than traditional freshwater production from surface sources.

19.3.2 Growing water-intensity of energy

For a variety of economic, security and environmental reasons, including the desire among high-income countries to produce a higher proportion of energy from domestic sources and to decarbonize energy systems, many of the preferred energy choices are more water-intensive. For example, nuclear energy is produced domestically, but is also more water-intensive than other forms of power generation. Carbon capture and sequestration, which is an option for decarbonizing coal combustion and other scrubber technologies, are also much more water-intensive than unscrubbed coal-fired generation. As environmental controls are tightened on carbon and other pollutants, water use at power plants for flue gas management is likely to increase.

The move towards more water-intensive energy is especially relevant for transportation fuels, such as unconventional fossil fuels (oil shale, coal-to-liquids, gas-to-liquids, tar sands), electricity, hydrogen and biofuels, all of which can require significantly more water to produce than gasoline, depending on how they are produced. It is important to note that the push for renewable electricity also includes solar photovoltaics (PV) and wind power, which require very little water, and so not all future energy choices are worse from a water-perspective.

Almost all unconventional fossil fuels are more water-intensive than conventional fossil fuels (Figure 19.5). While gasoline might require a few litres of water for every litre of fuel that is produced (including production and refining), unconventional fossil sources are typically a factor of 2–5 more water-intensive. Electricity for plug-in hybrid electric vehicles or electric vehicles are appealing because they are clean at the vehicle's end-use and it is easier to scrub emissions at hundreds of smokestacks than millions of tailpipes. However, because most power plants use a lot of cooling water, electricity can also be about twice as water-intensive than gasoline per mile travelled if the electricity is generated from the standard grid that has high fractions of thermoelectric generation. If that electricity is generated from wind or other water-free sources, then it will be less water-consumptive than gasoline. Though unconventional fossil fuels and electricity are all potentially more water-intensive than conventional gasoline by a factor of 2–5, biofuels are particularly water-intensive. Growing biofuels consumes approximately 1000 L of water for every litre of fuel that is produced (King and Webber, 2008). Sometimes this water is provided naturally from rainfall. However, for a non-trivial and growing proportion of biofuels production, that water is provided by irrigation.

Sustained higher energy prices and emerging political consensus about climate change and energy security have brought fossil fuels into new scrutiny. Consequently, several countries are seeking an energy solution that is domestically sourced (addressing some of the national security concerns), abundant (addressing the concerns about resource depletion), and less carbon-intensive (addressing the concerns about climate change). Because significant volumes of oil are imported in many countries, and because this sector is a major contributor to carbon emissions, it is on the short-list of targets for change by policymakers, innovators and entrepreneurs.

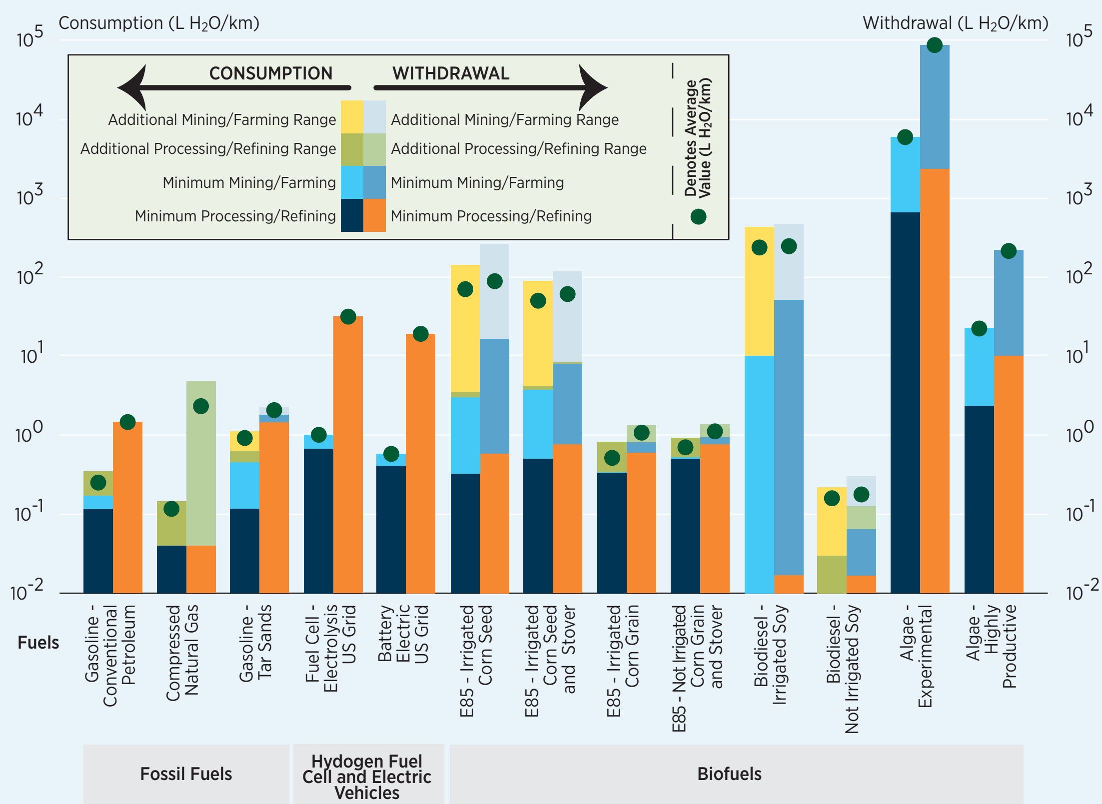
Some energy options are unconventional fossil fuels (including compressed natural gas, coal-to-liquids, tar sands and oil shale), hydrogen, biofuels and electricity. While these options have their merits, most of their production methods are more water-intensive than conventional petroleum-based gasoline and diesel (King and Webber, 2008). The production of oil shale and tar sands is very water-intensive. For example, in situ oil shale production might use vast amounts of electric power to heat the bitumen underground, and that electric power will likely need water cooling. Tar sands production uses steam injection to reduce the viscosity of the tars. While coal production is not particularly water-intensive, creating liquid fuels from coal using Fischer–Tropsch processes requires water as a process material. Hydrogen can also be very water-intensive if produced by electrolysis (Webber, 2007).

However, if hydrogen is produced from non-irrigated biomass resources or by reforming fossil fuels, its water-intensity is on par with conventional gasoline production and use. Notably, the biohydrogen pathway is not yet economical or scaled-up.

Biofuels are also very popular because they can be grown domestically and consume CO_2 during photosynthesis. They also hold the potential for displacing fossil fuels. The real challenge for biofuels is their water intensity (King and Webber, 2008), but there are also some

FIGURE 19.5

Water intensity of transportation



Notes: The water-intensity of different fuels in litres of water required per kilometre travelled, show great variation from irrigated biofuels (at the high end, withdrawing and consuming more than 100 L of water per km) to electricity from wind or solar resources (at the low end, requiring approximately 0 L per km). Water consumption (left stacked bars read on left axis) and withdrawal (right stacked bars read on right axis) in L per km for various fuels for light duty vehicles. Water use from mining and farming is designated differently from that used for processing and refining. Where a range of values exists (e.g. different irrigation amounts in different states), a minimum value is listed with an 'additional range'. Otherwise, the values plotted are considered average values. FT = Fischer–Tropsch; FCV = fuel cell vehicle; US Grid = electricity from average US grid mix; and Renewables = renewable electricity generated without consumption or withdrawal of water (e.g. wind and photovoltaic solar panels)

Source: Beal (2011, fig. 5-2, p. 273).

important water quality impacts (Twomey et al., 2010). Recent analysis indicates that irrigated biofuels can require over 100 litres of water for every kilometre travelled in a light-duty vehicle (King and Webber, 2008; NAS, 2007), approximately 1,000 times more water per kilometre than conventional gasoline. When scaling up this kind of production to prepare for national biofuels mandates, water can become a critical limiting factor.

Conclusions and recommendations

The nexus of water and energy is fundamental to society, is intertwined in many ways, is under strain, and that strain is projected to become worse as worldwide demand for both increases more quickly than population and the effects of climate change manifest themselves. While the energy–water relationship might appear intractable, there are many opportunities to mitigate its worst aspects through new technologies, new concepts for how to reuse water effectively, new markets that put a price on water, and recognition that conserving water and conserving energy are synonymous. Though the world's water situation appears dire for many reasons, it also presents an opportunity to address the problem and there are many tools available. In particular, policy engagement is warranted.

Because there are many rivers, watersheds, basins and aquifers that span several regions and/or countries, there is a need for national and international engagement on energy–water issues. Unfortunately, there are some policy pitfalls at the energy–water nexus. For example, energy and water policymaking are typically disaggregated. Further, the data on water quantity are sparse, error-prone and inconsistent. National databases of water use for power plants contain errors, possibly due to differences in units, formats and definitions between state and federal reporting requirements. For example, the definitions for water use, withdrawal and consumption are not always clear.

Despite the potential pitfalls, there are policy opportunities at the energy–water nexus. For example, water conservation and energy conservation are synonymous. That is, policies that promote water conservation also achieve energy conservation; and policies that promote energy conservation also achieve water conservation. Some policy actions for the energy–water nexus are to:

- Collect, maintain and make available accurate, updated and comprehensive water data. Without good data about water reserves, flows and use, it will be difficult for analysts to assess the situation and for policymakers to respond; this hurdle remains one of the top barriers to effective action.
- Invest heavily in water-related research and development (R&D) to match recent increases in energy-related R&D. R&D investments are an excellent policy option for national and international bodies because local governments and industry usually are not in a position to adequately invest in research. Consequently, the amount of R&D in the water sector is much lower than for other sectors, such as pharmaceuticals, technology or energy. Topics for R&D include low-energy water treatment, novel approaches to desalination, remote leak detectors for water infrastructure, and air-cooling systems for power plants. In addition, R&D for biofuels should emphasize feedstocks, such as cellulosic sources or algae that do not require freshwater irrigation.
- Develop regional water plans that consider increased demands for electricity, and regional energy plans that consider increased demands for water. For example, the rise of biofuels or electricity as fuel substitutes will have very different regional impacts. Biofuels will affect water use in rural, agricultural areas, whereas electric vehicles will affect water use at power plants near major population centres.
- Encourage resource substitution to fuels that have water, emissions and security benefits. Some fuel sources, such as natural gas, wind and solar PV need much less water and reduce emissions of pollutants and carbon.
- Support the use of reclaimed water for irrigation and process cooling. Using reclaimed water for power plants, industry and agriculture can spare a significant amount of energy and cost. However, financing, regulatory and permitting hurdles restrict this option. Reuse water can also reduce the demand for freshwater, for example by using reclaimed water (e.g. treated wastewater) for power plant cooling or other industrial uses along with irrigation. There is precedent for such action, as 'nearly 80% of water used in the industrial sector in Japan is currently recycled' (Oki and Kanae, 2006, p. 1071). While most cities would refrain from using treated wastewater as a source of drinking water, this avenue is also available and has been implemented, for example, in water-scarce Singapore and the International Space Station without ill effects. Consequently, it is recommended that municipalities affected by water-scarcity should move aggressively towards the use of reclaimed water.
- Support the use of dry and hybrid wet–dry cooling at power plants. Not all power plants need wet cooling

all the time. Finding ways to help plants upgrade their cooling to less water-intensive versions can spare significant volumes of water to meet public supply or in-stream flow requirements.

- Establish strict standards in building codes for water efficiency: revised standards for low-flow appliances, water-heating efficiency, purple-piping for reclaimed water, and rain barrels to reduce both water and energy consumption.
- Invest aggressively in conservation. Water conservation can be a cost-effective way to save energy, and energy conservation can be a cost-effective way to save water. Therefore, conservation has cross-cutting benefits.

Conservation is one of the easiest and most cost-effective approaches to reducing both water and energy use, especially as saving water is synonymous with saving energy, and vice-versa (Cohen et al., 2004; Hardberger, 2008). While conservation will not solve all of society's energy and water problems, it will buy some time while new solutions are developed.

Note

1 Many numbers used in this description are for the USA because the data are available with greater fidelity and comprehensiveness than for other countries and regions. While these numbers are suitably representative for the energy–water relationship in general, there will be some variation in other regions due stage of economic development, prevailing climate and technology choices.

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CHAPTER 20

Freshwater for industry

UNIDO

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Acknowledgement Igor Volodin (Coordinator)

Industry's need for water has not fundamentally changed, but it has become more critical and it is a function of water productivity in a sustainability context.

Economic forces, comprising several factors that affect the demand side, are the strongest influence on water for industry. Climate change is the main supply side driver.

Cheap, plentiful water can no longer be taken for granted. There are uncertainties with the quantity and quality of water both for industry and its supply chain.

Challenges for industry include adapting to water scarcity, changing management paradigms and minimizing environmental impacts.

Opportunities exist in proactive integrated water management using corporate water strategies that are outward looking and involve a commitment to innovation and implementation.

20.1 Key issues

Industry's need for water has not fundamentally changed, but it has become more critical over recent decades. The issues involved are the supply of and demand for water, the use and consumption of water, and wastewater discharge, all key issues for the industry to be profitable in the context of environmental sustainability.

20.1.1 Water quantity

On a global scale, industry uses relatively little water in comparison to the agriculture sector, but it does require an accessible, reliable supply of consistent and acceptable quality. Data indicate that approximately 20% of the world's freshwater withdrawals are used by industry, but this figure varies widely from region to region (UNEP, 2008) (Figure 20.1). The available data generally combine industry and energy use; it has been estimated that only about 30 to 40% of this use is for actual industry and the balance is used in various forms of power generation (Shiklomanov, 1999).

The demand for water is expected to increase in parallel with population growth and maybe even exceed it (Pacific Institute, 2004). Water management in industry is considered in terms of withdrawals and consumption. This is expressed as:

Water Withdrawal = Water Consumption + Effluent Discharge (Grobicki, 2007)

The total water withdrawal from surface water and groundwater by industry is usually much greater than the amount of water that is actually consumed (WWAP, 2006, ch. 8). Improved water management is generally reflected in overall decreased water withdrawal or use by industry. This makes obvious the connection between increased productivity and decreased consumption and effluent discharge. Indeed, if discharge becomes zero then the water component of increased water productivity is solely a function of water consumption.

20.1.2 Water quality

It is not uncommon for industry to use higher quality water than it requires, often because there is a conveniently located local supply – either a natural source (groundwater, a river or a lake) or a suitable municipal service. Water of lesser quality may be adequate for many industries, allowing the use of recycled and reclaimed water from other sources. Conversely, some industries such as food processing have requirements more demanding than those for drinking water. The pharmaceutical and high technology industries require very high quality water and further treat the water from their primary supplies.

The water quality of effluent discharges is also important to industry as pollution can affect large volumes of fresh water. While statistics show that industry, in the macro view, is not necessarily the worst polluter in terms of concentrations and loads, its effects can be very significant, particularly on regional and local scales (World Bank, 2010, fig. 3.6). Industrial contamination tends to be more concentrated, more toxic and harder to treat than other pollutants. The persistence of these contaminants with respect to their degradation and rate of movement though the environment and hydrological cycle is often lengthy.

20.1.3 Water productivity and profit

Industry needs to maximize economic output and profit yet use water efficiently and wisely. The measure of water productivity is how much dollar value can be obtained from each cubic metre of water used (Grobicki, 2007; World Bank, 2010, fig. 3.5). Figures range from well over US$100 to less than US$10 per cubic metre depending on the country (WWAP, 2009, ch. 7). As technology improves, industrial water productivity increases. Low productivity may indicate that water is undervalued or is simply abundant. High productivity is linked to high reuse as withdrawals are reduced.

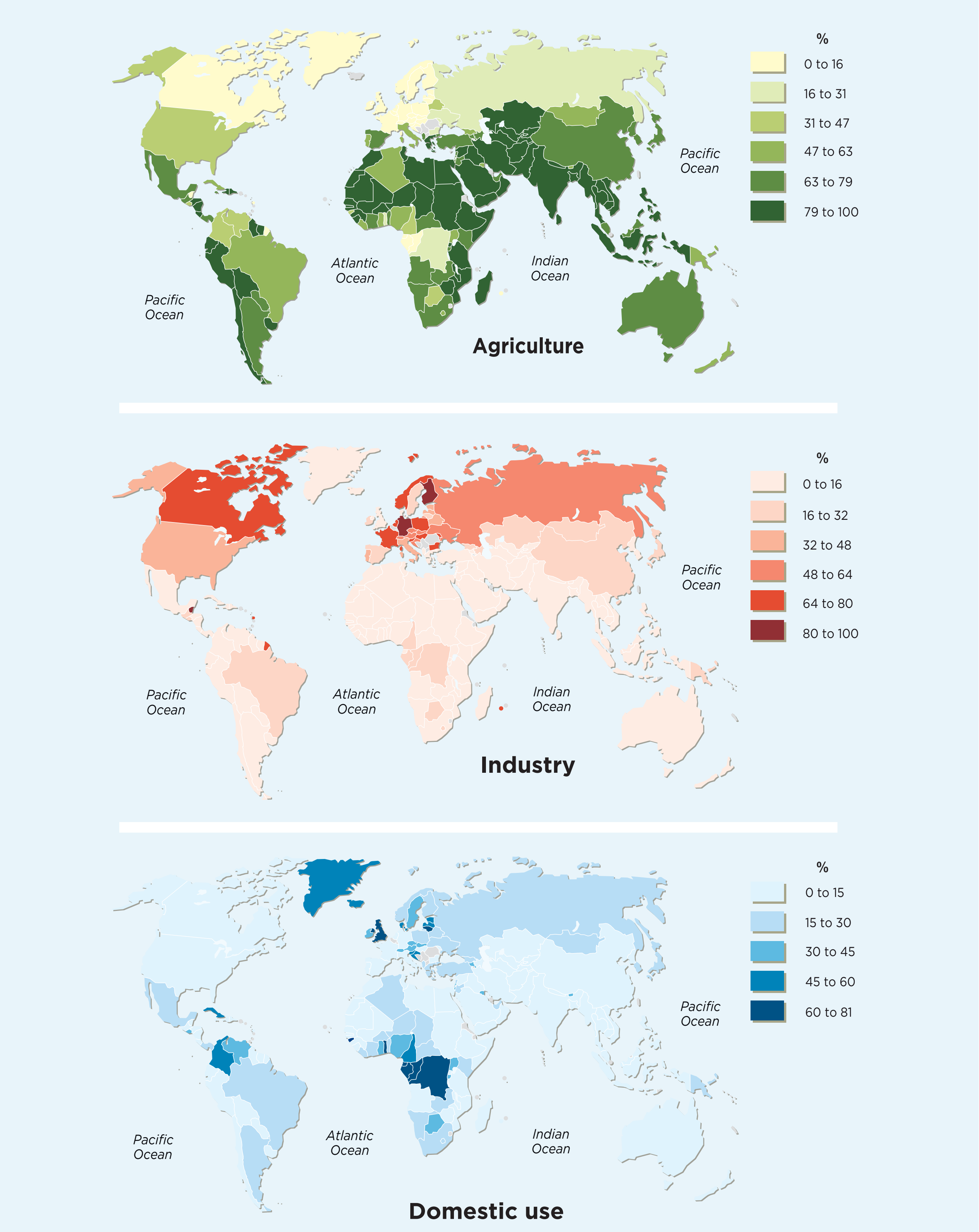
The virtual water content of industrial products is another way to view how much water is being used in industry. Virtual water is the volume of fresh water consumed in all steps of the production process. It is usually considerably more than the actual water contained in the product. The global average virtual water content of industrial products is 80 L per US$ required to produce the commodity (Hoekstra and Chapagain, 2007). However, in the United States (USA) the number is 110 L; in Germany and the Netherlands it is about 50 L; and in Japan, Australia and Canada it is only 10–15 L. In large developing nations, such as China and India, the average number is 20–25 L per US$.

20.1.4 Cleaner production and sustainability

There is a need to break the paradigm of industrial growth linked to environmental damage and to decouple industrial development from environmental degradation. At a fundamental level this involves cleaner production and sustainability. Cleaner production has

FIGURE 20.1

Global freshwater use by sector at the beginning of the twenty-first century



Source: UNEP/GRID-Arendal (http://maps.grida.no/go/graphic/freshwater-use-by-sector-at-the-beginning-of-the-2000s, by P. Rekacewicz, based on data from the World Resources Institute).

many facets, and one of its main objectives is to move towards zero discharge. Zero discharge changes the balance of the water productivity equation and is a key concept in matching water quality to use (WWAP, 2006). In moving towards zero discharge, an attempt is made to convert wastewater streams into useful inputs for other industries and industrial clusters. It seeks to find a use for all effluents that would otherwise be discharged by recycling them or selling them to another user. If an industry approaches this goal then its overall water consumption will equal its withdrawal. Practically, this means that withdrawal will decrease to meet consumption.

The hydrological cycle includes significant industrial intervention, such as effluent discharge into surface water bodies, the infiltration of contaminants into groundwater, and the atmospheric distribution and fallout of contaminants into water bodies (Figure 20.2). Loops of recycled and reclaimed water are included in the hydrological cycle. Recycled and reclaimed water may rejoin the cycle after much delay or perhaps never, if zero discharge becomes a reality. Zero effluent discharge is the ultimate goal for water quality (WWAP, 2006).

20.2 External drivers

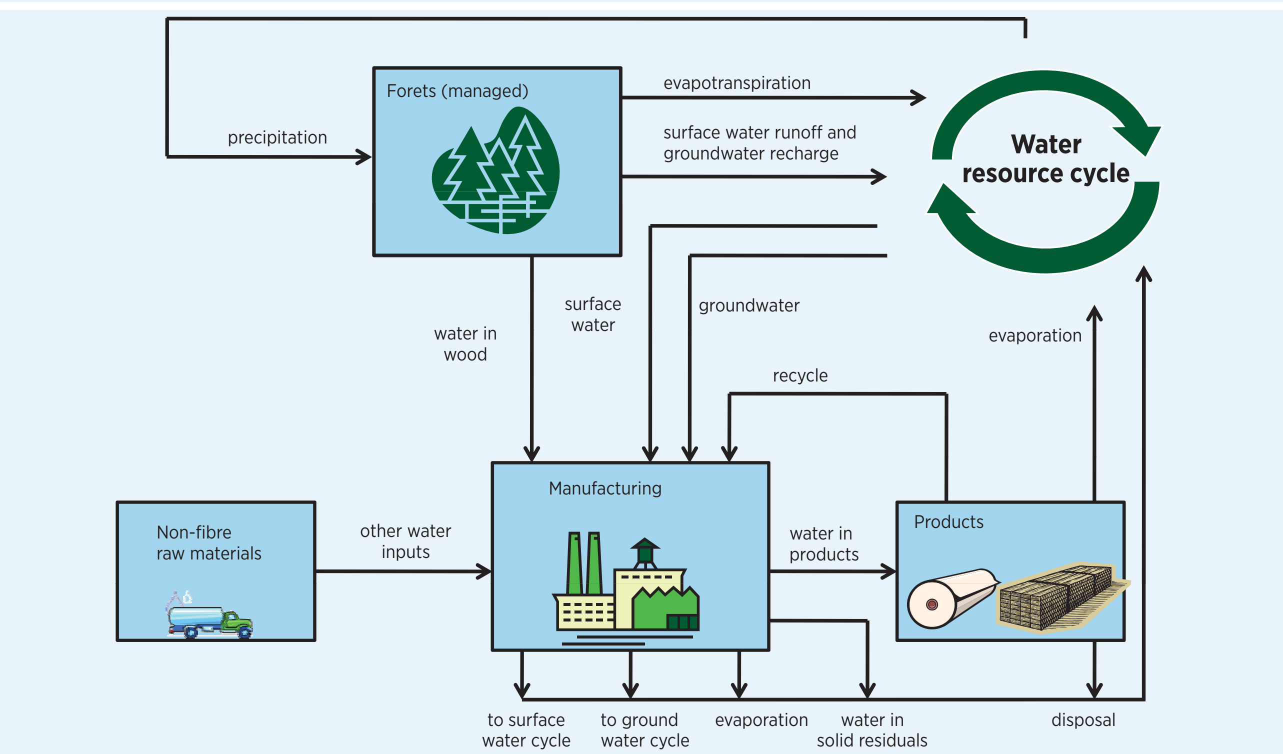
The water need of industry is strongly influenced by external drivers that add a layer of uncertain complexity to corporate water management. These external drivers often act in an indirect way through a chain reaction, with many consequences. They are essentially recent phenomena and, although their impacts on water are evident, their exact effects are unpredictable. The problem is magnified because more than one factor may pressure a driver, the relationships between factors and drivers are interactive and changing, and these relationships are difficult to control. The external drivers discussed below appear to be the most influential for industry. Other drivers such as ecosystem stress, societal values, and security, while important, tend to be more local in nature.

20.2.1 Economic forces

Economic growth and development are the main drivers of the challenge to water resources (2030 Water Resources Group, 2009). Economic forces affect water, but at the same time the state of water resources influences the economy, and water is seen as both a threat and a constraint to economic growth (WWAP, 2009).

FIGURE 20.2

Water profile for the Canadian forest products industry (million m^3 per year)



Source: NCASI (2010, fig. 2.1, p.2)

Concerns were expressed at the 2009 Davos World Economic Forum that the world is moving to 'water bankruptcy' and that this is one of the world's most pressing problems (TSG, 2009).

Competition for water resources

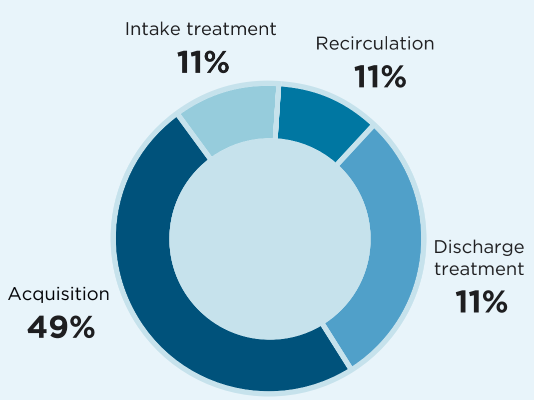
Industry will find itself competing more and more for limited water resources as demand and consumption increase in all areas. The Pacific Institute (2007, p. 7, referencing FAO, 2007) states, 'according to the United Nations, if present consumption patterns continue, two-thirds of the world's population will live in water-stressed conditions by the year 2025'. Lack of water is already a major constraint to industrial growth in China, India and Indonesia (Pacific Institute, 2007). Further demographic pressure is resulting from globalization, which 'with its accompanying move of labour industries from high-income to low-income countries, is creating high water demand outside of its abundant sources, often in urban areas' (WWAP, 2003, ch. 9, p. 244). Agriculture, the biggest single user of water by far, will remain the biggest competitor for this resource, potentially in conflict with industry.

The valuation of water

Underlying the competition for water is the concept that it is an 'economic good' and thus subject to market forces in terms of its cost. Figure 20.3, for example, depicts the cost components in manufacturing industries in Canada. Balanced against the economic good

FIGURE 20.3

Water costs in Canadian manufacturing industries by cost component, 2005



Source: Statistics Canada (2007).

notion is the belief that access to water is a human right. Therefore, there are competing trends of full-cost pricing of water versus more customary subsidies or essentially free water.

Privatization of water supply and treatment

Superimposed on the debate over the value of water is the increasing trend towards privatization of water supply and treatment – which may also include the management and ownership of water systems – particularly in high income countries (Pacific Institute, 2004).

Financial crises

The forecasts for recovery time from the 2008 global financial crisis vary greatly, as do the predictions for the success of the recovery. Financial planning in such circumstances of uncertainty is difficult and may be very short term. Moreover, as a result of the crisis, the dynamics of the world economy may change substantially. There is a growing recognition of water's value in the global financial infrastructure and it is felt that investments in water will be less affected than other investments by the current financial crisis (TSG, 2009).

In times of crisis, governments, primarily in developed countries, resort to deficit spending and much of the money goes to infrastructure. This spending may be beneficial to industry because the design and construction of infrastructure for water management and treatment that is more efficient should provide confidence in adequate supplies of good quality water. On a global scale, the pursuit of cost savings will drive industry to find more economical ways of operating; one option is the optimization of resources through the adoption of advanced technologies and practices that lead to zero discharge.

Trade

Trade is a driver for industry and water through multilateral environmental agreements (MEAs) and international standards. MEAs, such as the Basel Convention, are used to control international trade for environmental reasons and were originally devised to protect developing countries from the activities of developed countries. However, trade from developing countries now faces the hurdle of meeting the requirements of the developed countries. These requirements include ISO certifications, environmental management systems (EMS) and corporate social responsibility (CSR). These have, in turn, led to product manufacturing standards, which include energy efficiency and climate change (carbon footprint) requirements, and these affect industrial water use. Industry in developing countries is facing stricter requirements and some control by the multinational companies to which they supply their goods. A benefit for industries in these countries is the better management, including of water, such requirements necessitate, and the resulting increased efficiency.

Water trade is typically a local issue, because it is not practicable to transport water in bulk over large distances. However, the concept of virtual water puts water trade on a global scale. Virtual water trade is trade in goods and services that consume a considerable amount of water – often in their production and usually less so in their product. It is 'a tool for determining the movement of water through international trade' (WWAP, 2009, ch. 2, p. 35). Therefore, while international trade can aggravate water stress, it can also relieve it through virtual water trade. It has been estimated that virtual water accounts for 40% of total water consumption and that 20% of this virtual water is in industrial products (WWAP, 2009, box 2.1). The state of a country's water resources can be improved or made worse if goods with a large water footprint are exported or imported.

However attractive the trade of virtual water is, there are some important constraints (TSG, 2009). It has been suggested that this trade strongly reflects trade in agricultural products, which have large water footprints (GWI, 2008). Consequently, developing countries with little industry but many small farmers will export water and industrialized countries, regardless of their natural resources, will import water in food. Reversing this flow of virtual water is not practicable as 'you cannot tell peasant farmers in North Africa, India or North-East China that they should give up their land and become advertising executives or bank clerks because those professions use less water' (GWI, 2008). The situation is made more complex where an industrialized country such as the USA is also a major agricultural exporter.

20.2.2 Climate change

Climate change is a fundamental driver affecting water availability (supply side) and in turn it pressures demand side drivers for water. The resulting pressure on industry is the need to secure and maintain an adequate water supply. Fulfilling this need will become increasingly difficult with the unpredictable location and timing of climate change impacts. It could happen that many industrialized countries, which are found in the mid-latitudes and the Northern Hemisphere, will have their supplies come under stress. Competition among users will intensify in some regions when existing adequate supplies become scarce. As a result, industry may need to relocate.

Conversely, some lower income countries, which are often under water stress at present, may find their supply increases. In many cases multinational corporations have already relocated to lower income countries to take advantage of cheaper labour – with more water in these areas the trend might be expected to continue and increase, though improvements in water infrastructure will be required to take advantage of increased supply. An indirect benefit from the increased industrial presence may be improved manufacturing quality and labour conditions and better-protected ecosystems, as the markets for their products are mainly in higher income countries with demanding environmental standards and labour laws.

20.2.3 Technological innovation

Technological innovation applies to the quality of both water supply and treatment of wastewater in industry, which have a direct bearing on cleaner production and sustainability. The constraint to treatment to achieve high quality water is cost rather than technical capability. Revolutionary technological breakthroughs that will transform the treatment of water seem unlikely, but there have been many incremental technological advances and continual cost reduction (TSG, 2009). The idea is to commission the most economic system for the level of quality required.

20.2.4 Policies and governance, laws and finance

At all levels of government policies, strategies and regulations concerning water have a direct bearing on industry and are backstopped frequently by economic measures. Industry can to some extent influence government, but it is only one stakeholder in the process of devising water policy, a process that has many competing interests and drivers. Government initiatives form a variety of 'carrot and stick' approaches that will either encourage or force industries into more environmentally sustainable practices. However, well-intentioned government strategies can inhibit progress; for example, waste regulations in the USA prevent waste transfer in industrial clusters (Das, 2005).

20.2.5 Public input into water policy

Public involvement in decisions over water resources and policy is increasing (Pacific Institute, 2004, 2007). Such decisions may affect the lives of many people and thus their input is important. Protests, opposition to projects and globalization, and water controversies are becoming more common. With the media involved, bad publicity over water can affect business in a very negative way. Industry must strategically think about and plan its need for water to avoid disputes and confrontation.

20.3 Principal risks and uncertainties

In the past, water was not seen as an uncertain component of the process of the successful and profitable operation of an industry; it was taken somewhat for granted that supply would be easy and relatively cheap to secure. Discharges of wastewater presented more of a challenge but, providing standards were met, effluent was permissible. The recent number of new external drivers on water and its management has now made water use a much riskier proposition for industry (Figure 20.4). To run an industry well, water is required in the right quantity, in the right quality, at the right place, at the right time and at the right price (Payne, 2007). All these factors are now subject to greater uncertainty.

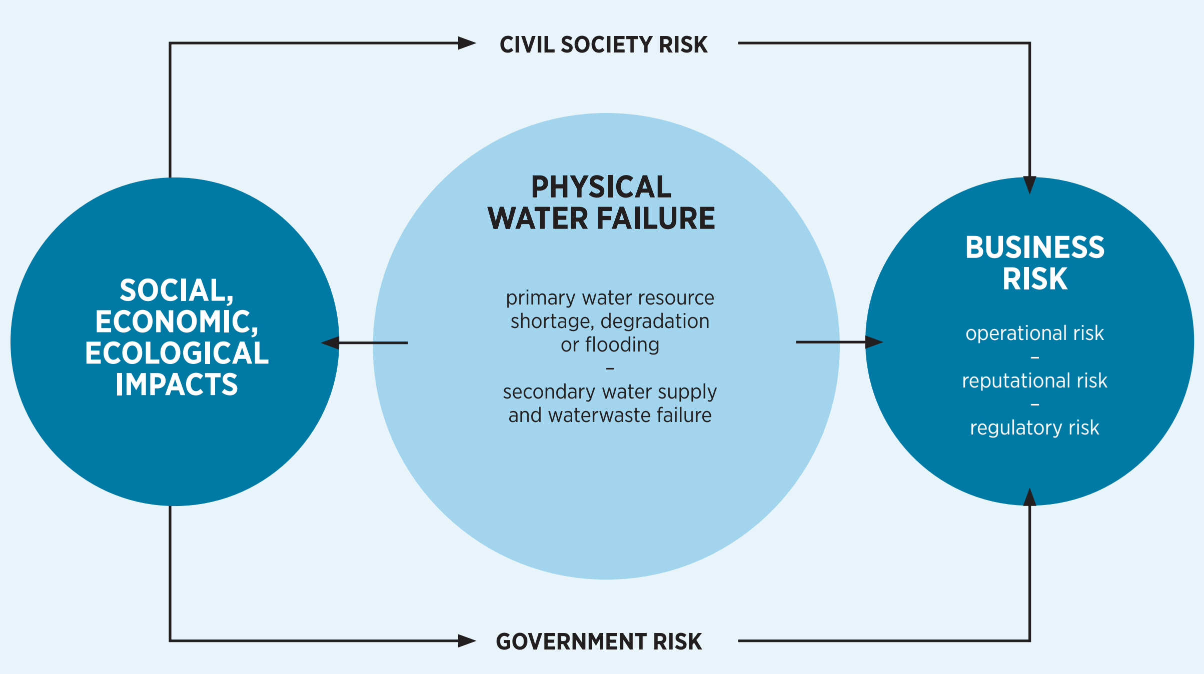
20.3.1 Reliable supply

Water scarcity is seen as an increasing business risk and the security of supply to industry is dependent on sufficient resources (2030 Water Resources Group, 2009) (Figure 20.5). This situation is compounded by geographical and seasonal variations, which are now more unpredictable, and perhaps underestimated, being subject to the risks associated with climate change, which 'challenges the traditional assumption that past hydrological experience provides a good guide to future conditions' (IPCC, 2008, p. 5).

This situation then leads into water allocation and the competing needs for water in a region, which may be beyond the control of industry. This is especially true in transboundary water situations where the needs of two or more countries may conflict.

FIGURE 20.4

Inter-relationship of water risks between business, government and society



Source: SABMiller and WWF-UK (2009, fig. 2, p. 5), courtesy of SABMiller/WWF (refer to www.SABMILLER.com/water).

20.3.2 Adequate quality

Water quality risks associated with both supply and discharge affect industry. Many industries require high quality water and may use pre-treatment because natural sources of water are increasingly likely to be polluted. It is estimated that 40% of US rivers and 75% of Chinese rivers are heavily polluted, and that river water in the US may be reused up to 20 times before it reaches the sea (TSG, 2009). Groundwater is being overexploited, contamination is increasing, and saltwater intrusion is resulting from groundwater overdraft in coastal regions. Industry is exposed to these risks and the costs associated with combating them. There will be more reliance on reusing reclaimed or recycled water in the future, and in this context, there is clearly a need to improve the match between water quality and use.

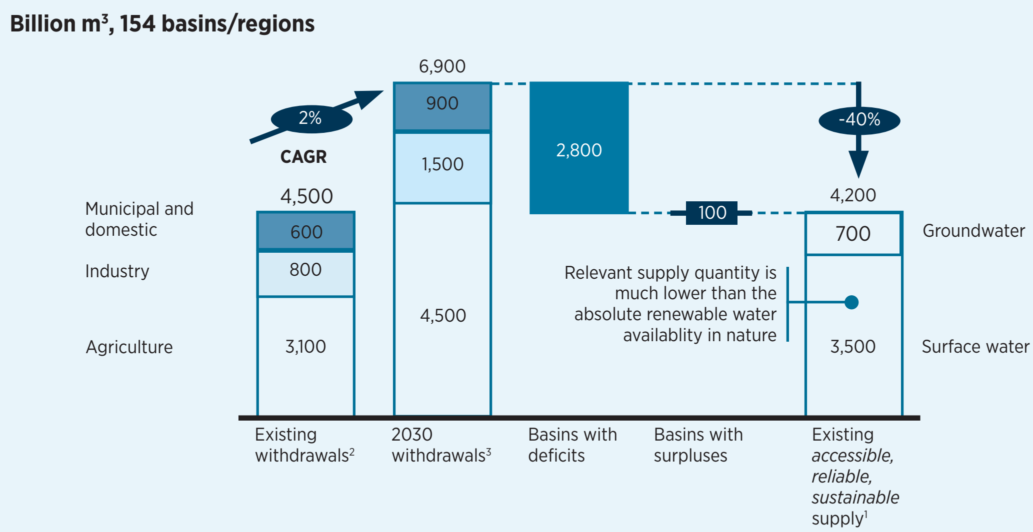
Wastewater discharge regulations and standards present risks to industry. In developed countries there are pre-treatment requirements before effluent can be sent to municipal treatment plants or discharged to watercourses. In developing countries, it is estimated that 70% of industrial wastes are discharged without any treatment into usable water supply (WWAP, n.d.). Therefore, there is considerable pressure on industry to clean up its effluent and while compliance will doubtless become stricter and more onerous, the actual criteria and severity of standards will vary from jurisdiction to jurisdiction. The associated risk is that of investment in new treatment technology which may be obsolete within a few years. Industrial accidents such as uncontrolled discharges may result from economic and other drivers to move ahead quickly, possibly with unproven technology and in sensitive locations. Water quality issues therefore present restrictions on industrial expansion.

20.3.3 Supply chain disruptions

The increasing interest in water footprints highlights the importance of the supply chain in delivering the necessary raw materials and other items that an industry needs to function (Figure 20.6). The links in the supply chain are subject to external drivers and risks associated with a reliable supply of water for each industry involved in the supply chain. A significant break in this chain can result in great difficulties for an

FIGURE 20.5

Aggregated global gap between existing accessible, reliable supply and 2030 water withdrawals, assuming no efficiency gains



[1] Existing supply which can be provided at 90% reliabillity, based on historical hydrology and infrastructure investments scheduled through 2010; net of environmental requirements.
[2] Based on 2010 agricultural production analyses from IFPRI.
[3] Based on GPD, population projections and agricultural production projections from IFPRI; considers no water productivity gains between 2005–2030.
Source: 2030 Water Resources Group (2009, p. 6) (the Water 2030 Global Water Supply and Demand model; agricultural production based on IFPRI IMPACT-WATER base case).

industry. Such risks, with several factors coming into play, are very difficult to accommodate and make contingency plans for.

20.3.4 Government and water management

It is the practice of governments to set their own policies with respect to water, based on multifaceted agendas of particular concerns from the national to local levels. Priorities change and this variation and unpredictability makes it particularly difficult for industry, especially global companies, to locate successfully to some countries. The situation is especially difficult if regulations change after a company has started operations. As such, companies must be proactive in their efforts to anticipate these uncertain situations and take measures to address them in advance. The government perception of water risk may be at odds with industry. Poor policy and decisions may lead to overutilization of water resources in existing locations and underutilization in others. In addition, if the anti-industry bias of some governments, particularly in the light of environmental activism, is added to the new and emerging role of the public, with its own agenda in water management, the outcomes are very uncertain.

20.4 Challenge areas

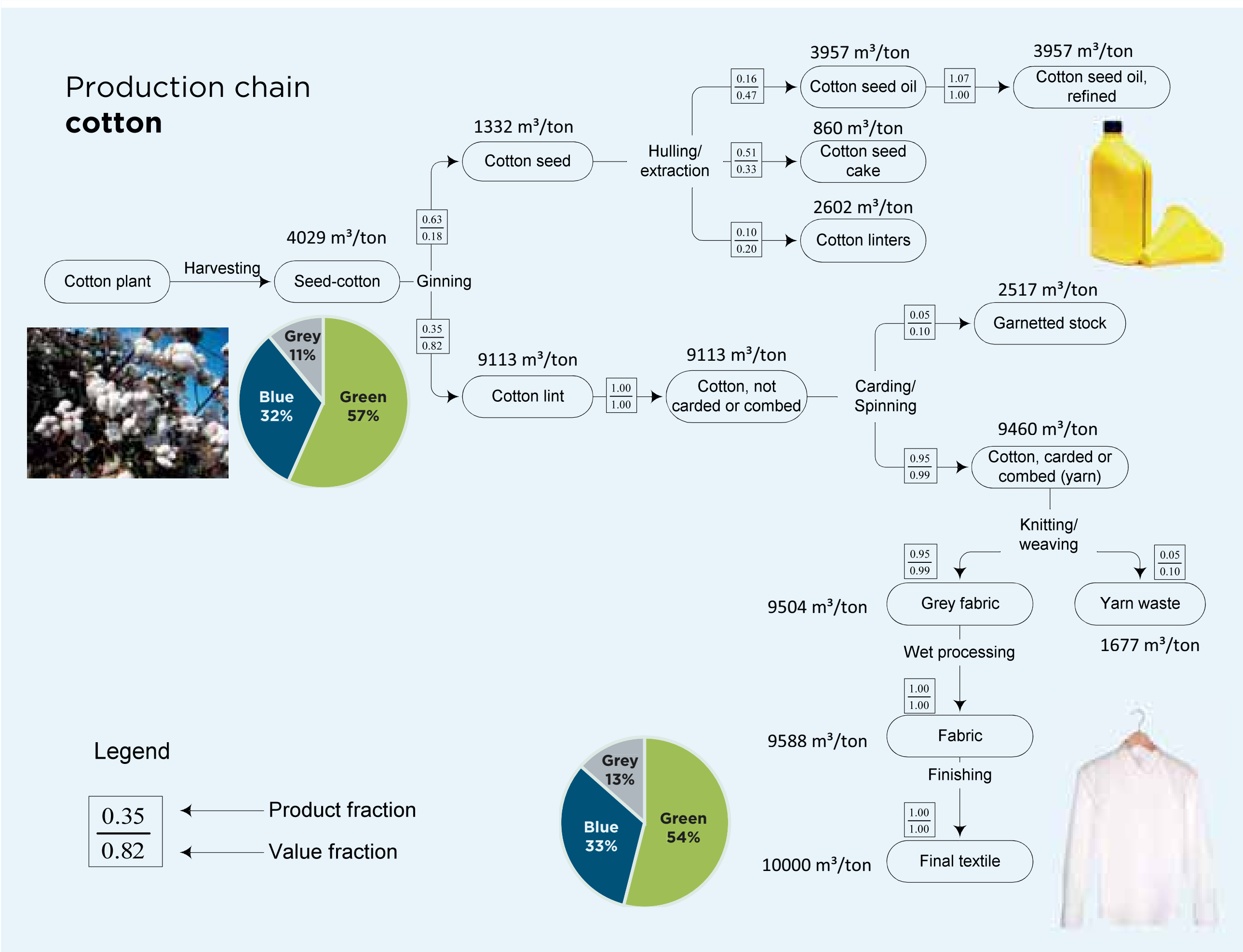
The main challenge to industry is how to remain viable by properly responding to all the new water resource drivers – their unusual pressures, their heightened levels of uncertainty and their associated risks.

20.4.1 Adapting to water scarcity

Water scarcity is probably the most pressing challenge for industry. Bridging the water gap will be a

FIGURE 20.6

The production chain for cotton



Note: The average water footprint of printed cotton (e.g. a pair of jeans weighing 1 kg) is 11,000 L per kg.
Source: Mekonnen and Hoekstra (2010).

major difficulty, and improved efficiency to meet demand and business-as-usual for supply approaches are expected to fill only approximately 40% of the gap (2030 Water Resources Group, 2009) (Figure 20.7). Scarcity may not only be simply lack of water but also inadequate delivery due to poor infrastructure or water management. Tied in to this economic shortage are ancillary challenges such as ensuring industry access in competitive situations while not coming into conflict with local communities (Pacific Institute, 2007). Resulting allocations may be constraints to find sites for sourcing, production and retail activities, particularly for those industries using large quantities of water or needing high quality water.

Meeting basic water needs

The failure of some governments in developing countries to provide basic water needs for their population places industry in a difficult position with respect to those needs on a human rights basis (Pacific Institute, 2004). The challenge is to balance public and private benefits. Many questions have been raised about the responsibilities of companies to provide or improve water for basic needs while using water for their own purposes. There are risks around this issue to a company's reputation as well as to potential financing from international agencies and institutions.

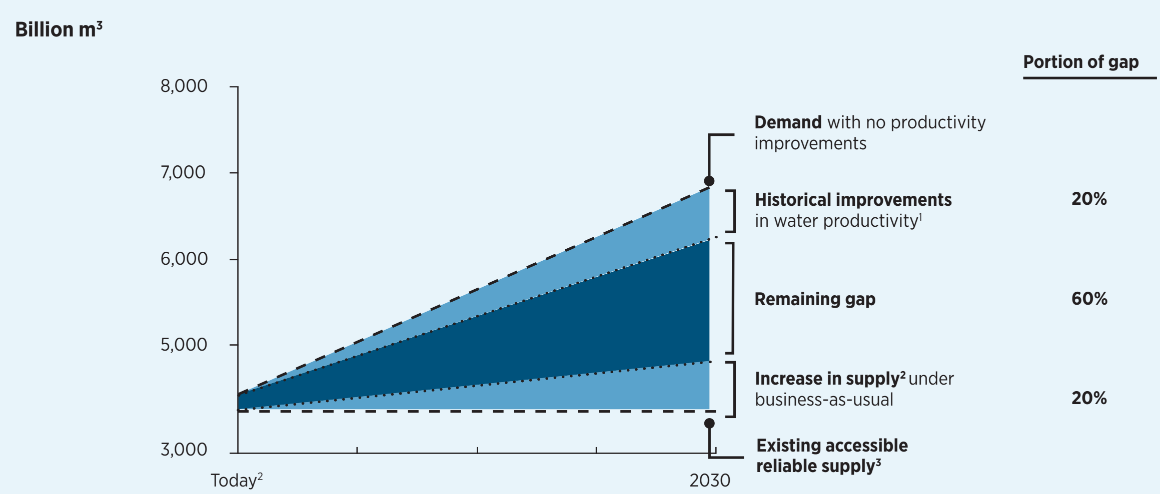
Determining water budgets

Water scarcity forces industry to understand how much water it really needs. To increase the efficiency of water use in a facility, it is necessary to know its water budget and particularly its losses. This is the baseline for water savings. Industry must know its own water balance – the ratio of the input of water to the output of water (Figure 20.8). Thus the challenge for industry is to establish its water footprint or profile to see where efficiencies may be achieved. This is dependent on good data and a consistent approach to measurement and monitoring.

The combined challenges of water scarcity and water quality generate an associated challenge: how to increase water productivity and prevent pollution. Water productivity appears to decrease with total water consumption, and economic growth usually comes through increased consumption rather than by increased productivity (WWAP, 2003). The focal point of this challenge is how to move to zero discharge. The challenge of water productivity is to do more with less; in other words, to make every drop count. If industry is to react positively to pollution prevention, particularly in tough regulatory regimes, then cleaner production and zero discharge are

FIGURE 20.7

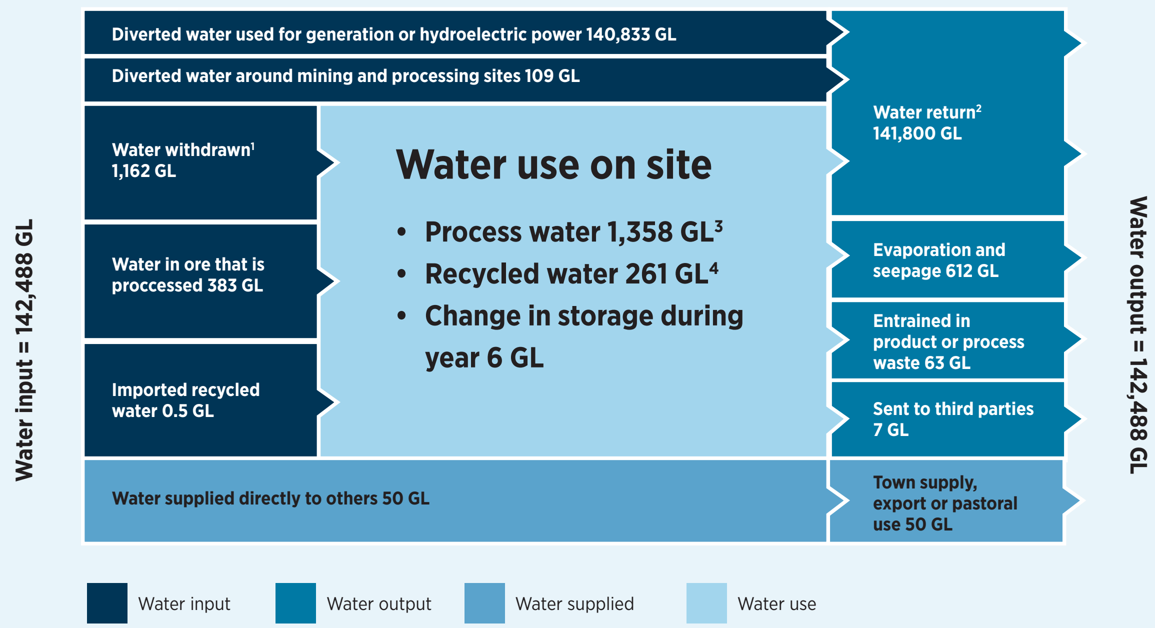
Business-as-usual approaches will not meet demand for raw water



[1] Based on historical agricultural yield growth rates from 1990-2004 from FAOSTAT, agricultural and industrial efficiency improvements from IFPRI.
[2] Total increased capture of raw water through infrastructure buildout, excluding unsustainable extraction.
[3] Supply shown at 90% reliability and includes infrastructure investments scheduled and funded through 2010. Current 90%-reliable supply does not meet avarege demand.
Source: 2030 Water Resources Group (2009, p. 7) (based on the Global Water Supply and Demand model, IFPRI and FAOSTAT).

FIGURE 20.8

Rio Tinto's water balance (2009)



[1] Including onsite impounded/imported surface, onsite/imported ground water (including dewatering) and marine water
[2] Including process effluent, dewatering water discharged without use and non process water
[3] Including mining (dewatering), milling, washing, power generation, dust suppression etc.
[4] Tailings, sewage or water contaminated in process that has been treated for reuse
[5] The difference between total water input and total water output is 'changed-in storage'.

1 GL = 1 gigalitre of water (1 billion litres)
Source: Rio Tinto (n.d.a).

principal objectives. Similarly, closed-loop production system can offer industries another option for pollution prevention. Individual industries can obtain economic and environmental benefits from applying this principle in their operations; however it is best achieved through industrial eco-parks, where industries from very diverse sectors can make use of by-products, traditionally considered as waste, from other industries into their production process, thereby reducing costs in raw materials and/or reducing treatment and disposal cost (Figure 20.9).

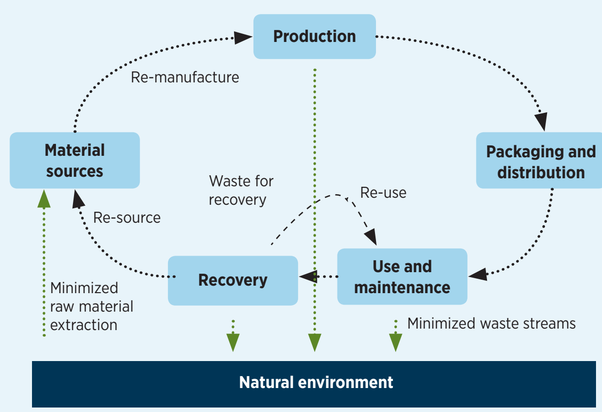
The challenges in water productivity are expressed on a geographical basis in the disparity between high and low income countries (WWAP, 2003, ch. 9). High income users have better water productivity than low income users, and while water productivity of low income users can equal that of high income users, it is generally only on a small scale. As low income countries tend to be in areas of water scarcity, and this scarcity has become more unpredictable with climate change, the challenge of water productivity correspondingly becomes even greater.

The cost of water

Industry is conditioned to pay little for water, but increasing scarcity will result in higher charges, to which will be added higher charges for treatment and discharge. Some countries have already implemented a different price structure for industry – paying more per unit than the public and paying increasing amounts per unit as more water is used. These impacts on industry will naturally force a response towards greater efficiency of water use, as the economic realities of the cost of water will increase production costs. These effects will have repercussions in the industrialization taking place in developing countries, where water is frequently at a premium, and they may influence the location of new plants.

FIGURE 20.9

The closed-loop production system



Source: OECD (2009, p. 10).

Small and medium-sized enterprises in low income countries

The economic importance of small and medium enterprises (SMEs) in low income countries is well known. However, the geographical location of the SMEs often causes additional stress on already stressed local supplies of water. The concepts of water productivity and cleaner production are either unknown or sidelined in the effort to make goods and provide jobs. However, the downside is that the markets for the SMEs' goods, which are often in high income countries, have requirements that the manufacture of goods they import be environmentally sustainable. This creates a situation where survival of these SMEs is dependent on the proper, productive and environmentally friendly use of water – a considerable challenge requiring the means and the know-how to move forwards.

20.4.2 Changing management paradigms

Notwithstanding the challenges presented by uncertain water issues, business and industry is still charged with making a profit and return on investment. Actions taken to meet this goal must be carried out in the context of corporate, social and environmental responsibility. The challenge is not to work in isolation from government, the public and other stakeholders, but to turn the situation into a win–win one. There are subchallenges such as obtaining financing, investing in new technology, and improving the reliability and consistency of the data upon which many decisions are made. There is a need to become risk smart not risk averse.

20.4.3 Minimizing environmental impacts

Industry has impacts on its primary supplies of water and their ecosystems and therefore it has a responsibility to mitigate these impacts for the benefit of all water users and the environment. These impacts can be at a water basin or transboundary scale. Industry creates hotspots (sources) that can impact aquifers and river pathways that can cross several countries and discharge through coastal areas into large marine ecosystems. As the drivers involved become more complex, inter-related and unpredictable, effects and consequent challenges may be magnified over these large areas.

20.5 Opportunities

There are ways to address the issues, risks and challenges of water productivity, but they require implementation. Information without action is not real progress. The overarching challenge for industry is to play its role in halting the unsustainable exploitation and contamination of freshwater resources worldwide (Box 20.1). In meeting this challenge there is an opportunity to increase productivity, efficiency and competitiveness in a sustainable way. This may be summed up as integrated water management (IWM), which takes into account company requirements and the needs and interests of stakeholders and the environment. Through an IWM approach an industry identifies and manages water-related risk and opportunities that affects them either directly or indirectly, this in turn allows them to respond in time to changing trends and have a better business performance in the long run (CBSR, 2010).

20.5.1 Management and strategy

In a broad perspective, the problems surrounding water productivity in industry and the related problems surrounding water globally are inter-related, not isolated, and as such need management, a strategy, planning and action that interconnect solutions for greater effectiveness. Overarching these considerations are the concepts, ideas and visions of new and different ways of considering water and its use that provide the necessary guidance down the chain of implementation. In meeting its challenges industry must first look to management priorities and style, company values and culture to encourage positive response from within its

BOX 20.1

Water stewardship at Molson Coors

In the beer brewing process, water usage is measured as the total volume of water used for each volume unit of beer produced. Molson Coors' water use ratio is about 4.55 hL/hL. Water is used in the brewing process (the quality of beer is directly tied to the quality of the water used to produce it); for cleaning brew kettles and fermenting and ageing tanks; in the packaging lines (for rinsing bottles and cans before packaging); and for cooling machinery. Also included in the equation is water used in buildings to support the needs of the workforce. The vast majority of cleaning and rinsing water is treated to meet or exceed regulated standards, and then discharged. A small percentage is lost to evaporation.

The industry has established a working group entitled the Beverage Industry Environmental Roundtable (BIER). Formed in August 2006, the objective of this group is to bring together leading global beverage companies to define a common framework for stewardship, drive continuous improvement in industry practices and performance, and inform public policy in the areas of water conservation and resource protection, energy efficiency and climate change mitigation.

Molson Coors scores water usage at each of its breweries to identify strategic ways in which it can use less water in production, thus reducing its impact on the environment and helping enhance water's sustainability. Molson Coors has set the global target to improve water efficiency year over year by 4% (2008–2012). Water data and overall environmental performance data are verified by an independent third party before publication.

In 2009, Molson Coors committed to conducting watershed assessments at each brewery locations. In the United Kingdom (UK) and Canada, it commissioned studies of water resources, water use and water disposal at each facility to be fed into its country strategies and global policy. The study in Canada covers the entire supply chain, including the overall impact Molson has or could have in the communities where it operates.

Source: Global Compact (n.d.).

own sphere. Proactive measures by industry will not only anticipate the future but help to shape it (Pacific Institute, 2007). Innovation, investment and collaboration are key elements; they require a strategic approach rather than the ad hoc solutions more commonly found.

Water footprint

In order to develop a truly successful water strategy industry must have the necessary data available; to be able to evaluate water risks, it is necessary to know the water use in an industry. The customary approach of mass water balance is only part of the picture; water footprints or profiles are increasingly being introduced to estimate an industry's real water use. Estimation of footprints or profiles may involve using a water diagnostic tool and water scenario planning supports (WWAP, 2009, ch. 2, referencing WBCSD, 2006).

The water footprint takes into account all the obvious water content in a product as well as the less obvious inputs and uses of water in production and consumption (virtual water). Complete water footprints can be quite complex; for example, the concept of a water footprint for business adds on the indirect water use in the producer's supply chain. Thus there is the operational water footprint and the supply chain water footprint. There are also considerations up and down the supply chain, such as the water involved in agricultural raw materials or end-use, if water is involved in utilizing the product (e.g. soap). Therefore, a water footprint reflects the true amount of water used, which may not be immediately apparent from looking at the end product. In addition, 'the ecological or social impact of a water footprint obviously depends not only on the volume of water use, but also on where and when the water is used' (Water Footprint Network, n.d.*a*). All this knowledge can direct strategy for water use to increase its productivity (output per drop) both on the supply and the demand sides (Box 20.2).

Risk assessment

In developing a water strategy a company needs to evaluate its exposure to water risks – including hydrological, economic, social and political factors in different geographical contexts – and plan for them in its decision-making.

Water strategies

Once the issues have been evaluated a company is in a realistic position to adopt a water policy, which is

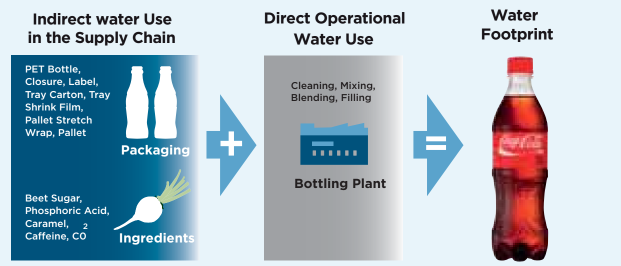
BOX 20.2

The water footprint of Coca-Cola®

Researchers at the Twente University in the Netherlands in collaboration with Coca-Cola Enterprises Inc. (CCE) and Coca-Cola Europe studied the water footprint of a 0.5 L PET bottle of Coca-Cola produced at CCE's Dongen bottling plant in the Netherlands.

The accounting process began with water used in the supply chain to produce ingredients and other components (e.g. bottles, labels, packing materials). Ingredients include sugar made from sugar beets grown in the Netherlands, carbon dioxide, caramel, phosphoric acid and caffeine. The supply chain water footprint also included overheads, which account for water used to produce the energy that powers the plants and for water used for building materials, vehicles, fuel, office paper and other items not directly related to operations. Water used in operations is the water incorporated into the product as an ingredient and water used in production processes.

FIGURE 1



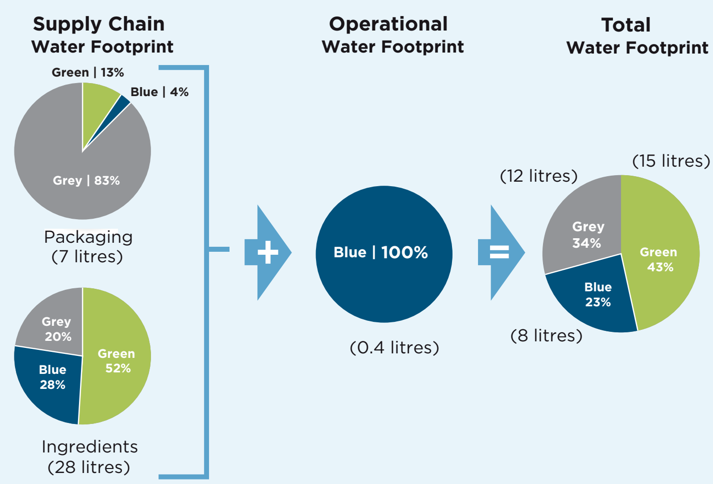
Indirect and direct water footprint components of 0.5 L of Coca-Cola in a PET bottle

The results, including all components, are shown in the second figure. The estimates are that the green water footprint of the 0.5 L Coca-Cola beverage is 15 L, the blue water footprint is 8 L and the grey water footprint is 12 L.

More than two-thirds of the total water footprint comes from green and blue water. The green and blue (consumptive) water footprints are primarily associated with sugar beet production in the supply chain. The sugar beets are largely rainfed (green water) in this water-rich temperate climate, but some external (blue) water supply is required for irrigation. Green water makes up approximately two-thirds of the consumptive water footprint and nearly half of the total water footprint. Blue water accounts for approximately one-quarter (or much less according to a subsequent study) of the total water footprint. Approximately one-third of the total water footprint is grey water, which is associated with the supply chain. A portion of the nitrogen applied as fertilizer to the sugar beet fields is released to receiving waters. Cooling water associated with PET bottle production results in a thermal load, which was considered in the grey water component.

The operational water footprint, 0.4 L, equates to only about 1% of the total water footprint. It is entirely blue water, representing water added as an ingredient. The grey water footprint associated with operations (water used for domestic purposes in the Dongen plant) was determined to be zero because all wastewater is treated to meet or exceed wastewater treatment standards in a public wastewater treatment plant and returned to the environment under The Coca-Cola Company's 'Recycle' commitment.

The supply chain overhead water footprint was calculated and found to be negligible. Before the study, there was recognition that the overhead component is a part of the overall water footprint of a product, but it was unclear how relevant it was.



Water footprint of 0.5 L of Coca-Cola in a PET bottle produced in Dongen, the Netherlands. The green water footprint refers to the consumption of green water resources (rainwater stored in the soil as moisture); the blue water footprint refers to consumption of blue water sources (surface and groundwater); and the grey water footprint refers to pollution and is defined as the volume of freshwater that is required to assimilate the load of pollutants based on existing ambient water quality standards.

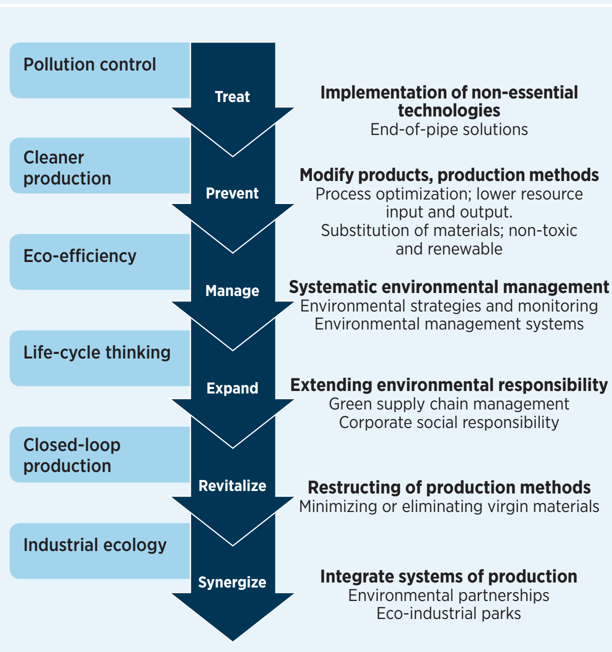
Source: The Coca-Cola Company and The Nature Conservancy (2010, pp. 11, 12 [figures, and pp. 11-15 text adapted]).

likely to embrace strategies for everything from corporate values to communication. These strategies may include:

- Promoting CSR and environmental sustainability (Figure 20.10). These principles include recognizing environmental inter-relationships such as those between water and energy and links to air emissions and climate change.
- Encouraging a paradigm shift to 'cradle-to-cradle' industrial operations – providing a service to customers to allow them to use a product and return it to the manufacturer for recycling (McDonough and Braungart, 2002; WWAP, 2006, ch. 8). Waste then has value as raw material for other production processes.
- Using the Precautionary Principle to promote action, develop options and assist decisions.
- Introducing EMS. The company culture should be such that it promotes the use of ISO 14000, best environmental practices (BEP) and best available techniques (BAT). Internal documents should reflect clarity and certainty in their application and they require regular updating with the latest science. A commitment to continuous improvement on water issues makes a strong statement, as does regularly reporting performance.
- Setting measurable goals and targets with respect to water efficiency, conservation and impacts.
- Decoupling material and energy consumption and integrating the need for energy with the requirements for water.
- Communicating frequently and effectively with the public and local stakeholders regarding the economic and environmental benefits of various industrial policies, strategies and measures to increase awareness, encourage confidence, and gain support and cooperation in issues surrounding water (Marsalek et al., 2002). Successful implementation of policies depends on a proactive, rather than a reactive, response from industry. Stakeholder engagement and direct participation can moderate conflicts.
- Collaborating with government agencies. In the attempt to implement better management and more productive ways of using water in industry, it is not the technical know-how that is the main impediment, but the framework within which to promote, encourage and accomplish increased water productivity. Alignment of corporate strategy with local, regional and national agencies is beneficial (Pacific Institute, 2007). If industrial growth and environmental protection are seen as compatible then industry may adopt such measures for better business rather than compliance reasons (WWAP, 2003, ch. 9). Beneficial actions may then be taken at a plant or company scale, with or without regulations (Box 20.3).
- Becoming involved with organizations such as the CEO Water Mandate (UN Global Compact, 2011) the World Business Council for Sustainable Development (WBCSD, 2006), and, through the United Nations Industrial Development Organization (UNIDO)'s role in the United Nations (UN) Global Compact Inter-Agency Team, to assist particularly in the area of Supply Chain and Watershed Management (UN Global Compact, 2011), which involves:
    - Encouraging and engaging suppliers to improve their water conservation, quality monitoring, wastewater treatment and recycling practices
    - Building capacities to analyse and respond to watershed risk
    - Encouraging and facilitating suppliers in conducting assessments of water usage and impacts
    - Sharing water sustainability practices – established and emerging – with suppliers

FIGURE 20.10

The evolution of sustainable manufacturing concepts and practices



Source: OECD (2009, p. 10).

BOX 20.3

Industry–government collaboration: Rio Tinto and the Western Australian Water Corporation

The Rio Tinto HIsmelt® site is just south of Perth in Western Australia. The new iron smelting technology is more efficient than conventional methods but requires cooling water. An agreement was made with the state water utility to use treated wastewater rather than obtain potable water from the city's system, which supplies water to 1.5 million people.

The Water Corporation was considering the feasibility of building an effluent treatment plant and Rio Tinto's offer to buy the treated water for the HIsmelt facility ensured enough demand to make this plant viable. As a result, the Water Corporation was able to commission the project.

The HIsmelt facility runs on the community's recycled wastewater, which is finally evaporated. The Water Corporation has a long-term client and Rio Tinto has access to a ready supply of water, cleaned and treated to a high industrial standard. Moreover, local water supply is preserved and there is reduced effluent discharge to the ocean.

Sources: Pacific Institute (2007, p. 35); Rio Tinto (n.d.b).

  - Encouraging major suppliers to report regularly on progress achieved related to goals
- Partnering with intergovernmental organizations such as the UN to benefit regions in distress and promote advances in technology.

20.5.2 Implementation and innovation

Industry has many opportunities to address the challenges it faces and turn them into win–win situations with other major stakeholders such as governments, intergovernmental organizations, non-governmental organizations (NGOs), the private investment sector, academia and the public. In this context, the following are some of the initiatives that industry has underway and should be reinforced and others that might be brought into play.

Decreasing water use and increasing water productivity

The obvious first step for industry is to reduce water use by conservation and recycling as well as by discharge reduction and quality improvement. Measures to these ends include:

- Conducting a water audit and developing a water footprint.
- Using zero discharge and water optimization techniques to drive industrial processes (Das, 2005). This involves integrating supply side and demand side needs and considerations. Zero discharge is used to nullify water footprints by full recycling and no waste and changes the balance of the water productivity equation (Water Footprint Network, n.d.*b*). In moving towards zero discharge, wastewater streams are converted into useful inputs for other industries and industrial clusters. Zero discharge is a step-by-step process that industry implements through strategic corporate planning leading to design and implementation. It not only influences industry on a local scale (cleaner production and increased profits), the accumulated results also have basin, transboundary and wider impacts.
- Employing water recycling and the use of reclaimed water where possible to dovetail with zero discharge.
- Using water loss management to locate, measure and repair the sometimes huge water losses from old underground infrastructure. This might include development of surface leak detection systems, robotic and video pipeline monitoring technologies, high-precision flow monitoring and metering technologies, and pipeline rehabilitation systems (TSG, 2009).
- Providing full and consistent monitoring and reporting of the performance of applied technologies used in industry, in terms of both effectiveness and cost. Real-time monitoring of processes has distinct advantages in catching problems and contamination early and accompanying data management systems are equally important (TSG, 2009).

Introducing new technology

BAT can incur significant cost and may take time, so transition periods are necessary and implementation by regulation needs a thoughtful approach. The objective is to find the most effective technology that is technically viable, can be implemented economically and is reasonably accessible. Meeting this objective may involve:

- Adopting new green technology and incorporating natural treatment systems. It is felt by some that simpler approaches, such as sand filtration and enhanced wetland treatment, may be easier and cheaper to implement than more common traditional treatment technologies and may play a significant role in helping solve the vast majority of the world's water shortages (TSG, 2009).

BOX 20.4

UNIDO MED-TEST integrated approach

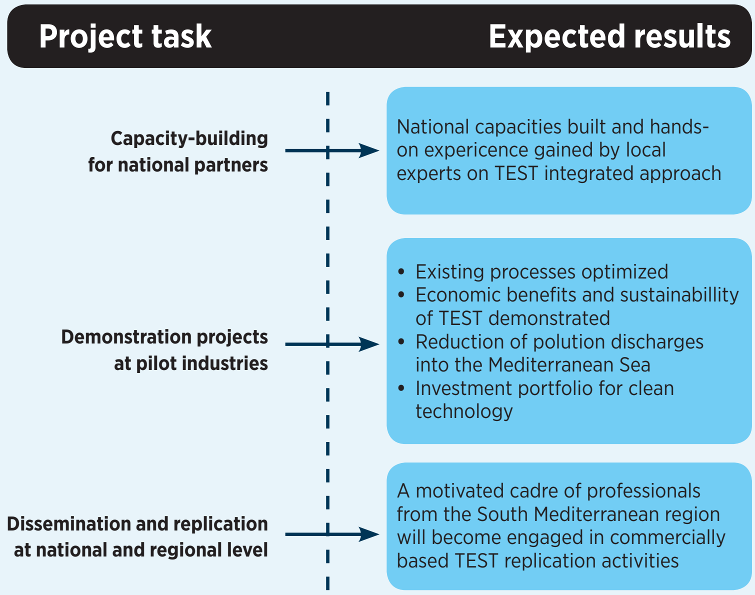
MED-TEST is a UNIDO green industry initiative supported by the Global Environment Facility (GEF) and the Italian Government to address priority hotspots of industrial pollution identified in the Mediterranean Strategic Action Plan (SAP-MED). MED-TEST is a component of the Strategic Partnership for the Mediterranean Large Marine Ecosystem (LME) of the United Nations Environment Programme (UNEP)-Mediterranean Action Plan (MAP) aiming to support governments in implementing national strategies for reducing industrial discharges. The MED-TEST project (2009–2011) targets Egypt, Morocco and Tunisia, with the potential to be extended to other countries of the MED region.

Enterprises of the South Mediterranean Region are facing numerous challenges in their effort to maintain or increase their competitiveness on the local market, access international markets with good quality products, comply with environmental standards and reduce their operational costs. The MED-TEST project has been designed to assist enterprises in dealing with these challenges and in building a long-term sustainable business strategy.

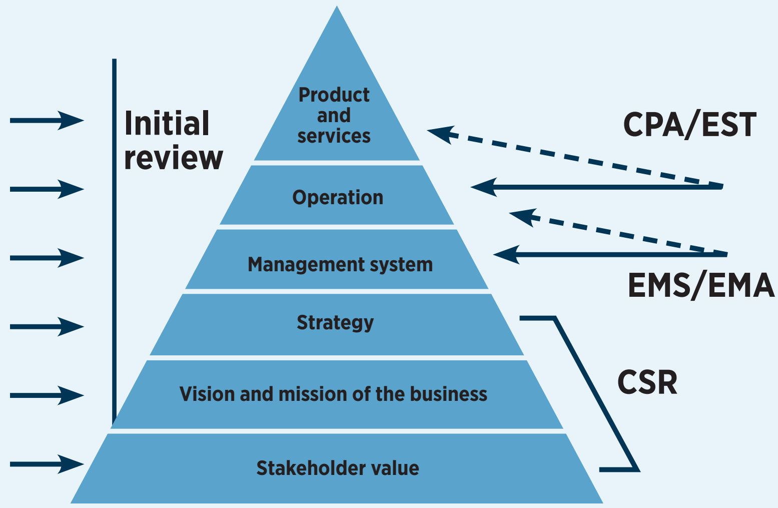
TEST (transfer of environmentally sound technology) builds on management of change within each level of the management pyramid: operational, management system and strategic. The TEST approach integrates and combines the essential elements of traditional tools such as cleaner production assessment (CPA), environmental management systems (EMS), environmental management accounting (EMA), technology transfer and corporate social responsibility (CSR), applied on the basis of a comprehensive diagnosis of enterprise needs (initial review).

The introduction of the TEST integrated approach at the enterprise level follows this sequence:

- The existing situation is improved by better management of existing processes
- The introduction of new cleaner technology (or if not sufficient, of optimized end-of-pipe solutions) is considered
- The lessons learned from each TEST project's implementation is reflected in the respective company's business strategy



Outline of the MED-TEST project



TEST tools and the management pyramid

Source: UNIDO (n.d.b).

- Continuing and expanding the use of the transfer of environmentally sound technology (TEST) methodology (UNIDO, n.d.*a*) in conjunction with environmental management accounting (EMA) (Box 20.4).
- Working with government and academia in joint research programs to develop new technology.

Employing eco-innovation

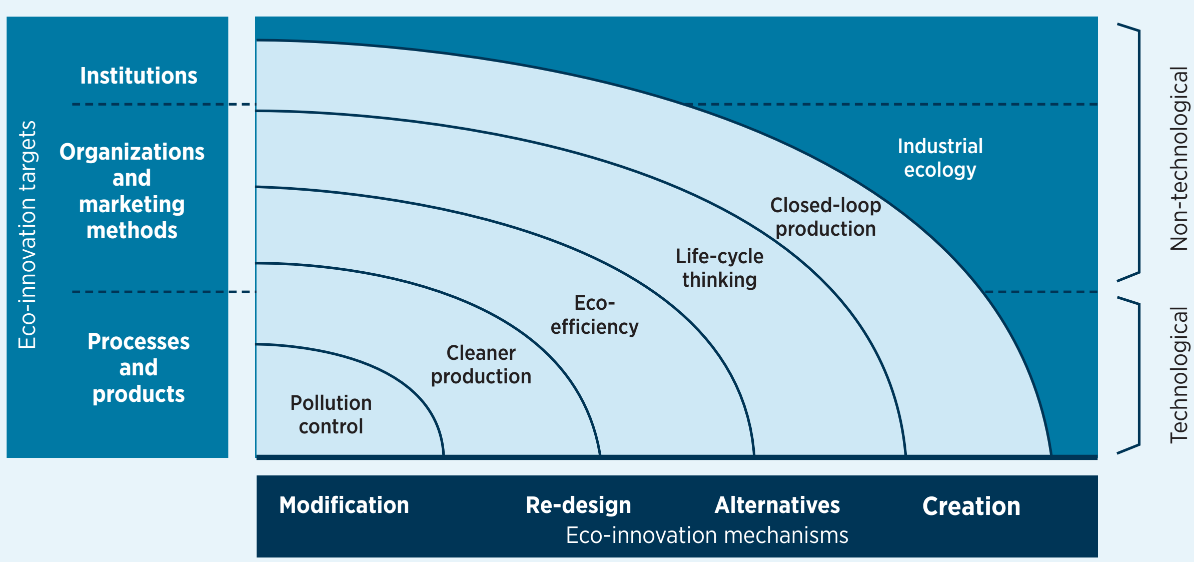
The development of industrial ecology as a part of sustainable development is a relatively recent concept used to look at the inter-relationship between industrial and economic systems and natural systems (Das, 2005). Industrial ecology connects with zero discharge in restructuring industry to eliminate waste as an alternative to end-of-pipe solutions (Figure 20.11).

Some points for industry include:

- Incorporate industrial ecology and design for environment (DFE) into industrial design and overall planning (Das, 2005).
- Relocate to eco-industrial parks. This mutual grouping of industries to reuse wastewater has many apparent advantages, but there are obstacles to be overcome, such as corporate reluctance to partner with unrelated industries and the fear of dependency on a single water supplier (Das, 2005). In older areas not amenable to such groupings, the transportation of wastewater may be a large problem. New industries with large water demands that do not require drinking water quality may need to locate near existing or new sewage treatment plants.
- Invest in environment and ecological restoration. Such programmes may include investment in upstream watershed restoration and in supply chain areas, which provides a win–win situation for business and communities and may have a more favourable cost–benefit than technological solutions (Pacific Institute, 2007).
- Adopt a life-cycle approach, whereby all stages of the products life is assessed, including raw material extraction, manufacture, distribution, use and disposal. This may be in the context of closed-loop systems. For example, the existing UNIDO programme for chemical leasing provides a big incentive to zero discharge (Chemical Leasing, n.d.*a*). It also improves the efficient use of chemicals and has economic and environmental benefits by closing the loop between the supplier and user of chemicals (Figure 20.12): the supplier sells the function of the chemicals and together with the user is involved in managing the life cycle of the material.

FIGURE 20.11

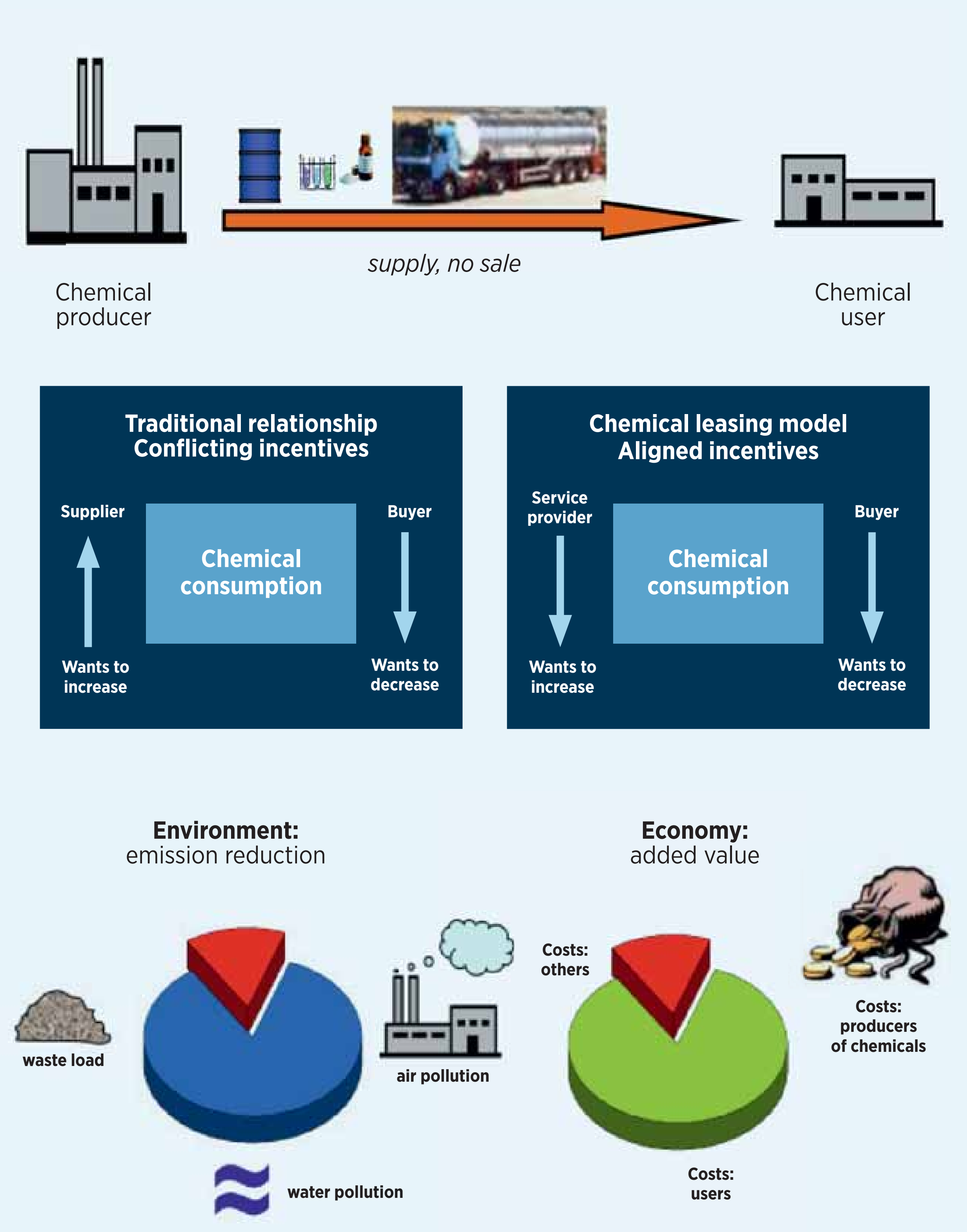
Conceptual relationships between sustainable manufacturing and eco-innovation



Source: OECD (2009, p. 15).

FIGURE 20.12

The concept of chemical leasing



Source: Chemical Leasing (n.d.b).

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CHAPTER 21
Ecosystems

UNEP

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Ecosystems can be managed so as to sustain water availability and its quality – services provided by ecosystems – and thereby help achieve water security. The continued availability of water (of sufficient quantity and quality) depends on the continued healthy functioning of the ecosystems that supply it, while the ecosystems themselves are dependent on receiving sufficient water. This can be summed up as 'nature for water security; water security for nature', a phrase that neatly encapsulates the linkages that decision-makers have to take into account.

Ecosystems provide a wide range of services (e.g. food and fibre, nutrient recycling, climate regulation, flood and drought regulation, and tourism and recreation), all of which are underpinned by water security. Water use by all is dependent on ecosystem functioning, as are the other natural resource-based goods and services that support human society. Maintaining the ability of ecosystems to support ecosystem services is therefore critical for socio-economic well-being and sustainable development.

Managing ecosystem services is about trade-offs. Trade-offs are not necessarily about choosing one benefit over another. They are as much about sustainable multiple benefits and balanced investments to achieve an optimal outcome.

Sustainable development, including water security, is dependent on maintaining ecosystem services. Ecosystem management is therefore key.

Many ecosystem services are not generally considered in economic planning but can generate very high economic values. They are often considered as being provided free of charge by nature, but in many cases this is incorrect because they can be expensive to rehabilitate or replace artificially when degraded or lost. They are also finite and can be over-used.

There is an urgent need to incorporate ecosystem-based thinking into water governance. Water allocation needs to be based on sustainable supply, which is determined primarily by ecosystem boundaries, and not on demand.

Sustaining and restoring ecosystems is an essential response to the increased risks and uncertainty posed by climate change.

Risks and uncertainties arising from natural disasters such as floods, landslides and droughts (including those triggered by extreme storms, earthquakes and tsunamis) can be reduced by maintaining or restoring natural infrastructure. The economic benefits of reducing this vulnerability are substantial through both reducing the frequency and severity of impacts and creating more stable conditions post impact.

As a consequence of escalating pressures, ecosystems and their services continue to be degraded and lost. This increases risk. Freshwater ecosystems are the most threatened of all. The ability of ecosystems to continue providing the water resources services that we depend on is being severely compromised, with already catastrophic effects for humanity.

Sustaining or restoring ecosystems to ensure continued availability of the ecosystem services on which we depend can be a cost-effective and more sustainable solution than traditional approaches to achieving water security. Natural infrastructure solutions should be part of all options considered, alongside physical infrastructure, and assessments should factor in the co-benefits on offer, which are often high with natural solutions.

The need is to make ecosystem-based approaches mainstream under an improved and more holistic policy and management framework that capitalizes on the benefits on offer to help us achieve more sustainable solutions.

21.1 The challenges

Ecosystems are at the heart of the global water cycle. All freshwater on earth is ultimately dependent on their continued healthy functioning. Ecosystems provide a spectrum of services that benefit human society in all regions of the world, including the essential regulation of water quantity, mitigation of extremes of flooding and drought, and preservation of water quality. Ecosystems also cycle the water on which they themselves depend, thereby underpinning all terrestrial ecosystem services, such as food production, climate regulation, carbon storage and nutrient recycling. This water cycle also significantly influences the functioning of estuaries and deltas, including the significant services they provide, such as regulating land formation, coastal protection and food from fisheries.

Ecosystem loss and degradation usually results in a reduction in the delivery of these water-related services. The services previously provided by nature often have to be substituted by engineered solutions (e.g. flood control structures or water treatment facilities), usually at great economic investment and operational cost and with low sustainability. Changes in land use can significantly alter the availability of water; for example, deforestation has an impact on surface water availability and quality. Likewise, land cover depends on continued water availability; for example, forests are dependent on groundwater. Maintaining the extent and healthy functioning of ecosystems should be an integral part of dealing with water security issues. Using natural infrastructure can offer more cost effective and sustainable solutions either instead of, or in parallel with, hard engineered approaches. The challenge is to integrate ecosystem-based thinking and management approaches and water and land use planning in all sectors.

Historically, ecosystems have been treated as unproductive users of water by some groups. At the other end of the spectrum, many groups have advocated attention to them based on biodiversity, protection and conservation arguments, often articulated abstractly with regard to pressing development issues. Fortunately, perceptions are shifting towards managing human interactions with ecosystems (the environment) to support water-related development goals.

The case for ecosystem-based solutions in water policy and land and water management is supported by considerable successful local practice. The challenge is to mainstream the approach as the provider of economically and environmentally sustainable water management solutions. As recognized by the Fifth World Water Forum (Istanbul, March 2009), there needs to be a paradigm shift from 'Water for Nature' to 'Nature for Water'. This requires that decision-makers:

- understand that the availability of appropriate quantities of water of sufficient quality is a service provided by ecosystems and therefore sustaining or restoring ecosystem infrastructure is a tool to achieve water security;
- are fully aware of the direct or indirect dependence of most, if not all, socio-economic sectors, on the maintenance of sustainable ecosystem services and the nature of those services;
- understand the factors that are putting ecosystem functioning at risk;
- value ecosystem services properly, including through calculation of the economic costs of replacing them with engineered solutions;
- implement transparent and impartial policy development and management that recognizes that ecosystems can promote cost-effective solutions with the added potential to deliver multiple benefits for sustainable development; and
- implement the changes necessary to put the solutions into practice.

21.2 The role of ecosystems in regulating water quantity and quality

A simplified introduction to water ecosystems was provided in the first edition of the *World Water Development Report* (WWAP, 2003), with a focus on wetlands and freshwater components of ecosystems such as streams, rivers, lakes and marshes. This introduction needs considerable expanding to include other ecosystem components such as forests, grasslands and soils that also play a significant role in the ecosystems.

Surface vegetation (land cover) regulates runoff of water as well as soil erosion at the land surface. Plant leaves influence how rainfall reaches the ground and their roots help infiltration of water into soils. This significantly reduces erosion, stabilizes slopes (reducing land-slides), potentially reduces flood risks, and sustains soil moisture and the recharge of groundwater. Plants also take up water from the soil and release it back into the atmosphere as water vapour (transpiration), which can have a significant influence on local, regional and even global rainfall patterns. The benefits of this process are most obvious in regions where extensive tracts of original forest cover remain, such as the Amazon and Congo basins. Removal of this vegetation can reduce local, regional and global rainfall. But the relationships are complex; for example, planting of non-native tree species with high water requirements, particularly in dry areas, can lead to groundwater depletion. Proposals for extensive changes in vegetation cover should always be subject to rigorous assessment of the impacts on water cycling.

Wetlands – such as swamps, marshes, peatlands and shallow lakes – play perhaps the most obvious role in the water cycle, as they by definition permanently or intermittently store water. For example, floodplain wetlands store floodwater and slow its flow, helping reduce flood risk downstream. Wetlands also regulate nutrients, sediments and other potential pollutants, acting as an effective natural water treatment infrastructure (Box 21.1).

Mountain ecosystems comprise a complex mosaic of snowfields, glaciers, bare rock, boulder fields, screes, streams, rivers, lakes, grasslands and forests, and are the source of many of the world's major river systems. The Himalayan massif alone supplies the Brahmaputra, Ganges, Indus, Mekong and Yangtze rivers, among other major river systems in Asia, providing water, year round, to approximately one billion people (Rao et al., 2008).

BOX 21.1

Wetlands as water treatment infrastructure: Kolkata, India

Kolkata city generates some 600 million L of sewage and wastewater every day. The manmade East Kolkata Wetlands was declared a Ramsar site in 2002 for its use of this 125 km^2 (12,500 ha) area for sewage treatment, fish farming (4,000 ha) and irrigated agriculture (6,000 ha). Waste is pumped into the fish ponds of the East Kolkata Wetlands where biodegradation has a cumulative efficiency in reducing biological oxygen demand of more than 80% and coliform bacteria reduction exceeds 99.99% on average. The wetlands also provide about one-third (11,000 metric tons) of the city's annual fish demand and water from them is used to supply rice paddies (yielding 15,000 metric tons of rice per annum) and supports vegetable production.

Source: Department of Environment, Government of West Bengal, India (2007).

21.2.1 Ecosystems as water infrastructure

The term 'ecosystem infrastructure' has been introduced to acknowledge that ecosystems can, and do, perform similar functions to conventional engineered water infrastructure. Ecosystem infrastructure is now commonly used to address water quality needs (Box 21.2). A functioning floodplain moderates peak flows by allowing the water to spread out over a wide area, at the same time enabling sediments to settle; removing floodplains requires their benefits to be replaced by engineered flood and sediment control measures. Investment in the maintenance of 'soft' ecosystem infrastructure needs to be seen as an equally valid option to investing in 'hard' engineered infrastructure. In many cases, the former will prove to be many times more cost effective than the latter, while also providing additional benefits such as support for fisheries, tourism and biodiversity. But the interactions between landform, land cover, climate and the water cycle are complex and location-specific, and solutions for a particular situation require targeted investigation (Emerton and Bos, 2004).

21.2.2 Water allocation and environmental flows

Ecosystems are themselves dependent on receiving sufficient water for their continued functioning. Key elements for water allocation to sustain that functioning include:

- Assessments based on the economic values of water-related ecosystem services and trade-offs between users
- Adequate knowledge of how local and regional ecosystems underpin water security including water quantity, quality and timing for both ecosystem and direct human needs
- A participatory, scale appropriate approach
- Building water governance capacity
- Allocation decisions to be based upon managing and protecting *supply*, rather than simply responding to *demand*

The quantity of water needed to maintain all of the water-dependent or water-related ecosystem services that are required in a given area is often referred to as the 'environmental flow' (Dyson et al., 2008). However, current approaches to environmental flow are too often restricted to considering surface-water flows, in particular, minimum flow requirements for rivers (Box 21.3). They also need to consider groundwater, soil moisture and evapo-transpiration components necessary to sustain the water cycle.

BOX 21.2

Ecosystem solutions for water quality risks

The use of natural infrastructure to protect water supplies, particularly drinking water for cities, is already widespread. For example, the Water Producer Programme, developed by the Brazilian National Water Agency, provides compensation to farmers to safeguard critical headwaters which supply water to nine million people in the São Paulo metropolitan region. Success has spawned similar approaches in other regions of Brazil (The Nature Conservancy, 2010*b*). Likewise, the páramo grassland of Chingaza National Park in the Colombian Andes plays a crucial role in maintaining water supplies for eight million people in the capital city, Bogotá. An innovative public–private partnership has set up an environmental trust fund through which payments from the water company are transferred for managing the páramo sustainably, potentially saving the water company around US$4 million per year (Forslund et al., 2009, p. 31).

BOX 21.3

Maintaining flows: The Mekong River Agreement

The Mekong River Agreement (1995) between Cambodia, Lao People's Democratic Republic, Thailand and Viet Nam provides a framework for cooperation oMaintaining flows: The Mekong River Agreement and specifically requires minimum stream flows which are to be 'of not less than the acceptable minimum monthly natural flow during each month of the dry season'. An Integrated Basin Flow Management programme has been undertaken by the Mekong River Commission Secretariat since 2004 to provide information to the riparian states regarding the predicted costs and benefits of land and water development. It also supports inter-government dialogue on the trade-offs that may be necessary between development, social and environmental impacts enabling agreement on a mutually acceptable framework for sustainable development and to promote reasonable and equitable transboundary sharing of beneficial uses.

Sources: Mekong River Commission (2010) and Srinetr (2009).

21.2.3 Economic valuation of ecosystem services

Assigning economic values to water-related and water-dependent ecosystem services is one of the most effective means of enabling investments and operational costs to be directly compared (Box 21.4). It also is important to shed light on the gender dimensions of development because reliance on different ecosystem services varies considerably between genders (and economic classes). (See Chapter 23 for a treatment of ecosystem services within a water valuation framework.)

The fact that water underpins *all* ecosystem services generates high values when the value of water is calculated in this fashion. But amongst the full suite of ecosystem services there are those that relate more obviously and directly to water as a resource (e.g. flood mitigation and water quality). Valuing ecosystem services is sometimes regarded as difficult; but for some, it is relatively simple. The costs of flood impacts, for example, and the investments in, and operational costs of, artificial flood-control structures are frequently well known and often reflect the value of flood-mitigation services that ecosystem infrastructure previously provided. Likewise, the loss of clean water as an ecosystem service is partly reflected in costs of artificial water treatment or the economic impacts of poor water quality.

Advances in the economic valuation of ecosystem services have been made over the past 20 years and a range of techniques can now be used in practice: these are summarized by Emerton and Bos (2004), Emerton (2005) and De Groot et al. (2006). TEEB (2009*a*) provides a comprehensive overview of the topic, including noting the reliance of the poor on these services directly. TEEB (2009*b*) concluded, *inter alia*, that there is a compelling cost–benefit case for public investment in ecological infrastructure (especially restoring and conserving forests, mangroves, river basins, wetlands, etc.), particularly because of its significant potential as a means of adaptation to climate change. Even for many terrestrial ecosystems (such as forests), values related to water services outstrip more conspicuous benefits (such as timber products and carbon storage). For example, TEEB (2009b) provides examples of the water-related services provided by forests, which account for more than 44% of the total value of the forests, and exceed the combined value of climate regulation as well as food, raw materials, and recreation and tourism services. The valuation of water-related ecosystem services remains an imprecise science, and although it can provide good comparative indicators of where priorities should lie and has led to some increased national focus on relevant issues, it generally remains poorly applied. However, most reports caution that many ecosystem values, especially those relating to local benefits, are context-specific, meaning they should not necessarily be transferred from one case to another.

With attention turning to climate change risks and vulnerabilities, a greater incentive is in place for valuation studies concerning water-related ecosystem services. High values are being derived. For example, Costanza et al. (2008) value the extreme weather mitigation services (not including other services) provided by one hectare of wetland in the United States of America (USA) at US$33,000 for a single storm event. In Mexico, the value of water associated with protected areas for all human consumptive uses is estimated at US$158 million annually, with water used directly for human consumption valued at US$15 million annually (The Nature Conservancy, 2010*a*). Globally, between 33% and 44% of cities obtain their water from forested protected areas. These examples demonstrate an underlying convergence of interests around ecosystems although progress remains constrained by considerable diversity in the terminology in use.

The business advantage of maintaining ecosystem services is being more widely recognized and beyond just the bounds of corporate social responsibility. For example, the multibillion dollar Scottish whisky industry works closely with the Scottish Environment Protection Agency to develop and implement best practice in managing the environment to sustain the water resources upon which the industry depends. This includes the conservation of fragile peatland ecosystems and active participation in river basin management planning.

BOX 21.4

Assessing ecosystem services in the Mississippi River Delta, USA

Ecosystems of the Mississippi River Delta provide US$12–47 billion in benefits to people every year in terms of hurricane and flood protection, water supply, water quality, recreation and fisheries. If this natural capital were treated as an economic asset, the delta's minimum asset value would be US$330 billion to US$1.3 trillion (at 2007 values). However, this natural capital is being squandered through human-caused ecosystem loss and degradation. Doing nothing to invest in natural infrastructure in the coming decades would cost an estimated US$41 billion per year through lost ecosystem services, whereas protection, rehabilitation and restoration of natural infrastructure would have an estimated net benefit of US$62 billion annually.

Source: Batker et al. (2010).

The World Business Council for Sustainable Development (WBCSD), working in conjunction with the World Resources Institute, has developed the Corporate Ecosystem Services Review, which helps companies identify and measure the risks and opportunities arising from their impact and dependence on ecosystem services (WBCSD, 2010*a*). The WBCSD has also developed a publicly available Global Water Tool, which helps companies and organizations map their water use and assess risks relative to their global operations and supply chains (WBCSD, 2010*b*). Building on both tools, the WBCSD has launched the Ecosystem Valuation Initiative, which is working to develop a Guide to Corporate Ecosystem Valuation that makes the case for ecosystem valuation as an integral part of business planning and corporate decision-making (WBCSD, 2010*c*). WBCSD's Vision 2050 explores potential pathways by which a global population of nine billion people could be living sustainably by 2050, with particular emphasis on the role of business in relation to drivers of change (WBCSD, 2010*d*).

21.2.4 Payment for ecosystem services

Making payments to land owners and users can be an important tool for incentivizing land and water management practices that maximize ecosystem services (payment for ecosystem services [PES]), benefiting downstream users, where there is a clear cause-and-effect link between upstream management practices and downstream benefits. Cost recovery is likely to be easiest when certain groups already pay the consequences of lost services so that financing can be transferred from those groups to people able to reinstate a service. The clearest examples of this are with water quality (Boxes 21.2 and 21.5) and flood mitigation (e.g. compensating farmers for increased flood risks in farmland to reduce flood risk for people living in cities). PES schemes are most likely to succeed when:

- demand for ecosystem services is clear and financially valuable to one or more players;
- supply is threatened;
- specific resource management actions have the potential to address supply constraints;
- effective brokers or intermediaries exist;
- contract laws not only exist but are enforced, and resource tenure is clear; and
- clear criteria for evaluating equitable outcomes across partners are established, perhaps involving the participation of independent assessors.

BOX 21.5

Vittel, France

Nestlé S.A. produces one billion bottles of Vittel®-branded mineral water every year at Vittel in north-east France. To reduce contamination risk as far as possible, Nestlé has established a payment for ecosystem services (PES) scheme whereby farms within the protection zone for the Vittel aquifer are provided with incentives to adopt farming practices that contribute to nitrate reduction (e.g. conversion of arable land to pasture). By 2004, all farms in the area had joined the scheme. An independent study concluded that the scheme was a cost-effective means for Nestlé to virtually eliminate a significant risk to its business, while farmers were able to enter into 30-year payment agreements, benefit from debt cancellation and acquire additional land.

Source: Perrot-Maître (2006).

Further information on PES is provided by, for example, Forest Trends, The Katoomba Group, and UNEP (2008); Emerton (2005); Emerton and Bos (2004); and Smith et al. (2006).

21.3 Ecosystem status and trends

The overall negative global trend in the status of ecosystems presented in the second and third editions of the *World Water Development Report* (WWAP, 2006, 2009) as well as in the fourth *Global Environment Outlook* (UNEP, 2007) and third *Global Biodiversity Outlook* (CBD, 2010*a*) continues. This is also reflected in regional assessments (such as UNEP, 2008).

The Millennium Ecosystem Assessment (MA) conducted from 2000 to 2005 remains the most comprehensive overall assessment available to date. An overall synthesis report, a corresponding synthesis for wetlands and water (as well as for other specific sectors) and detailed technical reports from which these syntheses were compiled are available on the MA website (http://www.millenniumassessment.org/en/index.aspx). Referring specifically to wetlands and water, the MA found that (MA, 2005):

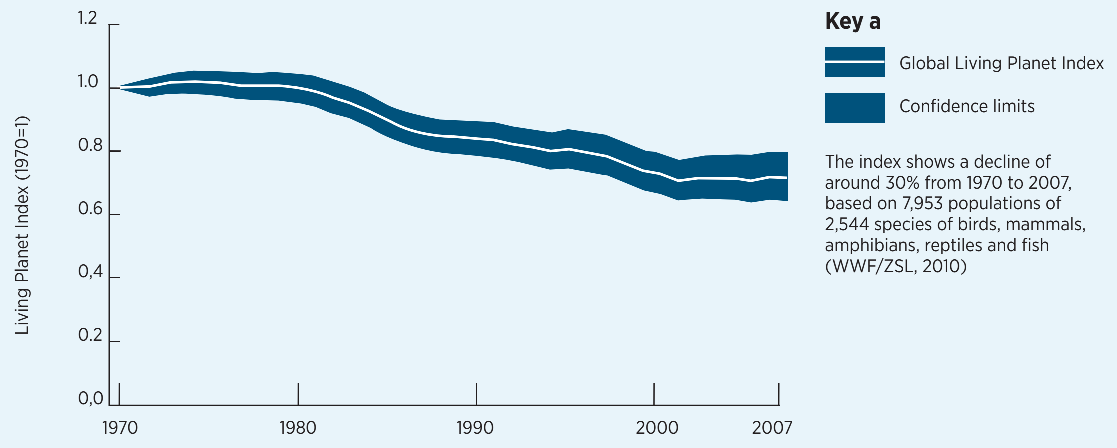
- Water scarcity and inadequate access to water are key factors limiting economic development in many countries. However, many water-resource development schemes have not given adequate consideration to the trade-offs with other valuable services provided by wetlands.
- Cross-sector, ecosystem-based approaches to natural resource management that consider the trade-offs between different ecosystem services are more likely to deliver sustainable development.
- Particularly important trade-offs are those between agricultural production and water quality and quantity, and between water use and biodiversity.

The third *Global Biodiversity Outlook* (CBD, 2010*a*) provides stark evidence that the loss and degradation of freshwater ecosystems remains the fastest of all the major biomes. This overall decay cannot be stemmed simply through declaring protected areas because of the interconnected nature of these ecosystems and in particular basin-scale interactions between land and water. For example, data from the Ramsar Convention on Wetlands national reports show that while wetland protected area is increasing, most wetland sites are degrading (CBD, 2010*b*). A review of the Convention on Biological Diversity (CBD's) work in this area (CBD, 2010*b*) concluded that the drivers of biodiversity loss remain unchanged and are all escalating and include conversion of habitat, fragmentation, the impacts of water use (particularly by agriculture), land use and other impacts on water quality and invasive alien species; excessive nutrient loading has emerged as an important direct driver of ecosystem change in inland (and coastal) waters and pollution of groundwater remains a major concern; the surface and groundwater portions of the water cycle have been subjected to massive changes by direct human use on local, regional and continental scales; and the global limit of ecological sustainability of water available for abstraction has been reached and regionally, this limit has already been exceeded for about one-third of the human population and it will rise to about half by 2030.

The Living Planet Index (LPI) measures trends in populations of more than 1,000 vertebrate species – fish, amphibians, reptiles, birds, mammals – from all around the world, providing a useful proxy for assessing ecosystem health (WWF, 2008). Taking into account different biomes, freshwater biomes continued to show a faster overall (global) rate of LPI decline than marine and fully terrestrial biomes, with a particularly rapid decline in tropical regions. Population trends in temperate (largely the developed) regions remain stable or are possibly improving, but in tropical (largely developing) regions they continue to decline (Figure 21.1). This trend is mirrored specifically for the data for freshwater dependent populations but

FIGURE 21.1

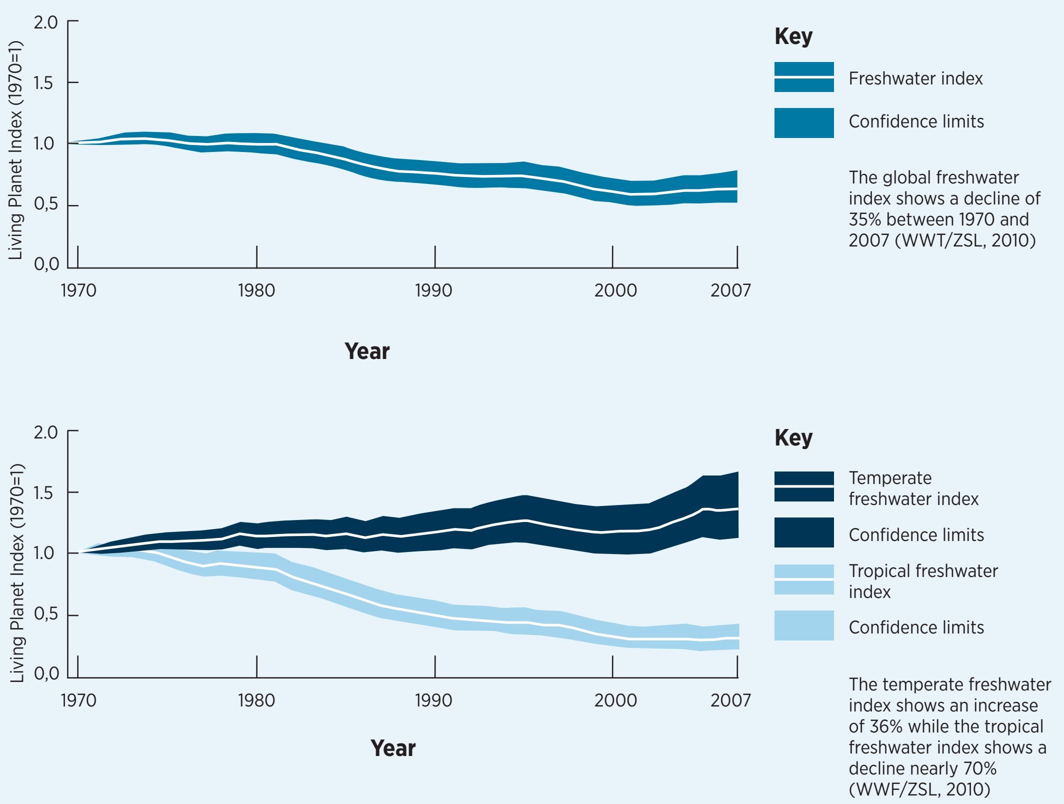
The Global Living Planet Index, all biomes (1970–2007)



Source: WWF (2010).

FIGURE 21.2

The Freshwater Living Planet Index (1970–2007)



Source: WWF (2010, p. 26).

these show more rapid decline (Figure 21.2). This is explained by biodiversity being higher in developing regions and this being where the many pressures and impacts are being felt most acutely. However, many of the drivers of ecosystem degradation in developing regions, and emerging economies, are determined – at least in part – by consumption in developed countries. While the local footprint of developed nations may appear to be stabilizing (or improving, as per Figures 21.1 and 21.2), much of their environmental footprint is now effectively being exported to the developing world and this is reflected in particular through deteriorating freshwater ecosystem conditions. The 2010 *Living Planet Report* (WWF, 2010) shows a continuation of the downward trend in the global LPI and the disproportionately adverse status of freshwater ecosystems.

21.4 Risks, vulnerabilities and uncertainties affecting ecosystems and water security

Ecosystems – and their contribution to water security – are subject to many risks, vulnerabilities and uncertainties from both natural (e.g. climate variability) and increasingly from escalating human-caused pressures at various scales, from local watershed degradation to global climate change. Ecosystems have evolved to be resilient to the impacts of extreme natural events such as floods, droughts, hurricanes, earthquakes, volcanic eruptions and tsunamis and to some extent can cope with human-induced degradation. But many consequences of ecosystem decay and catastrophic disasters are triggered or made worse through their mismanagement, leading to a reduction in their capacity to sustain the benefits humans need them to supply.

21.4.1 Principal pressures on ecosystems

The second and third editions of the *World Water Development Report* (WWAP, 2006, 2009) reviewed the principal pressures and impacts on ecosystems, focusing largely on freshwater components. These were summarized under the following headings:

- Habitat alteration (e.g. by drainage and conversion of wetlands)
- Fragmentation and flow regulation (e.g. by dams and reservoirs)
- Pollution
- Invasive species
- Climate change

Taking a wider view of ecosystem types that play a key role in achieving water security (e.g. forests, grasslands and coastal wetlands), a slightly modified approach is (a) to consider the impacts on water-related ecosystem services of three broad categories of change (ecosystem conversion, ecosystem fragmentation and ecosystem degradation) and (b) to examine the underlying indirect drivers of these changes, such as population growth, economic development and changing consumption patterns.

> **BOX 21.6**
>
> **Net benefits of ecosystem conversion**
>
> The Millennium Ecosystem Assessment (MA, 2005) found that the net present value of intensive farmland occupying the site of a converted wetland in Canada was less than half the value of the unconverted wetland, while an intensive shrimp pond in Thailand represented less than one-quarter of the value of an unconverted mangrove.

Ecosystem conversion

Ecosystem conversion (e.g. draining a wetland to grow a single crop) usually results in simplification of service provision and often increasing one service (e.g. food) at the expense of others (e.g. nutrient cycling and water regulation). In effect, this is trading other benefits for food production, but usually net ecosystem benefits decline (Box 21.6). There will also be parallel increases in other drivers of ecosystem change through, for example, significant decrease in water quality and quantity due to runoff of fertilizers and pesticides, abstraction of water for irrigation, and interruption or escalation of sedimentation processes.

Ecosystem fragmentation

Ecosystem fragmentation results in reduced connectivity between once contiguous tracts of a given ecosystem. Rivers are the classic example whereby ecologically disconnected sections are created by the construction of dams or floodplain drainage (Box 21.7). Similarly, blocks of forest may be clear-felled and converted to other uses, leaving disconnected fragments of the original forest. New transport corridors and urban expansion are additional common causes of ecosystem fragmentation. The remaining components will be smaller in extent, less complex in structure, and less diverse and consequently less resilient to external pressures. They will deliver fewer ecosystem services less effectively (e.g. lower capacity to regulate surface-water flow and sediment transport).

Ecosystem degradation

Ecosystem degradation occurs when the ecological functioning of an ecosystem – and therefore its capacity to deliver ecosystem services – is reduced, even if its type and extent are maintained. Diffuse or point-source pollution is one of the most serious forms of ecosystem degradation affecting water security (Box 21.8).

21.4.2 Non-linear ecosystem change: The 'tipping point' concept

The Economics of Ecosystems and Biodiversity (TEEB, 2009) underlines that ecosystem loss and degradation do not always result in an immediately detectable or proportional response in terms of lost ecosystem services. Instead, a 'tipping point' may be reached, where rapid and catastrophic collapse occurs following a period of apparent stability. CBD (2010*a*, p. 6) concludes that 'there is a high risk of dramatic biodiversity loss and accompanying degradation of a broad range of ecosystem services if ecosystems are pushed beyond certain thresholds or tipping points. The poor would face the earliest and most severe impacts of such changes, but ultimately all societies and communities would suffer.' A growing concern, increasingly backed by scientific evidence, relates to tipping points in forest ecosystems and their ability to support the water cycle (Box 21.9).

21.4.3 Climate change

Climate change threatens water security in many regions of the world by triggering, accelerating or intensifying (or all three) changes to the water cycle. These changes are occurring, and will continue to occur, primarily at the ecosystem level. In turn they will alter the availability (both quantity and quality) of water for ecosystems, thereby adding additional stress to ecosystem services to that resulting from other human-caused pressures on ecosystems.

BOX 21.7

Fragmentation of the Danube River basin, Central Europe

Along the Danube River more than 80% of the main river channel has been regulated by dams, while only one-fifth of the original floodplain remains functional, with significant impacts on the capacity of the river basin to deliver ecosystem services.

Source: ICDPR (2010).

The Intergovernmental Panel on Climate Change (IPCC) Fourth Assessment Report (IPCC, 2007) lists 32 examples of major projected impacts of climate change across eight regions (covering the whole earth). Twenty-five of these include primary links to hydrological changes. Of the other seven, water is implicated in four and two are general. Only one (coral bleaching) refers to major impacts not obviously linked to the hydrological cycle (being caused by the acidification effects of carbon dioxide). Notably, most of the impacts on terrestrial vegetation (and therefore also on fauna) are driven largely by hydrological shifts (changes in humidity, permafrost, snow and ice cover, rainfall patterns and groundwater).

The IPPC technical paper *Climate Change and Water* (IPCC, 2008) states that major changes in water brought about by climate change include:

- Changing precipitation patterns, intensity and extremes
- Reduced snow cover and widespread melting of ice
- Changes in soil moisture and runoff

The report (pp. 7–8) also concludes unambiguously that 'the relationship between climate change and freshwater resources is of primary concern and interest', that so far 'water resource issues have not been adequately addressed in climate change analyses and

BOX 21.8

Groundwater nitrate contamination in the United Kingdom

In common with many parts of Europe, intensification of UK agriculture and the over-application of nitrate fertilizers during the twentieth century led in particular to the degradation of groundwater in areas with thin or free-draining soils (or both) from which nitrates were leached rapidly by rainfall. More than 60% of nitrate pollution in the UK is attributable to agriculture. In conformity with European Union (EU) and national legislation, the UK government has designated nitrate vulnerable zones within which the application of nitrate-based fertilizers is restricted, with the aim of ensuring that groundwater nitrate levels do not exceed the permitted drinking water limits. Nevertheless, drinking water still needs to be subject to a range of expensive compensatory measures, including the mixing of groundwater from different sources (to ensure sufficient dilution of nitrates from contaminated areas) and denitrification.

Sources: Defra (2010); Tompkins (2003).

climate policy formulations' and, according to many experts, that 'water and its availability and quality will be the main pressures, and issues, on societies and the environment under climate change'.

The IPCC (p. 4) also observes that the area of land classified as very dry has already more than doubled since the 1970s and that 'many semi-arid and arid areas (e.g. the Mediterranean Basin, western USA, southern Africa and north-eastern Brazil) are particularly exposed to the impacts of climate change and are projected to suffer a decrease of water resources due to climate change'.

Global climate change compounds the vulnerability of all ecosystems, but is perhaps more noticeable, or critical, for those where water is a key variable, such as wetlands, deserts and forests, as well as those that are already suffering from the adverse impacts of conversion, fragmentation and degradation. For example, a wetland in a semi-arid region that is already stressed due to over-abstraction of water may be lost altogether if there is a regional decrease in precipitation as a consequence of climate change.

Adaptation responses to climate change can be maximized by ensuring that ecosystems are as intact and healthy as possible. For example, protecting coastal ecosystems may help prevent incursion of seawater into freshwater systems during storm events, which are predicted to become more frequent in some parts of the world. MA (2005) concluded that the adverse effects of climate change, such as sea level rise, coral bleaching, and changes in hydrology and in the temperature of water bodies, will lead to a reduction in the services provided by wetlands. Because of their intimate and direct role in hydrology, removing the existing pressures on wetlands and improving their resiliency is one of the most effective methods of coping with the adverse effects of climate change.

BOX 21.9

Ecosystems on the edge: the Amazon basin forests and water

Deforestation in the Amazon basin is leading to a decrease in regional rainfall because of the loss of cloud-forming evapo-transpiration from the forest. As the climate becomes drier it is less able to support rainforest vegetation. At the same time, the loss of forest cover removes the continuous supply of decaying vegetation that generates the nutrients on which the forests depend. These feedback loops mean that apparently moderate deforestation of the Amazon basin, of the order of 20% by surface area, could nevertheless reach a 'tipping point', beyond which forest ecosystems collapse across the entire Amazon basin, with devastating impacts on water security and other ecosystem services. Such impacts may have far-reaching – beyond the Amazon basin itself – effects (e.g. on regional agriculture and global carbon storage). Worryingly, deforestation is already at 18%.

Source: World Bank (2010).

21.5 Ecosystem-based approaches to the management of water

The second edition of the *World Water Development Report* (WWAP, 2006) introduced the concept of ecosystem-based management (EBM), which essentially requires those making decisions about the allocation and management of water to think more holistically by including ecosystem considerations as part of water management. EBM investments and interventions are directed at sustaining or enhancing the ecosystem component of the water cycle through the use of ecosystem (natural) infrastructure.

As explained above, the ecosystem is the ultimate source of all water. Both direct human use of water and the impacts of climate change essentially involve impacts which are delivered, either directly or indirectly, through ecosystem change. The relationship between ecosystems and water implies that they are impacted by water use (and climate change). This is something that has always been known, if often articulated in different ways such as 'environmental impact', and it frames the relationship negatively (although this remains an important topic) and reinforces debate over 'development' versus 'environment'. More important, in terms of policy influence, the ecosystem–water relationship means that ecosystems can be proactively managed in ways that help humans achieve water-related development objectives. This places ecosystems as solutions (not problems) and is essentially a cornerstone of EBM.

The Ecosystem-Based Management Tools Network (2010) proposes that EBM is a process which:

- Integrates ecological, social and economic goals and recognizes humans as key components of the ecosystem
- Considers ecological – not only political and administrative – boundaries

- Addresses the complexity of natural processes and social systems and resulting uncertainties using adaptive management
- Engages multiple stakeholders in a collaborative process to define problems and find solutions
- Incorporates understanding of ecosystem processes and how ecosystems respond to environmental changes, whether natural or caused or influenced by humans
- Is concerned with the ecological integrity of ecosystems and sustainability of human uses of ecosystems and ecosystem services

When applied to water, EBM can deliver win–win solutions that contribute to poverty alleviation and economic development. They are often more cost effective than conventional engineering-based solutions, but not always so. Approaches should consider EBM solutions alongside other options (e.g. hard engineering) and proceed on the most holistic and best evidence base as possible, factoring in relevant uncertainties and risks. Assessments of all optional approaches should include benefits in terms of resilience/sustainability (risk reduction) and the co-benefits on offer, which for EBM can be considerable.

21.5.1 The role of ecosystems in enhancing water security

EBM can deliver specific and immediate water-related benefits cost effectively. Sustaining or restoring ecosystems usually also increases resilience to change, thereby mitigating present and future risks and enhancing sustainable water security. EBM approaches also apply across scales, from local interventions (e.g. wetland restoration to address localized flooding) to basin scale and beyond, and can address single or multiple water-related needs. Key areas in which EBM already has a proven track record include water quality (Box 21.2) and regulating the extremes of water, in particular flooding (Box 21.10). At all but the smallest scales, EBM is usually multifunctional and rarely a stand-alone approach but rather integrated into catchment level management and included for addressing water stress under drought conditions (Box 21.11).

21.5.2 Ecosystems and integrated water resources management

As discussed in the third edition of the *World Water Development Report,* integrated water resources management (IWRM) (considered here as homologous with integrated river basin management, IRBM) is potentially one of the most useful water resource management tools at various scales. In principle, IWRM involves an integrated approach to land and water management which should recognize that, from an ecosystems functioning viewpoint, any distinction between the two is entirely artificial. In practice, many applications of IWRM do not fully incorporate ecosystem-level approaches. IWRM is often focused on visible (surface) water management and even where groundwater is included (which is becoming more often the case), soil moisture is often absent. In particular, IWRM rarely incorporates the management of evapo-transpiration (e.g. the impacts of land cover change). The management of wetlands, as drivers of local and often basin-scale hydrology, is likewise included irregularly. IWRM can indeed be complicated and its application is evolving based on learning by doing. But because of the intimate relationship between ecosystems and water, IWRM will not be truly integrated, or fully effective, until applied at the ecosystem scale.

Rigorous ecosystem-based thinking in IWRM requires:
- Identifying how relevant ecosystems, or their components that maintain water quantity and quality in a given area and all the ecosystem services they provide (bearing in mind they all depend on water) – including the role of terrestrial systems, especially vegetation and soil functions – support water security

BOX 21.10

Wetland restoration as a sustainable option to address increasing flood risk: The Wash, United Kingdom

Due to the combined factors of rising sea level and land subsidence the artificial flood-protection embankment adjoining part of The Wash, an extensive estuary in eastern England, was coming under increasing pressure from wave attack during high tide. It was estimated that potential breach of the current defences would result in flood damage approaching £20 million. The cost of repairing and maintaining the embankment over a period of 50 years was estimated at £2.06 million, whereas ‘managed realignment’ (moving the flood bank landward and enabling the development of intertidal marshes and mudflats seaward of the realigned bank) was costed at £1.98 million, affording flood protection over a considerably longer period of time and creating significant benefits for nature conservation and recreation. An additional £150,000 was added to the local economy in the first year following restoration through increased recreational use of the area.

Source: Friess et al. (2008).

BOX 21.11

Ecosystem-based management integrated into the management of the Komadugu Yobe basin, Nigeria

The Komadugu Yobe River ecosystem, supplied by a subcatchment of the vast Lake Chad basin, is part of the natural infrastructure of northern Nigeria. In the semi-arid Sahel, rainfall variability is high and severe drought a frequent hazard. The great majority of the basin's human population – which has doubled in the past three decades to more than 23 million – live in poverty. Over the same time period, flow in the river fell by 35% due to construction of two dams since the 1970s, abstraction of water for large-scale irrigation and regional reduction in rainfall.

A society already in social and economic crisis was thus confronted with ever-increasing pressure on vital water resources. The river's natural cycle of seasonal flooding and drying had been replaced by perennial low flows, causing loss of benefits (ecosystem services) that communities had historically relied on. Livelihoods dependent on fishing, farming and herding were devastated. Fish habitats were silted up, the loss of seasonal floods meant that cropland remained dry, and scarcity of water led to conflict. With growing impacts from climate change, the adaptive capacity of the Komadugu Yobe ecosystem and the communities it supports became even more fragile, just when resilience was needed most. The situation was not untypical of many river basins in Africa and elsewhere and its history typified by sector based approaches to water, lack of valuation of the full suite of benefits (services) available to be managed and the absence of any ecosystem level thinking.

However, crisis stimulated change. Restoration of the river basin's natural infrastructure, alongside existing built infrastructure, has strengthened adaptive capacity and resilience to climate change. Beginning in 2006, the federal and state governments and other stakeholders, including dam operators and farming, fishing and herding communities, came together to negotiate a plan for coordinating and investing in restoration and management of the basin. In addition to agreeing on a Catchment Management Plan, they drafted a Water Charter, spelling out the agreed principles for sustainable development of the basin and the roles and responsibilities of each stakeholder. Reform of water governance is enabling transparent co-ordination of water resource development, including remediation of degraded ecosystems and, eventually, restoration of the river's flow regime. Dialogue has reduced the number of cases of conflict to just a handful per year, and governments have pledged millions of dollars in new investment for basin restoration. This progress offers, for once, a potentially more sustainable future. Ecosystem-based management (EBM) was not a separate approach but integrated, or rather a framework for, more holistic and inclusive planning and management. Importantly, EBM delivered more sustainable water solutions and the ecosystem was not regarded as a 'user' (competing with other uses) but its management a means to deliver greater overall benefits from water.

Source: Smith and Barchiesi (2009).

- Identifying factors, including risks, vulnerabilities and uncertainties, that affect the functioning of those ecosystems and therefore services and how this impacts water security
- Taking measures to (a) manage the ecosystem so that it continues to deliver, or increases delivery, of all the benefits that are required and (b) minimizes risks, vulnerabilities and uncertainties so as to try to safeguard, as far as possible, overall ecosystem integrity and resilience (even beyond a narrow 'water' focus)

Tools for implementation can include, for example, removal of perverse incentives, including laws, regulations and financial mechanisms, that favour ecosystem degradation (such as grants for wetland drainage or conversion); payment for ecosystem services (PES); and investment in ecosystem restoration and rehabilitation (where justified through thorough and impartial analysis).

Further guidance on IWRM in practice has been provided by a number of initiatives; for example, the Global Water Partnership Toolbox (2008). The *Ramsar Wise Use Handbooks* (fourth edition: The Ramsar Convention on Wetlands, 2011) provide comprehensive guidance on integrating wetlands into IWRM – especially *River Basin Management* (Handbook 9), *Water Allocation and Management* (Handbook 10), and *Managing Groundwater* (Handbook 11).

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CHAPTER 22

Allocating water

UNESCO-IHP and UNESCO-IHE

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Water allocations in a majority of river systems and aquifers have already exceeded or are fast approaching water availability limits. Water diversions have to be reduced, and water re-allocated within sectors.

Water entitlements, water allocation, water distribution and water use are dynamically linked. With an increasingly variable hydrological cycle and rapid socio-economic development, there is a need for adaptive allocation mechanisms that deal with this as well as with the accompanying uncertainties.

In regions where there are large discrepancies between where the water is and where it is needed, the construction of large inter-basin transfer projects is likely to continue – despite the recognized advantages of moving the products of water rather than the water itself. Increased rainfall variability and greater pollution loads can have disastrous consequences. New reservoirs that are built to deal with increased variability in river flow may often negatively affect water quality and aquatic ecosystems, which give rise to serious governance issues.

In many cases, water re-allocation has been focusing on agriculture-to-urban water transfers where farmers are compensated by urban users for increasing the availability of water through temporary or permanent transfers. The rationale for such water transfers is often economic.

As concern over the environment grows, some water managers are investigating innovative ways of enhancing environmental water transfers by changing the operating rules of dams to improve the seasonality and availability of water for ecosystems.

Water banks have been created to improve the reliability of water markets. A public intermediary buys water from the willing sellers and sells it to buyers. Water trading markets can make more water available for high-value uses.

When making water allocation decisions, the international community is increasingly recognizing that access to water is a human right.

Water managers can benefit from the experience of other sectors that deal with the allocation of scarce resources. They can see how these sectors deal with uncertainty and risk management.

Water allocation policies need to recognize and correct racial and gender inequities in water use by addressing the expectations of all stakeholders in an equitable and transparent manner.

Building a shared vision and trusted knowledge base is crucial for individual water users to make responsible decisions when promoting integrated water resources management at the river basin level.

22.1 Allocating water

22.1.1 Introduction

A water allocation system has four main aspects, of which water allocation is one:

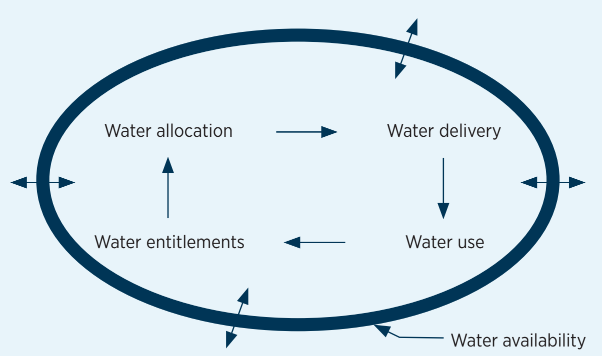
- *Water entitlements,* whether they are formal or informal, confer on the holder the right to draw water from a particular source (Le Quesne et al., 2007). The important point here is that the entitlement is considered legitimate by others.
- *Water allocation* describes the process of sharing the available water between legitimate claimants and distributing it to them (after Le Quesne et al., 2007).
- *Water delivery* (or *control*) is the physical act of supplying water to those who are entitled to it, in such a manner that they can use it.
- *Water use* is any deliberate application of water for a specified purpose (Perry, 2007).

Water entitlements, water allocation, water delivery and water use are dynamically linked, and are constrained by the amount of water that is available at a specific time. Using water creates expectations of similar use in future. If such use is continued over time, an entitlement emerges which may be difficult to ignore or claim back, yet the amount of water available is prone to natural and man-made fluctuations and changes (Figure 22.1).

These four linked aspects can be characterized by looking at the time scale over which they operate. Water entitlements can endure for many years, while water allocation activities typically adopt a time horizon of one hydrological year, often trying to resolve issues of water scarcity by re-allocating water between sectors and between and within seasons. Water distribution and delivery are often based on weeks, days and hours, and water use is an instantaneous activity. As the hydrological cycle becomes increasingly variable, and as socio-economic development continues to change rapidly, it is important to establish what kind of allocation mechanisms can deal with change effectively and flexibly.

FIGURE 22.1

Water entitlements, water allocation, water distribution and water use are dynamically linked, and take place within the boundary of (changing) water availability



This challenge area chapter reviews water allocation issues and refers to a number of examples around the world where change and uncertainty were dealt with in interesting ways.

The chapter first outlines the main issues. It then reviews new water allocation paradigms that incorporate the role of markets and reallocation between sectors, and some modern computational developments that incorporate stochastic information to deal with uncertainty and risk. This chapter also highlights recent developments in the area of allocating water as a human right. Finally, it draws the conclusion that a common vision and a trusted knowledge base shared between water users is key for the individual water users to make the right decision.

22.2 Main issues

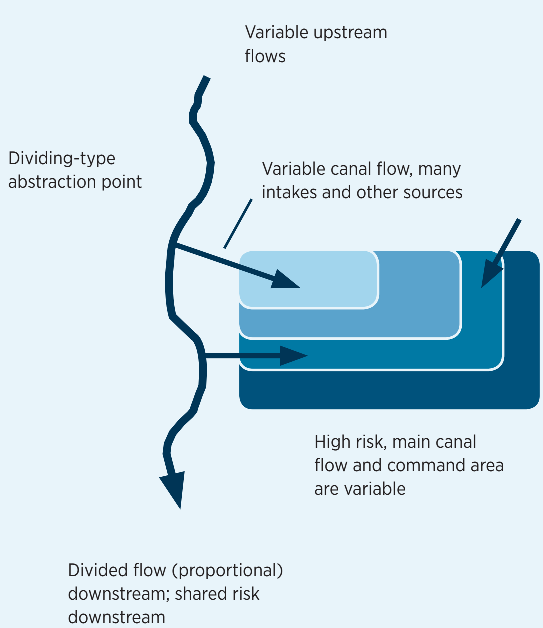
All over the world, the pressure on water resources is increasing, leading to situations where there is not always enough water to satisfy everyone's needs. Then choices have to be made about how to share, allocate and reallocate the increasingly scarce water. Water systems are 'closing', giving rise to difficult decisions about how water should be diverted, how it should be allocated within sectors and how it should be transferred between sectors. Such dilemmas throw up debates of a normative kind: what principles guide decisions on water allocation and how can the principles of equitable access, economic efficiency, sustainability and customary norms and values be reconciled in specific contexts?

Water allocation has strong *spatial and temporal dimensions.* Decisions can span decades, years, seasons, months, days, hours and even minutes. Think of the granting of water rights or permits to large irrigation schemes that are expected to last for decades or centuries; then think of hourly allocation schedules for short-term reservoir releases to cover peak demands in the electricity grid. Water allocation is generally a localized activity, but it must consider larger hydrological units and the expected inflows as well as the resulting outflows.

Many long-lasting water systems display a remarkable capacity to cope with change. In such systems, which often lack the physical capacity to fully control water flow, institutions evolved alongside specific physical design principles that were able to deal with long-term variability in supply and demand. Such institutions, which have their roots in customs and traditions, have tended to strongly embrace equity and fairness, which gives them sufficient legitimacy to enforce decisions. Examples are quoted by Leach (1961) and Martin and Yoder (1988) on two Asian cases. Several Latin American examples are referred to in Van der Zaag (1993) and Boelens and Davila (1998); while Manzungu et al. (1999) and Mohamed-Katerere and Van der Zaag (2003) refer to a number of African examples. Lankford (2004) has proposed incorporating the flexibility of these systems into the design of new smallholder irrigation systems (Figure 22.2).

FIGURE 22.2

Designing a flexible irrigation system based on risk sharing, proportional water allocation and an adaptable irrigated area



Source: Lankford (2004, fig. 1, p. 39), with permission from Elsevier.

BOX 22.1

Wicked problems in water management

As basins become closed, the interdependencies of stakeholders, the water cycle, aquatic ecosystems and institutional arrangements increase. In such contexts, especially where competition for water is acute, water management readily gives rise to 'wicked' problems (Rittel and Webber, 1973).

Wicked problems are clusters of inter-related problems characterized by high levels of uncertainty and a diversity of competing values and decision stakes. Wicked problems cannot be solved by any single organization and are intractable – since what constitutes a solution for one group of individuals often causes a new problem for another. Because wicked problems are characterized by competing views and often involve power disparities, they enter into the realm of politics (Wester et al., 2008).

But pressure on the resource is increasing everywhere, and existing as well as new water institutions face more frequent water allocation dilemmas that are increasingly complex and may be considered 'wicked' (Box 22.1). Existing rules need to be adapted and new rules, rights and duties, and organizational arrangements may need to be crafted.

There are often large spatial discrepancies between where the water is and where it is needed. So the construction of large inter-basin transfer projects is likely to continue, despite the acknowledged advantages of moving the *products* of water rather than the water itself (that is, the virtual water concept in the context of proposed transfer schemes. See, for example, Ma et al. (2006) on China and Verma et al. (2009) on India.

There is more and more demand for food, fibre, feed and biofuels. But in many river systems, large intersectoral transfers will have to be made from the agricultural to the urban and industrial sectors. The water shortage in agriculture *must* lead to enhanced water productivity, both from blue water (crops that use irrigation and supplementary irrigation) and from green water (rainfed crops).

The increasing pressure on water resources is mainly driven by four inter-related processes:

- Population growth and mobility;
- Economic growth;
- Increased demand for food, feed and biofuel; and
- Increased climate variability.

The results often lead to unsustainable water use, which manifests in drying lakes (for example, the Lerma-Chapala case described in Box 22.7), estuaries becoming more saline, and falling groundwater levels (for example, the Deschutes case described in Box 22.4, and the Andhra Pradesh case described in Box 22.8).

Some of the external drivers interact in unexpected ways – as was seen with the policies and measures aimed at mitigating climate change through subsidies on biofuel production. The issues of water quantity and water quality are often linked. The increased variability in rainfall combined with a growing pollution can have disastrous consequences, for example in cases where dry season flows dwindle and chemical concentrations and water temperature surge to unprecedented levels. New reservoirs that are built to deal with increased variability in river flows affect water quality and aquatic ecosystems, usually negatively.

As a result of such developments in nearly every region of the world, institutions charged with water allocation face dilemmas that are difficult to solve, yet they are operating under increased scrutiny and may not have sufficient knowledge or understanding of hydro-social system dynamics. This gives rise to serious *governance issues* – water institutions are charged to make decisions, the outcomes and consequences of which are difficult to anticipate. Will water institutions be able to adapt to shifting circumstances and changing levels of uncertainty? (Box 22.2.)

22.2.1 Access to water is a human right

The allocation of water should adhere to the law and help to implement legal conventions at national and transboundary levels (see, for example, Wolf, 1999; Van der Zaag et al., 2002; Drieschova et al., 2008). The international community is increasingly recognizing water as a human right (Box 22.3). This right is referred to – both implicitly and explicitly – in many international and regional treaties and declarations. Among these are the Universal Declaration of Human Rights, the International Covenant on Civil and Political Rights (ICCPR), the International Covenant on Civil and Political Rights (ICCPR), the Geneva Convention, and the African Charter on Human and People's Rights.

After this brief overview we conclude this section by identifying four key issues in allocating water:

- How should water be allocated in times of shortage? Should certain types of use (domestic, environmental, industrial, energy and agricultural) have more priority or should the shortage be shared in an equitable manner? Should established uses and users be protected from newcomers? Is there a role

BOX 22.2

Principal uncertainties related to water allocation

Uncertainty has been defined as the lack of certainty about the nature of a phenomenon, process, system, quantity, estimate or future outcome, arising from incomplete knowledge of the relevant phenomena or processes, measurement error, model error, and imprecision associated with random factors (UNISDR, 2009).

Three types of uncertainty should be considered in water allocation decision-making:

- The *first* uncertainty relates to water availability, and the need to be able to estimate future surface and groundwater availability at different times. This uncertainty is strongly linked to climate and our lack of understanding of hydrological processes. It not only relates to the stochastic nature of these processes (which is in fact a fairly well understood uncertainty), but also to the non-stationarity of these stochastic processes, associated with long-term changes in climate and land use, and the complex feedbacks between them.
- The *second* uncertainty relates to our inability to predict future water demands and uses. The further we look into the future, the more this uncertainty increases. This uncertainty is strongly linked to uncertainties about future policies on a diverse spectrum of issues and in many sectors, which are difficult to anticipate and predict.
- The *third*, and arguably the largest uncertainty, is posed by our institutions and organizations. It relates to the risk that our institutions may not be addressing the real issues, or might take decisions that they later come to regret. This can occur if decisions are based on unreliable data that are taken as facts or on models that represent reality in biased ways, or because inadequate monitoring systems were used. This type of uncertainty increases when situations that have to be dealt with that are unique and have no historical precedent. In a changing world, these unique events will occur more frequently.

BOX 22.3

Water as a human right

In 2002, the Committee on Economic, Social and Cultural Rights (2002, articles 11 and 12) defined the right to water as the right of everyone 'to sufficient, safe, acceptable, physically accessible and affordable water for personal and domestic uses'. It further specified that signatories should ensure access to 'a minimum essential amount of water [and] adequate sanitation,' and should develop and implement a national water strategy and monitor progress made on realizing the right to water. The primary responsibility for the implementation of the right to water falls upon national governments.

On 28 July 2010, the United Nations General Assembly adopted a non-binding resolution, sponsored by Bolivia, which declared that access to clean water and sanitation is a fundamental human right. The resolution called on member states and international organizations to offer financial and technical assistance, in particular to developing countries, in order to provide clean, accessible and affordable drinking water and sanitation for everyone. The resolution invited the UN Independent Expert to report annually to the General Assembly. While 41 countries abstained, the resolution received the support of 122 of the Member States.

Source: Léna Salamé, personal communication (2010).

for markets and market transactions? If so, how can social and environmental public good values associated with water be protected?

- Water rights, permits and entitlements, as well as allocation systems, provide security and predictability. Their aim is to reduce risk. But there is a trade-off between reliability and quantity – the more secure the supply is, the smaller the flow. How can water allocation systems deal with uncertain inflows while maximizing beneficial use?
- How can water institutions be transformed into learning organizations that are forward looking, can anticipate change and adapt?
- More competition for water and tensions between users seem inevitable. These may lead to disputes and conflicts that are most likely to manifest themselves locally. How can we anticipate these rising tensions, and what strategies exist to transform them into enhanced cooperation?

The above key water allocation issues will be discussed later. First, we turn to some of the new water allocation paradigms designed to deal with uncertainty.

22.3 New water allocation paradigms in the face of uncertainty

Global change, socio-economic development, new demographics and climate change all increase competition for water. Societies face hard choices when allocating water between competing uses. Because water is a vital resource used in multiple sectors (including the environment), its allocation is inherently a political and social process – which opens it to the scrutiny of many and varied interested parties.

Because markets for this vital resource are usually absent or ineffective, allocating of water between competing demands is achieved administratively taking into account, often conflicting, social objectives such as economic efficiency, social equity and ecological integrity. Various allocation mechanisms have been developed in order to reconcile the principles of efficiency and equity (Dinar et al., 1997).

To deal with the growing demand worldwide for energy and water, societies have augmented supply by constructing more power plants and transmission lines and more hydraulic infrastructures such as dams and pumping stations. But this strategy has reached its limit in many regions. In the energy sector, for instance, rising concern about global warming and energy security have favoured conservation and the development and implementation of efficiency-promoting measures. For water, a similar trend can be observed with the 'closure' of river basins – that is, when available water resources are fully committed (Molle et al., 2010). More attention is now being given to strategies that attempt to increase the productivity of water through *temporary* reallocation, either within the same sector or across sectors. (This contrasts with permanent transfers, where water rights change hands permanently.) A temporary reallocation strategy lends itself to a water market and to market-like transactions where high-value water users would compensate low-value water users for the temporary right to use their water. Lund and Israel (1995) review types of water transfers such as permanent transfers, dry-year options, spot markets, water banks, and so forth.

Most of the studies on water reallocation reported in the literature focus on transfers from agricultural to urban use – where farmers are financially compensated by industries and/or municipalities for increasing the water available to them through either temporary or permanent transfers.

The rationale behind agriculture-to-urban water transfer is often economic. The productivity of water in urban uses is generally much higher than in agriculture. Agriculture can also cope better than other sectors with a larger variation in supply. For example, Booker and Yong (1994) analysed the efficiency gains of from intrastate and interstate water transfers in the Colorado River basin in the United States. They found that significant gains were possible, especially if both consumptive and non-consumptive use values were considered in the reallocation process.

Ward et al. (2006) investigate the effectiveness of market-based water transfers to deal with severe and sustained droughts in the Rio Grande basin, also in the United States. Using a hydro-economic model of the basin, they found drought damage could be reduced impressively if an interstate market program were enacted. This market would reallocate drought-induced water losses from higher-value water uses to lower-value uses. More specifically, farmers could reduce their losses by trading water for money whenever the income from the traded water is larger than the income that would have been produced using the same water in agriculture.

Water markets are more the exception than the rule. In fact, water markets are prone to market failure – meaning that private property and the resultant 'free' market cannot be relied on to achieve efficiency or augment supply through water reallocation. The main reasons for market failure are: the 'public good' nature of some water uses, the externalities associated with allocation decisions, and the presence of natural monopolies. Note that transaction costs must also be considered. If water markets are to serve society, water rights would have to be carefully defined and managed, and this would require continuous public sector involvement, which may lead to highly regulated water markets.

Despite these issues, incentives for water exchanges persist. The creation of water banks, such as the California Water Bank, is an attempt to improve the reliability of water markets (Jercich, 1997). Here, a public intermediary acts to create a population of buyers and sellers. The public intermediary buys water from the willing sellers and then sells it to buyers. With this system, water managers are confident they can find the water they need at a predictable price. It also means that public good services, such as environmental flows, can in principle be protected. The case of the Deschutes River basin nicely illustrates the feasibility of this strategy (Box 22.4).

BOX 22.4

Deschutes River Basin: Water banking for surface water and groundwater

This case is about reconciling water demands between different uses and users, in a situation where there are strong interconnections between groundwater and surface water. Tribal, environmental and irrigation interest groups came together in the mid-1990s to improve stream flow and water quality in Deschutes River basin in Oregon in the United States. This has materialized largely in restoring stream flow to depleted streams. It has also assisted municipalities to meet the groundwater needs of rapidly growing populations, and helped irrigation districts to improve their water delivery systems and maintain financial stability in face of changing customer bases.

Water banking tools were designed specifically to respect existing water rights, and to not jeopardize the validity of these rights when they are temporarily transferred to the water bank for use by other people for instream flow restoration. The system is flexible and offers temporary and permanent options, which builds wider support among water users and potential market participants. It also has a strong regulatory foundation which provides stability and accountability, thus meeting concerns of the regulatory agencies, especially those responsible for the administration of water rights.

Source: Heather MacKay, personal communication (2010).

A dry-year option (Characklis et al., 2006) is an alternative to water markets and water banks. It is a contingent contract between a buyer and a seller. The dry-year option gives the buyer the right, but not the obligation, to use water owned by the seller. Usually, the contract specifies the circumstances under which the option can be exercised. For example, it could be a target flow in the river or the water level in a reservoir. One advantage of a dry-year option is that it deals with the problem of hoarding, which can be observed with water users who require a high reliability of supply.

As mentioned above, most of the water reallocation studies focus on agriculture-to-urban water transfers. However, with growing environmental concerns, some water managers are also investigating the option of environmental water transfers (see Boxes 22.4 and 22.8). For example, Hollinshead and Lund (2006) analyse the least expensive strategies for staged seasonal water purchases for an environmental water acquisition programme in California. Suen (2006) use a multi-objective model to characterize the trade-off relationship between environmental flows and human needs. Tilmant et al. (2010) determine the reservoir operating policies and the opportunity cost for power companies to restore floods in the Zambezi River basin (Box 22.5).

BOX 22.5

Modelling the benefits of jointly operated reservoirs in mitigating environmental impact in the Zambezi River basin

The Zambezi River basin is one of the largest basins in Africa. It is a largely untapped resource where water is used primarily for generating electricity. There are four main dams on the Zambezi. The Kariba Dam (1959, Zambia/Zimbabwe) and the Cahora Bassa Dam (1974; Mozambique) are both located on the main stem. They have installed capacity of 1350 MW and 2075 MW respectively. The other two are located on the Kafue River in Zambia. The Kafue Dam has an installed capacity of 900 MW, while the Itezh Itezhi Dam acts as a storage dam.

Significant work is underway to plan new reservoirs in the basin. These large storage facilities have traditionally been designed and managed to maximize revenues from energy generation. This has altered the hydrological regime by disrupting the ecosystems and their livelihood functions such as fisheries. Up to now, each of the reservoirs has operated in isolation.

Implementing hydropower–to–environment water transfers in the Zambezi requires the development of new reservoir operating policies that help to restore degraded ecosystems in the lower Zambezi without undue adverse effects on generating hydroelectricity. One way to achieve this is to coordinate reservoir releases. The coordinated operation of the reservoirs as one system could reduce the environmental impact while minimizing the benefits that had to be foregone. Preliminary findings indicate that the reduction in total energy output varies from 1.5% to 6%, depending on the type of flood to be restored in the lower Zambezi. The question is whether society wishes to incur such costs (or forego such benefits) in order to reduce negative environmental impacts.

Source: Tilmant et al. (2010).

22.3.1 Risk management and hedging

Any attempts to formulate the water resources allocation problem must be made without a perfect knowledge of future water supplies. Hydrological uncertainty exposes risk-averse water managers and users to a volume (supply) risk, which has to be managed. The traditional approach to the problem, which consists of increasing supply by constructing reservoirs and pumping stations, has reached its limit in many cases. This is because the social, environmental and economic costs have become so high that there are now incentives for non-structural measures such as water transfers to increase supply.

Where irrigated agriculture is important, this sector can absorb some of the fluctuations in climate, and thus serve as a kind of buffer by transferring risk from urban users to farmers using an option contract (see above). The idea is that one party (urban users) is willing to pay a premium for transferring the supply risk. In other words, one party seeks to secure additional water in order to reduce its exposure to hydro-climatic variability. The supplier (the farmers) must be able and willing to bear further supply risks after compensation. With such a risk-transfer mechanism, the benefits must of course exceed costs for both parties. A review of agricultural production risks and their management can be found in World Bank (2005). Gomez Ramos and Garrido (2004) design an option contract between farmers and a Spanish city. Brown and Carriquiry (2007) propose a combined option contract–insurance system to increase the reliability of supplying water to Manila in the Philippines. The idea is to transform the variability from the hydrological to the financial space where it can be levelled out using insurance products.

Risk management is also fairly common in the hydropower sector where hydropower companies are exposed to the hydrological supply risk. Water release decisions are combined with sophisticated financial products such as forward contracts and options to limit the risk exposure of the company (Mo et al., 2001, Kristiansen, 2004). With the liberalization of the electricity sector in many countries, hydropower companies now face a new source of risk: the price risk. This cannot be hedged using bilateral contracts because prices tend to increase during dry periods, which is precisely when the hydropower companies cannot rely on their own production to meet their commitments. This creates a contracting dilemma for the hydropower sector: if lightly contracted, it will be exposed during low price periods which may occur frequently and last for some time; if heavily contracted, it will be exposed to extremely high prices in the dry periods, when it may not produce enough to meet its contract (Barroso et al., 2003).

Water resources allocation problems address the issue of how water should be combined with other scarce resources to obtain the greatest return. This in turn implies that the consequences associated with the allocation decisions can, in principle, be valued. Because there usually are no markets, and even when there are they are usually absent or ineffective, allocation decisions can seldom rely on market prices. Instead, it is necessary to assess accounting or shadow prices that reflect the value of water (Young, 2005). To achieve this, economists have developed and implemented various non-market valuation techniques to address water resources management problems (Loomis, 2000).

22.4 Opportunities: How the key water allocation issues can be addressed

The water allocation challenges identified in this report are major and complex. Yet there are also opportunities that can mitigate the risks and uncertainties that we face. In this section, we address the four key water allocation issues: water shortages, uncertainty, anticipating change and dealing with conflict.

22.4.1 Dealing with water shortages

How should water be allocated when there is a shortage? Should certain types of use (domestic, environmental, industrial, energy generation or agricultural) be prioritized over others, or should the burden of shortages be shared in an equitable manner? Should established uses and users be protected from encroachments by new entrants? Is there a role for markets and market transactions? If so, how can social and environmental public good values associated with water be protected?

All the water bodies in the case studies reviewed faced periods of severe water shortage, and they all dealt with this in different ways. In the Murray–Darling basin in Australia, a maximum level of water abstraction was set and water reallocation occurred through transferring water use rights, either on a short-term basis or over the long term (Box 22.6). In the Lerma–Chapala basin in Mexico, irrigators had to decrease the amount of water they were using for irrigation and were forced to release water stored in their reservoirs to supplement dwindling levels in Lake Chapala. This was done to ensure Guadalajara's water supply and to support environmental and tourism needs (Box 22.7). In Andhra Pradesh in India, irrigators reduced groundwater abstractions in cases where recharge rates were low as a result of low rainfall. Because they are aware that water scarcity is a recurring problem, they have shifted to crops that need less water to grow, but which fetch higher market values. As a result, farm incomes have increased over time (Box 22.9).

What we learn from these cases is that water is still being used inefficiently and wastefully. But more *can* be done with less. This requires a new attitude to water; we must become more water wise. Water demand management is central to this, and significant gains can still be made. In the domestic and industrial sectors, demand-side measures are normally more cost-effective than supply-side solutions. In irrigation, this is often not the case because a conversion to more efficient irrigation technologies tends to be capital intensive. Here, the first option is to change to growing crops that need less water, but fetch a higher price at market. Limited and temporary water transfers from agriculture to the domestic and industrial water sectors may create conditions that allow farmers to adapt.

In countries that experience 'economic water scarcity', supply-side options must not be discarded. Such countries require a greater ability to physically control water. An opportunity may present itself in the future in the form of funds being made available to help countries adapt to climate change. With these funds, new infrastructure can be provided that is better at buffering societies and water systems against increased climate variability. If properly designed and implemented, such infrastructure could give an enormous boost to poverty alleviation in many rural areas and could thus contribute to achieving the Millennium Development Goals.

These types of investment have the potential to be 'no regrets' measures; however, the challenge will be for adequate policy and design decisions to be made in the first place. There is debate about whether water buffering infrastructure should be large and centralized or small and distributed – both of which pose very different institutional requirements, governance demands and environmental impacts (Van der Zaag and Gupta, 2008). Obviously such infrastructure

BOX 22.6

Sustainable diversions limits (SDLs) in the Murray–Darling basin

The Murray–Darling River basin is the most significant river system in Australia. The basin covers 14% of Australia's mainland and covers around 1 million km² across large parts of Queensland, New South Wales, Victoria, South Australia and all of the Australian Capital Territory.

In accordance with the Water Act 2007, the Murray–Darling Basin Authority prepared a basin plan to manage water resources. The plan ensures that future water use is placed on a sustainable footing so that there is enough water for a healthy environment as well as for other uses. The plan sets mandatory Sustainable Diversion Limits (SDLs) for surface water and groundwater. The limits must reflect an environmentally sustainable level of water withdrawal, which is defined as the level at which water can be taken without compromising key environmental assets, key ecosystem functions, the productive base or key environmental outcomes. As well as meeting the basin's environmental requirements with the SDLs, the Water Act 2007 also requires the basin plan to optimize social, economic and environmental outcomes.

Source: Akhtar Abbas and Frank Walker, personal communication (2010).

development needs to consider issues of adaptive capacity, and robustness, as well as issues relating to the conjunctive use of groundwater and surface water (see the Deschutes and Andhra Pradesh cases). Various aspects associated with this are dealt with in detail in other chapters of this *World Water Development Report.*

22.4.2 Dealing with uncertainty

Water rights, permits and entitlements, as well as allocation systems, provide security and predictability in an uncertain world. Their aim is to reduce risk. But there is a trade-off between reliability and the amount of water one can use – the more secure the smaller the flow. How can water allocation systems better deal with uncertain inflows while maximizing beneficial use?

Such a risk-based approach needs a precise understanding of the water system –how much water is available, how much is needed, and when and where is it needed. This requires the ability to establish accurate water accounting systems (Molden and Sakthivadivel, 1999) that include quantified knowledge of water fluxes (inflows, outflows, abstractions, consumption, etc.) and the changes in groundwater and surface water stocks in a given basin over a given period of time.[1] Detailed monitoring of water stocks and fluxes can combine conventional ways of data collection with new ways that use remotely sensed data for rainfall, evaporation, open water levels and changes in groundwater storage.

BOX 22.7

Unresolved water allocation in the Lerma–Chapala basin

The Lerma–Chapala basin straddles five Mexican states and provides surface water and groundwater for nearly 900,000 ha of irrigation farms. It also supplements the water needs of Mexico's two largest cities, Mexico City and Guadalajara, and the touristic Chapala Lake at its downstream end. The Lerma–Chapala basin is now 'closed' as a result of increasing human pressure on its water resources, which have depleted the levels of blue water and made the basin very sensitive to climatic fluctuations. The lack of accurate water accounting in the basin, and the relatively wet period in the 1960s and 1970s, resulted in an overestimation of water availability and the 'overbuilding' of the basin. This is a common phenomenon in closing basins, and makes it very difficult to reduce water use levels once a basin has closed.

The institutional response to basin closure has focused on surface water allocation mechanisms, resulting in the 1991 surface water allocation agreement. The continued decline of Lake Chapala and Guadalajara's increasing concerns about its water supply, led to a revision of the 1989 water allocation agreement between 1999 and 2004. The negotiations were conducted at the highest political level between the basin states, Guanajuato, Jalisco, Mexico, Michoacan and Queretaro and focused on achieving an agreement on rainfall and runoff data and new formulas for water allocation.

One of the results was the transfer of water from upstream reservoirs to Lake Chapala, which alienated irrigation farmers from the negotiation process. The water challenges in the basin remain, and water crises will inevitably recur during periods of low rainfall.

What can be learned from this case is that difficult zero-sum allocation decisions need legitimacy, both scientifically and politically. Scientific legitimacy requires reliable data and information, and sound interpretation of these data; political legitimacy requires an inclusive approach that involves all those who will be affected by allocation decisions in the decision-making process.

Source: Phillippus Wester, personal communication (2010).

BOX 22.8

Farmer managed groundwater systems in Andhra Pradesh

The Andhra Pradesh region of India faces severe problems with the over-exploitation of groundwater. In the 1990s, a project started to promote participatory hydrological monitoring among smallholder farmers. This was followed by the Andhra Pradesh Farmer Managed Groundwater System (APFAMGS) project, which is a community-based project that focuses on developing the capacity of groundwater users to manage their resource in a sustainable way.

The APFAMGS has a demand-side approach to groundwater management, where farmers learn about their groundwater system in such a way that they can make informed decisions about their water use. Sustainable groundwater management is feasible only if users understand the occurrence, cycle and limited availability of groundwater. And they must also accept that collective decisions taken on groundwater conservation ultimately safeguard their own interests.

Thus, the burden of controlling water extraction is transferred to individuals in communities who know the 'why and how' and act on sound information rather than because they are bound by rules and regulations. The project does not offer any incentives in the form of cash or subsidies – the assumption is that access to scientific data and knowledge will enable farmers to make the right decisions.

This has had measurable effects:

- Changing to crops that need less water and adopting new irrigation methods have led to reductions in the amount of water used.
- Farmers have consistently improved their profitability with the net value of outputs per ha nearly doubling.

A combination of the following factors appears to explain the success of this approach:

- Opportune information on groundwater availability as a key input to farmers' risk management paradigm – with relatively small monsoons usually being followed by reduced sowing in the dry season;
- The low-storage, fast-response, hard-rock aquifers that are replenished annually provide a natural limit on water over-use;
- Estimates of the available groundwater and projected demands being provided in time to inform dry planting;
- Repeating crop water planning over a number of years provides a sound framework for farmers' decisions;
- Reductions in groundwater over-use are not coming from altruistic collective action, but from many individual farmers making informed risk-management decisions – hence no authoritative leadership is required for enforcement.

Source: Garduño et al. (2009).

Much can be learned from prediction of ungauged basins (PUB) experiences.

22.4.3 Anticipating change

How can water institutions be transformed into learning organizations that are forward looking and can anticipate change?

All the case studies in this chapter highlight how important it is to understand the hydro-social system and its dynamics. The Andhra Pradesh case on groundwater management demonstrates the knowledge dimension most convincingly (Box 22.8). The most important lesson is that stakeholders themselves need to have an intimate knowledge of and appreciation for the resource on which they rely – which leads to an interest in carefully monitoring system behaviour. This creates a kind of distributed intelligence among a group of water users that may be considered a prerequisite for any organization to learn. The co-learning stakeholder management structure can be supported by appropriate access to scientific data, expertise and knowledge that can help to select alternative management choices and shared decision-making on how to use scarce water resources.

22.4.4 Dealing with conflict

It seems inevitable that there will be a rise in competition between water users as well as differences of opinion and other tensions. This may lead to disputes and conflict. How can we anticipate these rising tensions, and what strategies are there to transform them into enhanced cooperation?

Competition over water can escalate into conflict. But where decision processes are considered legitimate and fair, competition can also evolve into cooperative deals. Difficult questions are raised when making allocation decisions. Two examples:

- Which is more important, the livelihood of a fisherwoman living in a remote village near a river, or an urban middle-class person who requires internet and electricity?
- Two (hypothetical) communities live on opposite sides of a watershed divide. One is located in a relatively water-rich basin and the other in a water-scarce basin. How does the second community's right to development relate to the first community's right to live in a healthy and undisturbed environment? (Gupta and Van der Zaag, 2008)

These questions point at the normative and political dimensions of allocation decisions. Where stakeholders have been involved in decision-making and where they have been respected and receive fair treatment, then it is likely that the outcome will be sustained and enforced. This requires norms, such as the norm that a household that is to be resettled due to dam construction may not become worse off, not now but also not in the future (WCD, 2000). Multi-stakeholder planning in the Alouette River in Canada (Box 22.9) is an example of inclusive decision-making that has far-reaching consequences.

Another way of addressing water allocation's conflict potential focuses on promoting interdependency between the users of the shared water resource, while simultaneously unlocking the additional benefits that can be gained through cooperation. Examples are benefit-sharing projects and rewards for environmental services systems, which can be developed between user groups within countries but also between riparian countries. Examples of how this worked between riparian countries can be seen in the cases of the Santa Cruz River basin (Box 22.10), the Zambezi River basin (Box 22.4) and the Blue Nile River basin (Box 22.11).

BOX 22.9

Multi-stakeholder planning in the Alouette River in Canada

ity, BC Hydro, came under mounting public pressure from a number of community groups, a range of NGOs and the media to change the ways their dams operated. There were calls for the release of in-stream flows, and increased participation in decision-making processes surrounding water management in the province.
An opportunity to implement change came in 1994 when BC Hydro applied for an expansion of generating capacity at its Stave Falls power plant. Yielding to demands that flows in the contiguous Alouette River (which feeds the Stave Falls scheme) be augmented, the provincial government decided that a water use plan be conducted as a condition for going ahead with the Stave Falls upgrade. As a result, a multi-stakeholder process, which came to be known as the Alouette Water Use Plan (AWUP), was launched in 1995 to review the operating plans of the Alouette scheme.

The AWUP was an inclusive and science-based process, which had the potential to solve longstanding problems. It was based on structured decision making, which combined objective, scientific data with the values people placed on different water uses. This was crucial for its acceptance.

The process was hailed for building trust between the different parties and for gradually replacing the antagonism that had characterized previous interactions between BC Hydro and other stakeholders. As a consequence, the provincial government mandated BC Hydro to draw up water use plans for all its facilities within a five-year period. This resulted in the development of 23 WUPs, which revised the operating plans of 30 BC Hydro dams.

Source: Lucia Scodanibbio, personal communication (2010).

BOX 22.10

Groundwater use and re-use in the transboundary Santa Cruz River basin

Climate change, hydrological variability, and rapid urban growth characterize the United States–Mexico border region and pose significant challenges for the planning and allocation of limited water resources. On the Arizona–Sonora border, the upper Santa Cruz River has only ephemeral surface flows. Meeting the water needs of 300,000 inhabitants greatly increases groundwater dependence. The basin's aquifer is shared by the sister cities, Nogales, Arizona, and Nogales, Sonora – but groundwater is allocated separately on either side of the border in accordance with prevailing national and state laws and institutions.

Adequate wastewater treatment has enlarged the water pie on both sides of the border. This was possible through joint bi-national management of urban wastewater, which is the result of years of cooperation. Two important lessons of particular relevance to bi-national groundwater management are, first, that informal collaboration based on shared trust must be strengthened through international accords, and second, that scientific data and joint studies provide the basis for operational agreements.

Source: Sharon Megdal, personal communication (2010).

Potential conflicts between water consumers and environmental water uses can be resolved through changing the operating rules of dams (Box 22.12). New approaches to dam planning and operations that optimize water allocation benefits across a range of resources and values are required to achieve more sustainable dam operations. These solutions must occur at the level of entire systems because dams are only one element of larger water management systems.

BOX 22.11

Triple win on the Blue Nile through transboundary cooperation on infrastructure development

The upper Blue Nile River Basin in Ethiopia has a huge potential for hydropower generation and irrigated agriculture. Controversies exist as to whether the numerous infrastructural development projects that are on the drawing board in Ethiopia will generate positive or negative externalities downstream in Sudan and Egypt. In order to examine the economic benefits and costs of developing reservoirs on the Blue Nile for Ethiopia, Sudan and Egypt, Goor et al. (2010) developed a basin-wide integrated hydro-economic model.

The model integrates essential hydrologic, economic and institutional components of the river basin in order to explore both the hydrologic and economic consequences of various policy options and planned infrastructural projects. Unlike most of the deterministic economic-hydrologic models reported in the literature, a stochastic programming formulation has been adopted in order to:

- Understand the effect of the hydrologic uncertainty on management decisions;
- Determine allocation policies that naturally hedge against the hydrological risk; and
- Assess the relevant risk indicators.

The study reveals that the development of four mega dams in the upper part of the Blue Nile Basin would change the drawdown refill cycle of the High Aswan Dam. Should the operation of the reservoirs be coordinated, they would enable an average saving for Egypt of at least 2.5 x 10^9 m^3a^{-1} through reduced evaporation losses from the Lake Nasser.

Moreover, the new reservoirs (Karadobi, Beko-Abo, Mandaya and Border) in Ethiopia would have significant positive impacts on hydropower generation and irrigation in Ethiopia and Sudan: at the basin scale, the annual energy generation is boosted by 38.5 TWh a^{-1} of which 14.2 TWh a^{-1} due to storage. Moreover, the regulation capacity of the above mentioned reservoirs would enable an increase of the Sudanese irrigated area by 5.5%.

Sediment fluxes poses another important dimension to these development plans, which were not considered in this study.

Source: Goor et al. (2010), with some areas of text reproduced.

BOX 22.12

Innovative approaches for improving dam planning and operations for optimized water allocation benefits

In several countries, changes in the way dams operate have been prompted by re-allocating water from consumptive to environmental uses Watts et al. (2011).

In the United States, an ongoing effort known as the Sustainable Rivers Project is changing operations at US Army Corps of Engineers' dams. The project currently involves twenty-nine dams in eight river systems as demonstration sites for national implementation.

In the Yangtze River, China, a proposal is being advanced that proposes to move flood-risk management out of hydropower reservoirs and to invest a portion of the consequent increased revenue from generating hydropower from the additional store water into flood-risk management on the floodplain and ecosystem restoration and conservation.

In South Africa, the Berg River Project is the first large in-stream dam that was designed according to international best practice standards, such that it can release both low and high flows that will coincide as closely as possible with natural inflows and natural flood events.

In Australia, a series of trial variable flow releases from Dartmouth Dam in the Murray-Darling Basin implemented and monitored between 2001 and 2008 demonstrate that it is possible to reduce the negative impacts of transferring consumptive water between reservoirs by altering established dam operation practices. The results from these trials were used to develop new interim operating guidelines for Dartmouth Dam.

These examples demonstrate that more sustainable approaches for dam planning and operations are possible and require close collaboration between participating organizations and stakeholders. To achieve sustainable river management at global scales will require considerably more investment in trials and demonstration sites that can illustrate new approaches, opportunities and solutions.

Source: Robyn Watts, personal communication (2010), from the results of the UNESCO Workshop 'Challenges and Solutions for Planning and Operating Dams for Optimised Benefits' held in Paris, 26–28 October 2010.

In South Africa, the National Water Act (No. 36 of 1998) introduced the Water Allocation Reform (WAR) programme to address race and gender imbalances that had been created in the water sector as a result of discriminatory legislation in the country in the past (Seetal, 2005). WAR derived its mandate from the Constitution, the National Water Policy, the National Water Act and other related legislation. The Position Paper for Water Allocation Reform in South Africa outlined the rules for allocating water to promote race and gender reform, while at the same time supporting the government's programmes for poverty eradication, job creation, economic development and nation building. This included addressing the expectations of the historically disadvantaged majority South Africans, but also dealing with the fears and uncertainty of a historically advantaged minority – primarily by minimizing the impact on existing lawful users and supporting the stability of the rural economy.

Conclusion

Water allocation lies at the heart of water management. In a world that experiences gradual and sudden changes, in terms of population, diet, land use, economic markets and climate, water allocation is an increasingly important topic.

The experiences reviewed in this chapter show that such conditions require a sound knowledge about water availability and water use, as well as the capacity to monitor infrastructure. Interactions between groundwater and surface water need to be understood, as do the effects that changes in land use have on both groundwater and surface water fluxes at different levels.

It is up to institutions to make sense of the status quo and guide decision-making. This is not trivial, as in more and more cases, allocation decisions are zero-sum. Often, a large variety of sectoral interests needs to be considered and weighted according to social, economic, ecological, cultural and political criteria. Such criteria are difficult to put under one encompassing metric, so it is not easy to reach consensus on preferences and priorities. The principles underlying allocation decisions should therefore be known, and be seen to be legitimate and just.

Finally, and importantly, a changing environment demands that institutions become learning organizations that are ready to develop and implement adaptive management practices.

Some of the cases reviewed in this chapter have shown that tools, such as water accounting and integrated hydro–economic models, can assist the water allocation process. Based on a good understanding of system interactions, optimal decisions can be reached – which allow fair compensation to be given to those who have to forego some immediate water benefits.

In some cases, market-like mechanisms can assist in finding optimal solutions, for example where uncertainty and risk can be transferred differentially between the interested sectors or parties, depending on their ability to cope.

In most cases, it was shown that building the knowledge base of water users is the essential element that the many individual water users need to be able to reach the right decisions.

There is a need for effective stakeholder engagement in decision-making in order to ensure transparency and fair treatment. The environmental sustainability, economic viability and social acceptability of water allocation decisions, rests on true stakeholder engagement, which comes from recognizing their democratic right to influence the management of water resources. A distinction must be made between the commonly practised 'cosmetic' stakeholder consultations and true empowerment where a community takes control of its water management future. True stakeholder empowerment leads to more legitimate and cost-effective solutions that have a better chance of being implemented.

It is time to rethink the operations of water infrastructure in a way that both enhances the synergy between water users, and fosters the benefits of cooperation. Systems need to be flexible, which can be achieved through a combination of investment in both infrastructure and human resources and innovative management solutions.

The water reform process also needs to recognize and correct racial and gender inequities in water use by addressing the expectations of all stakeholders in an equitable and transparent manner.

Notes

1 Such information will enable the inclusion of the state of the water resource in national accounts, viz. the United Nations Statistics Division's Standard for Environmental–Economic Accounting for Water (SEEA-W), and the UN's international recommendations for water statistics (UN, 2010); see also Brouwer et al., 2005).

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CHAPTER 23

Valuing water

UN DESA

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Acknowledgements With the support of Jack Moss (AquaFed), David Coates (UN CBD), Peter Borkey and Roberto Martinez-Hurtado (OECD), and Diego Rodriguez (World Bank). Thanks to Jake Burke (FAO), Rudolph Cleveringa (IFAD), Claudio Caponi (WMO), Ti Le-Huu (UNESCAP), Nikhil Chandavarkar (UN DESA), Thomas Chiramba (UNEP), and William Cosgrove and Richard Connor (WWAP) for comments and materials provided and to Maria Mercedes Sanchez (UN DESA) for proofreading.

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Failure to properly recognize the full value of water, including its benefits and costs, is one of the root causes of water resources mismanagement and the political neglect of water issues.

A valuation of the benefits of water is essential in order to improve the decisions of governments, international organizations, the donor community and other stakeholders.

Valuation is a powerful instrument for making the public aware of water's many benefits. Without a doubt, it brings the less-visible benefits of water into the public arena.

Providing reliable information on the benefits of water development and water resources conservation will help to convince governments and stakeholders that water needs to be given priority in national policies. Having the right information will help to target investment, make real differences to economies and societies – and so help to eradicate poverty.

Water valuation is central to the water-related decisions of public and private agents. It can help water managers and stakeholders to choose between water supply and demand alternatives and to recognize the options that will improve welfare while simultaneously sustaining ecosystem services. Water valuation also helps water managers to design subsidies, public incentives and economic instruments that respond to current water challenges.

Water valuation is a tool that can be used to shape cooperative agreements to protect and share the benefits of water resources conservation.

More efforts need to be made to analyse the costs and benefits of water and to incorporate this analysis into decision-making. This helps in the move towards more integrated and holistic socio-economic approaches. Ways of looking at the valuation of water have been shifting from a rather limited focus on the economic benefits, to a more comprehensive focus that also takes into account social, cultural and non-market values. Valuation methods need to be chosen and adapted so that they respond better to policy questions and management needs.

23.1 Introducing the issues

Water is essential for human life. It is used in the production of food, the generation of energy and the manufacture of goods. It is vital to the economy and for preserving the structure and functioning of ecosystems and all the environmental services they provide (Box 23.1). The importance of these benefits makes the provision of water services crucially and intimately linked with development, both as an integral part of a strategy for socio-economic progress and as a precondition for holding on to the advances that have already been made.

However, decisions about how water is used and managed and about how scarce resources should be conserved are still being taken using only part of the information on its multiple benefits. The 'non-visible', external and indirect benefits (and costs) of using water are mostly ignored by end users when they decide how much water to use and what to use it for. This is often true of businesses when they make decisions about what to invest in and produce; of farmers when they decide what crops to grow; and of governments and institutions when they make decisions about priorities for water investment, management and allocation.

This lack of understanding of the multiple benefits of water results in water issues being given a low political priority. It also causes fragmentation of resources and underinvestment, or overinvestment, in water infrastructure. Ultimately, this results in water being given a low priority in national development programmes and in strategies for reducing poverty. It also leads to inefficiencies in how water is used in the many areas of the economy where it is an essential production input.

BOX 23.1

Categories of economic values

Direct use values: The direct uses of water resources for consumption include inputs to agriculture, manufacturing and domestic households. Non-consumption uses include hydroelectricity generation, recreation, navigation and cultural activities.

Indirect use values: The indirect environmental services provided by water include waste assimilation and the protection of habitats, biodiversity and hydrological functions.

Option values: These refer to the value of having the option to use water directly or indirectly in the future.

Non-use values: These include water's bequest value (passing on this natural resource to future generations) and the intrinsic value of water and water ecosystems, including biodiversity, the value people place simply on knowing that a wild river, for example, exists.

Source: UNSD (2007).

Valuation, or 'valuing', is a process that judges the importance of water for human welfare. It refers to all the ways that can be used to identify, assess, measure and eventually assign a value to the importance that each benefit, and potential benefit, has for human welfare. Bringing this knowledge to the policy arena can improve water management in many significant ways. Valuations of the economic and social development benefits of water will push water management issues up the political agenda and will help decision-makers to make informed judgements about development opportunities and challenges. Valuation is also important because there are trade-offs to be considered when examining the various management options. Sometimes using available water for one purpose means forgoing the benefits that another use would bring. Valuation results in information that allows economic efficiency and political and social priorities to be addressed more transparently. It might also have a role in resolving water conflicts by indicating the potential shared benefits that come from cooperating to preserve critical water assets (such as transboundary river basins or common pool underground waters) rather than competing for their use.

23.1.1 Valuing the benefits of water so that it can be made a priority in the political agenda

Water is important for development. But if this is so, why do so many poor countries still lack water infrastructures, have difficulty benefiting from water's productive uses and suffer from poor access to basic sanitation and water supply services?

Part of the answer lies in the fact that most of the benefits obtained from (and the costs incurred by) investing in water and water management are external to the agencies and firms making the investments. Valuation shows that the benefits that countries derive from having water exceed the benefits obtained from the direct productive uses of water. In order to understand this, it is necessary to analyse how the overall productivity of all sectors is constrained by the availability and quality of water facilities (Kemp, 2005).

Better access to and more widespread availability of water expands the productive capacity of the economy by, for example, increasing the productivity of land or labour, and improving the quality of crops, energy and other products. Valuation also shows the important benefits that improved water infrastructures and services bring to production – having access to water is a cost-effective and safe way of reducing production costs. Farmers' incomes increase substantially when they shift from rain-fed to irrigated agriculture. Hydroelectricity provides energy for production and reduces reliance on expensive fossil fuels. Deliberation on the importance of these direct benefits has supported decisions to invest in multipurpose infrastructures as an effective way of fostering productivity and saving costs in all the activities to which water contributes as a production input (Box 23.2).

BOX 23.2

Valuing water's indirect benefits to support investment decisions

The Bhakra multipurpose dam system in northern India generated indirect benefits in two ways. First, the inter-industry links that were forged resulted in increases in the demand for inputs from other sectors. Second, the direct outputs of the dam led to higher levels of income, increased wages and generally higher levels of economic prosperity. For every rupee of direct benefit in terms of electricity generated, farms irrigated, water supplied, floods controlled and drought prevented, the indirect benefits amounted to an additional 0.9 rupee. The gains perceived by rural workers were also higher than the gains for other rural and urban households. This showed that one of the benefits of the project was that it led to a more equal distribution of income (Bhatia et al., 2007).

'The multiplier for the Sobradinho Dam in Brazil was estimated at between 2.0 and 2.4 depending on what assumptions are applied to the supply of labour and capital. This means that for every US$1 invested, there was a total economic return of US$2 to US$2.4.'

Source: SIWI, WHO and NORAD (2005, p. 22).

Valuation also highlights the importance of the intangible health benefits of improving basic sanitation and access to safe drinking water. Improved health means fewer lost working days – and increased productivity. The effects of better health can be seen in people living longer and having a better quality of life. Better services contribute to human development by allowing people to look and plan further into the future. They also enhance capacity so that people see the benefits of spending time acquiring an education, in the knowledge that they will have the better health conditions that will allow them to benefit from it into the future.

The World Health Organization believes that half the consequences of malnutrition are caused by

TABLE 23.1

Overall benefits of achieving the MDGs for water and sanitation

Types of benefit	Breakdown	Monetized benefits (in US$)
Time saved by improving water and sanitation services	• 20 billion working days a year	US$63 billion a year
Productivity savings	• 320 million productive days gained in the 15–59 age group • 272 million school attendance days a year • 1.5 billion healthy days for children under five	US$9.9 billion a year
Health-care savings		• US$7 billion a year for health agencies • US$340 million for individuals
Value of deaths averted, based on discounted future earnings		US$3.6 billion a year
Total benefits		**US$84 billion a year**

Sources: OECD (2010); Prüss-Üstün et al. (2008); Hutton and Haller (2004).

inadequate water, sanitation and hygiene. Providing access to safe drinking water in poor societies is one of the most effective labour-saving measures. For governments to consider just the financial value of health-care savings in their budget decisions, would be to overlook the importance of less visible, but in many cases more significant, economic values (Table 23.1). In poor countries, this is a concern because when the financial benefits are lower than the economic ones, the effort made to improve water services is usually less than what is required for economic development.

Information about the macroeconomic performance of poor countries – measured in gross domestic product (GDP), employment and productivity – has helped to confirm the vital correlation between water and economic development, and the potential that water development has to boost economic growth: Countries without improved water management and access to water and sanitation services, with per capita annual income below US$750 grew on average at only 0.1% per year, which is equivalent to being trapped in the same level of income, while countries in the same range of income but with better access to water services grew at 3.7%, a rate that, if sustained in the long term, might guarantee their escape from poverty and help them converge to middle income economies (SIWI, WHO and NORAD, 2005).

BOX 23.3

Valuing the effects that water-related diseases have on productivity can improve investment targeting

In a study in 2008, the World Bank presented an estimate of the economic effects of mortality from malaria, pneumonia and acute lower respiratory illnesses in Ghana and Pakistan. The same study also looked at the prevalence of diarrhoea and malnutrition. A human capital approach was applied to quantify lost wages that resulted from environmental factors. The long-term direct and indirect costs in Ghana and Pakistan were estimated at 9.3% and 8.8%, of their respective GDPs. At least half of this impact is attributed to water-related environmental risks.

The 1991 cholera epidemic in Peru was treated at a cost of US$1 billion, but could have been prevented by expending US$100 million.

Source: Moss et al. (2003).

23.1.2 Valuing the benefits of water can support pro-poor strategies and better targeting

The benefits of water, when properly valued, show that projects aimed at improving access to basic sanitation and safe drinking water make economic sense. And what is more important, they show that they are effective in promoting equity, in stimulating gender fairness and in opening new windows of opportunity for the poor and for future generations. Valuing the many non-financial benefits of water is essential to enable societies to take advantage of development opportunities, to focus on poverty alleviation and to avoid unsustainable trends in water policy (Box 23.3 and Figure 23.1).

Valuation of the health benefits of investing in water and improving water management shows that providing basic water and sanitation services is essential to halt the poverty spiral of low income, low savings and low investment in human and physical capital. ‘Poor people in Africa spend at least a third of their incomes on the treatment of water-related diseases like malaria and diarrhoea. … The cost of the productive time lost due to these diseases as well as widespread human

BOX 23.4

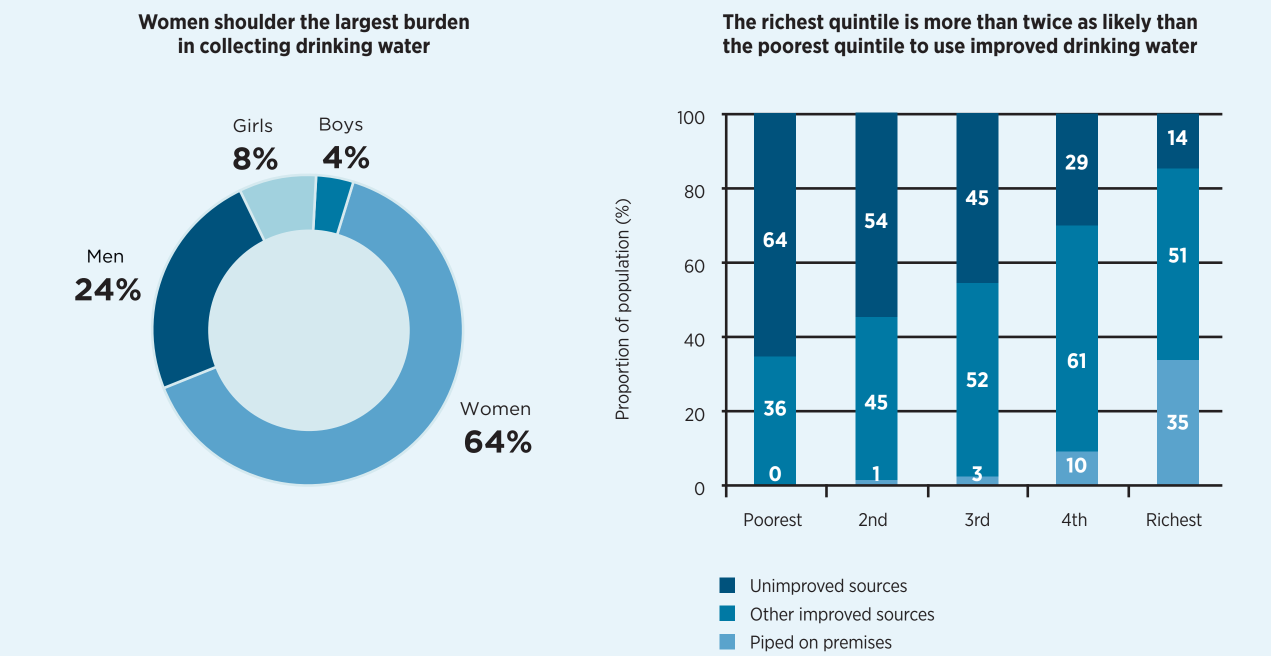
Valuing the benefits of water can define international priorities and target support at the poor

The Copenhagen Consensus sought to compare the costs and benefits of a broad range of development interventions in order to help define international priorities. It did this by evaluating benefit–cost ratios (BCRs) using standardized methodologies across a number of sectors. In 2008, Whittington et al. carried out an exercise on a range of low-cost water and sanitation sector interventions. Not all water and sanitation projects would pass a benefit–cost analysis, especially because of the substantial up-front capital investment required, which yields benefits over a long period. As a result, it is vital to evaluate the costs as well as the benefits of alternative investments, given that different service levels may yield comparable benefits at very different costs.

The Whittington study (2008, p. 3) concluded by stating: ‘the key to successful water and sanitation investments is to discover forms of service and payment mechanisms that will render the improvements worthwhile for those who must pay for them. In many cases, the conventional network technologies of water supply will fail this test and poor households need alternative, non-networked technologies’.

FIGURE 23.1

Access to water and potential gains in terms of gender, equity and education opportunities for children.
Left panel, distribution of those who usually collect drinking water; right panel, proportion of the population using drinking water piped on premises, other improved drinking water source or an unimproved source, by wealth quintile, sub-Saharan Africa.



Note: For families without a drinking water source on the premises it is usually women who go to the source to collect drinking water. Surveys from 45 developing countries show that this is the case in almost two-thirds of households, while in almost a quarter of households, it is men who usually collect the water. In 12% of households, however, children carry the main responsibility for collecting water, with girls under 15 years of age being twice as likely to carry this responsibility as boys under the age of 15 years. The real burden on children is likely to be higher because, in many households the water collection burden is shared, and children – though not the main person responsible – often make several roundtrips carrying water.
Sources: WHO and UNICEF (2010).

suffering must also be added to this' (SIWI, WHO and NORAD, 2005, p. 13).

People who do not have access to water from a safe facility that is located nearby pay a high opportunity cost for collecting the minimum amount they need to satisfy their basic needs. Although this cost is not measured in monetary terms, it is effectively paid in terms of lost time, lost school days and lost working days. Making water available to the poor is a means of freeing up human capital that can then be put to creating wealth. A valuation of these benefits justifies the collective provision of water because self-provision for household consumption is proportionally more expensive for the poor than for the rich and represents a heavier burden for women and children. But it is important to understand which interventions will bring about the greatest benefits, based on levels of service and ability of poor households to pay.

Halting the poverty spiral is generally possible if income earning opportunities for the poor are increased. Improving water supply for productive uses, particularly for food production, would facilitate this (Box 23.5). Agriculture is still the main livelihood and the engine of growth for three-quarters of the world's poor, who still predominantly live in rural areas. Strategies to reduce poverty need to focus on improving farmers' incomes and building resilience in this sector. Valuing the impacts of higher yields and the effects of growing a greater variety of crops can help to bring about better poverty reduction strategies relating to the agricultural use of water. Knowledge of the value of higher incomes and the impact of lower food prices

BOX 23.5

Valuing the benefits of sanitation can foster government action and redouble the focus on sanitation

- 2008 was the International Year of Sanitation. This helped to put the neglected sanitation crisis onto the agendas of government leaders, the donor community, and civil society.
- The Sanitation and Water for All initiative aims to encourage donor governments and recipient countries' finance ministers to increase the efforts being made in the area of sanitation.
- Sustainable Sanitation: The Five-Year Drive to 2015 is an advocacy vehicle committed to keeping sanitation high on the political agenda, promoting national coordination and inspiring actors in the sanitation and health fields.

All these efforts are built, to a large extent, on the results of valuation analysis that show the links that sanitation and health have with economic development and environmental sustainability. The crucial information came from the work of the World Health Organization (WHO) (which highlights the important economic benefits of appropriate sanitation actions), and the UN-Water GLAAS analysis of existing drinking water and sanitation financing and its recommendations. Recommendation 1 says: 'Developing countries and external support agencies to demonstrate greater political commitment to sanitation and drinking water, given their central role in human and economic development.'

helps to measure those effects and target strategies appropriately.

23.1.3 Valuing the benefits of water can inform water management choices

Water valuation makes a real contribution by providing relevant information on the value of the different types of benefits and costs attached to the different courses of action open to water managers. Some of these courses of action complement other water and sanitation initiatives, while others are mutually exclusive (Table 23.2).

Each alternative considered on its own can be assessed as an individual project. Nevertheless this information, while useful, is not enough to make a decision. It requires comparing the value of its opportunity costs with the best available alternative. Dams, for example, are used to store water for drinking, irrigation, and hydroelectricity generation as well as flood management. All these uses provide considerable benefits to society. However, dams have negative effects on the hydromorphological conditions of rivers by modifying aquatic habitats and influencing other valuable ecosystem services downstream. The impact of the value, or the cost, of losing these services must be considered when assessing the overall economic benefits of a dam. It is perhaps even more important to consider the alternative options for storing water, as was done in the case of New York when the city needed to plan a new water supply system (Box 6). Alternatives can include using natural infrastructure such as wetlands, soil or groundwater to store water. Each of these, along with other options, will provide co-benefits such as fisheries, water purification or flood mitigation. In the case of desalinated water, it may be more expensive to produce but its provision is more dependable. The cost of provision, however, needs to be compared with the full cost of using alternative sources of water. This comparison should include environmental costs that would not occur if the overuse of resources were prevented.

The relevant comparison of opportunity costs and benefits that are either obtained or foregone with each management option in the decision-making process are varied and context specific – for example, when considering how new infrastructure projects may (or may not) be more beneficial than demand-management options for ensuring water security. Demand management may be the most cost-effective way of increasing available water, but existing arrangements may make it financially unviable for water distribution managers. Managers will 'sell' fewer services, and so get a reduced income. With price caps on water services and no support from governments, this may affect the funding that is available for the operation, maintenance and replacement of infrastructures – and the viability of the services themselves.

When assessing alternative courses of action, it is also important to consider that the market price cannot capture the full range of benefits that water brings to people and economies. Benefits and costs that affect peoples' welfare through, for example, water pollution and exhaustion, are often absent in the balance of costs and benefits that individuals and firms take into account when making decisions. For example, when judged on the basis of their own interest, using groundwater may be financially cost effective for farmers. But it can exhaust water supplies and transfer the

TABLE 23.2

Types of benefit attached to different water and sanitation interventions

Investments options	Types of benefit
Providing access to safe water and sanitation	
Providing access to safe water near the home • Building water access point • Building and operating water treatment plants • Providing point-of-use water treatment methods **Providing access to sanitation and hygiene** • Building sanitation facilities • Promoting the adoption of hygienic practices **Wastewater collection and transport** • Collecting wastewater via sewerage networks • Collecting and transporting pit sludge outside the home	**Health benefits** • Reduced incidence of waterborne diseases (e.g. diarrhoea) and of water-washed diseases **Non-health benefits/economic benefits** • Time saved for productive activities • Reduced coping costs **Economic benefits** • Increase in productivity • Use of urine and faeces as economic input • Impact on tourism from improved amenity **Other benefits** • Increases in overall cleanliness, dignity and pride • Increased school attendance, especially for girls
– downstream, in wastewater treatment for safe disposal	
• Building and operating wastewater treatment plants • Ensuring safe disposal of residual sludge • Relying on natural treatment processes	**Health benefits** • Reduced incidence of waterborne diseases (e.g. diarrhoea) and of water-washed diseases • Benefits from improved recreational waters **Environmental benefits** • Reduced eutrophication **Economic benefits** • Reduced pre-treatment costs downstream (for drinking water and industrial purposes) • Protection of commercial fish stocks and aquaculture • Enhanced tourism activities • Increased water supply for irrigation • Saving of fertilizers through use of sludge **Other benefits** • Recreational benefits • Increased property values
– upstream, in managing the supply/demand balance sustainably	
Protecting water resources • Establishing catchment protection zones • Establishing voluntary agreements • Establishing regulations **Increasing and ensuring supply** • Building storage capacity • Building abstraction capacity • Developing alternative sources, such as aquifer recharge, desalination, re-use of treated effluent • Adopting drought management plans **Managing demand** • Reducing leakage (on the network and within customers' premises) • Introducing incentive pricing • Installing water-saving devices • Raising awareness and educating the public	**Environmental benefits** • Reducing pressure on available resources (especially groundwater) and improving river flows • Economic impact on use of water for economic activities (agriculture, hydropower) **Economic benefits** • Reduction in water pre-treatment costs • Uninterrupted supply for production processes • Downsizing of facilities • Reduced need for desalination (energy savings) **Other benefits** • Increased quality of life due to reliable water supply • Indirect benefits (e.g. linked to recreational activities on dams)

Source: OECD (2011).

costs to other water users. Where short-term profits are higher than real economic costs, boom and bust outcomes result, and sustainable development may be undermined. There are many examples of much effort having been put into building water infrastructures that eventually became useless when water resources were exhausted.

The external costs incurred by the overuse and degradation of water resources often remain ignored until a crisis is reached – by which time the value of the infrastructure itself is usually reduced and is compromising the sustainability of services. If institutions governing water fail to properly manage its use, there is a danger of market incentives favouring short-term financial benefits at the expense of the integrity of the resource base and its long-term economic value. Worldwide evidence of the overexploitation of surface water and groundwater unveils this fact. It is expected that by 2025, 1.8 billion people will live in countries or regions with absolute water scarcity and two-thirds of the world population could be affected by water stress conditions (UNESCO–WWAP, 2006). In many places, society has been willing and able to go further with investment opportunities where the short-term financial returns for water users are transparently inferior to the economic benefits that will be available as a result of long-term sustainability.

23.1.4 Valuing non-market benefits can prevent critical ecosystem services from being neglected

Ecosystem services are the benefits, or services, that ecosystems bring to people. Drinking water, water for food production and the generation of hydroelectricity are all ecosystem services – as are other often neglected services such as nutrient recycling, climate regulation, cultural and recreational benefits and flood mitigation. Most of the decisions that have to be taken are actually about maximizing one particular service, often at the expense of others. In this way, water decisions nearly always involve trade-offs. The objective should be to optimize the delivery of multiple inter-related ecosystem services. The purpose of effective valuation is two-fold. First, to identify and recognize what services are involved in the trade-off (even if they can't be valued). And second, to quantify values as much as possible in order to assist in calculating trade-offs.

Some of the non-market services provided by ecosystems can be relatively easily quantified and generate substantial values. Examples include the value of ecosystems such as wetlands in flood mitigation, and forests in sustaining drinking water quality. It is the growing recognition of these values that is motivating greater interest in the restoration of these services. Valuation has often shown that conserving ecosystems, or reversing their degradation, is not only a sustainable ecological alternative (very often with multiple benefits), but is also economically beneficial.

Valuation essentially provides evidence that economic benefits are relinquished when policy, management and investment cause avoidable environmental degradation. For producers of goods and services who use water directly, water prices and costs are the basic criteria for water-use decisions. But prices often do not reflect the real production costs or economic value of water. In particular, prices often do not reflect the decline in the natural capital stocks that support the production of all ecosystem services. Therefore, decisions taken on infrastructure investments are disconnected from what is efficient and sustainable for the economy and the environment as a whole.

Better awareness of the issues and more sharing of information on the economic benefits of maintaining or restoring natural capital is also important when trying to reach collective agreements and when trying to design financial incentives that align individual behaviour with the common good. Valuation and better communication of the costs and benefits are crucial for taking better individual and collective decisions on the use of water.

BOX 23.6

Balancing benefits and costs when assessing water management options: New filtration infrastructures versus water catchment protection in New York

'Presented with a choice between provision of clean water through building a filtration plant or managing the watershed, New York City easily concluded that the latter was more cost effective. It was estimated that a filtration plant would cost between $6 billion and $8 billion to build. By contrast, watershed protection efforts, which would include not only the acquisition of critical watershed lands but also a variety of other programs designed to reduce contamination sources in the watershed, would cost only about $1.5 billion.'

Source: Daily and Ellison (2003).

BOX 23.7

Valuing non-market ecosystem services in the European Union can inform decisions on environmental objectives in planning processes

In the European Water Framework Directive, valuing the costs and benefits provides the information required to assess whether the opportunity cost of improving water bodies – is disproportionate compared with the potential socio-economic and environmental benefits, and to then decide on the precise objectives and timing of measures to improve water status in the river basin management plans. It is widely accepted that in many water bodies there are more welfare gains to be obtained by improving the ecological status than by allowing their further degradation.

There are now a number of examples that demonstrate the benefits of environmental improvements and influence water planning and decision-making (Box 23.7).

23.1.5 Valuing to assess trade-offs in water allocation decisions

Water ecosystems have only a limited ability to continue to provide water services to the economy. So it is important for economic growth that water is used well and allocated to its various uses efficiently. Competition can be managed and degradation prevented by having sufficient accurate information about the economic, social and environmental value of water in its various uses. This will also help with re-allocating water so that it provides greater benefits to the economy and to society. There will be trade-offs to be considered too and decisions to be taken about which benefits to forgo when using water for one purpose instead of another.

In a world of scarcity, the valuation of water productivity in agriculture also needs to be considered. Information needed by governments so that they can assess whether water is being used for low-yield crops in water-scarce areas – and if so, determine alternative crops or uses that would make the greatest contribution to the economy. Such a valuation provides a database that farmers can use to make informed decisions about investing in improved infrastructure and crop varieties, and that governments can use to target their investment and to formulate incentives for improving efficiency in water use.

Legal frameworks and institutions need to be set up and better ways of allocating water need to be found. These need to be done using principles – such as equity and efficiency – that may be politically difficult to implement in practice. There is also a need to improve the mechanisms that deliver desired objectives to a range of diverse stakeholder interests (Box 23.8). If there are institutional arrangements that allow water to be allocated to where its use is most valuable, this may help in drawing up mutually beneficial allocation agreements. Establishing legal frameworks for decentralized water management is the type of institutional arrangement that has become important in many water scarce countries. These can be used to implement economic instruments such as water trading, licences and rights to use water. Water trading has developed in countries such as Australia, the United States, India, Chile and Spain (Box 23.9).

BOX 23.8

Stakeholder-oriented valuation can support allocation decisions water management in Tanzania

In the United Republic of Tanzania, some areas face severe water scarcity. Demand for water has been growing and there is conflict between the energy and irrigation sectors, between these sectors and conservationists, and between upstream and downstream users. In 2005, the government established a legal framework that decentralizes water management and increases stakeholder involvement by including local catchment area committees, river basin associations and water-users associations. A participatory approach to water valuation – through surveys, data collections and workshops to analyse data and results – was implemented to enable local stakeholders to engage in implementing IWRM.

Indicators for economic, social and environmental values were considered including crop water productivity in different zones, value across all water sectors, income from water-related production activities, food security (including the nutritional value of crops), access to drinking water, conflict over water, environmental base flows and environmental changes. The valuing process supported decisions to change to crops that use less water, to improve capacities to increase water productivity, to review existing water rights and the training of water-users associations, and to coordinate farmers' own marketing of agricultural products in order to increase income and improve stability.

Source: Hermans et al. (2006).

23.1.6 Valuing water can help to contain water conflicts and promote cooperation in preserving water resources

In the context of access to critical transboundary water resources, valuing can inform governments about the advantages of cooperation instead of competition or conflict. Working towards a common vision of the value of shared water resources is a powerful instrument for finding a way in which agreements in international disputes over water can be self-enforced.

Countries are more likely to cooperate when the net benefits of cooperating are perceived to be greater than those of non-cooperation – and this is even more likely when the sharing arrangement is perceived to be fair. The advantages of cooperation and collective action are easier to see when the benefits can be made visible to each one of the parties (Box 23.10).

Valuing provides key information that allows stakeholders to move towards cooperative agreements. It also enables the creation of benefits for all those involved in providing solutions. For example, valuing the benefits that water catchment protection can have in securing adequate supplies of quality water can open up solutions that were not envisaged. This can include cost saved by reducing the need for downstream treatment. Protecting watersheds also leads to a broad range of positive environmental effects on the quality of water in water bodies, in groundwater resources, in soil resources and the quality of water available for vegetation and for native flora and fauna.

BOX 23.9

Valuation of scarcity in water markets

Values associated with water can be observed directly through market activity in arid regions where there is trading, where water is fully allocated and where irrigation is under pressure from municipal, industrial and, in some cases, environmental, demands. There are some basins where rights to use water are defined, enforced and tradable. Market prices in examples in the United States (in California's Central Valley, Colorado's South Platte basin and Nevada's Truckee River basin), and in Australia (in the Murray-Darling basin) confirm that the value of water use varies considerably and that it is driven by variations in market conditions and supply.

Data suggest that in many river basins, market transfers are happening in line with the agricultural value of water, but at a rate that's below the value of water to the domestic consumer or industrial user. Markets that don't have significant urban demand see prices that reflect the agricultural production value of water, which is calculated as the difference in the price of irrigated versus dry land. Where there is significant urban demand, prices are driven by this and shaped by the cost of transferring the water to urban use through conveyances and so forth.

Market values for permanent water rights acquisitions are roughly one order of magnitude greater than the prices for temporary allocations. From this it can be deduced that capitalization rates will be roughly on the order of magnitude expected given current costs of credit. The market value of water is intrinsically regional, or even local, because physical limitations constrain the scope of cost-effective trade. As a result, price observations from one context may have little relevance in another.

Source: Aylward et al. (2010).

23.1.7 Valuing water to design appropriate subsidies and targeted financing

Despite the substantial economic returns involved in providing water services to households, to industry and for food production, the basic water needs of people in many poor countries are still not being met. This is a result of a combination of the inability of individuals and business to pay and too few financial incentives to invest in the required facilities. These are key reasons why decisions should be taken to give water operators and community service providers better access to loans and well-targeted subsidies (Box 23.11).

BOX 23.10

Valuing benefits supports cooperation in international river basins

Benefit-sharing agreements exist for various international rivers, including the Danube, the Niger, the Okavango and many others. The Organization for the Development of the Senegal River was created in 1972. Disagreement about the competing rights of Mali, Senegal, Guinea and Mauritania was no impediment to the four countries reaching an agreement to share the benefits of various river projects. A common knowledge of the benefits was essential for building an institutional framework: 'the development of multi-purpose water resources infrastructure is expected to yield expanded opportunities for growth, reduced immigration and poverty, and improved health and livelihoods of the population while also preserving the environment' (World Bank, 2009, p. 12).

Valuation can help to identify when it is justifiable to charge water fees that are lower than full cost of recovering the investment.

Valuation can also give society crucial information that can be used to find practical solutions that ease the transition from the subsidized tariffs that are designed to stop poverty spirals, to a set of self-financed services that make water services financially sustainable.

In many poor countries, only a small portion of the benefits of water services can be funded entirely by the public or by private organizations. On purely financial grounds, providing water is not an attractive opportunity for private businesses. This can lead to poor maintenance and the deterioration of privately run water infrastructure and basic services. The consequence of this is a vicious downward spiral of underinvestment leading to poor service that undermines the ability to capture adequate revenue to operate, maintain and invest in systems (Figure 23.2).

BOX 23.11

Valuation can support the design of subsidies and targeted financing

There are economic benefits to be had from improving access to basic sanitation and safe drinking water. The benefits of irrigation have been estimated by the World Bank to yield average rates of return of 20%. However, financial problems and mismanagement can lead to the downfall of many irrigation systems. The prices of agricultural products have been falling and some investments are now less financially viable. There may be a need to stabilize the income of poor farmers who are subsisting below a certain income level and who are exposed to regular drought and crop insecurity.

Valuing the social and environmental consequences of abandoning financially unsustainable systems has found that there should be support for the implementation of financial packages and other capacity building programmes (such as record keeping and the collection of fees) by international donors. Donor resources that are already in place are being redesigned to help attract other resources and investment. They are also focusing in providing funding to bridge the gap between investment in infrastructure and income generation. This supports the development of local capital and financial markets including microcredit initiatives and local banks and is consistent with the aims of output-based aid.

Source: Grimm and Richter (2006).

Changes in the provision and management of water from being mostly self-collected to being a communally provided set of water provision services might mean that people have more time and better health. But they still won't have enough money to pay the financial cost of the services they get. In the first stage of this, even if the valuation exercise shows that the expected economic benefits are undeniable (particularly for the poor) people cannot afford to pay the full financial cost of the service. So in the absence of a collective action, they will continue without access to basic sanitation and safe water.

But improvements in water access might not be sustainable in the medium term if society and water institutions are not able to manage the transition from the initial stage (where the priority is to improve access to basic services) to an advanced stage where the financial sustainability of providing water needs to be ensured. New ways have to be found to transform the new opportunity of improved access to water into effective education, crop diversification or earning prospects for the poor.

Valuation is useful for determining what economic incentives are required to align individual behaviour with collective targets and objectives. For example, valuing less-visible non-market ecosystem services can provide clearer indications of the value of preserving or restoring ecosystems. Such valuation can be simpler than is often thought. For example, the loss of an ecosystem's ability to deliver clean water can be estimated from the point of view of the cost of rectifying the problem artificially (for example, the cost of artificial water treatment) or from the point of view of the economic cost of living the consequences of poor quality water (for example, a fall-off in productivity, higher health-care expenses, etc.). In many instances, the absence of an ecosystem service is already generating an economic, and often direct, financial cost. Identifying where benefits arise and costs are incurred helps to ascertain how costs can be transformed into incentives that will bring more efficient economic outcomes (Box 23. 12).

23.1.8 Valuing can support decisions on what measures to take to improve water security

There are increasing demands on water and less-predictable rainfall patterns and water flows (including a higher frequency and intensity of extreme events such as floods and droughts). So better water security and more-resilient management options have an increasingly higher value. Valuation approaches should factor in and provide information on the benefits, or risks, of increased or decreased water security. When done effectively, they should shed light on the costs and benefits of more resilient management options. The information that a valuation approach provides about the changing values of water in its various uses can be vital for implementing adaptive planning and management. It can also help to prevent inappropriate uncontrolled individual responses to risk and uncertainty.

Management that makes water supplies secure has a critical role in making the benefits of development more predictable. Poor and water-scarce societies that are now trying to establish systems to supply water and basic sanitation services are faced with the potential adverse effects of climate change (World Bank, 2010; Danilenko et al., 2010; Box 23.13).

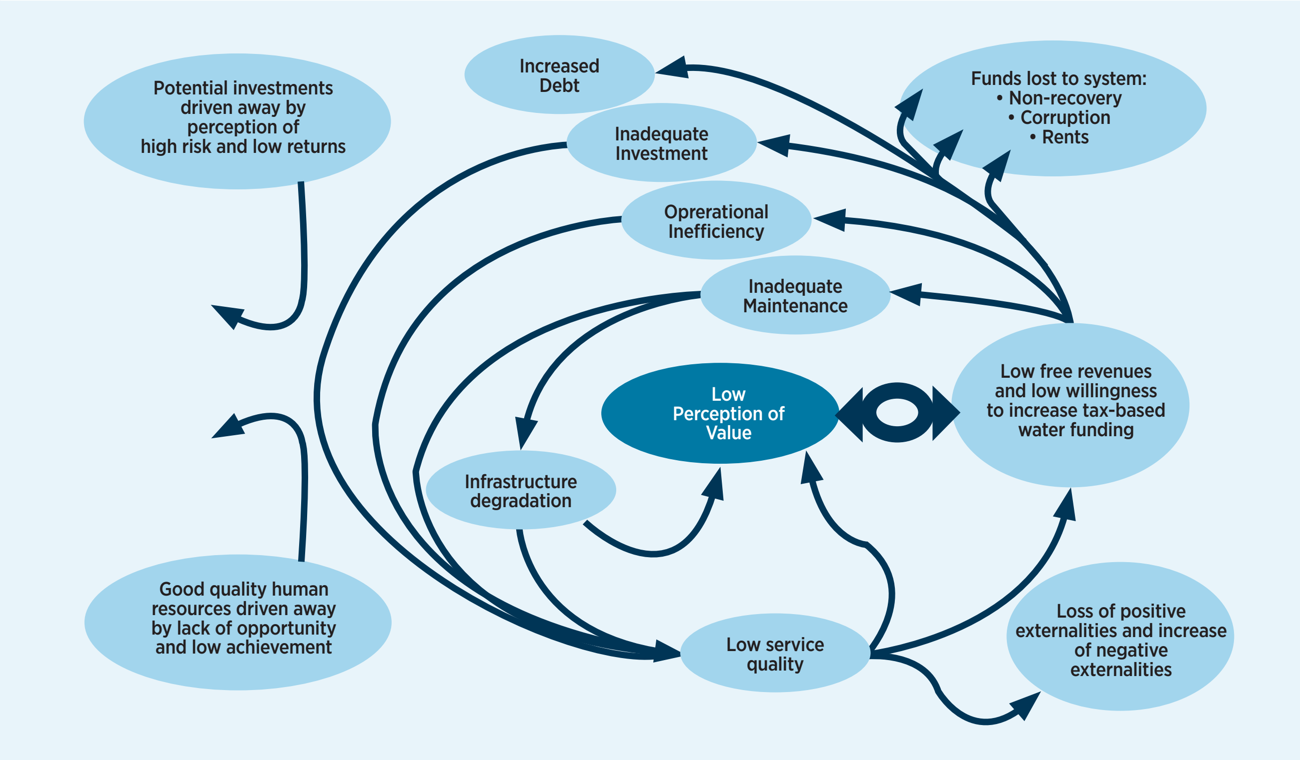
Collective decisions on measures that will increase water security and facilitate the financial resources to do so cannot be properly informed without a proper valuation of the benefits and costs. Valuation can improve the accuracy of the information that private and public agents use to take better-informed decisions with full knowledge of the costs involved. Water storage schemes and infrastructure, water conservation programmes and improvements in efficiency are all examples of the kinds of measure that are already considered beneficial, but which are even more valuable in a climate stress context. Other measures, which need only be considered in the face of uncertainty, may include the diversification of water sources (such as desalination and non-conventional sources), the upgrading of storm water systems, the reversal of coastal developments to reduce exposure, the recovery of floodplains for flood protection and the recovery of aquifers for buffering security stocks.

Valuing can provide valuable information on the capital and maintenance cost of these various options. And it can also give an insight into the benefits and opportunity costs involved in water security and other ecosystems services.

Economic incentives can have a role in enhancing adaptive capacities. When water supply and quality

FIGURE 23.2

The vicious spiral of low funding



Source: Adapted from Moss et al. (2003, fig. 4, p. 13) by J. M. Moss.

vary unpredictably over time and from location to location, stakeholders and water users might be more efficient than public authorities in finding the most cost-effective and appropriate answers. For example, valuation can support water trading and the design and implementation of a weather-based insurance scheme that may provide incentives to invest in water saving and make water allocation and reallocation decisions acceptable, and adaptable. Such a scheme may be contingent on changes in water supply and the stabilization of income and economic output.

The extent to which some of these measures need to be taken depends on how individuals and governments value the increased security they provide. It also depends on how they value the benefits that have to be foregone in each case. A higher aversion to uncertain events means a higher risk premium – that is to say, the more people fear exposure to extreme events, and the more likely these events are seen to be, the more people will be willing to pay for insurance. Valuing the private willingness to pay to increase security is an important step in judging the extent to which available measures would be financially viable.

Valuing provides reliable evidence of the potential damage and reduction in welfare that may result from leaving risk responses to spontaneous individual answers instead of implementing collective and more comprehensive anticipatory responses to water variability and climate change. Leaving risk response to individual efforts to defend and maintain production

BOX 23.12

Valuing compensation payments for environmental services in China

China's ecological compensation mechanisms are a modern variant of traditional government payments to providers of ecological services. The government transfers money and compensates land owners (or land users) for specific actions that produce environmental benefits. There are various applications of the eco-compensation approach. These include compensation paid to residents living near water sources or reservoirs to migrate to other areas, subsidies paid to sewage treatment plants, compensation to support the forestry sector in upstream areas and payments to farmers to compensate for lost production caused by reducing the use of fertilizers and pesticides.

At the central government level, China has developed and implemented some of the largest public payment schemes for ecosystem conservation in the world. These schemes include the Sloping Land Conversion Program (SLCP), the Natural Forest Protection Project (NFPP), and the Forest Ecosystem Compensation Fund (FECF). The SLCP (also called the 'Grain for Green' program) was initiated in 1999 to restore natural ecosystems and mitigate the adverse impacts of farming in previously forested areas or marginal land. Farming these lands resulted in flooding, the sedimentation of reservoirs, and dust storms. Farmers who enrol in the scheme receive payments for seeds, seedlings, and management expenses. It is one of the largest public transfer schemes in the world, reaching some 30 million farms spread over 7 million hectares (ha) of cropland. It disburses around US$8 billion per year. The FECF programme targets the management of privately owned forests. It compensates land owners for the ecosystem services provided by their land and for the land and resource use restrictions that are subject to when they participate in the programme. The scheme currently covers 26 million ha in 11 provinces, and costs the government about RMB 2 billion ($253 million) annually – of which about 70% goes to farmers, who are paid an average of US$9 per hectare. Local governments are encouraged to provide additional funds. In December 2004, the FECF was extended to the entire country. It covers key state-owned non-commercial forests, as well as woodlands in areas that are at risk from desertification and soil erosion.

Source: Jian (2009).

BOX 23.13

Valuing the economic loses of droughts and the effects of climate change can make the case for political action

In Kenya, droughts occur on average once every seven years. Their economic cost (as was the case on the 1999–2000 drought) was equivalent to one-sixth of the gross domestic product (GDP). This figure suggest that if the country could decouple its economy from rainfall variability, its annual economic growth could increase by 3.5% (SIWI and WHO, 2005).

Nicholas Stern's review, *The Economics of Climate Change* found that climate change had a significant impact on economic output. In a baseline climate-change scenario, the review estimated that climate change would be responsible for a 2.5% loss in GDP in India and South East Asia by 2100, and would cause a 1.9% loss in GDP in Africa and the Middle East over the same period.

Source: Stern (2007).

activities could lead to the extension or intensification of existing vulnerabilities. Spontaneous answers from people, businesses, and farmers in rural communities depend on their perception of value and risk, the options available to them and their individual economic incentives. The lack of a planned and coordinated response to increased scarcity and risk will favour individual answers that do not necessarily produce the best or most sustainable outcomes. For example, they may add more pressure to cultivate marginal land or adopt unsustainable cultivation practices because erratic rainfall has made yields drop. All of these possibilities could reinforce water scarcity and land degradation and endanger the biodiversity of both wild and domestic species. They might also increasing vulnerability and jeopardize the ability to respond to climate and other risks later on.

Showing the difference between the financial and economic costs and benefits of alternative actions is a useful way of underlining the importance of a planned, anticipatory and coordinated response to water management challenges. Collective actions instead of spontaneous individual responses are required as well as implementing risk management options instead of coping with the consequences of extreme events and adapting to negative trends. Valuation may play a critical role in showing the advantages of cooperation, leading to better responses and higher security, instead of individual actions.

23.2 Challenges for Valuing water

Many valuation methods already exist and, have been tested in a variety of situations and contexts that are relevant for policy decisions. Water valuation methods vary according to how they obtain information about the importance that people give to water benefits.

In spite of its relevance to policy and in spite of the growing number of successful examples, valuation is still controversial. Among the issues most commonly discussed are: the usefulness of the various valuation approaches for any specific decision problem; the robustness of the results provided by valuation exercises; the comparability of costs and benefits when both are obtained from different sources, at different geographical scales and with different valuation methods (UNSD, 2007 and Chapter 8).

Water valuation is still challenging because data is often not available and is expensive to collect and because assumptions sometimes need to be made to overcome the absence of relevant information. Water

TABLE 23.3

Valuation techniques for water

Valuation techniques	Comments
1. Water as an intermediate input to production: agriculture, manufacturing Residual value Change in net income Production function approach Mathematical programming models Sales and rentals of water rights Hedonic pricing Demand functions from water utility sales	Techniques provide average or marginal value of water based on observed market behaviour.
2. Water as a final consumer good Sales and rentals of water rights Demand functions from water utility sales Mathematical programming models Alternative cost Contingent valuation	All techniques execpt contingent valuation provide average or marginal value of water based on observed market behaviour. Contingent valuation measures total economic value based on hypothetical purchases.
3. Environmental services of water: waste assimilation Costs of actions to prevent damage Benefits from damage averted	Both techniques provide information on average or marginal values

Source: UNSD (2007, table 8.1, p. 120).

benefits are usually site-specific and cannot be easily transferred from context to context. Methods and assumptions are not standardized and uncertainty in the numerical results obtained may be quite high. Valuation methods have been developed in response to these limitations and the results are validated by extensive scientific research. However, the assumptions, the numerical results, and the limitations on how valuation results can be used to assess policy options, are still difficult to communicate to stakeholders.

Decision-making contexts have favoured valuation methods and results that are less controversial in that they do not involve sensitive value judgments and are easier to communicate to stakeholders (Table 23.3). These are methods where, in the main, results are initially obtained from directly observed behaviour in existing markets – rather than from laboratory tests or chosen experiments in implicit markets and artificially created decision environments. They are also methods that can make the best possible use of the information that is already contained in existing market prices to derive the value of other water benefits. Examples of contexts where these methods have been used are welfare measures such as averted costs (for example measures to value the costs that were avoided when clean, safe drinking was obtained); averted damage (methods to value the flood mitigation services provided by the environment); the residual value (methods to show how crop yields and farmers' incomes increased when irrigation was made possible); and avoided treatment cost (from the water purification services provided by the natural water course instead of by manufactured systems). These methods provide useful information about three important categories of water benefits: water as an intermediate input to produce other goods, water as a final consumer good and the environmental services of water.

Considering values and specially value perspectives is of great importance in implementing measures – especially measures related to adapting to climate change because these will necessarily mean a change to the status quo. Managing participatory decision-making is becoming increasingly important. In practice, valuation and the consideration of value perspectives are fundamental when balancing trade-offs. They also support decision-making processes where compromises need to be reached between different stakeholders – especially when managing water demands and allocation decisions (Hermans et al., 2006).

There is a need to develop valuation frameworks that can be used in information gathering and policy-making. The links between ecosystems and human well-being are complex. A basic conceptual framework has been developed by the Millennium Ecosystem Assessment that provides a logical structure for the analysis and valuation of ecosystem services (Millennium Ecosystem Assessment, 2005). Including information on the value of water in water accounting frameworks would be an important step forward. The UN Statistics SEEAW framework (System of Environmental-Economic Accounts for Water) provides such an integrated information system to study the interactions between the environment and the economy (UNSD, 2007). It can provide the basis for progress, specifically because it covers the stocks and flows associated with water. There is also a need for further adaptation of valuation methods so that they can better respond to policy questions and management needs.

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CHAPTER 24

Investing in water infrastructure, its operation and its maintenance

The World Bank

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Acknowledgements Research assistance was provided by Olusola Ikuforiji. This work is a product of the staff of The World Bank with external contributions. The findings, interpretations, and conclusions expressed in this work do not necessarily reflect the views of The World Bank, its Board of Executive Directors, or the governments they represent.

Developing countries face a growing funding gap as they try to keep up with the rehabilitation, operation, and maintenance of aging water infrastructures. New water systems must also be built to cope with growing populations, increasing demands for water, changing consumption patterns and climate change.

More than 80% of water investment comes from public funds. While the international private sector has brought vital efficiency improvements, their appetite for risk in developing countries is low and diminishing. Public or private, availability of resources for water infrastructure is becoming more uncertain.

This gap can only be filled by an optimal mix of funds that is different for each country. But regardless of the formula, all countries can improve the use of money in the water sector and all actors have a role to play.

When service providers are able to recover more costs, they can stop the vicious cycle of degraded services, making them better equipped to mitigate the risks associated with climate change and the volatility of financial markets.

By improving the way funds are allocated, transferred, and used, governments can do more with scarce resources and reach a level of governance that enables them to benefit from private sector innovation and long-term financial sustainability.

In the meantime, development institutions can provide stopgap assistance and promote the consideration of greener infrastructure strategies. Assessment of tradeoffs at the national level can yield demand-side interventions that are more cost-effective than large scale systems and decrease the fiscal burden on poor countries.

24.1 Water, risk and uncertainty

24.1.1 Background

Economies will not grow and poverty will not be reduced without sufficient investment in water services and water resource infrastructure. Poor quality water and limited access have substantial implications for the poor, ranging from ill health caused by unsafe water and sanitation to reduced productivity (Fay et al., 2005). But adequate and well-managed infrastructure underpins water's role as a driver of socio-economic development.

The 10th Millennium Developments Goal (MDG) aims to halve the number of people worldwide who do not have access to improved drinking water and sanitation. This is a necessary condition for other 2015 MDGs, including the goal of reducing poverty. According to the World Health Organization (WHO), 80% of diseases in the developing world are caused by unsafe water, poor sanitation and a lack of hygiene education. Women and girls in developing countries benefit immensely from well-sustained water supply and sanitation services. The enrolment of girls in school rises when latrines are provided, and the improvement of safe water sources frees women from spending hours every day drawing water and carrying it home (WaterAid, 2005).

The 2011 MDG report reveals that between 1990 and 2008, more than 1.8 billion people gained access to improved sources of drinking water. This raises the proportion of the population with access from 77% to 87%. Progress, however, is uneven. The ratio of rural to urban inhabitants who don't have access to improved drinking water is 5:1. And meeting the sanitation target has proved daunting. Although the number of people with improved access to sanitation rose from 43% in 1990 to 52% in 2008, over half of the world's developing nations are still without access to adequate sanitation (UN, 2011). And the food, energy and financial crises have exacerbated matters.

24.1.2 Global crises

Water is a critical input in production and services, which means that it is directly affected by the global financial, energy and food crises (Winpenny et al., 2009). To guarantee water security, it is necessary to address how these crises affect water.

According to the *Global Monitoring Report 2010: The MDGs after the Crisis,* the financial crisis left some 50 million more people in extreme poverty in 2009 and 64 million more likely to fall into that category by the end of 2010. The report also projects that an additional 100 million people may lose access to drinking water by 2015 (Box 24.1).

The water sector is vulnerable to economic vagaries. Levels of investment in water were already low before the crisis in most developing countries – and these levels are now even lower, with private sector participation in particular falling sharply. An analysis of the World Bank's Private Participation in Infrastructure (PPI) project database shows that by the end of the first few months of full-scale financial crisis, the number of projects had fallen by 45% and associated investments by 29% compared with the same period in 2007 (World Bank and PPIAF, PPI Project Database).

Winpenny et al. (2009) highlights other impacts that the crisis had on financial flows to the water sector. In a financial crisis, public funding is more limited and tariff revenues fall as poverty deepens. This, in turn, reduces the ability of service providers to access private finance (i.e. loans, bonds and equity). However, international aid agencies and multilateral development banks have made a renewed commitment to increase assistance to the water sector to offset these changes.

The food crisis is being driven by population growth and a surge in energy prices. This has led to higher food prices and brought more people below the poverty line. With the global population expected to increase to nine billion by 2050, Hanjra and Qureshi (2010) estimate a 3,300 km^3 per year water gap for food production. Agricultural productivity – which accounts for over 70% of worldwide water consumption – has to be increased to meet these demands.

Food security depends on a sustainable and efficient water management system. Rosegrant et al. (2002) predicts a severe food crisis by 2025 unless fundamental policy changes are made to change future water use. New investments in irrigation infrastructure and water productivity can minimize the impact of water scarcity and partially meet the water demands for food production (Falkenmark and Molden, 2008).

Climate change will impose an additional cost on achieving and sustaining water security. An analysis of the impact that climate change may have on water resources was conducted by the Intergovernmental Panel on Climate Change (IPCC). The analysis expects serious shortages of water in semi-arid regions, which

BOX 24.1

The impact that the financial crisis has had on access to improved water supply sources: Three alternative scenarios

The Global Monitoring Report 2010 created three possible scenarios to analyse the effects that the financial crisis would have on Gross Domestic Product (GDP) growth in developing countries: the post-crisis trend, the pre-crisis (high growth) trend and the low-growth scenario. These were used in projecting the percentage of the population in developing countries who would not have access to improved water sources.

- The post-crisis scenario shows the effects on GDP assuming a relatively rapid economic recovery starting in 2010. This is the report's base case forecast.
- The pre-crisis (high growth) scenario shows what the effects on GDP would have been had developing countries continued the impressive growth pattern that occurred between 2000 and 2007. The impact that the crisis had on the MDGs can thus be measured by comparing the post-crisis trend with the pre-crisis trend.
- The low growth scenario assumes that the things that got worse because of the financial crisis will continue to adversely affect GDP in the medium-term, resulting in little or no growth for about five years, followed by a slow recovery.

(Percentage of the population without improved water source)				2015		
Region	2015 Target	1990	2006	Post crisis	Pre crisis/ High growth	Low growth
East Asia and Pacific	16	32	13	3.3	0.6	4.1
Europe and Central Asia	5	10	5	0	0	1.8
Latin America and the Caribbean	8	16	9	5.4	4.5	7.1
Middle East and North Africa	6	11	12	8.3	7.4	10.0
South Asia	13	27	13	9.3	5.1	10.2
Sub-Saharan Africa	26	51	42	39.1	38.8	39.8
All developing countries	12	24	14	10.1	9.6	11

Source: World Bank (2010a, table 4.2, p. 105).

will result in an increase in the frequency of droughts (Bates et al., 2008).

Extreme water situations affect almost everyone, but the poor will suffer most because of where they live, their low incomes, their deficient infrastructure, and the great reliance they have on climate-sensitive sectors such as agriculture. For example, over a three-year period, Kenya was hit by extreme floods that cost its economy 16% of its GDP and by an extreme drought that cost 11% of its GDP. Poor water management will only exacerbate these problems (World Bank, 2004). Zambia's economy too is prone to hydrological variability that will cost it US$4.3 billion in lost GDP over ten years and lower its agricultural growth by one percentage point each year (World Bank, 2008*a*). Because the dominant livelihood is rain-fed subsistence farming, droughts and floods significantly affect food security in these regions.

Between US$13 billion and US$17 billion is needed annually to help developing countries' water resources sectors to adapt to climate change (World Bank, 2010*b*) – and that's just the cost of adapting the hard infrastructure.

24.2 Investment needs in the water sector

24.2.1 Global estimates

Water infrastructure in any country requires huge investment. And water services generally do not recover their basic operation and maintenance costs. In developing countries, where funds for anything are scarce and where systems are already under tremendous pressure, funding for water represents an enormous financial burden. Data on water investments are sparse and incomplete because estimating actual needs is difficult and fraught with uncertainty. This stems from the lack of reliable data on public spending on infrastructure, current stocks, lack of a systematic way of monitoring spending and difficulty in tracking the flow of investments. Fay et al. (2010) asserts that a thorough analysis of investment needs requires four distinct steps:

- Understand how much is being spent and how that relates to the current quantity of infrastructure and its quality.
- Set a target and have it priced. The infrastructure gap is the difference between current spending and the target.
- Determine how much of the gap can be bridged through improved efficiency.
- Calculate what additional spending is needed once the improved efficiencies are in place (financing gap).

There are difficulties at every step. Countries and financial institutions do not account for infrastructure investment in a clear way in national accounts, and inefficiencies in the system are difficult to estimate.

Yepes (2008) estimates that investment requirements for water, sanitation and wastewater treatment in low and middle income countries will amount to US$103 billion between 2008 and 2015.[1] This is in line with the $72 billion estimated by WHO for meeting the water supply and sanitation (WSS) MDGs (OECD, 2010*a*).

On a regional level, the Africa Infrastructure Country Diagnostic (AICD) estimates the investment needed for water, sanitation and irrigation (Foster and Briceño-Garmendia, 2010). To close the infrastructure gap in WSS, meet the MDGs and achieve national targets in sub-Saharan Africa within ten years, an annual investment of approximately US$22 billion is needed. US$3.4 billion is needed to double Africa's irrigated area.

24.2.2 Public contributions to water

A snapshot of the current flow of public funding to the water sector

The lack of centralized and reliable information makes estimating current public spending in the water sector challenging. It is hard to imagine such a deficiency given that the public sector contributes approximately 80% of all WSS infrastructure costs (Winpenny, 2003, from Prynn and Sunman (2000).[2]

Most of the limited information on public spending stems from the OECD's Development Assistance Committee (DAC). Aid flows, known as Official Development Assistance (ODA), has become the main source of statistics, although it includes only aid from government sources. Aid from private sources, including from non-governmental organizations (NGOs), is not captured.

Official development assistance (ODA) for water and sanitation has been rising sharply. According to DAC, average annual commitments rose from US$3.3 billion in 2002–2003 to US$8.2 billion in 2008–2009.

24.2.3 Investment and risk

Private contributions in water

The main source of reliable information on private investment in infrastructure is the Private Participation in Infrastructure (PPI) database. This provides information on more than 4,800 infrastructure projects dating from 1984 to 2010, which are owned or managed by private energy, telecommunications, transport and water companies.

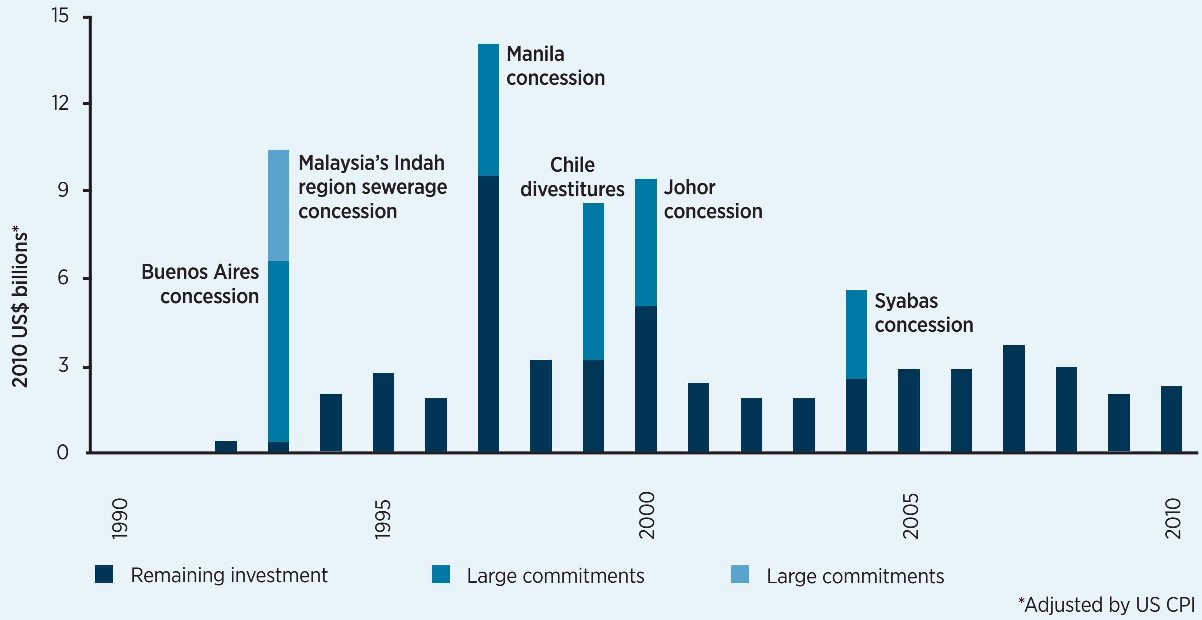
In its last reporting period (July 2011), PPI reported that in 2010, seven low- or middle-income countries implemented 25 water projects that involved private investment of US$2.3 billion (Figure 24.1).[3] The number of new projects with private participation that started in 2010 was 34% lower than 2009 and was the lowest annual number since 1995. Despite fewer new projects starting, annual investment commitments in 2010 were 17% higher than in 2009.

New private activity in 2010 included twenty-five projects, with the three largest comprising 76% of the investment volume. Two countries (China and Brazil) accounted for twenty of the projects and 36% of the investment. Fifteen of the projects were in China and fourteen of these were small to medium sized wastewater treatment plants. Overall, private activity in 2010 focused on water and sewage treatment plants, accounting for seventeen of the projects and US$1.4 billion in investment (Figure 24.2).

Analysis of investment commitments to all sectors (energy, telecom, transport and water) reveals water represents 1% of total private participation in developing countries (World Bank, 2011). And the financial crisis is imposing new challenges for financing. Public resources are scarcer than ever and the private sector is reluctant to engage in new undertakings that could involve additional risks. International investments bring the added risk of fluctuating exchange rates, which domestic lenders do not face. Between 1995 and 2005,

FIGURE 24.1

Investment in water projects with private participation (1990–2010)



Source: Perard (2011, fig. 1, p. 1) (PPI Project database).

the portion of private international flows to WSS fell by 6%, while local private flows rose by 10% (Jimenez and Perez Foguet, 2009).

Investment risk in the face of uncertainty

Even in the developed world, robust utilities are vulnerable to climate-induced risks such as drought, interstate disputes over water, and regulatory changes. A 2010 study by New York-based global equity investors, Water Asset Management and non-profit organization, Ceres, looked at six water utilities in the United States to assess their vulnerability to changes in water availability up to 2030 (Leurig, 2010). The study informs investors buying public utility bonds about the potential risks associated with changes in hydrological variability – risks which aren't currently reflected in the bond ratings issued by the three largest ratings agencies. Ceres reports that ratings agencies endorse the over-use of water by rewarding utilities that sell more of it, despite very real supply constraints in the medium term.

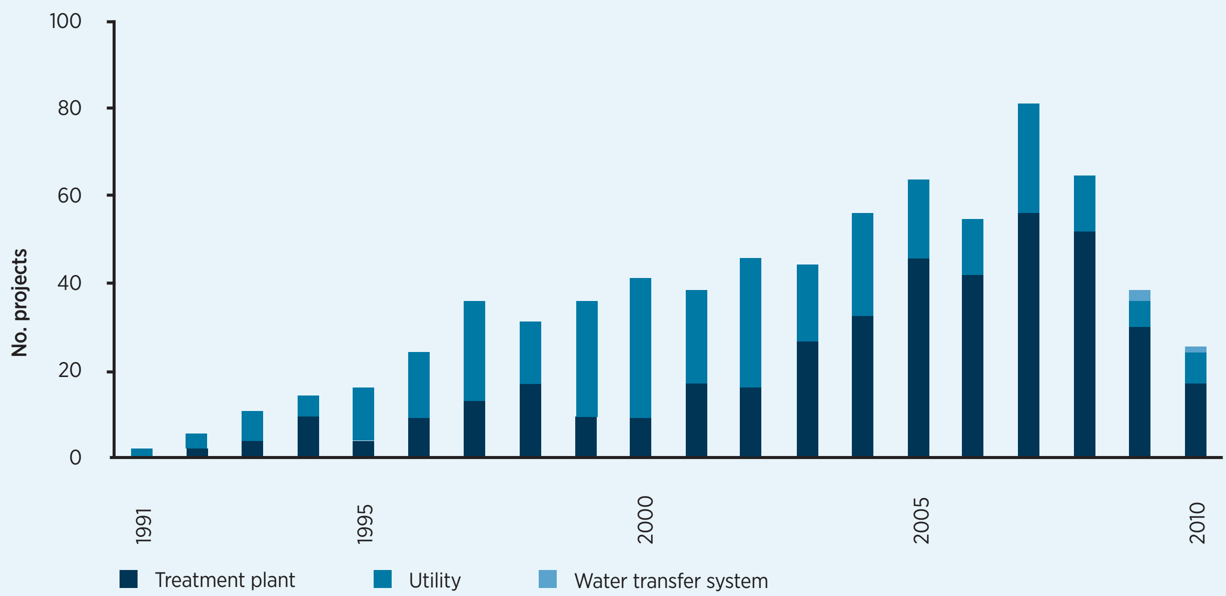
Cities in Arizona and Nevada rely on Lake Mead as a primary water source, but a decade-long drought is reducing available supplies. On the other side of the country, the City of Atlanta may have to reduce supplies by 40% on foot of a new judicial order to make more water available for environmental services. While each utility has a different capacity to manage such risks, their ability to attract financing remains more or less unscathed because these issues go unreported. The Water Asset Management–Ceres' analysis sheds light on the real need to factor climate risks and uncertainty into long-term planning, financing and tariff adjustments, in addition to developing sound adaptation plans. For developing countries, failure to address the uncertainty of water supplies today will only exacerbate risks and curtail effective long-term strategic financial planning.

24.2.4 Opportunities in green growth and green economy agendas

The challenges of population growth, food and energy security, urbanization, volatile international financial flows, and climate change call for sustainable solutions that reduce reliance on natural resources. The 'green economy' agenda is being promoted across developed and developing countries alike in an effort to transform business, including the planning and design of new infrastructure. Fay et al. (2010) argue that when planning sustainable development, it is necessary to consider the significant environmental implications of expanding infrastructure and to assess the interactions between infrastructure policy and environment policy.

FIGURE 24.2

Water projects with private participation, by subsector (1990–2010)



Source: Perard (2011, fig. 2, p. 1) (PPI Project database).

The green economy challenges policy-makers to improve the design of our water infrastructure, and offers an opportunity to reverse the trend of over-consumption. But green infrastructure comes at a cost. In Korea, the National Strategy for Green Growth and the Five Year Plan (2009–2013) is expected to cost 2% of GDP (OECD, 2011*b*). For developing countries, such a price will prove even more difficult to bear. Fostering green investment in these countries will require solid incentives such as expanding funding, enhancing political will, establishing a well-defined institutional framework – and, most importantly, initiating policy reforms that reduce harmful subsidies and promote an enabling investment climate. In addition to formulating polices to increase economic productivity without damaging the environment, it is also imperative to intensify global environmental research and ease technology transfer for clean technologies.

24.3 Financing the gap

24.3.1 A Linear reform agenda

Developing countries alone need to invest US$72 billion a year to meet water sector demands. This is on top of the estimated US$15 billion needed for climate change adaptation measures. While investment needs are growing exponentially, developing countries are coming out of the financial crises with fewer available resources. Given the already low capacity of utilities to recover costs, what's required is a more efficient combination of tools that will finance the gap between demand and supply.

Narrowing the financing gap involves a four-step reform agenda. First, service providers must reduce a range of inefficiencies to increase revenues and lower costs. Second, providers should tap available public funding (including ODA and subsidies), while governments improve the efficiency and efficacy of funds. Third, having improved profitability and the quality of the service they provide, utilities can begin raising tariffs to reflect the real costs of the service. Finally, once they have the necessary political will and institutional capacity, providers should form public-private partnerships and apply for commercial loans.

24.3.2 Providing a more sustainable service

Inefficiencies as implicit subsidies

Inefficiencies in water provision come in many different guises. Low water productivity, high rates of drinking water consumption and the subsequent flows of wastewater that need to be collected and treated are all the by-products of inefficiency.

In Africa alone, water utilities loose approximately US$1 billion a year as a result of operating inefficiencies associated with poor maintenance, overstaffing, high distribution losses and under-collection of revenues (Foster and Briceño-Garmendia, 2010). The AICD suggests that Africa's water supply resources would go considerably further if various inefficiencies – amounting to US$2.7 billion a year – could be addressed. In seventeen countries, these inefficiencies – consisting of mispricing (where tariffs are below the cost of the services), collection inefficiencies and water losses, are in the order of 0.6% of GDP. Reducing inefficiencies will not entirely close the existing finance gaps, but it will reduce them considerably and enable systems to operate better. It may also postpone the need for certain investments and will certainly boost the financial health of utilities and pave the way to private financial resources by improving creditworthiness.

Examining hidden costs shows that policy decisions are being made that are not cost-effective. Among the main causes of losses in water agencies are tariff regimes that don't allow for cost recovery, an official tolerance of arrears and low collection rates and a tolerance of pilferage. All of these mean that there is not enough money to carry out maintenance or to invest in new infrastructure – which is implicit borrowing from future taxpayers or future water users.

Efficiency improvements

Governments need to consider eliminating the technical and managerial inefficiencies associated with delivering water services. They also need to concentrate on creating a policy and regulatory and environment that will attract investment – and this should be done before looking for public and private finance (Beato and Vives, 2008).

Non-revenue water (NRW) is a major source of inefficiency in water utilities (Box 24.2). Kingdom et al. (2006) shows that unaccounted-for water is responsible for losses of almost US$14 billion each year. This includes an estimated 45 million m^3 of treated water that leaks from urban water supply systems every day and another 30 million m^3 delivered to consumers but not billed for as a result of pilferage, corruption, and poor metering. It is estimated that about 70% of these losses are incurred in developing countries, where utilities urgently need additional revenues in order to expand, and where many connected customers have to deal with intermittent supply and poor water quality. The benefits of reducing the amount of NRW are obvious, but programmes aimed at this require strong institutional capacity and substantial financial resources. Reducing NRW is not only a technical issue. If water tariffs are too low, the cost of reducing NRW may exceed the monies saved.

Billing and collection

Experience has shown that improving billing goes beyond simply delivering invoices and bills. Transferring management to an organization that has financial autonomy will reassure users that their payments are going to the service provider. Autonomous organizations that have strong user participation and are transparent in the way they set water charges are more likely to achieve high collection rates. Water user associations can play an important role in this (Box 24.3). Incentive systems that encourage the prompt collection of fees can also contribute to improvements in cost recovery.

The role of technology choice

Choosing the right technology is important in reducing service costs. This affects initial investment costs as well as operation and maintenance costs. And lower capital costs don't necessarily mean low running costs (Box 24.4).

BOX 24.2

Reducing the amount of non-revenue water

Inaccurate metering, unauthorized consumption and leakages all results in non-revenue water (NRW). NRW should be considered within the broader context of utility reform in order to ensure that appropriate funds and resources are allocated. The full scope of the problem should be identified at the onset by characterizing the sources of NRW through a baseline assessment.

The private sector has much to offer here. Under a performance-based services contract, a private firm's remuneration is based on enforced operational performance measures. This strategy was adopted by the Companhia de Saneamento Básico do Estado de São Paulo (SABEP) water utility that serves the São Paulo metropolitan region in Brazil. Under a three-year contract, a private contractor assisted the utility to improve the production and delivery of water through such activities as better micro metering. This increased revenue and reduced the city's debt. The outcome led to a 45 million m^3 increase in the volume of metered consumption and increased revenues of US$72 million.

Source: Kingdom et al. (2006).

Assumptions about technology choices can make significant differences in total investment requirements. The cost of supplying water and sanitation services varies widely with the level of service provided – especially in rural areas because of lower population densities and higher transport costs. In view of such large cost differentials, coupled with the fact that an expensive, high-quality service is likely to be used only by richer consumers – there is a rationale for providing a minimum level of service to consumers. Then higher levels of services can be added on and financed by households themselves.

It is also important to standardize the technologies used in any country. Using multiple technologies makes spare parts harder to find (and therefore more expensive), and there is not always the local knowledge to deal with many different technologies. A Water Aid Study conducted in seventeen districts in Tanzania found a negative correlation between the number of different technologies used in these districts, and the functionality rate of rural water points.

Technology can also be transformational in filling the water gap for a green economy (Figure 24.3). While new treatment systems and dams can supply more water, there are a variety of lower-cost, and often greener, options for managing demand. For example, large quantities of water can be saved in India through the use of better and more drip irrigation technologies so that new raw water sources don't have to be exploited. In China, industrial water reuse systems can save water and reduce the need to build expensive transfer systems. Many of the technologies that can make a difference already exist and are in use in developing countries. Further application needs to be supported by institutions and promoted by sector leaders.

24.3.3 The real cost of water

Water as an economic good

Pricing water to recover investment, operation, and maintenance costs has been a contentious issue for decades. The Dublin principles confirmed that water is a scarce resource and an economic good – so economic principles and incentives need to be used to improve allocation and enhance quality. Yet including more economic incentives in water pricing has proved difficult. Historically, WSS and irrigation charges have been systematically under-priced. So achieving full cost recovery through tariffs and user charges alone will require price hikes that are difficult to manage politically, and may make water services unaffordable. Full cost recovery through tariffs has proved elusive even in many developed countries.

What is cost recovery?

Water fees are collected from users for two main objectives, to cover costs and to encourage efficient water use (Box 24.5). The first objective is to cover the direct financial costs in order to guarantee a sustainable service. These direct costs cover the basic operation and maintenance of the service, the renewal of existing infrastructure, and the possible capital expansion of water services. In many countries, utilities and irrigation agencies pass only a fraction of these direct costs on to users. Utilities in developing countries barely cover their basic operation and maintenance costs – in 2008, operating revenues covered 105% of operation and maintenance costs (IBNET, 2010). Yet large differences exist between utilities in terms of achieving cost recovery (Table 24.1).

BOX 24.3

Water users associations as an essential component in improving cost recovery: An irrigation systems example from the Kyrgyz Republic

An on- farm irrigation project was implemented in the Kyrgyz Republic between 2000 and 2008. Its aim was to increase crop production through reliable and sustainable water distribution across seven administrative regions. Farm infrastructure was also rehabilitated under the management of water users associations (WUAs). The targeted WUAs represented 166,000 members, who managed some 710,000 hectares, or 70% of the country's irrigated land.

Members from each participating WUA signed an agreement to repay 25% of the farm rehabilitation costs, raise irrigation fees to support their WUA, and pay the water supplier an irrigation service fee for water delivered to the WUA's headgate.

Considerable success was achieved:

- The performance of the WUA members was improved.
- Infrastructure that fed 120,000 hectares was rehabilitated, and irrigation water delivered to farmers in 80% of the rehabilitated systems now closely matches demand.
- Three agricultural seasons later, irrigation service fees have doubled on average and collection rates by WUAs are close to 100%.
- Overall cost recovery rose from about 20% to 60%, and at least 80% of water users were satisfied with the performance of WUA management.

Source: World Bank (2008b).

The proportion of utilities that were not able to cover their basic operation and maintenance costs increased from 35% in 2000 to 43% in 2008 – with most of that increase occurring since the fuel crisis hit the sector and increased operating costs substantially. The effect is especially noticeable in low-income countries, where there was a sharper increase in the number of utilities that could not cover basic operation and maintenance costs. In irrigation, overall cost recovery rates tend to be even lower. Easter and Liu (2005) show that federal irrigation projects in the United States generally do not recover more than 20% of costs from farmers. In developing countries, the picture is even grimmer.

The second objective for charging for water involves pricing to provide incentives to use water more efficiently. Not charging for water often results in unsustainable levels of consumption that result in early depletion of water resources – which ultimately increases the costs of production.

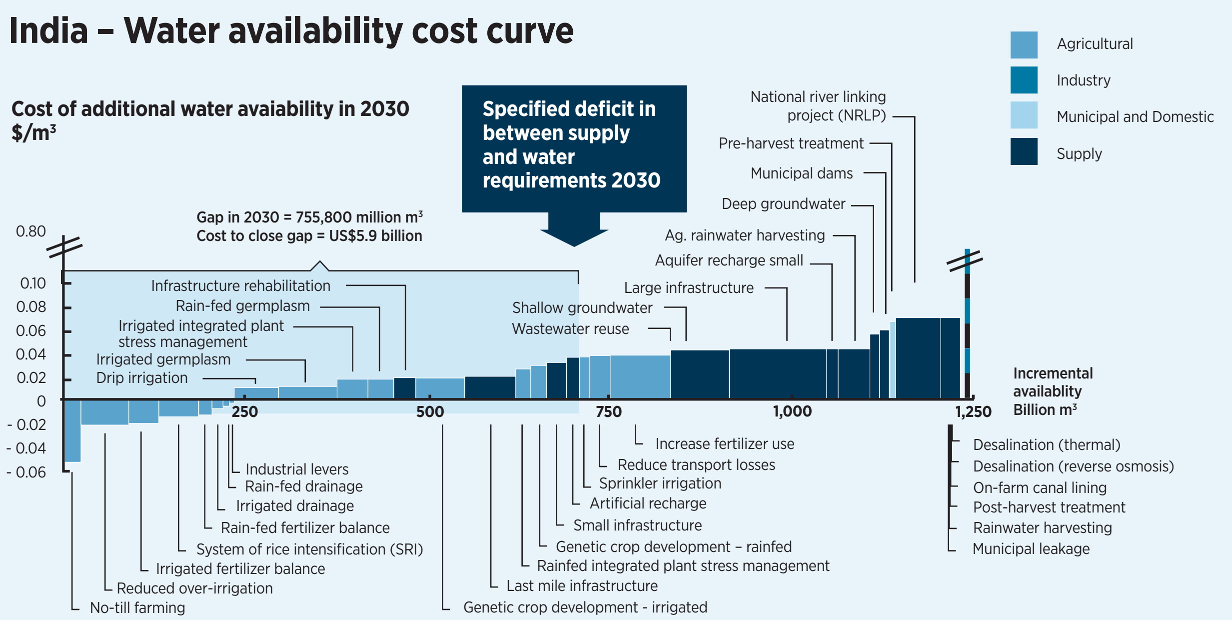
Improving water use efficiency requires increasing the value of each unit of water consumed. This is already politically difficult, but it will become more important as water scarcity increases. To guarantee economic sustainability, users should be charged the full supply costs, plus the costs created by any externalities.[5] Externalities

BOX 24.4

The cost of agricultural water demand

The 2009 report, *Charting our Water Future: Economic Frameworks to Inform Decision-Making*, is a study carried out by the 2030 Water Resources Group and led by the International Finance Corporation and McKinsey & Company. It provides an evaluation of the scale of the water challenge, estimating that by 2030, global water requirements may grow by over 40% from 4,500 billion m^3 to 6,900 billion m^3.

Demand for agricultural water, which currently accounts for 71% of water used, is projected to be most significant in the poorest regions - India (1,195 billion m^3), sub-Saharan Africa (820 billion m^3), and China (420 billion m^3). In India, closing the 2030 gap could cost between US$0.10 per m^3 and US$0.50 per m^3. Meeting new demand by building large infrastructure (right side of the curve) will be costly. However, many of the demand-side interventions (left side of the curve) are not only more cost effective, but support a green economy by focusing on resource savings over increased exploitation. By assessing the trade-offs between new infrastructure and demand-side measures, countries can define the appropriate mix of interventions for filling the gap between future water demand and supply.



The report proposes that future demand for water could be met through cost-effective measures using existing technologies.

Source: 2030 Water Resources Group (2009, p. 12).

include the cost to producers and consumers (economic externalities) and to public health and ecosystems (environmental externalities). Including externalities is likely to substantially increase the total cost of many water services, which is why few pricing systems in the world include them in their pricing structures.

Inadequate cost recovery is a function not only of low tariff levels, but also of low collection rates, unaccounted-for water and other operational efficiencies. The 2009, evaluation of water sector projects conducted by the Independent Evaluation Group of the World Bank concluded that for WSS projects, the factor that contributed most to successfully meeting cost recovery targets was improving collection rates (IEG, 2009). Most often this involved increasing the capacity and willingness of water institutions to collect fees from beneficiaries. Increasing water tariffs also had a discernible impact on overall project results (World Bank, 2010*c*).

24.3.4 Improving the use of public funds

Subsidies revisited

When consumers do not pay the full cost of the service, someone else has to bridge the finance gap. This is either future consumers, current or future taxpayers or a combination of these.

Most of the financing gap is paid for by government subsidies (taxes). Subsidies are ubiquitous in the sector for funding both capital outlay and operations and maintenance costs. There are various instruments through which subsidies are channelled. These include capital and operating subsidies, social safety nets, consumption subsidies, and cross-subsidies.

In developed countries, capital subsidies are relatively common. In the United States, capital investments are often funded through tax-free municipal bonds. This

BOX 24.5

What the European Union Water Framework Directive says about water pricing

Article 9 of the European Union Water Framework Directive (WFD) required Member States to adopt water pricing policies by 2010 that provided adequate incentives for the efficient use of water resources.

Water service costs include environmental costs, and are based on the *polluter pays* principle – whether that user is industry, agriculture or individual households. The rationale behind the polluter pays principle is to mitigate environmental problems through reliance on economic efficiency.

The WFD's concept of cost recovery is based on two levels of recovery, financial recovery and environmental and resource recovery.

- Financial costs or the full cost of supply: This includes the costs of providing and administering water services. It includes all operation and maintenance costs, capital costs (including initial outlay and interest payments), and any return on equity.
- Resource costs: These represent opportunities lost to other uses as a result of the depletion of the resource beyond its natural rate of recharge or recovery (for example, costs linked to the over-abstraction of groundwater).
- Environmental costs: These refer to the cost of damage that water use imposes on the environment and ecosystems (for example, the ecological quality of aquatic ecosystems can be damaged and productive soils can become saliferous and degraded).

Sources: Garrido and Calatrava (2010); Francois et al.(2010); Commission of the European Communities (2000).

TABLE 24.1

Median operating cost coverage in utilities

Year	2000	2001	2002	2003	2004	2005	2006	2007	2008
Operating cost coverage (ratio of operating revenues over operation and maintenance costs)	1.11	1.13	1.10	1.11	1.08	1.07	1.07	1.08	1.05
Standard deviation	0.55	0.56	0.58	0.61	0.57	0.56	0.55	0.54	0.50
Number of utilities reporting	579	615	723	999	1 151	1 173	1 379	1 229	930

Note: The 2008 data collection cycle is not yet complete.
Source: Van den Berg and Danilenko (2011, table 3.6, p. 23).

means that utilities are provided with an implicit subsidy. Similarly, in the European Union, utilities receive generous capital investment grants to aid compliance with stringent wastewater standards. In developing countries, water sector subsidies are provided in the form of capital grants and also often in the form of operating subsidies, which creates severe distortions in the production and consumption of services. Operating subsidies have considerable drawbacks because they distort incentives for more efficient use of water. Highly inefficient systems that receive operating subsidies do not have any incentives to improve services.

In water supply and sewerage systems, where coverage is far from universal, subsidies tend to benefit those already connected to the piped system – which tends to be better-off households. A 2007 evaluation of thirty-two water subsidy programs showed that quantity-based subsidies, the most common type of subsidy, do not reach the poor customers they target (Komives et al., 2007). Connection subsidies, as well as consumption subsidies that are means-tested or geographically targeted, have a better record of reaching the poor than quantity-based subsidies.

The AICD also showed that in Africa, around 90% of beneficiaries with access to piped water are the richest 60% of the population. In such a context, any subsidy for piped water is largely captured by better-off households. In irrigation, wealthier farmers tend to benefit more proportionally from subsidies than poorer farmers.

The World Panel for Financing Water Infrastructure calls for a greater assurance that resources for subsidies are budgeted in advance, as part of a trend towards a more 'sustainable cost recovery' (Winpenny 2003). When large government subsidies are not provided directly and on a regular basis, water agencies tend to postpone maintenance, which shortens the life-span of the assets and means that infrastructure needs to be replaced more often. Irregular and inadequate subsidies can also result in investments not being made and untreated wastewater being discharged into water bodies, groundwater resources being over-exploited, and higher pollution levels.

Cross subsidies, whereby industrial users pay more to support the cost of residential use, are quite common in WSS, and the direct fiscal repercussions are small. Whether this instrument can work depends largely on the tariff structure. Maxing out cross-subsidies can be problematic. If costs become too expensive for non-residential water users, they may opt out of the piped water supply system, thereby undermining utilities' revenue base. The International Benchmarking Network for Water and Sanitation Utilities (IBNET) database[4] shows that in 2008, the average water company charged non-residential users up to 1.35 times more per cubic meter than they charged residential users. High levels of cross-subsidies tend to be more common in low-income countries than in middle-income countries.

Because subsidies distort incentives, some basic principles should be set in place. Subsidies should:

- be predictable to ensure longer-term planning and budgeting;
- be transparent, and reviewed continuously to ensure that they provide incentives to improve performance;
- be reduced over time to allow charges to take over; and
- take affordability into consideration.

Management of government transfers

Although there is sufficient scope for full cost recovery in the short-to-medium term, the role of government transfers is an essential element in ensuring the long-term sustainability of the sector. Although no global data exist on the size of government transfers in the sector, anecdotal evidence suggest that they are large. The prevalence of capital and operating subsidies is high. A significant portion of these hidden costs is used to support operation and maintenance of existing systems. These implicit subsidies tend to be regressive, benefiting a relatively small, well-off, group of consumers. In Africa, 40% of government transfers are used for operation and maintenance, resulting in capital investment being crowded out and limiting the capacity of countries to invest (Foster and Briceño-Garmendia, 2010).

Larger government transfers, however, will not necessarily result in improved access to sustainable water services. When large flows of resources in the sector are managed by the government, the efficiency and effectiveness with which they are managed becomes critical to the sustainability of the services. Countries must look at the incentives and potential bottlenecks in fiscal and public finance policies, and not only at the way that financial resources are managed.

A new tool that is proving instrumental in understanding the flow of public funds in water is the Public

Expenditure Review (PER). A PER is concerned with public-based (not always government) revenues and expenditure as expressions of public policy and public involvement in the economy (World Bank, 2009). It entails a careful examination and analysis of the fundamental drivers of public finance. The recommendations provide guidance to governments on critical reform processes that can be taken to ensure efficiency, efficacy and transparency in the use of public monies flowing to one or many sectors.

Since 2003, the World Bank has funded 40 PERs in which the water sector featured in some capacity. A quick assessment of some of the water sector PERs suggests that the efficiency and effectiveness of how governments allocate, disburse and use resources in the sector can be improved. A number of countries that have undertaken these exercises have adopted comprehensive budget legislation, reduced waste in public expenditure, given greater budget autonomy to local governments, and attempted to open budgets to public scrutiny (Deolalikar, 2008).

The efficiency (is the money spent on the right things?) and effectiveness (is the money spent well in light of the allocation decisions?) of expenditure can be affected by many factors. The World Bank is compiling a report based on findings from 15 PERs in sub-Saharan Africa (World Bank, 2012). It documents regional trends and provides opportunities for the more efficient use of public funds. For example, adequate regulations and institutions generally exist in the region, but capacity is weak. By bringing line ministries into the budgeting process, investments will be more realistic, appropriate, and responsive to needs. Countries can also improve adherence to procurement plans, create more bylaws to aid implementation of reforms, and reconcentrate utility staff to local levels to realize decentralization.

As demonstrated in many PERs, sector-specific issues play a major role in explaining the performance of translating funds into actual outcomes. Three ways in which efficiency can be enhanced are (i) by improving sector and investment planning; (ii) by improving the capacity to procure, disburse, audit and monitor resources; and (iii) maintain a sharper focus on incentives in the allocation of funds.

First, although its use has declined in recent years, cost-benefit analysis must be used to improve investment planning and prioritization. Water variability should be a key concern for long-term planning in both developed and developing countries. Sensitivity and risk analysis can help to determine how robust various investments are to changes in circumstance. Sector planning should be combined with multi-year budgeting to ensure that short-, medium- and long-term investments can be implemented properly.

Second, governments must improve disbursement functions, often a major source of the inefficiencies that cause higher procurement costs. For example, late funds result in budgets not being fully carried out, which may have implications for future access to funds. Many developing countries have inefficient mechanisms to transfer resources from central, to regional, and then to local authorities. Yearly budget cycles often entail that capital works must be contracted and completed within the cycle. Lack of capacity in procurement curtails and delays investment in the sector.

Third, by using results-based incentives, water agencies can access funds on the basis of their performance, as long as tangible and verifiable results are accomplished. Results-based financing (RBF) encompasses a range of mechanisms that are designed to enhance the delivery of infrastructure and social services through the use of performance-based incentives, rewards, and subsidies. A funding entity (typically a government or sub-governmental agency) provides a financial incentive, on condition that the recipient undertakes pre-determined actions or achieves particular outputs. Resources are disbursed not against individual expenditures or contracts on the input side (as is traditionally done), but against demonstrated and independently verified results that are largely within the control of the recipient.

RBFs can be structured in several ways depending on the objectives and goals set by the government. There are several types of RBF mechanism, including carbon finance strategies, conditional cash transfers, output-based disbursements, and advance market commitments. The application of RBFs in the water sector is quite limited, but in recent years some projects have been financed through the Global Partnership on Output-Based Aid (GPOBA). This is a donor trust fund managed by the World Bank. OBA in the water sector is generally a payment of a subsidy to cover pro-poor access. Service delivery is contracted out to a service provider (private or public utility or an NGO), with payment tied to the achievement of specified performance or outputs. OBA subsidies can either buy down the capital cost or cover the difference between an affordable user fee and a cost-recovery user fee, such as a consumption subsidy.

GPOBA has approved close to US$4 billion in grants. Of these, US$137 million is for WSS. There are currently 22 projects with World Bank participation with approximately US$140 million allocated to subsidies: 15 are water supply schemes, 3 are sanitation schemes, and 4 provide both water and sanitation (Kumar and Mugabi, 2010). Many of these projects are already showing promising results. Within less than a year, 6,700 connections were made in Cameroon (project target is 40,000); in India, 77,000 connections were completed in rural communities in Andhra Pradesh. There are, however, criticisms of OBA, including high costs and low leverage of commercial funds. Kumar and Mugabi argue that countries with sound regulatory frameworks, good capacity for implementing programmes, and experience with private sector provision have more success than others.

The role of external and internal governance in the sector

Good governance is part and parcel of the successful implementation of finance reforms. Good governance has several dimensions, from political stability, rule of law, government effectiveness, and regulatory quality, to voice and accountability and corruption control. Improving governance structures requires identifying the main actors and clarifying their exact mandate with regard to the key functions of: (i) policy formulation; (ii) asset management and infrastructure development; (iii) service provision; (iv) financing the sector and the development of water infrastructure; and (v) regulation of the service. Clarifying the contractual arrangement that allows the actors to interact with each other, and assessing the adequacy of the instruments used by the actors to fulfil their mandates are critical steps in understanding governance frameworks. Official policies are often not fully carried out in countries that have weak governance regimes. It is important to look at the de facto functioning of institutions rather than at the paper policy framework (Locussol and van Ginneken, 2010).

Improved sector governance, better management of public funds, and efficiency improvements at the utility level can improve water services for the end user. Providers can then consider increasing tariff levels to achieve greater (or full) cost recovery. At this stage, providers will be able to justify increases in tariff levels, enabling them to better save for future investments and achieve the creditworthiness needed to access domestic and international commercial finance in the long-run.

24.3.5 Translating reforms into revenue

Increasing tariffs

When users pay a larger share of the actual cost of water services, there is more rational use of water. However, raising tariffs when service quality is low is a difficult task. In many countries, water tariff increases are lower than inflation – which results in cheaper water over time. Keeping up with inflation is not a trivial factor. Prices must be determined not only to guard against further erosion of a water agency's revenue base, but also to ensure that no perverse incentive to consume more water is established.

Since 2000, the average revenue per cubic meter of water sold has more than doubled to US$0.71 in the utilities participating in IBNET (See Table 24.2). The variation in the revenues generated per m^3 water sold between utilities also levelled off – suggesting that more utilities are moving in the same direction.

Such reform is helping to reduce consumption. In low-income countries between 2000 and 2008, consumption fell sharply from 138 L per capita per day (lpcd) to 75 lpcd (Van den Berg and Danilenko, 2011).

Despite the incentive to conserve water, many countries still face significant challenges to increasing water tariffs. Even in OECD countries, keeping to real, rather than nominal, levels of tariffs has been tricky (OECD 2010), with several countries showing a decreasing average annual rate of change in tariff levels over the last decade when adjusted for inflation.

The role of public–private partnerships

PPPs were established in most developing countries to bridge gaps in financing, expertise and management in order to improve the performance of public utilities. These objectives can be achieved under various contractual schemes through collaborative efforts of the private operators and contracting government.

Marin (2009) analysed more than sixty-five water projects with PPPs in the urban water sector in developing countries over a fifteen-year period. Results suggest that though some projects performed better than others, the overall performance of water PPPs has been satisfactory. The urban population serviced by private operators in the developing world rose steadily from 94 million in 2000 to more than 160 million by the end of 2007 (Marin, 2009). PPP projects have provided to piped water to more than 24 million people in developing countries since 1990. Some of the major findings of the study include:

- *The largest contribution of private operators was through improved service quality and operational efficiency.* Improvements achieved through operational efficiency and quality service depends on the allocation of responsibilities and risks, which is based on multiple factors such as the incentive structure and the nature of the arrangement.
- *Efficient private operators have a positive, although mostly indirect, financial contribution.* They do this by improving the creditworthiness of the utility and allowing it to secure investment funding more easily and at better terms. A better service increases customers' willingness to pay, and this improves collection rates and makes raising tariffs easier. Experiences from Cote d'Ivoire and Gabon show that operating efficiently enabled investments to be funded through cash flows for more than a decade without needing to incur new debt.
- *Successful water PPPs have to be implemented within a well-conceived, broader sectoral reform.* Successful experiences in countries such as, Colombia, Cote d'Ivoire, and Morocco show that introducing PPPs was part of a wider reform to establish a sector framework that supported financial viability and accountability for performance. These countries had clear policies in place to move to cost recovery tariffs in a sustainable and socially acceptable manner.
- *Establishing a good partnership that achieves tangible results takes time.* It took a decade to achieve the desired results in Senegal. The outcome of a PPP depends heavily on solid collaboration, and government officials need to move away from old habits of interfering in the operation of water utilities.
- *Traditional classification of PPP projects as management contracts, lease-affermages, and concessions have become obsolete.* The most sustainable projects observed in the study did not fit into any of the traditional categories.

The study is the most comprehensive analysis to date in the sector and its recommendations are instrumental in ensuring the proper design of the next generation of PPP arrangements particularly given the fact that local private operators are entering the market more and more.

Conclusions and recommendations: The way forward

Global financial volatility and water stress have combined to bring a new set of challenges to the developing world. In the context of growing risk, more frequent floods and droughts, and uncertainty about the availability of capital and raw water supplies for drinking, sanitation and production, countries must analyse the trade-offs and make difficult decisions about how to finance vital water services.

Closing the financing gap in the water sector requires the application of a range of instruments including higher collection rates, more efficient service provision with lower costs, more targeted subsidies, and higher user charges. It is likely to be a longer-term process in which the appropriate mix of instruments will change over time. Such efficiencies, even in the absence of full cost recovery, will improve the ability of utilities to adapt to future risk, and will make them less dependent on external funding.

TABLE 24.2

Average revenues per m³ water sold (in US$) – median values

	2000	2001	2002	2003	2004	2005	2006	2007	2008
Average revenues	0.37	0.34	0.28	0.32	0.37	0.43	0.50	0.63	0.71
Standard deviation	0.34	0.34	0.37	0.42	0.47	0.50	0.53	0.59	0.51
Number of utilities reporting	567	632	725	982	1 137	1 154	1 188	1 203	878

Note: The 2008 data collection cycle is not yet complete.
Source: Van den Berg and Danilenko (2011, table 3.8, p. 26).

Decisions about how to allocate the cost of water services depends on political preferences, but it also depends on the structure of the local water market. It is important that an explicit agreement is reached on who pays for the uncovered portion of the costs. Without such an arrangement, the real costs of water services may be deferred into the future, seriously hampering short-term and medium-term sustainability. Any allocation of costs through stakeholders must take into consideration social equity and affordability. Subsidies play a critical social function in the distribution of equity.

Because the majority of funds in the sector are public monies, more attention should be paid to the efficiency and efficacy of public transfers and subsides. The political costs of removing subsidies is usually very high, particularly given that better-off users are usually the main beneficiaries. Tariffs that reflect the cost of inflation can assist in maintaining the trend toward lower per capita consumption, while those that account for environmental externalities can go one step further by addressing water scarcity and supporting a green economy.

Trade-offs will need to be made as financial sustainability is likely to be only one of several objectives that form part of a government's agenda to improve the performance of the water sector. Making these trade-offs more explicit will improve accountability and transparency. They may also incentivize much-needed reform, such as strategies for a green economy and improved conservation.

Public Expenditure Reviews and results-based financing are tools that can improve the functionality of a resource-constrained, inefficient sector. Similarly, public-private partnerships have some success in the sector and offer opportunities for risk-sharing in today's uncertain environment. Ensuring that institutional capacities are strengthened to implement some of the new methods and tools should be a priority.

Notes

1 Includes low income and low to middle income countries. Analysis is based on a 'top-down approach using data on infrastructure services and parameters for construction and maintenance costs to model investment needs'. (Yepes, 2008).

2 The sector's financial sources were estimated, in the mid-1990s, to be: domestic public sector 65–70%, domestic private sector 5%, international donors 10–15% and international private companies 10–15%.

3 Includes a second partial divestiture of a utility in China. Chongqing Water Affairs Company sold 6% of its capital (US$516 million) via an initial public offering on the Shanghai Stock Exchange.

4 The International Benchmarking Network for Water and Sanitation Utilities (IBNET) is the world largest database of performance data for water and sanitation utilities.

5 Externalities can be positive (benefits) or negative (costs). When externalities are positive, the economic costs of the water service are lower than the financial costs; the opposite is true when the externalities are negative.

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CHAPTER 25

Water and institutional change: Responding to present and future uncertainty

UNDP Water Governance Facility at SIWI

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A mounting water challenge is how to manage uncertainty of present and future variability in precipitation, evaporation, and water uses and demands. Policy-makers and water managers around the world grapple with water availability, water supply and water demand uncertainties, magnified by pressures such as climate change, economic growth, and population growth and mobility. These pressures impact on the spatial and temporal distribution of water resources. Uncertainty appears in technical, social and natural systems (Brugnach et al., 2009). Natural systems include for example climate change impacts.

Technical systems include human interventions that affect the supply of water, such as dams and irrigation canals. Social systems have cultural, political, economic, legal, demographic, administrative and organizational dimensions that add to the complexities of managing water resources. Growing populations and urbanization coupled with changing consumption preferences contribute to uncertainty in water demands. Various and often conflicting water demands have to be satisfied with varying levels of political will, scarce financial resources, and a deficit of effective institutions and management approaches.

An example of the impacts of complexities and uncertainty in water-related decision-making is illustrated by the Australian farmers who in 2007, swayed by a favourable rainfall forecast after a multi-year drought, took out loans or sold their expected crops on futures markets. Unfortunately, the rainfall that actually occurred was much lower than predicted, so many farmers were unable to repay their loans or were forced to buy crops at much higher prices than the prices at which they sold them to fulfil their contractual obligations (Brugnach et al., 2009).

One important aspect of managing uncertainty is the role of institutions. Institutions provide 'the rules of the game' and can provide incentives and disincentives for how well society can expect to adapt to uncertainty (North, 1990). In response to increasing water supply and demand challenges, water-related institutions are undergoing far-reaching changes worldwide. As well as the redefinition of roles and responsibilities, institutional arrangements and frameworks have provided direction on what is needed in terms of building and strengthening human, technological, information, knowledge and delivery capacities.

Uncertainty can be understood as a range of reasonably expectable future conditions that need to be taken into account for decision-making at all levels, from the individual farmer to international water and environmental negotiations (Brugnach et al., 2009). For example, the uncertainty in assessing the probability of a once-in-fifty-years flood needs to be offset by appropriate sensitivity analysis and the design of an adequate safety margin. The size of the margin depends on the available financial resources to invest in management and mitigation measures as well as on the risk propensity of the decision-maker and the population of concern. Despite some countries facing similar risks, their capacity to deal with it can differ considerably. For example, the Netherlands and Bangladesh both face recurrent flood risks, but the Netherlands is in a stronger economic position and can afford to invest heavily in infrastructure development and human capacity to reduce uncertainties in water management. The purpose of this chapter is to illustrate the growing need to strengthen water-related institutions, particularly with increasing water supply and demand uncertainties due to growing pressures such as climate change, economic growth and population growth. The chapter discusses what institutions are in relation to sustainable water development, and why they matter. It looks at some current challenges in water institutional reform. Finally, institutional responses and adaptive capacities to growing uncertainties are discussed and examples of attributes required for effective institutional change and implementation are provided.

25.1 Institutions: Form and function

25.1.1 Defining institutions

A broad definition of institutions provided by Ostrom (2005) is the prescription that humans use to organize all forms of repetitive and structured interactions including those within families, neighbourhoods, markets, firms, sports leagues, religious associations, private associations, and governments at all scales. Individuals and groups interacting within rule-structured situations face choices regarding the actions and strategies they take, leading to consequences for themselves and for others. Importantly, these systems are constructed by humans and are a complex mix of norms, conventions, rules and behavioural characteristics (North, 2000); that is, 'the rules of the game' with organizations as 'the players of the game'. Institutions involve rules that define roles and procedures for people; have a degree of permanency and are relatively stable; determine what is appropriate, legitimate and proper; and are cognitive and normative structures defining perceptions, interpretations and sanctions.

While formal and informal water institutions are part of overall institutional architecture, they affect social, economic and political life in different ways and a distinction is made between them.[1] Formal institutions are generally created by government policy, laws, rules and regulations, and they have the resources and authority to coordinate large numbers of users and areas. They are involved in the processes of extracting, distributing and using water. Such institutions are under the purview and responsibility of the political regime (e.g. parliament, government, courts, districts and municipalities) and agencies are set in place to perform functions such as water resources management, distribution of water services, regulatory monitoring and water quality protection. Non-governmental organizations (NGOs) such as water user associations and private water service providers can be part of the formal institutional set-up in addition to having watch-dog functions.

Informal institutions are part of traditional and contemporary social rules applied to water use and allocation. The 'players-of-the game', that is, those who define 'the rules of the game', can be community-based organizations, the local private sector, religious associations and so forth. Informal water-related institutions are usually equated with norms and traditions of how to allocate, distribute and use water resources. But informal water rights systems are not just 'customary' or 'archaic' – on the contrary, they can comprise a dynamic mixture of principles and organizational forms of different origins (Boelens, 2008). They can combine local, national and global rules and they often mix indigenous, colonial and contemporary rights. Important sources of local rights systems tend to be state laws, religious laws (formal or indigenous), ancestral laws, market laws, and the rights frameworks generated or imposed by water project interventions, each of which often sets its own regulations. Therefore, local water rights exist under legal pluralism, where rules and principles of different origin and legitimization co-exist and interact in the same water territory.

From the perspective of local water users in many parts of the world, legitimate water rights and authority are not only those laid down in legislation (Boelens, 2008). One example of such a water rights system is *Aflaj*, prevalent in many Middle Eastern countries. *Aflaj* are traditional and well-recognized (sometimes by legislation) systems of water allocation and distribution. Over the years *Aflaj* have set traditional practices for inter-temporal water resources allocation and established user rights on an ownership or a rent basis.

Informal institutions also include clientelism and corruption. Such discretionary practices can distort legitimate institutions and result in unpredictable and ineffective decision-making processes and outcomes in allocation of water resources and services between sectors and groups (see for example Stålgren, 2006 and Plummer, 2007). In the Central Asian Former Soviet Union countries Tajikistan, Kyrgyzstan and Uzbekistan, for example, local actors combine newly established rules of local water management (water user associations) with informal institutions that often originate from institutionalized Soviet and pre-Soviet patterns of behaviour (Sehring, 2009; Schlüter and Herrfahrdt-Pähle, 2011). This mixing of different institutional logics changes their meaning and can significantly limit proper implementation of the reforms. Because informal institutions can support, disrupt and replace formal institutions, it is important that informal institutions are incorporated into analyses of risks and uncertainties in the context of institutional design (or change) and implementation. For example, in Paraguay, informal private water supply systems were recognized and agreements were developed between local government entities and small-scale private water vendors. The outcome was easier control and monitoring of pricing and quality of service (Phumpiu and Gustafsson, 2009).

25.1.2 Institutions matter

Current institutional systems and how they function impose considerable constraints for doing business, according to a survey by Kaufmann (2005). Figure 25.1 illustrates business constraints and the importance of well-functioning institutions for effective regulation, corruption control and so forth. Conventional wisdom holds that insufficient infrastructure constitutes the major market access constraint. It is therefore striking that institutional and governance issues, such as performance of bureaucracy and corruption control, rank higher than infrastructure in regions such as sub-Saharan Africa, South Asia, Latin America, and transition economies in the survey.[2] Interestingly, the results show the importance of combining so-called 'soft' and 'hard' measures to improved water development and that institutional (soft) measures should have a higher priority than they typically have had.

Institutions are also shaped by larger social, political and economic contexts, and inevitably countries show great variation in institutional design. For example, in many countries in the Middle East and North Africa (MENA) region and in China, water institutions are characterized by strong government steering, top-down management and control. In contrast, many other countries around the world have moved towards institutions with increasing power diffusion across government, civil society and markets, and with a strengthening of institutional process features such as transparency, multi-stakeholder participation and accountability.

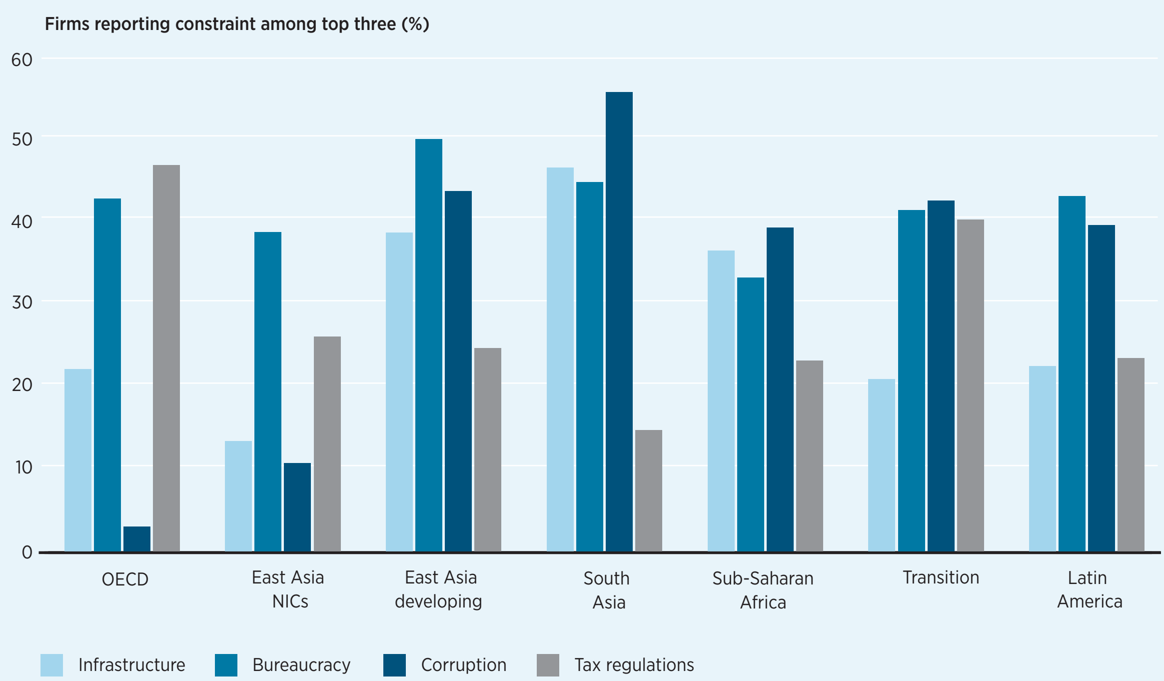
The effective performance of institutional functions can reduce natural, technical and social uncertainties. For example, if tensions and conflicts over shared water are successfully negotiated within a particular institutional framework, uncertainties in stakeholder behaviour will be reduced and this in turn will promote more predictable outcomes in water allocation and use. In performing its functions it is important for any institution to do the following.

Define roles, rights and responsibilities of stakeholders at all levels

Institutional arrangements define who controls a resource and how it is used. In this sense, institutions

FIGURE 25.1

Key constraints to doing business in several geographic and economic regions



Note: The question posed to the firm was 'Select among the above 14 constraints the five most problematic factors for doing business in your country'.
Source: Kaufmann (2005, fig. 2, p. 85).

are vital in establishing the working rules of rights and duties, and in characterizing the relationship of two or more users to one another and to a specific natural resource. For example, property *rights* can determine rights and *restrictions* to a resource. The efficiency and productivity of water use can also determine rights. In Kenya, water sector reforms have clearly delineated institutional arrangements, highlighting the roles and responsibilities of subsectors at both the service delivery level and the river basin management level. One outcome of these reforms is the facilitation of institutional set-ups such as the sector-wide approach to planning (SWAP), which provides for the delivery of institutional mechanisms such as partnership principles, codes of conduct and investment plans as well as coordination, monitoring and decision-making mechanisms – all of which are geared towards enhancing service delivery and accountability for the sector. Some other Kenyan reform features include the separation of the management of water resources from the provision of water services; the separation of policy-making from day-to-day administration and regulation; the decentralization of functions to lower level government agencies; and increased involvement of non-government entities in the management of water resources and in the provision of water services. Kenya has made progress in its water reform but has faced serious challenges in funding and capacity and thus has not yet been able to implement all introduced institutional reforms (MWI, 2005, 2009).

Determine restrictions on use and mechanisms for conflict mediation

Institutions set individual and collective restrictions on water use – who can use which water, how much of it, when, and for what purpose. Increasing the water supply–demand gap intensifies competition and conflict between water users, regions and economic sectors – such a situation can demonstrate limitations in existing resource allocation and management institutions, but importantly, these institutions can develop mechanisms to deal with such conflicting interests. In transboundary river contexts, water-related tensions may have been historically contained but given current water scarcity trends caused by both environmental and developmental changes, these tensions could escalate. A water scarcity–water conflict dynamic often constitutes a justification for institutional water reform and for the development of clearly defined regulatory and allocation mechanisms. The reforms of water institutions and the legal instruments governing transboundary water are, however, complex and often take a long time to debate and introduce; tensions could accelerate in the meantime. However, in some instances water tensions have accelerated institutional change. In Australia, long-standing water use tensions between environmentalists and farmers in the Murray–Darling Basin provide backdrop to the Landcare movement and to developing multi-stakeholder fora for managing water in its basin context. The competing water demands of states have served as the basis for institutional development of the Murray-Darling Basin water management framework. Conflicting visions of catchment management, such as the degree of stakeholder participation, have shaped institutional approaches in the state of New South Wales. Conflict avoidance can itself be a driver of innovation in the area of water governance. In South-East Asia, the spectre of resource-based conflict between the countries sharing the Mekong River has been a strong driver for cooperation through the Mekong River Commission (MRC) and an important justification of official assistance to the Commission (Boesen and Munk Ranvborg, 2004).

Reduce transaction costs and stimulate investment

The development of institutions and their effective enforcement contributes to, among other things, lowering the transaction costs of organizations and investors. Put simply, a transaction cost is a cost incurred in making an economic exchange; that is, the cost of participating in a market, such as in fee-based systems of provision of water and water-related services. Costs involved can include the search for information, bargaining for and deciding on proper fees, and policing and enforcement. From an economic perspective, effective institutional change takes place when transaction costs are less than the corresponding opportunity costs. Transaction cost analysis is seen by many as the core of institutional economics analysis but is seldom used in developing new water institutions. In Kenya, for example, some stakeholders see institutional changes such as the introduction of SWAP as potentially increasing the bureaucracy and level of complexity of the institution and removing decision-making further from the grass roots level. There is some concern that transaction costs could rise with SWAP and some NGOs fear that SWAP could result in reduced funding for them. This institutional reform is thus seen by some stakeholders as requiring high levels of transparency and high capacity of government monitoring systems, which would increase the probability of failure as these are weak points in the sector.

25.2 Institutional responses to uncertainty

Conventional water planning tends to be rigid and challenges remain regarding how to develop adaptive governance frameworks and institutions with increasingly uncertain and changing water futures. There are calls for more attention to be paid to resilient and adaptive institutions and approaches (GWP, 2009). The *World Water Development Report* 2 (WWAP, 2006) notes that insufficient access to water resources and services is not necessarily driven by water shortages but by the 'institutional resistance to change' that emanates from 'lack of appropriate institutions' to manage and secure resources for developing human capacity, management approaches, and provision of technical and physical infrastructure.

Without institutions capable of accommodating to uncertainty and shifting water supplies to where they are needed most, climate change and other drivers will impose significant impacts on water users and water-dependent communities. Yet much work remains to effectively integrate climate-related policies with water policies. This is problematic because many of the measures to adapt to climate change will have to be water-related (Björklund et al., 2009).

Institutional change or policy reform will be less effective unless it is coupled with enforcement of legislation to guarantee integrity and accountability in decision-making at all levels. Mismanagement, corruption, bureaucratic inertia and 'red tapism' all affect water management in detrimental ways. They increase transaction costs, discourage investments and can provide strong disincentives for water reform implementation and amplify risks and uncertainties for users. At the core they are symptoms of governance crisis. Recent studies confirm that for example petty corruption at the provider–consumer interface is one key area of risk that water projects and programmes must consider (Butterworth and de la Harpe, 2009). This calls for, among other things, more effective enforcement of regulatory institutions to monitor performance and expenditures of service providers.

In this section, some examples of response to uncertainty in decision-making are highlighted and analysed to provide snapshots of adaptive capacity of institutions; that is, to what extent are they flexible and robust to change as the social, political and ecological environment changes. Adaptive capacity has been defined as the potential or capability of a system to adjust, via changes in its characteristics or behaviours, so as to cope better with existing and future stresses. More specifically, adaptive capacity refers to the 'ability of a socio-ecological system to cope with novelty without losing options for the future' (Folke et al., 2002) and in a way 'that reflects learning, flexibility to experiment and adopt novel solutions, and development of generalized responses to broad classes of challenges' (Walker et al., 2002). In some cases new institutions might need to be created to deal with specific water challenges, as for example in the recent development of water quality trading for diffuse pollution and eutrophication management (van Bochove, et al. , 2011; Joyce et al., 2011).

Box 25.1 provides a detailed discussion of institutional change and adaptation in the context of water supply and sanitation services.

25.2.1 Evolving institutions

During the past decades many developing countries have been facing increasing challenges of water pollution such as those common in Western Europe and North America. This has led to the establishment of environment ministries, but much work remains to fully develop and implement pollution monitoring, legislation and regulation. It also seems likely that politically and financially weak ministries will face increasing tensions with water agencies responsible for water resources development projects. How governments will resolve these disputes is a challenge; there seems to be very limited institutions that can mediate water-related disputes between urban, rural and environmental interests.

Some interesting examples of how such disputes can be institutionally managed are found in so-called watershed markets. Put simply, watershed services are provided by upstream water users to downstream beneficiaries making some kind of payment or other compensations to those upstream. The 1998 New York City watershed agreement is well known (WWAP, 2009): in response to conflict with upstream water users over new land use restrictions and to protect New York City's water supply, a model was negotiated between farmers and the City that was built on financial compensation to farmers and guarantees that the City could acquire land only from willing farmers at fair market price. Similar agreements are emerging in other places in the USA; for example, the Cuyahoga River basin in Ohio identifies trading systems for stream, wetland and

BOX 25.1

Institutional change in water supply and sanitation services

Urban water supply services have traditionally been provided by state-owned and managed water utilities. A common trait in much reform around the world in the past decades has been that governments have attempted to turn state-owned water utilities into effective and viable organizations – with mixed success. The World Bank looked at 11 case studies (from Europe, Africa, Latin and North America, and Asia) of utilities that were well functioning and asked the question: Why have some public utilities become more efficient service providers while others have not been able to break the vicious cycle of low performance and low cost recovery? It presents a framework of attributes of well-functioning utilities and describes how these utilities have introduced key institutional measures.

The report concludes that water utilities are a part of the overall institutional landscape with its trends of change, which offers opportunities. The major transition of most utilities in the past decades has not been from public to private operation but from centralized to decentralized public provision. Fiscal squeeze has hit utilities hard: as public budgets decreased in the 1990s, infrastructure investments dropped disproportionally because governments have few discretionary spending categories. Under budgetary pressure, many public institutions have adopted new management tools, often borrowed from the private sector, to complement more traditional bureaucratic tools. Many countries have democratized, and an emerging civil society – including a consumer movement – has put pressure on utilities to deliver better services.

Institutional attributes

There is no perfect model for public utilities that guarantees good performance. But well-functioning utilities share these attributes:

- Autonomy: being independent to manage professionally without arbitrary interference by others. However, autonomy requires transparent processes so that regulators, consumers and others can exercise accountability and consumer orientation more easily.
- Accountability: being answerable to other parties for policy decisions, for the use of resources and for performance. Accountability extends to many different groups, such as regulators and the public (consumers).
- Consumer orientation: reporting on performance and listening to clients, and working to better meet their needs.

These attributes apply to the relationship between the utility and the environment in which it operates as well as to the internal functioning of the utility.

There are still noticeable obstacles to many utilities performing independently. Politicians can see utilities as a 'cash cow' if, for example, cost recovery rates increase. Many times staff is not held to account and practices of corruption and mismanagement are poorly addressed. Many sector reforms are currently underway, but meaningful consumer participation is often overlooked. In this respect, the launch of separate regulatory bodies has helped to some extent; for instance, Ofwat and its WaterVoice Committees in the United Kingdom (UK); the National Water Supply and Sanitation Council (NWASCO) and the Water Watch Group in Zambia; and the Consumer Consultative Council to be set up by the water and power regulatory body in Tanzania.

Institutional measures

The tools to achieve the above attributes can vary from case to case, but certain patterns of governance practices are emerging as being critical. Institutional measures to make public utilities more effective include corporatization, performance agreements, transparency and consumer accountability tools, and capacity-building.

Source: Baietti et al. (2006).

habitat mitigation banks as well as for water quality and carbon. The next step will be to quantify watershed services to establish who provides particular services and for what payment. An enabling feature for the Cuyahoga River basin system as well as in many other parts of the country is the existence of conservancy districts. These districts are organized along watershed borders and have the authority to tax and control land use (Flows, 2006).

25.2.2 Communication, coordination and integration among institutions of all scales

Institutions of all scales, local to global, need to respond to uncertainties. For an individual farm, droughts and floods are devastating events that threaten immediate income and future livelihood. There are increasing efforts to manage risk through insurance and other financial risk transfer instruments for smallholder rainfed agriculture in developing countries.

Basing insurance payouts on an objectively measured index (e.g. rainfall amount, modelled water stress, area-averaged production) that is correlated to loss instead of actual losses overcomes problems with moral hazard (the incentive for farmers to let crops fail), adverse selection (when less skilled farmers preferentially purchase insurance) and high transaction costs that have generally made traditional insurance unviable for smallholder farmers in developing countries (Brown and Hansen, 2008). As discussed in Box 25.2, some farmers in Kenya are now using financial risk transfer to lower crop yield risks related to rainfall variability. Another example is the World Bank's Commodity Risk Management Group that works with partners in several African and Latin American countries to implement bundled index-based insurance, credit and production packages that can overcome barriers to adoption of more profitable, intensified production technology by targeting the risk aversion of lenders (Brown and Hansen, 2008).

Local customary institutions can take a holistic approach to reduce uncertainties by accessing multiple water sources for multiple purposes (Sullivan et al., 2008). Five case studies undertaken by the International Centre for Integrated Mountain Development (ICIMOD) look at situations where people are responding to too much water (floods, water logging) or too little water (drought, water stress) across the greater Himalayan region: the dry mountain valleys of Chitral in Pakistan; the middle hills in Nepal; the Koshi basin floodplains in Bihar, India; the Brahmaputra floodplains in Assam, India; and the hill areas of Yunnan, China. Some of the key adaptation strategies were livelihood diversification and making use of and strengthening local institutions and social networks. Cultural norms and rules affect people's adaptive behaviour but importantly these are dynamic and can shift over time in response to needs. It was acknowledged that national institutions and policies strongly affect people's ability to adapt at the local level, but institutions and policies at the national level are rarely informed by adaptation concerns and priorities (ICIMOD, 2009).

Moving higher up the scale, institutions are required to regulate upstream and downstream water use and allocation at the watershed or river basin level. River basin management is not a new idea; it was applied,

BOX 25.2

Institutional adaptation at the local scale: Responding to climate uncertainties through farmer micro-insurance schemes

Many farmers are held back from investing to increase their yields due to many factors, such as unsecure land tenure and difficulties in accessing traditional credit markets. An increasingly important factor is the risks and uncertainties associated with flooding and drought. After a one-year drought a farmer runs the risk of not being able to repay an investment loan and therefore of losing his or her farm. One solution is to develop insurance schemes that use new information and communication technologies to protect farmers' investments from weather fluctuations.

For example, a micro-insurance scheme is emerging in Kenya that is supported by a national insurance company, a mobile phone network operator and an agribusiness. Farmers pay an extra 5% to insure a bag of seed, fertilizer or herbicide against crop failure. The agribusiness involved hopes to benefit from higher sales of its products and matches the farmers' investment to meet the full 10% cost of the insurance premium. Administration costs are kept to a minimum and the system is supposed to be self-financing. Local agents register a policy with the insurance company by using a camera phone to scan a bar code on each bag sold. A text message is then sent to the farmer's mobile phone that confirms the insurance policy. Farmers are registered at the nearest (solar-powered) weather station, which transmits data over the mobile phone network. If weather conditions worsen, a panel of experts uses an index system to decide if crops will no longer be viable. If they will not be, at this point payouts are made directly to farmers' mobile phones using the M-PESA mobile-money service. The system comes with minimal transaction costs because it has eliminated field surveys, most paperwork and the middleman.

During the trial, one area was hit with severe drought. This triggered compensation payments of 80% of farmers' investments. Without this insurance, farmers would have had severe financial difficulties to ensure seeds, fertilizers and so forth for the next cropping season. After a successful trial of 200 farmers, the initiative is now targeting 5,000 farmers in western and central Kenya.

Source: The Economist (2010).

for example, in Niger in the 1970s. The drought of the Sahel in the 1970s spurred the creation of river basin development authorities (RBDAs), which soon increased their responsibilities to encompass water management for the country as a whole. Their purpose in addition to general water resources management was to assure systematic use of groundwater and surface water, develop water for multiple purposes, supply irrigation water, control floods and control erosion. In some countries, such as Spain and Portugal, river basin organizations have been around for more than 100 years (Delli Priscoli, 2008). A recent Cap-Net study of river basin organizations points to some positive aspects of coordination among government agencies and water stakeholders. It also acknowledges, however, many cases where river basin organizations have a long way to go to manage water in equitable, sustainable and efficient manner (Cap-Net, 2008).

BOX 25.3

Time-bound multilateral institutions: An EU common water implementation strategy

A Common Implementation Strategy (CIS) was developed in May 2001 at the European level to support European Union Member States in addressing the scientific, technical and practical challenges of implementation of the EU Water Framework Directive. Most of the challenges and difficulties that arise during implementation will inevitably be common to all Member States, and indeed many of the European river basins are shared – crossing administrative and territorial borders – so a common understanding and approach is crucial to successful and effective implementation of the directive. A common strategy could limit the risks of the Directive being poorly applied and disputes subsequent to that scenario.

The focus of the CIS is to clarify and develop, where appropriate, technical and scientific information to assist in the practical implementation of the Directive. Such documents have an informal and non-legally binding character and are be placed at the disposal of Member States on a voluntary basis. The CIS is an example of a multilateral institution that is time-bound and subject-specific, designed to address the challenges faced by Member States in a co-operative and coordinated way; they are normally chaired by one Member State and funding is generally pooled by the Member States who manage the working groups.

Source: Common Implementation Strategy for the Water Framework Directive (2000/60/EC) 2001.

Moving on to regional scales, the European Union (EU) has developed a multilateral Common Implementation Strategy to support the implementation (and limit the risks and disputes related to implementation) of the Water Framework Directive (see Box 25.3). Water-related responses should be integrative and supportive of each other in a particular country or river basin. The EU's Common Implementation Strategy is an example of the supranational institutional level guiding country processes. The integrated water resources management concept provides guidance on horizontal and vertical coordination and integration of decision-making. Meaningful communication, built on an open flow of relevant data and information, is critical for unlocking the potential of integrative approaches.

25.3 Implementation of acceptable and workable institutions

In the earlier sections of this chapter, examples were provided of institutional development in relation to water resources access, use and allocation as well as to performance and distribution of water services. But why do some institutions work better than others? The development of institutions should be seen as path-dependent. For example, in a context where markets and regulatory functions are faced with severe constraints, it is not likely that water privatization will be effective; in a context where communities have limited resources and capacities, it is not likely that delegation of water management will work effectively. Institutional reform will have a greater chance of success if it has economic rationality; political willingness and sensitivity; and pays attention to social factors and stakeholders.

Robertson and Nielsen-Pincus (2009) suggest criteria that increase the chances of success of institutional reform: leadership and political will; social capital and inter-personal trust among participants; committed and cooperative participants; adequate and sustainable financing; participation and inclusiveness; adequate time; well-defined process rules; effective enforcement mechanisms; effective communication; adequate scientific and technical information; adequate monitoring; low or medium levels of conflict; limited (manageable) temporal and geographical scope of activities; training in collaborative skills; and adequate human capacities. Importantly, blueprints cannot be applied: what works in one context may not work in another. The factors for successful delegation of water governance in Canada capture some of the political, economic and social mechanisms essential for effective institutional change (Box 25.4).

25.3.1 Lowering transaction costs and avoiding free-riders

Water resource institutions determine who can use which water, how much of it, when, and for what purpose as well as set management responsibilities, fees and fee collection processes and so forth. Community-based water supply projects in rural areas have frequently proved untenable, with many communities being unable to raise sufficient funds to meet operation and maintenance costs of common water resources. Typical costs of community water projects include payment of electricity bills or for diesel to operate pumps; purchases of spare parts and maintenance; stationery for bookkeeping; staff transportation costs; telephone bills; and payment or compensation for bookkeepers and committee members. To keep the system operational, the members need to pay their fees.

'Free-riding' – when legitimate water users take more than their allocated share of water – can impose upstream and downstream disputes of water allocation. Free-riding also occurs when water resources are extracted by illegitimate users; that is, users who are not part of the institution. In sum, the free-rider is a water user who does not stick to commonly agreed rules. If too many free-riders operate in an institution, it will collapse because the transaction costs for monitoring and policing water users will be so high they outweigh the benefits, particularly in rural areas where water users can be dispersed over large areas and may lack shared community goals of fairness in water allocation and sharing of costs. In many places, social sanctioning serves as an effective way to minimize the number of free-riders. Social norms can generate costly punishment of community members breaking the rules – free-riders may run the risk of social exclusion or disrespect. Other ways to overcome the free-rider problem are community mobilization, social intermediation and institution building (Breier and Visser, 2006; Ostrom, 2000).

BOX 25.4

Water governance reform: Successful delegation of water governance in Canada

Water governance has undergone dramatic changes in Canada over the past decade, characterized by three key trends:

1. The introduction of new watershed-based delegated governance management models in a number of provinces.
2. Legislative and policy reform that has set higher standards for drinking water supply in a number of jurisdictions.
3. Greater citizen involvement in environmental policy-making and environmental management.

These trends have emerged due to several reasons: a shift in the view of the role and mandate of governments; new legal requirements (particularly with respect to First Nations, and also mandated by a new generation of environmental laws); awareness of the expertise available outside government, particularly in the context of decreased government resources; new approaches to citizen participation; increased emphasis on integrated management of environmental issues and watershed-based management; and concern over the implications of climate change for both water resources and supply.

In the context of overall water reform in Canada, the approach of delegated water governance is considered successful through the following factors:

- Effective leadership: clear structuring of processes, sustainable financing, adequate human resource support and the ability to implement recommendations.
- Inter-personal trust: transparency and respect for the rule of law.
- Committed participants: open or closed participation and an adequate range of participants.
- Sufficient scientific information: necessary for sound decision-making, this needs to be accessible to participants.
- Sufficient and sustainable funding: necessary to support collaborative bodies.
- Manageable scope of activities: it is important to limit scope and set targets.
- Policy feedback: a formal mechanism is needed to deal with recommendations from delegated water governance bodies.

Whereas the shift from state or centralized water management to community management and the increased participation of marginalized groups has in some instances provided new opportunities and benefits, such a shift might in some cases increase the burden on community resources and on women's labour and time.

Source: Nowlan and Bakker (2007).

Free-riders receive benefits without actually contributing anything, thus creating an unfair balance in the distribution of revenues or other resources. The social, political and economic dilemmas of free-riding occur not only in rural water supply but in any area and at any scale. Take for example urban drinking water supply around the world: some consumers – often in collusion with public officials – avoid paying fees by manipulating water metres or by other means. It has been noted that drivers of change, such as water scarcity, macroeconomic developments and natural calamities, interact to raise the opportunity cost of institutional change and reduce the corresponding transaction cost. This creates a conducive environment for institutional change.

25.3.2 Moving from inertia or resistance to political will

United Nations Secretary-General Ban Ki-moon's message on World Water Day, 22 March, in 2008 pointed to the lack of political will as the biggest problem in institutional reform: 'progress is hampered by population growth, widespread poverty, insufficient investments to address the problem and the biggest culprit: a lack of political will' (Ban Ki-moon, 2008). Institutional water reform needs to be firmly anchored among stakeholders and their leadership. If institutions are considered as unacceptable in their set-up and produce undesired outcomes, they will not receive support and stakeholders are more likely to keep the status quo or even develop their own informal rules rather than adhere to existing rules.

Because reforms change status quo, one can expect both support for and opposition to institutional reform agendas by affected groups. In some cases, the implementing agency may not have a reform agenda that coincides with that of the government initiating the reform. For example, an analysis of the parties involved in a proposed water fee reform for the capital of Honduras, Tegucigalpa, revealed that the public agency in charge of water supply was a major opponent to the reform. Support for institutional reform was driven by external international development agencies, but in this case, the support was not sufficient for reform to take place – for the reform to go forward it had to be supported by national power centres. In Pakistan for example, some government ministries and agencies opposed reform – part of which was to transfer power and financial resources from the irrigation ministry and its regional offices to area boards – because they felt it would affect them negatively (WWAP, 2006).

It has also been observed that bureaucratic behaviour can cause disincentives for effective institutional reform to deal with new challenges. For example, in efforts for decentralizing water decision-making and management, bureaucratic behaviour can lead to a pre-occupation of roles, hierarchies and procedures that protect the affected department from having to respond to institutional change. On an individual basis, staff members are concerned about employment security and station location. Clearly, the combination of organizational inertia or resistance to change coupled with staff concerns makes change hard unless pressure and/or incentives are applied by higher political and administrative levels (Holmes, 2003).

The importance of political will can be illustrated by water reform in some countries. In Canada, effective leadership is considered one of the required factors for institutional change in delegating water governance (Box 25.4). In Scotland, the transition from old to new regulatory approaches is not without tensions and inconsistencies, particularly at the legal and operational levels. Water disputes in Scotland are associated with the redesign of national administrative responsibilities and the re-establishment of a devolved parliament. There is still a gap in understanding the effective possibilities and tensions associated with the new regulatory regime based on the EU Water Framework Directive. For example, the income from new water charges was expected to cover 50% of the operational costs incurred by the Scottish Environment Protection Agency (SEPA), while the other 50% was to come from the government in the form of general taxation. It has been argued that despite a discursive construction and sustainability as well as stakeholder participation, the new institutional landscape has so far failed to improve long-term patterns of water use and conservation. Whereas formal changes in the legislation created a positive space for institutional reforms, the effective improvement of water policy and catchment management has been curtailed by political inertia and the hidden balance of power. The farming sector in Scotland through the National Farmers Union (NFUS) stated that new charges for regulating farms that abstract water have generated a lot of heat and debate with SEPA and the Scottish Executive (Loris, 2009; NFUS, 2006).

25.3.3 Building trust, integrity and accountability

Several studies on institutions bring up inter-organizational trust, inter-personal trust and networks as important for effective institutional development and implementation. In the case of local adaptation to climate change in the greater Himalayan region, social networks were seen as important to enhance adaptive capacities. Similarly, inter-personal trust was critical for effective delegation of water governance in Canada (Box 25.4). Recent case studies (Ross, 2009) suggest that trust – social trust within a community or trust between communities and public authorities – is more important the higher the risks and uncertainties involved. One case study area, Toowoomba in Queensland, Australia, was set in a high perceived risk context for a proposed water re-use scheme for potable water. Perceptions of risk had a very strong direct effect on acceptance of the scheme, and the trust, risk and acceptance relationship was stronger than it was for other case study areas. Moreover, the relational variables of procedural fairness, identification with one's community, in-group membership of the water authority, and shared values with the water authority were all found to affect trust, directly or indirectly. The credibility of the authority – measured as technical competence and a lack of vested interests – was found to have a significant impact on trust. In sum, the results highlight the need for water authorities and policymakers to build trust among stakeholders through procedural fairness, developing a sense of the water authority as a member of the community, and demonstrating technical competence and concern for the interests of the public (Ross, 2009).

A formidable problem in many water institutions is corruption (Transparency International, 2008; WWAP, 2009). In too many cases corrupt behaviour has become the norm and ironically, corruption can constitute an institution in its own right. Corruption not only undercuts development and raises the stakes regarding risks and uncertainties of water availability and allocation, it also undermines critical foundations of trust, the rule of law, fairness, and efficiency of water institutions. Well-functioning institutions have developed systems of accountability. Considering the frequency of corruption in water, formal systems of accountability are often deterred and replaced by discretionary decision-making, characterized by exclusiveness and limited transparency. This renders water institutions less effective and less prone to adapt to new challenges as the status quo is preferred to protect vested interests.

There is a growing knowledge base on measures to strengthen accountability and integrity and hence reduce corruption. The simplification of procedures, increased transparency and participation will go a long way in reducing corruption: this was illustrated in the World Bank-supported Kecamatan Development Project (KDP). This project has a scope of more than 34,000 villages across Indonesia and has supported the country's water sector by building 7,178 clean water supply units, 2,904 sanitation units and 7,326 irrigation systems. Corruption was initially involved: officials being bribed to award projects, funding cuts by upper levels of government, illicit fees being charged to users, and under-delivery of materials and services by suppliers. As a result the KDP built anti-corruption measures into its projects that emphasized simplification of procedures, transparency and information-sharing throughout the project cycle (WIN, 2009).

25.4 Opportunities for improving water institutions

Uncertainty in natural, technical and social systems is relevant to institutional responses because it can distort decision-making. Decisions made under conditions of uncertainty may underestimate or overestimate the challenges to which they respond, resulting in too-costly or non-required measures, or conversely, insufficient measures that can threaten investments and progress already made. Institutional responses are crafted and implemented by social systems, which can be as hard to predict as climate change and its impacts. An institutional response measure based on an acceptable degree of certainty how natural systems will behave in the near future may not go far if there are different perceptions on what is fair as well as disparate objectives and interest among water users in the social system. It is important that risk and uncertainty associated with climate change be put into context relative to other risks that water institutions face. Changes in water demand may be more important for some countries than changes in actual supply.

Uncertainty can partly be overcome by better data, information and knowledge(see Chapter 26, 'Knowledge and capacity development') but even so, the future will always be unpredictable and requires flexibility, hence the imperative to develop responsive institutions that can deal with at least some of the uncertainties. Situations of high natural, technical or social uncertainty can create disincentives for cooperation and stakeholder participation. The probability of institutional failure and thus the ability to deal with situations of uncertainty is higher the more actors who break the rules of the game without appropriate sanctions. For example, new water regulatory institutions in corrupt environments may not provide sufficient incentive for fairer and more effective water reallocation and improved accountability. Knowledge on how institutions can develop to better respond to present and future risks and uncertainties is rudimentary and there needs to be a lot more research into practical application of institutional measures to determine what works, and under what conditions it works. Long-term investment to build water institutions is needed; in particular, investment for monitoring in relation to governance and institutional performance is severely lacking.

This chapter has indicated some of the factors required for successful water institutions and highlighted that these vary considerably according to context. Effective institutional change and to what degree it can deal with uncertainty is closely related to path dependence as well as to context specific conditions. It is important that water decision-makers intensify their efforts to provide incentives for meaningful institutional change to better cope with uncertainty. Among other actions, the following should be taken into account.

Implementation challenges remain a big obstacle to effective water reform and management and should be more coherently addressed as part of institutional reform processes. Challenges such as vested political interests and accountability systems should be more carefully analysed and addressed as part of water related institutional reform. Many countries are plagued with implementation problems, driven by for example limited capacities and funding, elite capture of policy processes, and institutional gaps and fragmentation. As a part of overcoming some of these challenges this it is important to:

- Seek continuous alignment and implementation of water, energy, ecosystem and land policies within formal and informal institutions and processes that effectively guide actions for these areas. Currently many institutions tend to be fragmented, over-lapping and sometimes even conflictive. There is thus a lot of room for continuing to develop institutional linkages as a strategy to strengthen adaptive management. Hence, this also means increased policy synergies between issues related to water, food, energy and ecosystems.
- Address fundamental governance challenges – such as limited transparency, accountability and stakeholder involvement – that provide reform implementation disincentives. It is less likely that water institutions can perform their intended functions (e.g. fair and efficient water allocation or water services provision) in governance systems characterized by clientelism, corruption and vested political interests. In such cases decision-making gets more unpredictable and increases uncertainty in for example social systems for those that lack political and economic influence.
- Target particular capacity development, data and information needs and promote learning-oriented institutional processes. Experience suggests that institutional reform is an iterative learning process where institutional change is negotiated between different groups. There are no perfect solutions; there are only solutions that work in a particular context. Others have expressed this as 'look for the best fit, not the best practice' (Baietti et al., 2006).
- Go beyond formal regulation and incorporate informal institutions into analyses of risk and uncertainty. Water resources in many parts of the world are allocated by informal local institutions and formal regulatory systems may have only limited influence. To fully understand institutional drivers and implement effective water reform it is critical to look at the dynamics between formal and informal institutions. Meeting the challenge of reaching poor and marginalized groups of society – who normally depend on informal systems of water allocation and water services – will rely on water decision-makers providing incentives to strengthen local informal institutions and making water policies and regulations more supportive of them.
- Underline that financing remains an important challenge to cope with present and future uncertainties in social, natural and technical systems. Acceptable and functioning institutions underpin increased and more effective investments in water development. Poor institutions constitute amplified investment risk and affect the competitiveness of countries in global markets, the attraction of foreign direct investment, as well as impacting on firms in national and local markets. While the need for additional investment in water is acknowledged, much more focus has to be put on how to make most effective use of present funding for more informed investment decision-making to reduce risks and cope with uncertainties. There is thus a need

to develop better cost–benefit analyses of various investments options on how public and private sectors best should use their funding, capacities and knowledge.

Notes

1 Sociological studies suggest that informal institutions at local levels can be perceived as formal. Sometimes a distinction is made by using statutory and customary institutions.

2 It is acknowledged that there can be big variations between countries within a region. The results of the survey should be perceived as relative and not suitable for regional comparison.

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CHAPTER 26

Developing knowledge and capacity

UNW-DPC and UNESCO-IHE

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The water sector will increasingly be subject to externally driven changes, yet societies will at the same time expect more reliable water services and less risk. Our understanding of natural and social phenomena has gaps, and, therefore, knowledge and capacity development is a top priority on the international agenda.

To deal with the new and dynamic challenges, the adaptive capacity of individuals, society and institutions is to be enhanced.

Knowledge sharing and collaborative tools will become prominent. ICT will be a powerful instrument to disseminate information and involve stakeholders in decision-making.
The existing gaps in our knowledge about how global change is going to affect us and how all societies should continuously adjust their water sectors to new external changes and evolving internal demands put developing knowledge and capacity as a top priority on the international agenda.

Developing the adaptive capacity of individuals, society and institutions is needed to face the new and dynamic challenges caused by global change.

There is a need for an increased use of knowledge sharing and collaborative tools. The power of ICT should be used to accelerate the dissemination of information and impose social learning within water institutions.

26.1 A changing agenda

Sustainable water management is one of humanity's most important challenges – today and in the future. Rapid changes in the hydrological cycle, and increased incidence of hazards such as extreme weather events, are further complicating the processes of decision-making for stakeholders and water managers by increasing risk and uncertainty. For example, uncertainties in water management are associated with various hydrological, hydraulic, structural and economic aspects. Risks are also present at different levels of water systems including the risk of natural disasters, risks involved in the operation of water infrastructures, drought, and risks associated with investing in water projects. The resulting adverse impacts are neither uniform across time, space and sectors, nor fair to all groups. Box 26.1 illustrates the impact that natural disasters have on women as a result of their intensive involvement in water management and their weak adaptive capacities.

The knowledge to address many of these challenges does exist. However, there are still considerable gaps in what we know. For example there are gaps in our knowledge about how global change is going to affect us and what our responses should be. There are gaps in our understanding of how water services should be delivered, and of how to manage the resource of water more effectively and sustainably. This represents the first key challenge. But what is equally important is that even when the appropriate knowledge is available, it does not always get readily disseminated and shared – and translated into proper planning or effective action.

BOX 26.1

Gender challenges

In developing countries, women are generally responsible for producing food. This makes them the first to face the risks that come with drought and uncertain rainfall. Climate change often means that women and young girls have to walk ever further to collect water. For instance, women in sub-Saharan Africa spend 40 billion hours per year collecting water – equivalent to a year's labour by the entire workforce in France. The following are some examples that show that women are the first to suffer from the risk and uncertainty of climate change:

- Women, boys and girls are 14 times more likely than men to die during a disaster (Peterson, 2007).
- In Bangladesh, during the cyclone disasters in 1991, 90% of the 140,000 fatalities were women (Zeitlin, 2007).
- During the emergency caused by hurricane Katrina in the United States, most of the victims trapped in New Orleans were the poor African–American women with their children (Gault et. al., 2005; Williams et al., 2006).
- In Sri Lanka, it was easier for men to survive during the tsunami because boys are generally taught how to swim and climb trees while girls are not (Oxfam, 2005).

Source: UNDP (2009).

On the one hand, the time-lapse between research findings and widespread local actions is still too long. On the other hand, institutions are weak in certain developing nations, especially at local-government level and in many communities. While this constraining effect is especially noticeable in countries that are developing into modern economies, it is a challenge for all societies as they continuously adjust their water sectors to new external changes and evolving internal demands. Therefore, it is the weak capacity in the water sector institutions that is the key obstacle to enhanced performance, and not the shortfall in financial support, as was the case in the 1970s and 1980s.

The international development banks report ongoing problems in identifying feasible and well-prepared investment projects. For instance, in Asia, both the Asian Development Bank and the World Bank have been experiencing constraints over the past decade in their attempts to increase investment in the water sector. The European Union reports a similar situation; only a portion of the 2002–2010 structural funding for water infrastructure in the new member states in central and southern Europe was absorbed effectively. The European Commission assessed that this was caused *inter alia* by factors related to weak capacities in the sector's agencies – capacities in terms of the number of civil servants and specialists; of the skills and experience available; and of the prevailing managerial and policy environment in the public sector.

26.2 Developing capacity

26.2.1 Basic understanding

Capacity is an attribute of individuals, organizations and other forms of institutions. It is not something external to these individuals and bodies. In 2005, the OECD defined capacity as the 'ability of people, organizations, and society as whole to manage their affairs successfully'. Capacity development (CD) furnishes the frameworks, approaches and tools needed to carry out institutional development. By its very nature, CD is relevant only in the context of change, and it is part and parcel of change management (Alaerts, 1999; EuropeAid, 2005).

Capacity development and knowledge management are two sides of the same coin. This definition allows a measurable, operational interpretation to be given to capacity. It also emphasizes the link between capacity and a verifiable, on-the-ground impact after CD interventions have taken place. Seeing CD and knowledge management in this way also makes the case for developing critical 'extra' capacity to generate fresh knowledge to prepare for the future. Knowledge management has become a mainstream strategy used by private businesses to remain competitive, and therefore profitable, but most governments and sector agencies, and non-governmental organizations for that matter, still lack the structural provisions that would allow this learning to take place.

The application domain of CD is broad. However, there are a number of common situations where CD initiatives are having an effect.

- ***Improving technical competence*** Such an objective is generally readily appreciated and accepted because it can often be addressed by targeting the individual technical competences of staff and the skills mix in the organization. Generally, such programmes do not lead to structural change and reform.
- ***Improving overall performance and results*** To enable staff and other agents to build capacity and use it, improved incentives may have to be offered – for instance better career opportunities, higher remuneration, and education opportunities. It is often assumed that working on an organization's technical competence is enough to develop capacity. But a CD effort may also involve changes in legal and regulatory frameworks. Examples of such change process are the Uganda Water and Drainage Board (Mugisha, 2009; WWAP, 2009, p. 263) and the Netherlands Ministry of Transport, Public Works and Water Management – now the Ministry of Infrastructure and the Environment (Box 26.2).
- ***Strengthening accountability and making the local voice heard*** Sometimes there is a need to build the capacities of local groups and local councils to help them update their skills and build resilience (Box 26.3)
- ***Improving decision-making*** Increasingly, the aim of decision-makers is to help sectoral agencies and society at large to become better able to deal with uncertainty in the future. This is of special relevance when discussing geopolitical situations such as international river basin conflicts, health epidemics, climate change, etc. and calls for the establishment of a communications and information platform where

BOX 26.2

Changing tides: Change management at the Netherlands Ministry of Transport, Public Works and Water Management

All nations are regularly searching for better and more effective public administration systems. This is illustrated by changes that have taken place in the Netherlands' Ministry of Transport, Public Works and Water Management – which in 2010 became the Ministry of Infrastructure and the Environment. Institutional reform was implemented in a series of phases through capacity development and knowledge management processes.

Phase 1: Readiness for change In the 1970s, public pressure had forced the ministry to change to integrated water resources management and to acquire ecological expertise. But in the late 1990s, the ministry's decentralized structure with its regional directorates and dominant engineering services was deemed to be unable to cope with the new generation of national-scale projects and demands for tighter budget discipline.

Phase 2: Developing the new capacity The new institutional structure took shape between 2004 and 2007. The supportive capacity development included the following:

- Workshops, brainstorming sessions, leadership training and other interactive events.
- A new skills mix. Many experts became redundant, while personnel with new skills in the areas of contract management, budget control and communications were taken on.
- A communications strategy to keep the public and politicians informed about progress.

Phase 3: Lessons learned After the reform, the ministry and the executive agency were deemed to be better prepared for the new decade. The phased CD process allowed them to pilot new ideas and generate solutions, thus creating a fertile learning ground for learning-by-doing. At the same time, early retirement and release of seasoned senior experts severely eroded the ministry's knowledge base and its capacity to train new staff.

Source: Various reports including Metze (2009).

project initiators and government can adapt their initiatives and build a broader political consensus.[1]

- Education, research and innovation In its most traditional form, capacity development focuses on a country's educational, research and innovation systems. Such programmes can be narrow and specific or broad and general.

26.2.2 Developing adaptive capacity

As discussed in Section 26.2.1, ignoring uncertainty increases the risk of inappropriate water management decisions. adaptive water management (AWM) is designed to address increased uncertainty and risk by making them fundamental parts of the management approach. AWM uses the lessons learnt from the outcomes of management strategies. It considers changes in external factors in a proactive manner to develop a systemic process for improving management policies and practices. It maintains as its central objective to improve the adaptive capacity of the management regime in general (Pahl-Wostl et al., 2010) and particularly the actors involved. As noted by Bormann et al. (1993), 'Adaptive management is learning to manage by managing to learn.'

> **BOX 26.3**
>
> **Women's participation in the adaptation and mitigation processes**
>
> In many societies, women have unique climate change related skills, experiences and capacities that have been acquired over centuries of active participation in water management activities. Capacity development activities can add even more value to this knowledge and allow them to contribute positively to the identification of appropriate adaptation and mitigation techniques. The following are three real examples:
>
> - In 1998, the Honduran community of La Masica was given gender-sensitive community training about early warning and risk systems. During Hurricane Mitch a few months later, not a single death was reported in La Masica because the municipal government had been able to evacuate the population in time (Sánchez del Valle, 2000).
> - During a drought on the small islands of the Federated States of Micronesia, the women's ancestral knowledge of the islands' hydrology allowed them to identify places to dig wells for drinking water. (Anderson, 2002).
> - The floods in Bangladesh in 2004 left 280 dead, around four million evacuees, and thousands of others without food or housing. Recently, in the district of Gaibandha, a woman named Sahena has organized a committee to prepare the women for floods. The committee trains the women to make portable clay ovens, raise their houses, and use radios to hear floods warnings and news of climate change. Efforts such as Sahena's save many lives and empower women (Oxfam, 2008).
>
> *Source: UNDP (2009).*

While traditional technical knowledge and the capacity to manage water resources (as described in Section 26.2.1) remains important in the context of AWM, the ability of water institutions and management actors to absorb, adopt and implement new forms of management is dependent on additional knowledge and capacities. In AWM, capacity development refers to the development of the knowledge, skills and attitudes that are necessary for managers and professional organizations to increase their adaptive capacity and create institutions that are flexible and responsive enough to cope with risk and uncertainty (Van Scheltinga et al., 2010).

People's adaptive capacity needs to be analysed and quantified to face the risk and uncertainty caused by such sources as climate change. Therefore, the African Climate Change Resilience Alliance (ACCRA) has identified five characteristics of adaptive capacity. These can be used to analyse people's own adaptive capacity in the face of a combination of risk and stress. These characteristics also help to analyse how different programming approaches either support or hinder adaptive capacity. The five characteristics are summarized as follows (ACCRA, 2010):

- **The asset base:** These are the various financial, physical, natural, social, political and human capitals necessary to best prepare a system to respond to a changing climate.
- **Institutions and entitlements:** The ability of system to guarantee equitable access and entitlement to key resources and assets is a fundamental characteristic of adaptive capacity.
- **Knowledge and information:** Successful adaptation requires information about and understanding of future change, knowledge about adaptation options and the ability to assess them, and the capacity to implement the most suitable interventions.
- **Innovation:** A key characteristic of adaptive capacity relates to a system's ability to support innovation and risk taking.
- **Flexible forward-thinking decision-making and governance:** Informed decision-making, transparency, and prioritization each form key elements of

adaptive capacity.

There are different approaches to improving the adaptive capacities of individuals and institutions. For example, the Institute of Development Studies proposed an approach to develop adaptive capacity as one of three pillars of a new approach to Climate Smart Disaster Risk Management CSDRM (Mitchell et al., 2010). This approach involved over five hundred researchers, community leaders, non-governmental organization (NGO) workers and government officials from ten disaster-prone countries. The approach is outlined as follows:

- To strengthen the ability of people, organizations and networks to experiment and innovate.
- To promote regular learning and reflection to improve the implementation of policies and practices.
- To ensure that policies and practices to tackle changing disaster risk are flexible, integrated across sectors and scale, and have regular feedback loops.
- To use tools and methods to plan for uncertainty and unexpected events.

BOX 26.4

Enhancing adaptive capacity in the Mekong basin

In 2000, the Mekong delta faced the worst floods in 40 years. More than 800 people died, nine million were affected, and the costs of damages exceeded US$455 million. Since then, a range of initiatives have been implemented under the Flood Mitigation and Management Programme (FMMP). These included flood forecasting capacities, best practice guidelines for integrated flood risk management, guidelines for integration of flood preparedness plans, flood probability mapping and land use zoning, and an annual Mekong flood forum.

The FMMP's 2009 flood report highlighted how climate change specifically influenced flood risk. Climate change was also a key theme at the FMMP annual Mekong Flood Forum in 2010. The forum promotes learning across the Mekong basin. It provides governments and others involved in the programme an opportunity to gather data and to explore implications and responses by sharing their experiences. For example, the Asian Disaster Preparedness Centre (ADPC) is giving lessons on integrating flood risk management at district and provincial levels to countries facing similar challenges.

Source: Mitchell et al. (2010).

In 2009, CARE International proposed four related strategies to form an integrated approach that combines traditional knowledge with innovative strategies. The aim was to build adaptive capacity in order to face the new and dynamic challenges caused by climate change. (Table 26.1):

- Climate-resilient livelihood strategies in combination with income diversification and capacity building for planning and improved risk management;
- Disaster risk reduction strategies to reduce the impact of hazards, particularly on vulnerable households and individuals;
- Capacity development strategies for local civil society and government institutions so that they can provide better support to communities, households and individuals in their adaptation efforts; and
- Advocacy and social mobilization strategies to address the underlying causes of vulnerability; causes such as poor governance, lack of control over resources, or limited access to basic services.

26.3 Preparing a capacity development strategy

26.3.1 A rational comprehensive framework for analysis

Figure 26.1 illustrates the elements of capacity development. It also provides a comprehensive analytical framework that helps to guide assessments of CD needs and define appropriate, case-specific CD programmes (Alaerts and Kaspersma, 2009). The diagram identifies four levels of attention: the individual, the organization, the enabling environment, and civil society. It specifies, in broad terms, what capacity and knowledge imply, how CD can take place, what the potential outcomes are, and how the CD can be assessed after interventions.

Capacity, or the lack of it, can best be assessed through practical and narrowly defined proxies and checklists that are tailored to suit various situations and purposes (Lusthaus et al., 2002; Alaerts and Kaspersma, 2009).

The performance of the water sector and all its subsectors is the result of the effective action of individuals with the proper knowledge and capacity, who function in larger organizations such as ministries, local governments, water user associations and civil society organizations. Effectiveness depends both on the effectiveness of individuals and on the features that shape the capacity of the organization itself – its skills mix, its internal operational and administrative procedures, incentives, etc. Organizations with the right capacity and procedures still need an enabling environment to put the facilitating factors in place. Such an environment includes an enabling legal and regulatory framework, fiscal rules that stimulate action, and a broadly supportive parliament, electorate and consumer base. The scope and depth of the desired CD process will depend on the outcomes of the above analysis and the extent of the political support for change. The analytical frame is exhaustive and can

TABLE 26.1

CARE's framework for community-based adaptation

	Climate-resilient livelihoods	Disaster risk reduction	Capacity development	Addressing underlying causes of vulnerability
National level	- Government is monitoring, analysing and disseminating current and future climate information related to livelihoods - Climate change is integrated into relevant sectoral policies - Climate change is integrated into poverty reduction strategies and/or other development policies	- Government is monitoring, analysing and disseminating disaster risk information - Government is engaged in planning and implementing disaster risk management (prevention, preparedness, response and recovery) - Functional early warning systems are in place - Government has the capacity to respond to disasters	- Government has the capacity to monitor, analyse and disseminate information on current and future climate risks - Government has a mandate to integrate climate change into policies - National policies are rolled out at regional and local levels - Resources are allocated for the implementation of adaptation related policies	- Government recognizes the specific vulnerability of women and marginalized groups to climate change - Policy and implementation is focused on reducing these vulnerabilities - Civil society is involved in planning and implementation of adaptation activities
Local government and community level	- Local institutions have access to climate information - Local plans and policies support climate-resilient livelihoods - Local government and NGO extension workers understand climate risks and are promoting adaptation strategies	- Local institutions have access to disaster risk information - Local disaster risk management plans are being implemented - Functional early warning systems are in place - Local government has the capacity to respond to disasters	- Local institutions have the capacity to monitor, analyse and disseminate information on current and future climate risks - Local institutions have the capacity and resources to plan and implement adaptation activities	- Local planning processes are participatory - Women and marginalized groups have a voice in local planning processes - Local policies provide access to and control over critical livelihoods resources for all
Household and individual level	- People are generating and using climate information for planning - Households are employing climate-resilient agricultural practices - Households have diversified livelihoods, including non-agricultural strategies - People are managing risk by planning for and investing in the future	- Households have protected reserves of food and agricultural inputs - Households have secure shelter - Key assets are protected - People have access to early warnings for climate hazards - People have the mobility to escape danger in the event of climate hazards	- Social and economic safety nets are available to households - Financial services are available to households - People have knowledge and skills to employ adaptation strategies - People have access to seasonal forecasts and other climate information	- Men and women are working together to address challenges - Households have control over critical livelihood resources - Women and marginalized groups have equal access to information, skills and services - Women and marginalized groups have equal rights and access to critical livelihood resources

Source: CARE (2009), reproduced with permission of the CARE International Poverty, Environment and Climate Change Network (PECCN).

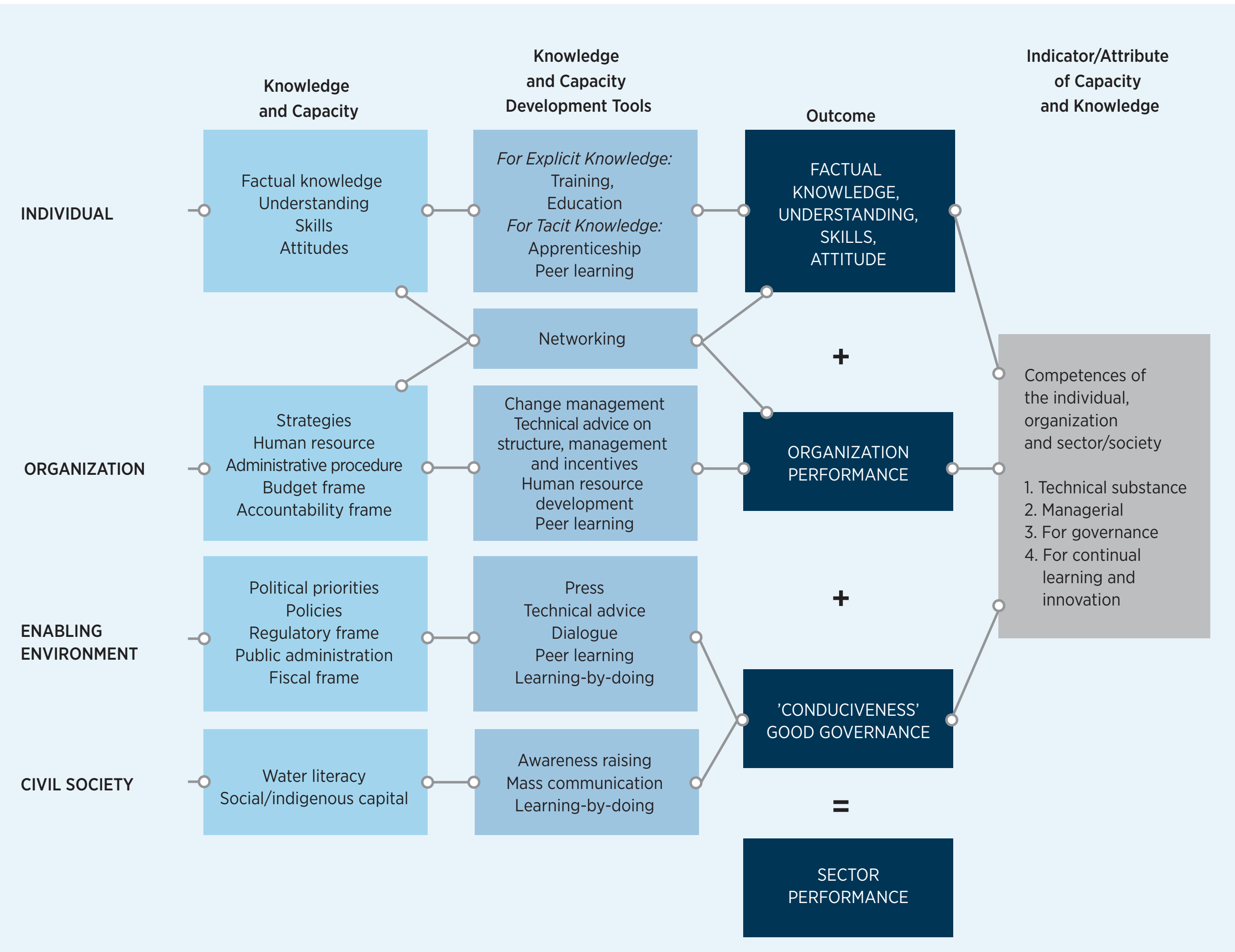
help to identify the sub-set of institutions where demand, readiness and likely impact may be highest. Knowledge, understanding and skills are generally developed through knowledge transfer instruments such as training and education. However, whether the desired capacity or knowledge is explicit or tacit dictates which instrument should be chosen. Tacit knowledge is eventually far more important because it shapes skills and deeper attitudes. This is best transferred through one-on-one interaction between junior and senior, apprentice and teacher. Organizational capacity is enhanced by educating staff and by helping the organization to learn from experiences. Technical assistance, management advice, learning experiences, comparison with peers, and benchmarking, are important instruments. Networks and information communication systems (ICSs) have an increasingly important role for improving knowledge and capacity and opening up new avenues for disseminating knowledge.

At the level of the enabling environment, governments and other actors also learn and become able to develop more supportive environments. Policymakers, government departments, and politicians also learn lessons from 'best practices' in other countries. Finally, the role of society is of course critically important as it shapes the nation's consensus for the future by electing politicians and holding its government accountable.

Eventually, 'capable' individuals and organizations possess aggregate competences to act. There are four types of aggregate competences (Baser, 2009; Alaerts and Kaspersma, 2009):

FIGURE 26.1

Schematic of capacity development at different levels, showing inputs, outcomes and methods of measurement



Source: Alaerts et al. (2010), reproduced with permission from Taylor & Francis.

- Technical or substantive competence is required to analyse and solve technical problems in a range of areas from construction to financial accounting.
- Organizations need a pool of leadership and management competences embodied in their senior staff. In many developing countries, agencies may score well on technical and civil engineering aspects skills, but may be less effective in managing personnel and administration. Management competences ensure that 'things get done'.
- An effective and sustainable water sector requires organizations that are able to foster and apply the principles of good governance – dialogue and communication with stakeholders, resource allocation within policy frameworks that aim for equity and poverty alleviation, sensitivity to vulnerable groups and transparency and accountability.
- Capable individuals and organizations are those who continuously learn and innovate. Learning and innovation do not come naturally; they require financial resources, personnel and managerial procedures.

26.3.2 Assessment of capacity and needs

As a first step, decision-makers should assess the institutional performance of the water sector or sub-sector. This should include all the institutions that are involved with it. A number of organizations and UN agencies are offering guidance and checklists for use in such assessments. Box 26.5 describes a number of relevant sources of information and further guidance is available in the second *World Water Development Report* (WWAP, 2006, p. 454–8).

In 2007, the United Nations Development Programme (UNDP) compiled a collection of CD assessment experiences and it offers a framework for assessing capacity. The core issues it lists are institutional development, leadership, knowledge, and mutual accountability. Some of the critical functional capacities it includes are the capacity to engage in multi-stakeholder dialogue, situational analysis, vision creation, policy and strategy formulation, budgeting, and monitoring and evaluation.

Once a CD assessment has been completed, a strategy and action plan can be derived. Such strategy should be shaped contextually through dialogue with stakeholders because there is no 'one size fits all' strategy. Addressing weak institutional environments is not a straightforward or linear process. It often works best through 'strategic incrementalism' where practical steps and incremental reforms are adopted, even if they don't fully address all the performance problems at once (Nelson and Tejasvi, 2009).

In 2008, the World Bank developed its own Development Results Framework to Assess Capacity. It did this by measuring capacity through the actual impact and performance in the field. The World Bank and UNDP frameworks derive partly from Lopes and Theison (2003), who suggest a checklist with key questions that should be considered in assessments (see also WWAP, 2006, p. 456).

BOX 26.5

Sources for capacity development

- **The UNDP capacity development website** (www.capacity.undp.org) includes key sources for generic information on how to perform capacity assessments. It includes initiatives, networks, resources and tools. It offers access to the Capacity 2015 initiative developed to operationalize the MDGs.
- **The South African Capacity Initiative** (SACI) (www.undp-saci.co.za) developed a Capacity Mobilization Toolkit for southern African countries, which takes into consideration the particularly complex human capacity challenges associated with the impact of HIV/Aids, poverty and recurring disasters.
- **The World Bank** provides an online Capacity Development Resource Centre (www.worldbank.org/capacity), which provides an overview of case studies, lessons learned, 'how to' approaches and good practices pertaining to capacity development.
- **The Canadian International Development Agency** (CIDA) has developed a CD toolkit (www.acdi-cida.gc.ca) that includes reference documents for capacity development.
- **The European Centre for Development Policy Management's** capacity development website (www.capacity.org) aims to look at policy and practice of capacity development within international development cooperation and provides a newsletter and a comprehensive material related to capacity development in all sectors.
- **The International Development Research Centre** (IDRC), the **International Institute of Rural Reconstruction** (IIRR) and the **International Service for National Agricultural Research** (ISNAR) implemented a project to better understand how CD takes place and how its results can be evaluated.
- A team from the **German Agency for Technical Cooperation** (GTZ) supported the Indonesian Government in preparing guidelines on how to organize and manage a needs assessment process. This resulted in a medium-term regional CD action plan.

The Asian Development Bank (ADB, 2008) provides a practical guide to CD at the sector level. According to this, three pre-conditions must be fulfilled for a successful CD process: there must be dissatisfaction with the current situation; a credible change process must have been proposed; and a vision of the future should be shared by stakeholders (Box 26.2). Again, it appears essential that the key stakeholders, particularly the government, need to own the change process.

At the sectoral level, many water management ministries and departments face staffing constraints and are seeking advice on building competencies. Two initiatives are currently mapping the water sector's human resources needs. UNESCO-IHP and UNESCO-IHE have been assessing water education needs in several regions. Together, the International Water Association (IWA) and the UK Department for International Development (DFID) in association with UNESCO-IHE are assessing the human resources development requirements for achieving the Millennium Development Goals (MDGs) for water supply and sanitation (WSS). A standardized methodological framework is being developed based on five country-based pilot studies.

26. 3.3 Assessment of adaptive capacity

Capacity development activities should seek to enhance the ability to cope with uncertainty and risk. The following are just some examples of abilities and functions that should be available at each CD level to ensure adaptive capacity:

- Individuals should have information on current problems, sources of risk and the desired direction of change. Behaviour should be proactive, and individuals should able to learn flexibly in a variety of ways, (Fazey et al., 2007).
- Organizations should have the ability to learn, to challenge their own established ways of thinking and acting, to react to unpredictable internal and external changes, and to produce social change and achieve mission impact.
- An enabling environment requires the freedom to adjust policies to the new reality of climate change

TABLE 26.2

Indicators for assessing adaptive capacity

Level	Indicators
Individual	• Are people generating and using climate information for planning? • Are people managing risk by planning for and investing in the future? • Do people have the knowledge and skills to employ adaptation strategies? • Are men and women working together to address challenges? • Do women and other marginalized groups have equal access to information, skills and services?
Organization	• Is the organization aware of which areas and groups are at risk? • Can the organization identify and assess the risks to the services being provided? • Is the organization addressing these risks in the local community strategy or community plan? • Have disaster risk management policies and practices been changed as a result of reflection and learning-by-doing? • Is there a process in place for information and learning to flow from communities to the organization and vice versa?
Enabling Environment	• Are the institutional frameworks adapted to the new reality of risks? • Are policies reviewed using the global change 'lens'? • Is the environment supporting the implementation of local disaster risk management plans? • What is the level of participatory planning processes at local levels? • Is there a mechanism for the communication of climate information? • Are the voices of women and other marginalized groups supported in local planning processes?
Civil Society	• Are civil society entities able to mobilize awareness and resources to manage the process? • Can the society learn from change? • Does the society seek creative solutions to change? • How long does it take the society to respond to changes? • Are there strong communication channels within the society?

Sources: CARE (2009); Maguire and Cartwright (2008); Urban and Mitchell (2011).

and other sources of uncertainty and risk. It is no longer realistic to have stable long-term policies for dealing with extreme weather events, flood, and drought; policies should acknowledge the new conditions where the baseline is inherently unstable and changing (UNDP, 2007).
- Civil society organizations and networks should be entities that mobilize and raise awareness. They should have the resources to manage processes, have strong communications links with organizations and individuals, and be able to innovate and create adaptive solutions using available resources and technologies.

Table 26.2 provides selected indicators from CARE's handbook (CARE, 2009) for assessing adaptive capacity to risks and hazards caused by climate change at the four levels of action.

26.4 Capacity development strategies and approaches

26.4.1 Education and training

Capacity development, and in a more general sense, the generation and dissemination of knowledge, can take place through formal, non-formal and informal education and training. The objectives of a CD initiative and the choice of processes and instruments used depend on the context because the institutions they focus on are the exponents of a particular set of economic, social and cultural factors.

As the global demand for managing water under conditions of risk and uncertainty increases, the lag between the demand for and the supply of qualified staff is becoming significant, especially in developing countries. The needs of the water sector in terms of the development of individual capacities can only be adequately addressed through the close collaboration of water and education professionals. The importance of primary and secondary education levels should not be underestimated as most of the people working on the water sector are formally educated only at these levels and most of the decisions affecting water resources are taken by people who have very limited formal water resources education. New water-oriented education, training programmes and approaches are needed to bridge the ever-widening knowledge and skills gap between developed and developing countries. A number of principal recommendations for action, made by 50 experts who participated in the workshop 'Education for Water Sustainability: Where Decades meet'[2] are summarized as follows.

At school

- Students should become aware of how precious water is and learn about water-related global challenges.
- To foster positive attitudes and behaviour teachers should promote the social, economic and environmental values of water through cross-curricula development and values education.
- Governments, together with other stakeholders, should develop databases of existing teaching and learning materials. Teachers should be trained to use these materials. Cooperation between governments and public enterprises can provide incentives to motivate teachers.

Vocational education and training

- Demonstration projects for integrating vocational education and training approaches into the water supply and sanitation (WSS) sector should be set up with the support of UNESCO. Occupational competencies regarding WSS should be developed and

BOX 26.6

How to save water in Palestine

The King Talal Secondary School in Nablus is a member of the UNESCO Associated Schools Project Network (ASPnet). It organized a series of excursions to enable students to examine water resources under the guidance of experts and to learn more about this precious commodity. The students then reported their experiences and ideas to the local media so that they could share what they had learned with the rest of the community. The school also introduced new and creative teaching methods and students were invited to translate their ideas and views through drawing, singing and putting on plays.

The main impact of the project is that it enhanced students' understanding of the significance of the water shortage facing the Palestinian Territories, and made them more aware of possible solutions. Students came to realize that access to water is a basic human right, as well as an individual and collective responsibility. The project also raised the students' awareness of the power of peaceful dialogue and generated cooperation between teachers and students and helped them to respect other points of view.

Source: UNESCO (2009).

introduced for the water workforce (especially in developing countries).
- Investment in infrastructure should be complemented by training technical staff and policy-makers to maintain and manage investments.

BOX 26.7

Adaptive water management (AWM) training helps groups to face uncertainty and risk

Example 1: Training educators how to teach AWM
The UN Water Decade Programme on Capacity Development (UNW–DPC) and the European Union Integrated Project, New Approaches to Adaptive Water Management under Uncertainty, ran a workshop in New Delhi in 2008 to train educators to disseminate the NeWater–GWSP (New Approaches to Uncertainty in Water Management–Global Water System Project) curriculum on AWM. The aim was to encourage the water managers and policy-makers of tomorrow to adopt an AWM approach to climate-proofing WSS strategies in the face of increasing climate-related uncertainty. By the end of the workshop, participants had drafted designs for adapting their water and environmental management studies curricula.

Lecturers and educators from developing countries in Latin America, Africa and Asia were trained by trainers from UNW–DPC, the University of Osnabrück in Germany, and Alterra Wageningen University and Research Centre in the Netherlands in the didactics of passing on the skills, knowledge and attitudes required for AWM.

Example 2: IWRM as a Tool for adapting to climate change
The Institute of Water Education (UNESCO–IHE) offers an online course for professionals actively involved in the water and climate sectors. Such professionals include local, regional and national policy-makers; NGO staff and representatives of the private sector dealing with adaptation; and junior university lecturers and scientists. The course objectives are to promote:
- Understanding of the concept of Integrated Water Resources Management (IWRM) in relation to climate change;
- Understanding of the climate system and the hydrological cycle;
- Awareness of the impact of climate change on society;
- Understanding of how to deal with risk and uncertainty; and
- Understanding of how to adapt to water changes and climate change.

Source: UNESCO (http://www.unesco-ihe.org/Education/Short-courses/Online-courses/IWRM-as-a-Tool-for-Adaptation-to-Climate-Change).

- Training should be developed with the help of educators to bridge the gap between theory and practice.

Higher Education
- Universities should open a window to the world by offering action research, problem-based learning and experiential learning. They should cooperate with society, and engage with the community in teaching and research.
- Universities need to develop mechanisms that ensure that teaching materials on basic water knowledge and on state-of-the-art of water management are freely available to all practitioners.
- The higher education sector should develop an academically recognized peer-review process for advanced and innovative teaching materials.
- Changes in academic structures should reflect the efficacy of successful university interventions in improving best practices in communities. We should emphasise effective action programmes.

There is no single body of knowledge about the way water should be managed. Universities must take measures to ensure that the existing variety of paradigmatic approaches is made available to the public.

26.4.2 Networking and sharing knowledge

Knowledge sharing is a fragile process because it requires individuals to share their personal beliefs with others, without physical or psychological impediment,

BOX 26.8

Adaptive river basin management: The NeWater online teaching curriculum

A curriculum for adaptive river basin management was developed as part of the training and education activities of the New Approaches to Uncertainty in Water Management (NeWater) project. NeWater's explicit aim is to provide an effective outreach mechanism for scientific results, methodologies and tools to stakeholders in the water sector, including university educators, water management practitioners and policy-makers. The curriculum has been implemented by the Institute of Environmental Systems Research at the University of Osnabrück, in Germany, at Alterra Wageningen University and Research Centre in the Netherlands and as part of the Global Water System Project. Details on the programme can be found at www.newatereducation.nl

Source: NeWater (n.d.).

to facilitate justification, explanation, persuasion and connectedness among peers. (Schenk et al., 2006). A useful indicator for knowledge facilitation in the water sector is the presence of formal and informal networks among sector specialists and peers. Such networks are of great importance when it comes to exchanging knowledge between government and other actors in the sector (Luijendijk and Lincklaen-Arriëns, 2009). Networks can take many forms, for example:

- Professional, formal associations of people with a specific technical background or expertise – for example, associations of water experts, social scientists or economists such as the International Water Association and the International Water Resources Association.
- Loosely organized networks of individual specialists who are often centred around a publication or newsletter – for example, journals such as the IRC's *Waterlines*.
- Communities-of-practice (CoPs) that are organized for a specified task. These usually operate within given time frames, have internal work agendas and agreed outputs such as publications or policy notes. The World Bank–UNDP Water and Sanitation Programme has managed CoPs on topics ranging from hand washing to low-cost sewage disposal.
- Networks of government, semi-government and non-governmental organizations that cooperate on a declared subject and that often receive funding for meetings, research, publications, workshops, and operational costs. Examples are Cap-Net, which is a UNDP initiative that connects about 25 educational and capacity building institutions; PoWER, UNESCO-IHE's partnership for water education and research, is a global network of about 30 research and education institutions ; Informal and social networks that are driven by cultural or social considerations but that may often be instrumental in bringing together people who can share both explicit and tacit knowledge.

26.4.3 Ownership as a key to effectiveness

Water management agencies close the door on opportunities for effective integrated water management when they don't give a voice to relatively powerless groups, such as women and indigenous people. Efforts to ensure the ownership of local stakeholders are often absent. The lack of broad commitment is systematically identified as a main reason why investments and programmes fail. For example, many WSS programmes in developing countries throughout the 1980s and 1990s proved ineffectual because the beneficiaries could not or did not want to use or maintain the new water supply systems and latrines. Numerous projects arranged for experts to assist in project preparation, but such experts were generally never mainstreamed into the engineering organizations.

International development aid too often proved ineffective because programmes were not well embedded locally. After the Paris Declaration in 2005 and the Third High Level Forum on Aid Effectiveness in Accra in 2008, it is now the norm for aid recipients to forge their own national development strategies, which ensure the broader ownership of policies and programmes (OECD 2005, 2008). The IWRM concept emphasizes that effective and sustainable water management requires the explicit involvement of stakeholders in planning and decision-making (see the Global Water Partnership Toolbox at www.gwptoolbox.org). The

BOX 26.9

Strengthening local ownership: The Lake Victoria Region Water and Sanitation Initiative

Twenty-seven capacity development interventions support the UN-HABITAT Lake Victoria Region Water and Sanitation Initiative (LVWATSANI). This initiative, which is helping Kenya, Tanzania and Uganda to achieve their MDGs for WSS, is an example of the modern integrated approach.

The Lake Victoria catchment provides livelihoods for about one-third of the combined populations of the three countries (30 million people). Most of the region's rapidly growing urban centres are experiencing unplanned growth, poor infrastructure, and a fragile ecosystem. Piped water leakage and low billing rates are usual and sanitation and solid waste collection are poor.

Progress to date. Initial investments have been completed: key water infrastructure has been rehabilitated or expanded, public latrines have been built, micro-credit for household latrines has been provided, and solid-waste removal equipment has been supplied – all resulting in better performance by the water utilities in the project towns. The CD design responds to the on-the-ground issues. Multi-disciplinary teams conducted in-depth interviews with the stakeholders and designed 27 tailor-made CD interventions. These included interventions on environmental services, pro-poor governance, equity and local economic development. All concluded with a personal action plan that requires each participant or group to identify the activities that are within their authority and capability and that will contribute to improving water environmental services.

European Union's Water Framework Directive mandates that river basin management plans in which the role of the informed and empowered stakeholders are treated as critical, should be developed for all river basins. Targeted CD programmes may then be required to approach and prepare these groups (Box 26.9).

In a rapidly changing world, our economies and well-being increasingly depend on accurate forecasting of future events and trends. There is a growing need to shape policies that best reflect the courses of action that are most appropriate technologically as well as representing the preferences of society. Challenges of broad social significance such as responses to climate change and public health threats require that society is informed and 'educated'. Consultation with an informed society can lead to policies that are owned by society – and diligently implemented by everybody in that society.

26.4.4 Information and communications technology (ICT)

The generation, manipulation and communication of information are essential parts of the decision-making process for organizations involved in water management. ICT is recognized as a strategic enabler in the process of developing innovative solutions to address problems such as water scarcity. ICT also facilitates the analysis of environmental data so that researchers and climatologists can build more accurate models for weather forecasting (ITU, 2010). The main areas in which ICT could play a pivotal role in water management are shown in Figure 26.2.

The cost of traditional face-to-face training courses and the time they consume significantly restrict CD plans. The rapid advance of ICT has made access to knowledge through eLearning easier, much more readily available and cheaper: eLearning, or preferably *blended learning*,[3] has helped to develop the capacity of water management stakeholders. It does this through its use of online training, online university courses, multimedia materials for public awareness, etc. The UN–Water Decade Programme on Capacity Development has developed an online system called UNWAIS+ (UN Water Activity Information System) which includes an eTraining pool (www.ais.unwater.org).

Mobile and wireless technologies are also providing a chance for users to learn remotely. This makes mobile-learning (mLearning) even more attractive than eLearning. Mobile technology applied to CD activities offers cost-effective learning opportunities. Mobile devices with expanding capabilities are now available at significantly reduced prices (UN DESA, 2007).

The department of Engineering Hydrology at the RWTH Aachen University in Germany is offering several online courses covering different water management

FIGURE 26.2

Major areas for information and communications technology in water management

Mapping of water resources and weather forecasting

- Remote sensing from satellites
- In-situ terrestrial sensing system
- Geographical information system
- Sensor networks and Internet

Asset management for the water distribution network

- Buried asset identification and electronic tagging
- Smart pipes
- Just-in-time repairs/real time risk assessment

Setting up early warning systems and meeting water demand in cities of the future

- Rain/storm water harvesting
- Flood management
- Managed aquifer recharge
- Smart metering
- Process knowledge systems

Just in time irrigation in agriculture and landscaping

- Geographical information system
- Sensor networks and Internet

Source: ITU (2010).

related topics (Box 26.10) as well as water exercises and mobile phone app quizzes.

26.4.5 Social learning: 'Learning together to manage together'

Social learning has been described as an alternative to transmissive expert-based teaching. It is a form of community-based learning (Capra, 2007) that takes place in networks or CoPs that are influenced by the governance structure in which they are embedded. Social learning requires relatively stable institutional settings which are not rigid or inflexible. Such conditions are developed through continued processes of social learning in which multi-level stakeholders are connected through networks that allow them to develop the capacity and trust necessary to collaborate in a variety of relationships both formal and informal (Pahl-Wostl, 2007).

Social learning supports the capacity development of managers to address uncertainty and risk more effectively. Successful social learning (learning in and with social groups through interaction) leads to new knowledge, shared understanding, trust and, ultimately, collective action. Learning may take place at different levels from *incremental improvements* (single-loop) through to *reframing* where assumptions are revisited (double-loop) and *transforming* where underlying values and world views may be changed (triple-loop) (Pahl-Wostl, 2007). Box 26.11 presents a good practice case for social learning implementation that enhanced adaptive water management.

BOX 26.10

The Online Training System for Water Professionals (TOTWAT)

TOTWAT is an EU-funded project under the umbrella of the TEMPUS programme coordinated by the RWTH Aachen University in Germany. The project aims to develop an eLearning system for water professionals in Egypt. More than ten training courses have been developed in the fields of modelling, water management, socio-economics, environmental engineering and interdisciplinary water management. The electronic contents of the courses are suitable for use by other water institutions in the Middle East and North Africa region. User feedback shows that such online training courses have a significant impact on the performance of water engineers, and more than 90% of users indicated that it helped them to share knowledge and learn from each other.

Source: TOTWAT project (2011).

26.5 The way forward

- There is a lack of best practice at all levels in analysing and assessing adaptive capacity for risk. There is a need to conduct regular capacity assessments including assessing the capacities of the workforce, the institutions, the key agencies, the policy and

BOX 26.11

Social learning and AWM in the South Indian Lower Bhavani

The Lower Bhavani Project (LBP) has an 84,000-hectare catchment area in the South Indian state of Tamil Nadu. One of the most significant uncertainty factors here is rainfall variability. Farmers frequently have to cope with unpredictable supplies of water and seasons without rainfall. The large-scale development of wells in the area shows how farmers have successfully managed to increase water availability during seasons when there is no supply. They have also learned to swiftly adjust their cropping patterns in line with the highly unpredictable variability of seasonal canal water supply, and have even adapted what they grow to cope with entirely rain-fed conditions.

The entire chain of system changes shows that social learning is taking place within the LBP system. The various actors have learned how to optimize the system within the limits of the technical infrastructure, the capacity of the reservoir, the discharge capacity of the canal and the unpredictable supply of water dictated the by erratic rainfall. The way farmers have learned from and been inspired by each other are examples of social learning between actors. From a long-term perspective, all the actors in the LBP system have learned from the environmental responses and from each other's behaviour. Together they have contributed to the alteration of governance structures and have developed new practices without being bound by the original technical infrastructure. All actors, thus, live with change, but few appear to remember what caused the change in the system and why it changed.
The AWM analysis shows that the LBP system has fulfilled the criteria of a complex adaptive system again and again. Several changes have taken place and earlier mistakes and failures have been addressed step-by-step to reach the present complex human–environmental–technological system. Social learning takes place at both system level and with individual farmers. The uncertainty factors have been considered one at a time during the system change cycles and have been included in the system design.

Source: Lannerstad and Molden (2009).

regulatory frameworks, and the main stakeholders. There is a need to identify realistic capacity development priorities that can be implemented within a practical time frame and which focus on ownership.

- There is a need to assess the capability of education systems and prepare adequate numbers of sector professionals who have the appropriate skills mix. This is particularly important for managerial and governance skills so that there is the ability to prepare and carry out investments. In this process, it is necessary to promote collaboration and cooperation between organizations and water and education experts.
- The water sector needs to engage in dialogue with society about investment initiatives and major policies. This ensures that decisions reflect actual expectations and foster ownership. The media needs to be taught about water issues so that their capacity to report on such issues is improved.
- Social learning should be promoted to build the adaptability of all stakeholders involved in making decisions about water management. This helps to increase flexibility and responsiveness when dealing with risk and uncertainty.
- ICT should be used more to reduce costs and offer more flexible learning opportunities. Investments made in high quality learning materials for adaptive water management can be used by water professionals and students across a wide area.

Notes

1 For example, Thorkilsen and Dynesen (2001) describe how an internet-based interactive facility was at the core of a broad knowledge sharing and communication effort to muster the support of politicians and the community and attract funding for one of Europe's largest and most controversial infrastructure projects, the rail and road bridge and tunnel across the Øresund Strait linking Denmark to Sweden.

2 This workshop was jointly run during the UNESCO World ESD Conference in Bonn, Germany in 2009 by the UNESCO International Hydrological Programme (IHP); the German Federal Ministry for the Environment, Nature Conservation and Nuclear Safety (BMU); and the UN Water Decade Programme on Capacity Development (UNW–DPC). Its purpose was to promote exchange between water and education stakeholders by linking the two UN Decades – the UN Decade of Education for Sustainable Development (UN DESD) and the UN International Decade for Action, 'Water for Life'.

3 Blended learning is a mix of different leaning environments, e.g. eLearning and face-to-face learning.

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CHAPTER 27

Water-related disasters

UNISDR

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Countries in all regions have been successful in strengthening their capacities to address the mortality risk associated with major weather-related hazards such as floods. Despite the increasing number of people living in floodplains, mortality risk relative to population size is now trending down. In East Asia and the Pacific mortality risk is now at a third of its 1980 level (UNISDR, 2011).

In contrast, countries have had a far more difficult time addressing successfully other risks. Economic loss risk due to tropical cyclones and floods is trending up because the rapidly increasing exposure of economic assets is outstripping reductions in vulnerability.

Water management should actively engage in shaping national agendas that reduce the risk from natural hazards and assist adaptation to climate change, in support of a coherent planning process that targets national and local sustainable development plans.

Disaster risk reduction needs to be an integral part of integrated water resources management (IWRM) to enhance and effectively protect water investments and to contribute to reducing risks. Reducing the risk of floods and drought, and in particular, promoting development practices that reduce the risk of floods and drought, will contribute to governments' efforts to adapt to climate change. One of the key challenges faced by decision-makers today is the need to increase understanding of which forms of investment are effective in reducing the risk of floods and drought – in the water management as well as in the broader development arena.

27.1 Introduction

This chapter addresses the risks associated with water-related disasters, in particular, floods and drought, and contributes to the broader topics of risk and uncertainty. It also addresses climate change issues by examining the impacts of climate change on extreme event trends, in particular, natural hazards (again focusing on floods and drought), as well as adaptation approaches based upon the reduction of risk related to water-related hazards. It focuses on policy responses and actions and their effectiveness, describing solutions, their applicability and their relation to risk. This component, along with the monitoring of risk trends for floods and drought, will be built up more systematically in future reports.

27.1.1 Disaster impacts

The most significant water-related disasters, such as floods, include flash floods, tropical cyclones and other storms, and ocean storm surges (Box 27.1). Other related events, including those triggered by earthquakes, comprise tsunamis, landslides that dam rivers, breakage of levees and dams, glacial lake outbursts, coastal flooding associated with abnormal or rising sea levels, and epidemics and pest outbreaks associated with too little or too much water.

One water-related disaster that seldom makes it into the impacts statistics is drought. Since 1900, more than 11 million people have been killed and more than 2 billion affected by drought, more than any other physical hazard (UNISDR, 2011). However, these figures are probably lower than the real total as few countries systematically report and record drought losses and impacts (Box 27.2), while those that do, such as the United States of America, report only insured losses (Figure 27.1).

BOX 27.1

Extreme water-related disasters in 2010

Water-related disasters account for 90% of all natural hazards, and their frequency and intensity is generally rising. Some 373 natural disasters killed over 296,800 people in 2010, affected nearly 208 million others, and cost nearly US$110 billion.

In 2010, extreme disasters included storm Xynthia in Western Europe (February) and the spate of heavy flooding in France (June). Unusually, Asia experienced fewer disaster deaths that year than the Americas and Europe, accounting for just 4.7% of total mortality. However, it remains the most greatly affected continent: some 89% of all people affected by disasters in 2010 lived in Asia, according to the Centre for Research on the Epidemiology of Disasters (CRED).

Of the list of top ten disasters with the highest death counts, five occurred in Asia. In Indonesia from May to August, floods killed 1,691 people and a further 1,765 were killed by mudslides, landslides or rock falls triggered by heavy rains and floods in August. In Pakistan, massive floods caused by heavy rains in the north-west from July to August covered one-fifth of the country's landmass, and caused the deaths of nearly 2,000 people.

In China, floods and landslides during the summer are estimated to have cost US$18 billion, while the Pakistan floods cost US$9.5 billion. Yet economic losses in 2010 still do not surpass those of 2005, when damage from hurricanes Katrina, Rita and Wilma alone amounted to US$139 billion.

Summary of flood disasters, 1980–2008	
Number of events	2 887
Number of people killed	195 843
Average number of people killed per year	6 753
Number of people affected	2 809 481 489
Average number of people affected per year	96 878 672
Economic damage (US$ × 1 000)	397 333 885
Economic damage per year (US$ × 1 000)	13 701 168

Source: EM-DAT (2010).

Source: CRED (2011).

BOX 27.2

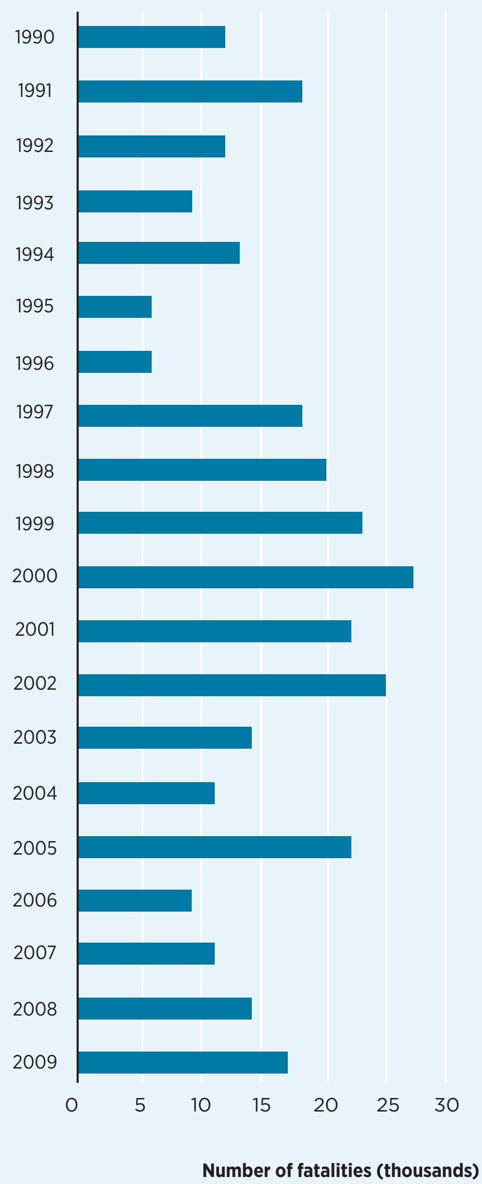
Data from a systematic registration of disaster in Mozambique

Mozambique is one of the few countries with a disaster database that systematically records drought losses (INGC, 2010). Here, the real scale of drought impacts becomes visible: since 1990, 8 million ha of crops have been damaged (of which half were destroyed) during drought events, 1,040 people have been killed, and an additional 11.5 million have been affected.

Source: UNISDR (2011).

FIGURE 27.1

Recorded drought fatalities per year, 1990–2009



27.1.2 Water-related disasters impact on development

Water hazards may be a natural part of our earth system, but the disasters that sometimes arise from them should be recognized as strongly interlinked with particular human vulnerabilities of our own making. Key factors that increase both the intensity of the hazard as well as the related vulnerability include environmental degradation; settlements in marginal hazard-prone lands; inadequate buildings and water management systems; lack of risk awareness and information; poverty and low capacities for prevention, preparedness and early warning; and lack of political and institutional commitment to reducing risks.

Disaster risk manifests itself as high impact catastrophes, as well as an increasing number of high frequency, lower relative severity losses, almost all of which are associated with water-related hazards. The risk of losses from these hazards is a factor of social and economic development (WWAP, 2009).

These impacts are an impediment to achieving the Millennium Development Goals (MDGs), because disasters regularly destroy accumulated development gains, in terms of damage and losses to infrastructure and other assets. In developing countries, these losses are generally not insured and imply a constant leakage of resources from development budgets to deal with relief and reconstruction, as well as the steady erosion of livelihoods, rendering vulnerable countries even more vulnerable.

For example, annual average disaster losses in Mexico, in the built environment alone, have been estimated at US$2.9 billion per year (ERN-AL, 2010). Current analysis of MDG monitoring suggests that incremental international aid of US$35 billion will be required annually from 2010 until 2015 to raise the standard of living of the nearly 1 billion people who live below the US$1.25 per capita income line, as well as to achieve the other MDGs (UNDP, 2010). Nearly US$8 billion is required to provide access to safe drinking water to those without access. While the current financial crisis is constraining abilities to increase aid flows, billions of US$ of development funding are being re-directed every year to restore development assets damaged or destroyed by disasters.

Losses in agricultural production are particularly significant (Box 27.3). The United Nations Economic Commission for Latin America and the Caribbean

(ECLAC) estimates that annual losses of US$1.3 billion have been associated with drought and other climate related hazards in Central America since 1975 (ECLAC, 2002). This represents more than 10% of the region's average annual Gross Domestic Product (GDP) and nearly 30% of its gross capital formation (Zapata and Madrigal, 2009).

27.1.3 Reducing the risk of disasters is intrinsic to development practices

The *Global Assessment Reports* (GARs) (UNISDR, 2009, 2011) demonstrate that exposure of people and assets to floods and drought is largely determined by historical and ongoing investments in infrastructure and in urban and economic development. In the case of small islands, often the entire territory is exposed.

Levels of disaster-related risk are socially constructed, often over long periods, by layers of decisions and investments by individuals, households, communities, private businesses and governments. Physical hazards may be modified. For example, a decision to drain wetlands may increase flood hazard in a city downstream. Similarly, the amount of people and assets exposed may increase due to decisions to locate economic and urban development in hazard-prone areas. However, choosing to live in hazard-prone areas may be the lesser evil for poor households. Older people and women are particularly vulnerable to these factors.

While public investment usually represents only a small proportion of total investment in any country – 14% on average and seldom more than 20% (UNISDR, 2009) – governments play a key role in shaping risk construction processes, through the effectiveness of planning and regulation as well as through their own investments in infrastructure and public services.

The GAR (UNISDR, 2009) provided further evidence that the poor are more exposed and vulnerable to natural hazards. In some countries, the areas that experience most disasters are actually those with the most dynamic economic and urban growth, or with prosperous rural economies. However, the studies initiated in the context of the above report provide evidence to show that communities in poor areas lose a higher proportion of their assets, confirming that they have higher levels of vulnerability (Table 27.1).

BOX 27.3

Example of drought impacts

Global data on drought impacts remains uncertain. However, local and regional examples provide a better understanding of the impacts of drought:

- In the Caribbean, during the 2009–2010 drought, the banana harvest on Dominica decreased from 2010 to 2009 by 43%, agricultural production in St Vincent and the Grenadines was 20% below historic averages, while in Antigua and Barbuda, onion and tomato crop yields declined by 25% and 30%, respectively (UNISDR, 2011).
- Australia experienced losses of US$2.34 billion during the 2002–2003 drought, reducing national GDP by 1.6%; two-thirds of the losses were agricultural, while the remaining one-third was attributed to knock-on impacts in other economic sectors (Horridge et al., 2005).
- During the 2002 drought, India's food grain production declined by 29 million tonnes, from 212 million tonnes in 2001 to 183 million tonnes in 2002 (Shaw et al., 2010).
- Due to a severe drought in Syria during the 2007–2008 growing season, 75% of the country's farmers experienced total crop failure (Erian et al., 2010); and more than a year after the drought ended, Syria's livestock population was estimated to be 50% below the pre–drought level (Erian et al., 2010).
- In Ceará, Brazil, agricultural drought risk is concentrated among smallholder farmers who do not hold water rights or have access to Ceará's irrigation and water–storage infrastructure, and whose livelihoods depend entirely on rainfed, dryland agriculture. As a result, GDP per capita of the rural communities is approximately one-third that of the urban settlements situated along the coast, and Human Development Index values of the rural districts are below 0.65, compared to 0.699 for Brazil as a whole (Sávio Martins, 2010; UNDP, 2010).

Source: UNISDR (2011).

27.2 Anatomy of disasters: Trends in flood and drought risk

Observation of flood and drought risk patterns and trends at the global level permits visualization of the major concentrations of risk. It also enables identification of geographic distribution of disaster risk across countries, trends over time and the major drivers of these patterns and trends.

The analysis presented in this chapter was developed by UNEP/GRID Europe PREVIEW (Project for Risk Evaluation Vulnerability Information and Early Warning), assisted by an interdisciplinary group of researchers from around the world.

Figure 27.2 shows the updated global distribution of mortality risk for three weather–related hazards: tropical cyclones, floods, and landslides provoked by rains UNEP, 2010). The areas of highest risk visible correspond to areas where concentrations of vulnerable people are exposed to severe and frequent major hazards. Flood mortality risk is highest in rural areas with a denser and rapidly growing population in countries with weak governance.

TABLE 27.1

Summary of case study findings on the social distribution of disaster loss

Country	Findings
Burkino Faso	The 1984–1985 drought affected the poorest third of a sample of rural households by 10% more than the wealthier third: the former experienced crop-income losses of 69% versus a 58% drop for the latter.
Madagascar	Tropical cyclone impacts led to a reduction of 11% in the volume of agricultural production of the poorest 20% households, compared to a 6% reduction in the case of the richest 20%.
Mexico	Municipalities with the highest number of loss reports also had large percentages of their population with high or very high levels of marginality, according to an Index of Municipal Marginality developed by the National Population Council; for example, Acapulco (54.4%), Coatzocoalcos (54.1%), Juarez (45%), Tapachula (54.1%), Tijuana (31.3%) or Veracruz (31%). Municipalities with high or very high levels of marginality had high proportions of damaged and destroyed housing. In one-third of these municipalities, between 10% and 25% of the housing stock was damaged or destroyed, while in another third this proportion was more than 25%. Over 20% had more than 50% of their housing stock affected. In contrast, only 8% of the housing stock was affected in municipalities with low or very low levels of marginality.
Nepal	Areas affected by floods tended to have lower poverty rates and higher per capita expenditures. Flooding incidence and impacts are concentrated in the highly productive lowland agricultural plains of the Terai belt in south-eastern Nepal. As flooding contributes to the soil fertility of the region, it also contributes to the wealth of the area. Areas affected by landslides tend to have higher poverty and mortality rates. Landslide impacts are heavily concentrated in districts in mountainous western Nepal with marginal rainfed agriculture, where the country's rural poverty is concentrated.
Orissa, India	A statistically significant relationship was found between families living in houses with earth walls and thatch roofs (typically the housing of the poor) and those most affected by tropical cyclone, flood, fire and lightning. The incidence of extensive risk loss reports was higher in the central-eastern coastal region, where there are higher levels of urbanization and relatively affluent agricultural areas on floodplains and deltas. Mortality in extensive risk disasters was concentrated in the districts of Bolangir, Kalahandi and Koraput in southern Orissa, which are characterized by repeated droughts, floods, food insecurity, chronic income poverty and localized near-famine conditions.
Peru	Rural households that reported a disaster impact in 2002 had on average less access to public services, were less well integrated into the market, and had a higher proportion of agricultural income.
Sri Lanka	A very strong correlation was found between the proportion of the population living below the poverty line and the number of houses damaged due to floods; a less strong but significant correlation was found between this population group and houses damaged due to landslides. This reinforces the case that exposed human settlements and unsafe, vulnerable housing are poverty factors that increase the likelihood of suffering greater loss due to natural hazard.
Tamil Nadu, India	Mortality in areas with manifestations of extensive flood risk was higher in areas with vulnerable housing. Similarly, tropical cyclone housing damage was inversely related to the literacy rate. If literacy is taken to be a proxy for poverty, again this indicates that the poor were more likely to suffer housing damage typically because their houses are more vulnerable or situated in more exposed locations. Mortality among the socially and economically excluded scheduled castes was also higher in blocks with a high proportion of vulnerable housing.

Source: UNISDR (2009, table 3.5, p. 80).

Across all weather–related hazards, countries with low GDP and weak governance tend to feature drastically higher mortality risk than wealthier countries with strong governance.

27.2.1 Flood risk trends

Disaster risk for floods has been calculated for large rural flood events, although the risk calculations do not include flash floods or urban flooding from inadequate drainage. The geographical distribution of flood mortality risk mirrors that for exposure (exposed assets). It is heavily concentrated in Asia, especially in Bangladesh, China and India. Between them these countries concentrate 75% of the modelled annual global mortality. Viet Nam also has high absolute and relative flood risks. The top ten countries at risk of floods (based on number of lives lost) are India, Bangladesh, China, Viet Nam, Cambodia, Myanmar, Sudan, Democratic People's Republic of Korea, Afghanistan and Pakistan (UNEP, 2010).

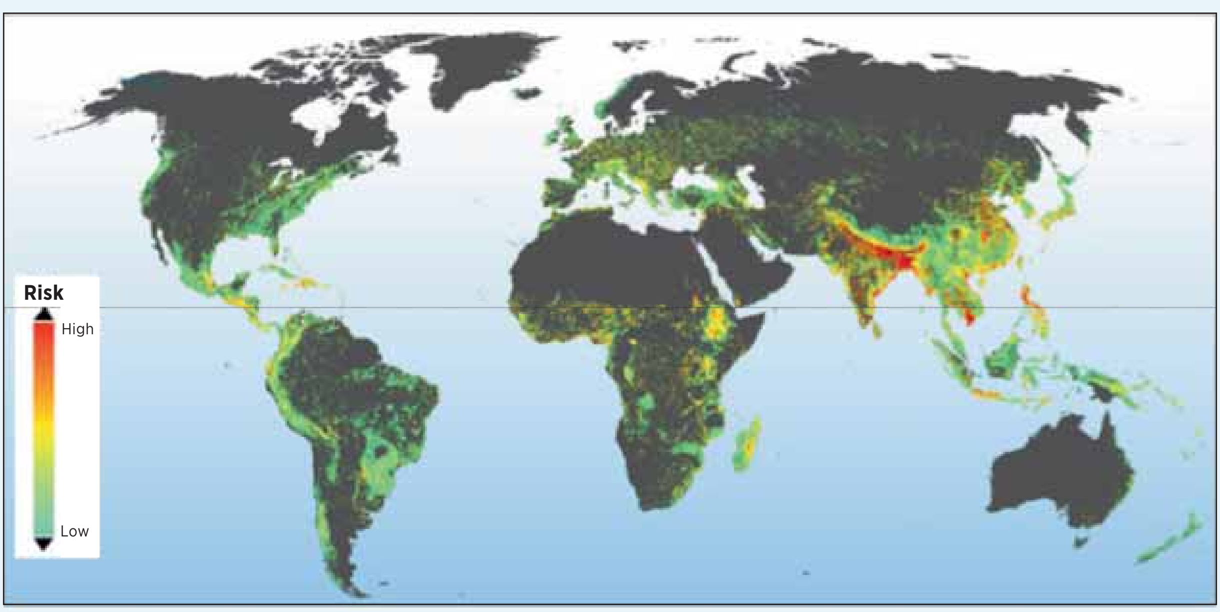
Between 1970 and 2010 the world's population increased by 87% (from 3.7 billion to 6.9 billion). In the same period, the annual average population exposed to flood increased by 112% (from 33.3 to 70.4 million per year) (UN-Habitat, 2010). Relatively speaking, more and more people are living in floodplains, meaning that the economic advantages of flood-prone areas for intensive agriculture, for example, outweigh the perceived risks. Within income regions, relatively more people are concentrated in flood-prone areas in lower middle-income countries and, in terms of geographic regions, in East Asia and the Pacific (Figure 27.3).

As Table 27.2 shows, more than 90% of the global population exposed to floods lives in South Asia and East Asia and in the Pacific. Exposure is growing most rapidly in the Middle East and in North Africa and sub-Saharan Africa. In contrast, exposure is stable in countries of the Organisation for Economic Co-operation and Development (OECD), while it is starting to trend downwards in eastern and south-eastern Europe and Central Asia, reflecting a broader trend of demographic decline.

Global vulnerability to flood hazard was stable in the 1990s, but has subsequently decreased (UNISDR, 2011). Vulnerability has declined in all regions except Europe and Central Asia and the OECD countries, where it has remained stable. As these are regional averages, there may be countries with increasing vulnerability. But in general the statistics reflect how improved development conditions have reduced vulnerability and led to strengthened disaster management capacities.

FIGURE 27.2

Hazard mortality risk (floods, tropical cyclones and precipitation-triggered landslides)



Source: Developed by the GAR team at UNISDR.

Flood mortality risk (Box 27.4) has decreased in all regions since 1990, with the exception of South Asia. In East Asia and Pacific, in particular, it has decreased by about two-thirds (UNISDR, 2011).

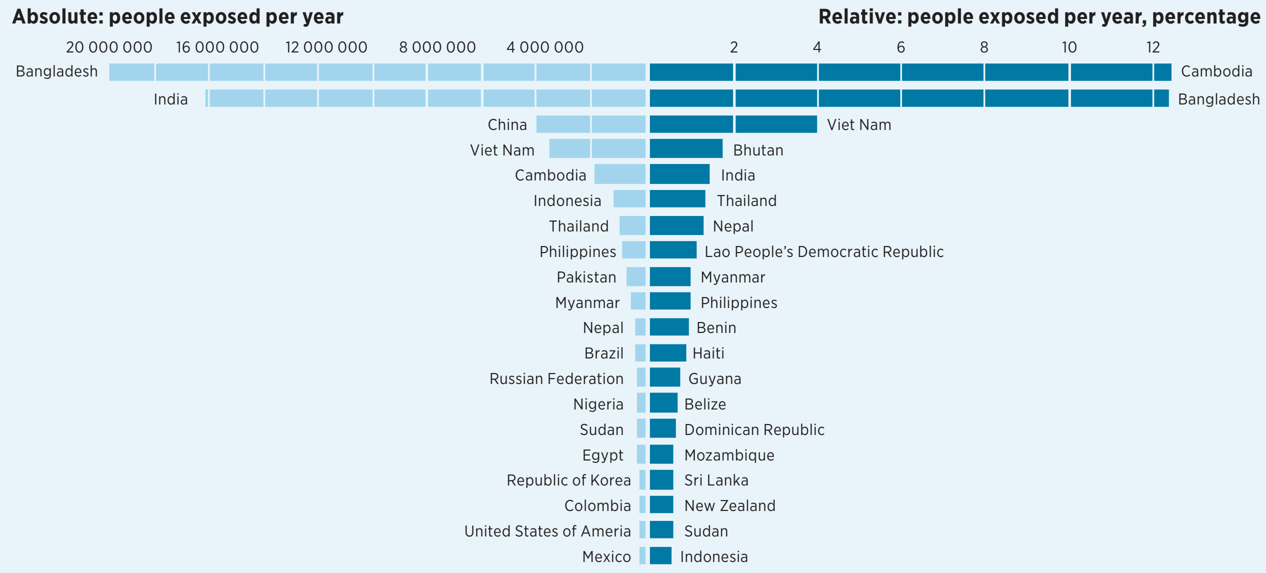
This growing vulnerability is reflected in the challenges faced by South Asia to reduce the impact of the August 2010 floods in Pakistan. These floods killed approximately 1,700 people and caused US$9.7 billion in damage to infrastructure, farms and homes, as well as other direct and indirect losses (ADB/World Bank, 2010). The map in Figure 27.4 contrasts modelled flood hazard and observed flooded areas in Pakistan. As with any flood event, some areas at risk of flooding did not flood in August 2010. The model did not highlight other areas that did flood.

27.2.2 Drought risk trends

Drought risks are only partly associated with deficient or erratic rainfall. Instead, they are primarily triggered by a range of drivers that include poverty and rural vulnerability; increasing water demand due to

FIGURE 27.3

People exposed to floods



Source: UNISDR (2009, fig. 2.14, p. 36).

TABLE 27.2

Flood exposure by region (in millions of people per year)

Region	1970	1980	1990	2000	2010
East Asia and Pacific	9.4	11.4	13.9	16.2	18.0
Europe and Central Asia	1.0	1.1	1.2	1.2	1.2
Latin America and the Caribbean	0.6	0.8	1.0	1.2	1.3
Middle East and North Africa	0.2	0.3	0.4	0.5	0.5
OECD countries	1.4	1.5	1.6	1.8	1.9
South Asia	19.3	24.8	31.4	38.2	44.7
Sub–Saharan Africa	0.5	0.7	1.0	1.4	1.8
World	32.5	40.6	50.5	60.3	69.4

Sources: Data from PREVIEW flood global model: Landscan 2008 (extrapolated between 1970 to 2010 using UN world population data).

urbanization, industrialization and the growth of agro-business; poor water and soil management; weak or ineffective governance; and climate change. Unlike the risks associated with tropical cyclones and floods, drought risks remain poorly understood. Drought losses and impacts are not systematically captured, standards for measuring drought hazard have only recently being introduced, and data collection constraints make it difficult to accurately model risk in many locations.

Meteorological droughts are usually defined as deficiencies in rainfall, from periods ranging from a few months to several years. Long droughts often change in intensity over time and undergo geographic shifts, thereby affecting different areas. Until recently, there was no agreed global standard for identifying and measuring meteorological drought. National weather services used different criteria, making it difficult to establish exactly when and where droughts occur. Consequently, drought has often been confused with other climate conditions such as aridity or desertification.

BOX 27.4

From the Disaster Risk Index to the Mortality Risk Index

The second *World Water Development Report* used the Disaster Risk Index (DRI) as the main indicator for monitoring flood and drought risk. This approach was subsequently reviewed and several institutions joined their efforts over a two-year period to develop a new methodology for the global modelling of hazards: the Mortality Risk Index (MRI).

The improved estimates of global disaster risk were made possible thanks to higher model resolutions and more complete data on geographic and physical hazard event characteristics, especially for floods, tropical cyclones and earthquakes. They also benefited from higher resolution exposure data on population and economic assets (sub-national GDP). The main improvement came from the 'event per event analysis'. Previous global studies such as the DRI used a 21-year returning period on average. This prevented the computation of specific event intensity. By analysing individual events and linking a hazard event outcome (i.e. losses) with the geographic, physical and socio-economical characteristics of the event, the model can incorporate more adequately the contextual conditions in which each disaster occurred.

Source: Peduzzi et al. (2009); UNISDR (2011).

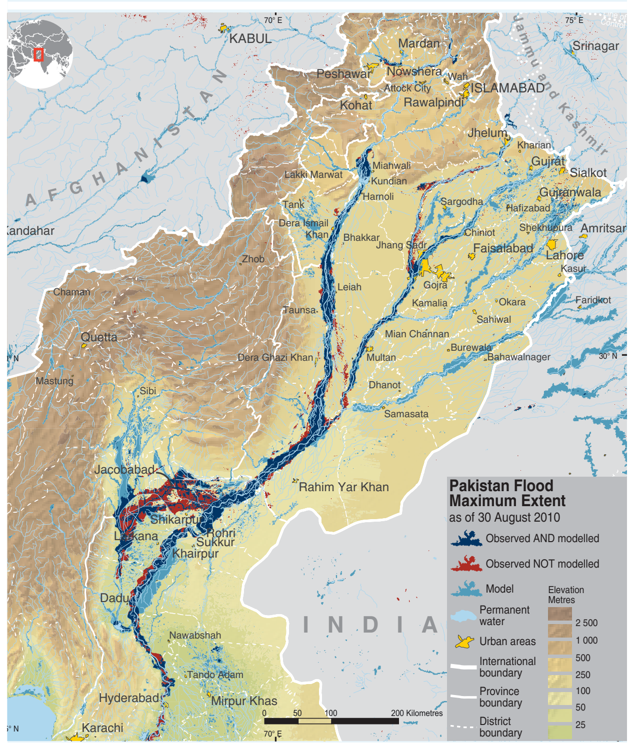
The World Meteorological Organization (WMO) has recently adopted the Standardized Precipitation Index (SPI) as a global standard to measure meteorological droughts, and is encouraging its use by national meteorological and hydrological services (NMHSs), in addition to other indices currently being utilized in each region.

The SPI (McKee et al., 1993, 1995) is a tool based on rainfall data, which can identify wet periods/cycles as well as dry periods/cycles. The SPI compares rainfall at a given location and during a desired period, normally from one to twenty-four months (Guttman, 1994), with long–term mean precipitation at the same location (Edwards and McKee, 1997). Positive SPI values indicate greater than normal rainfall in the chosen period and negative SPI values indicate less than normal rainfall (Figure 27.5).

At least 20 to 30 years (optimally 50 to 60 years) of monthly rainfall data is needed to calculate the SPI (Guttman, 1994). Given the lack of complete data series in many locations, and the fact that many drought-prone regions do not have sufficient rainfall stations,

FIGURE 27.4

Extent of flooding in Pakistan on 30 August 2010



Source: UNISDR (2011, fig. 2.13, p. 30).

many users have to apply interpolation techniques to fill in temporal and geographic gaps in the data.

The application of SPI will strengthen the capacity of countries to monitor and assess meteorological drought. Despite its simplicity, however, many countries are challenged by the low density of rainfall stations in some areas and their decline in number, given the low priority given to hazard monitoring in government budgets. Since the mid–1970s, for example, the number of rainfall stations maintained by Spain's national meteorological agency, AEMET, has declined from 4,800 to approximately 2,600 (Mestre, 2010).

Global drought risk models were developed in the context of earlier assessments of disaster risk (Dilley et al., 2005; UNDP, 2004). But the mortality drought risk index proposed by the United Nations Development Programme (UNDP) was unsuccessful because most droughts do not produce fatalities and most major recorded mortality, in sub-Saharan Africa for example, is concentrated in countries experiencing conflict or political crisis. Only weak correlations were found between the population exposed to meteorological drought and attributed mortality (UNDP, 2004). Drought impacts on human development provide a much more satisfactory metric than mortality for calculating human risk. But while these impacts are captured in locally specific micro–studies (de la Fuente and Dercon, 2008), systematic data is not available to calibrate a global risk model.

27.3 Water-related disaster risk drivers

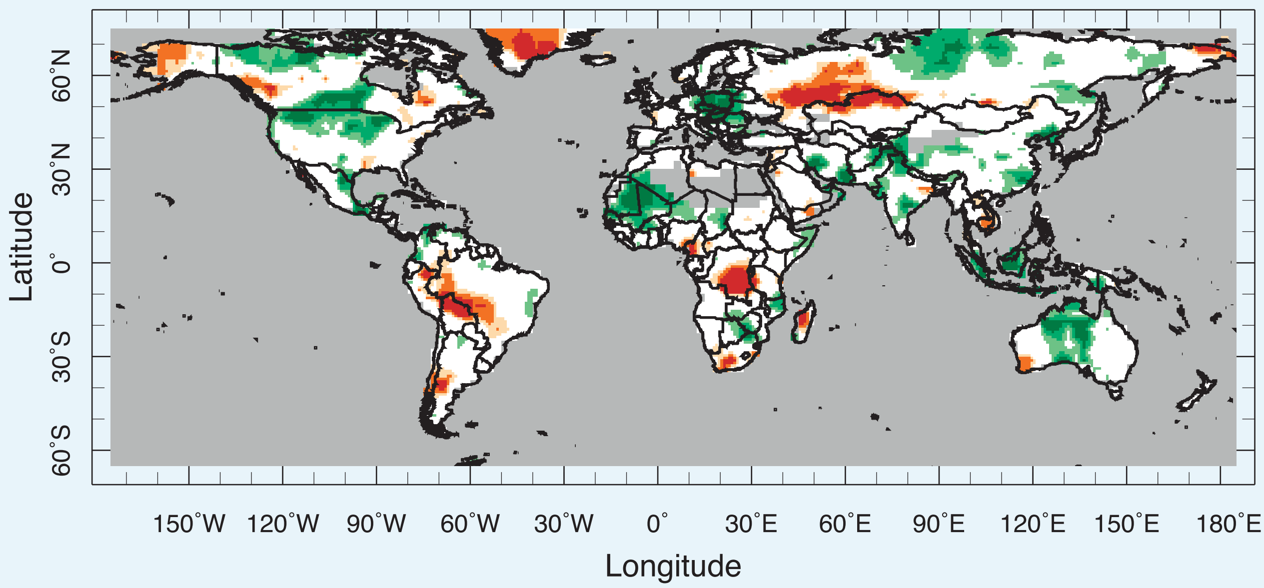
Understanding the underlying drivers of risk for floods and droughts is the cornerstone of any effort to reduce risk and future impacts. The examples provided below show that climate change, increasing poverty and inequality, and badly planned and managed urban and regional development all contribute to increasing the risk of natural hazards.

27.3.1 Climate change

As the reports of the Intergovernmental Panel on Climate Change (IPCC) have made clear, climate change leads to gradual changes in variables such as

FIGURE 27.5

Interpolated global map product for the six-month Standardized Precipitation Index (SPI) (April–September 2010)



Note: The map shows the global distribution of meteorological drought at the end of September 2010 using a six–month SPI. It highlights the drought in Russia associated with wildfires, as well as droughts in western Brazil, a normally humid climate, and southern Africa.
The green shading, from light green to dark green, shows increasing SPI values from 1.0 to 3.0 (moderately wet to extremely wet). The red shading, from light red to dark red, shows SPI values from –1.0 to –3.0 (moderately dry to extremely dry).

Source: International Research Institute for Climate and Society Data Library, Columbia University (see http://iridl.ldeo.columbia.edu/maproom/.Global/.Precipitation/SPI.html).

average temperature, sea level, and the timing and amount of precipitation. Climate change also contributes to more frequent, severe and unpredictable hazards such as cyclones, floods and heatwaves – 'extreme weather events' (IPCC, 2007). Other climate phenomena such as La Niña are thought to be linked to the floods and landslides that occurred from April to December 2010 in Colombia, and the floods in Queensland, Australia, which were triggered by rains that began in December 2010.

Economies that rely on primary resources and climate-sensitive sectors like agriculture are more vulnerable to greater climate variability and changes in average precipitation and temperature (OECD, 2010). For example, a warming of 2°C could result in a 4%–5% permanent reduction in annual per capita income in Africa and South Asia, compared with minimal losses (approximately 1%) in developed and larger developing countries (World Bank, 2010). These economies are ill prepared to absorb such decreases in income.

27.3.2 Weak risk governance capacities

Despite increased global awareness of disaster risk and climate change, and greater political commitment (as reflected in regional ministerial declarations in Africa [Declaration of the Second African Ministerial Conference on Disaster Risk Reduction, Nairobi, 14–16 April 2010] and Asia [Third Asian Ministerial Conference on Disaster Risk Reduction, Kuala Lumpur, 2–4 December 2008]), disaster risk reduction and management has been only timidly incorporated into development planning, and the institutional mechanisms required for such integration are still emerging (UNISDR, 2009). In addition, many bilateral and multilateral country assistance strategies for countries facing well-known risks are not planned with a risk sensitive lens. The outcome is that the exposure of people and assets to climate-related hazards is increasing faster than many low-income countries are able to reduce their vulnerabilities. Such countries often have difficulties in addressing underlying risk drivers such as ecosystem decline, poverty and badly planned and managed urbanization. The outcome is a rapid increase in the number of and loss of assets in disasters.

27.3.3 Badly planned and managed urban development

Informal settlements, inadequate housing, non-existent services and poor health are reflections of poverty. However, they are also reflections of weaknesses in the way urban growth is planned and managed. One example of an informal settlement called '9 October' in Lima, Peru, shows the relationship between poverty, poor planning and disaster impact. This particular hillside was urbanized informally from the bottom upwards by nearby agricultural workers. Multi-storey concrete and brick houses soon replaced early constructions of bamboo matting. By the 1990s,

> 9 October had a population of more than 1,300, as well as domestic electricity, water and telephone connections, and property titles. In 1999, a local development plan classified the area as a zone of environmental risk and social vulnerability due to high salinity in the soil which was eroding foundations and containing walls; two and three-storey houses occupying unstable sites without load-bearing capacity; and leaks from a deteriorated water and sanitation network, which were causing subterranean erosion. In June 2003, part of the hillside subsided and collapsed, damaging 280 houses of which 70 were destroyed. (UNISDR, 2009, p. 100)

Disaster risk may be increasing fastest in rapidly growing small and medium-sized urban centres than in either rural areas or larger cities. Large and megacities generally have stronger risk governance and investment capacities than small and medium cities. This finding is supported by the fact that in most Latin American countries, the number of disasters reported is increasing at a faster rate than in large urban centres and megacities (Mansilla, 2010). More than 80% of all reports of disaster loss in Latin America occur in urban areas. While each country has a different urban structure, between 40% and 70% of all nationally reported disasters occur in urban centres of less than 100,000 inhabitants, and between 14% and 36% take place in small urban centres. This proportion is growing. In Mexico, for example, small and medium urban centres accounted for 45.5% of total disaster municipal loss reports in the 1980s, but 54% since 2000.

27.3.4 Poverty and rural vulnerability

Within countries, poorer areas tend to have higher disaster risk, mirroring global patterns and illustrating the complex interactions between poverty and disaster risk analysed in detail in the *Global Assessment Report* 2009, as presented previously in the summary of case study findings on the social distribution of disaster loss. An exercise in Colombia showed that those municipalities with a greater proportion of unsatisfied basic needs and lower GDP per capita were more likely to experience a higher number of people affected and more houses damaged in floods (OSSO, 2011).

Rural poverty is both a cause and a symptom of drought risk in Kenya's Mwingi district. Between 70% and 80% of Mwingi's population depends on rainfed agriculture and livestock production for both food and income, and 60% of the population subsists on US$1 per day or less (Galu et al., 2010). Therefore, when drought occurs it can wipe out income and investments, leaving communities with limited means to buffer losses. During the 2008–2009 drought, for example, 70% of the population depended on food aid (Galu et al., 2010). While this massive relief successfully averted a food security crisis, it reveals the extreme vulnerability of many rural agricultural and agro-pastoral livelihoods.

Poor rural households, whose livelihoods depend on rainfed subsistence agriculture, are almost always the social group most exposed and vulnerable to drought. In many countries, they have been historically forced to occupy marginal drought-exposed land. And they often lack the resources to access irrigation technology or drought-resistant seeds, which could reduce their vulnerability. For example, sub-Saharan Africa's water storage facilities are severely under-developed, with a per capita storage capacity of 200 m^3 per year on average (as compared to 1,277 m^3 for Thailand and 5,961 m^3 for North America) (Foster and Briceno–Garmendia, 2010; Grey and Sadoff, 2006).

Groups of countries with small and vulnerable economies, such as many small island developing states (SIDS), land-locked developing countries (LLDCs) and least developed countries (LDCs), would appear to have particular difficulties in absorbing and recovering from disaster impacts (Corrales and Miquelena, 2008; Noy, 2009). SIDS, for example, often have higher relative disaster risk than larger countries because almost all of their population and assets are exposed to hazards such as tropical cyclones (Kelman, 2010; UNISDR, 2009), while their economies may be concentrated around a single vulnerable sector, such as tourism.

The expansion of intensive market agriculture and urbanization can lead to the sale of water rights, pushing the rural poor to farm marginal lands more intensively, and thereby increasing their drought risk further still (Fitzhugh and Richter, 2004). For example, Mexico's water management and land tenure policies date back to the 1910 revolution, and are based on communal ownership of land and water by smallholder farmers known as *ejido* – 25% of whom live in abject poverty. Nowadays, the *ejido* cannot compete with large farmers and agribusinesses. In the state of Sonora, nearly 75% of irrigation water is allocated to this sector, increasing the agricultural drought risk of the *ejido* (Neri and Briones, 2010).

27.3.5 Ecosystem degradation

Many ecosystems have been intentionally or unintentionally modified to increase the supply of certain categories of services, and institutions have been developed to govern access to, and use of, these services. However, because ecosystems produce many services simultaneously, an increase in the supply of one service, such as food, can frequently lead to declines in other services, such as flood protection. The Millennium Ecosystem Assessment identified modifications to ecosystems that have unintentionally led to the decline of regulating ecosystem services, including those responsible for reducing people's exposure to hazards, such as fires and floods.

Water management also affects the provision of ecosystem services in ways that modify levels of disaster risk. For example, the increasing demand on rivers for irrigation, as well as extraction of water for industrial and domestic use, reduces the sedimentation that

BOX 27.5

The Mississippi wetlands

The drainage of approximately 4,800 km^2 of wetlands in the Mississippi Delta in the United States of America was one of the underlying factors behind the scale of the flooding associated with hurricane Katrina. Many areas formerly above sea level lay below sea level at the time of Katrina as a result of wetland drainage, while the capacity of the wetlands to dissipate storm surge and absorb floodwaters had diminished. The forested riparian wetlands adjacent to the Mississippi River during pre-settlement times had the capacity to store about sixty days of river discharge. Today, the few remaining wetlands have a reduced storage capacity of less than twelve days discharge, implying an 80% reduction in flood storage capacity. This loss of wetlands also contributed substantially to the severity and damage experienced in the 1993 Mississippi Basin flood.

reaches the coast. This can affect downstream agricultural yields and fish productivity, damage the health of coastal wetlands, and increase coastal flood hazard levels. Excessive groundwater extraction is leading to a potentially irreversible degradation of aquifers, again with compound effects on rural livelihoods. Coastal and inland wetlands have a critical influence on both livelihoods and the regulation of flood and drought (Box 27.5).

27.4 Methodologies and tools for reducing water-related hazard risk

The elements that constitute effective methods and tools to reduce water-related hazard risk are context specific, as well as dependant on the perspective of the respective experts and institutions engaged.

During the analytical work undertaken for this chapter it became apparent that the identification of the most appropriate and effective methods and tools is seldom based on a sufficiently broad understanding of the underlying problem. For the meteorological community, the best approach to floods lies in better forecasting and issuing of early warnings, while for a ministry of infrastructure, the optimal approach will be structural in nature, such as the dams and levees required for both water storage and flood control. Of course, experience shows that a combination of different approaches is most effective. The cost–benefit of preventive investment against post-disaster financing mechanisms is also insufficiently taken into account. Post-disaster approaches include catastrophic risk financing and other insurance mechanisms, and the disbursement of response funds.

The World Conference on Disaster Reduction in Kobe, Japan in 2005 concluded a ground-breaking agreement that provides a clear mandate for action to reduce disaster risks; namely, the Hyogo Framework for Action 2005–2015: Building the Resilience of Nations and Communities to Disasters. The over-riding expected outcome of the Hyogo Framework for Action is the *'substantial reduction of disaster losses, in lives and in the social, economic and environmental assets of communities and states'.*

The Hyogo Framework emphasizes that disaster risk reduction is a central issue for development policies, as well as being of interest to various scientific, humanitarian and environmental fields, stressing that without concerted efforts to address disaster losses, disasters will become an increasingly evident obstacle to the achievement of the MDGs.

While the Hyogo Framework for Action provides a comprehensive set of actions that a country can take to strengthen its risk governance capacities, it does not provide a set of tools and methods from which national and local authorities can establish the most socially, environmentally and economical approaches to reduce risk.

Methods and tools are required to correct existing risk levels through actions such as retrofitting buildings, relocating settlements and restoring ecosystems. This, however, is more expensive than avoiding such risks in the first place. Given the high level of recurrent losses, it is usually cost-effective to correct the risks related to frequent recurrent disasters, but increasingly less so for very high intensity but less frequent events, given the costs involved and long periods before benefits are potentially realized. However, investments to protect critical facilities, such as schools and health facilities, against more extreme risks may be justified, for both economic and political reasons. For example, if a city government invests to relocate squatter settlements subject to recurrent flooding along a cyclone-prone coastline, this relocation programme will not only lead to a short-term reduction in high-frequency, low-severity losses associated with the floods, but would also reduce the periodic cyclone losses. In contrast, in other contexts, protecting an area against 100-year floods may encourage greater investment in the area, leading to increased losses in the event of a 500-year flood. Ultimately, all investments in risk reduction involve trade-offs between different social and economic objectives.

For certain intensive risks that cannot be reduced cost-effectively, risk transfer measures such as insurance and catastrophe risk pools/bonds can mitigate disaster impacts on physical assets and enhance the ability of governments to respond. One model that has demonstrated some success is the Caribbean Catastrophe Risk Insurance Facility (CCRIF). This risk-pooling facility is operated in the Caribbean for Caribbean governments. It is designed to limit the financial impact of catastrophic hurricanes and earthquakes on Caribbean governments by quickly providing short-term liquidity when a policy is triggered. Since 2007, 16 Caribbean governments have included CCRIF parametric insurance policies against hurricanes and earthquakes as part of their countries' disaster risk management portfolios. An example of the kind of payout provided by CCRIF is the US$6.3 million paid to the Turks and Caicos Islands after hurricane Ike made a direct hit in September 2008 (World Bank, 2010). However, the limited scale of the payouts in the context of growing levels of risk is becoming a concern for governments. The payout for Haiti following the 12 January 2010 earthquake was only US$7.75 million.

Traditional disaster management, including effective early warning, preparedness and response, is essential to strengthening resilience to and facilitating recovery from all manifestations of risk. A number of developing countries have made significant progress in this area, resulting in saved lives. Almost all households (98%) have access to radio and TV in Cuba; consequently, these comprise the main communication channels used by the national meteorological service (with government authority) to issue tropical cyclone and related flood warnings. In Bangladesh, far fewer people have televisions and radios, so the Bangladesh Meteorological Department conveys cyclone and storm surge warnings through multiple channels (fax, Internet, radio and TV). But the centralized warning centre of the Bangladesh Cyclone Preparedness Programme ensures that the warnings reach coastal communities. The centre alerts a network of volunteers through HF/VHF radio broadcasts, and they in turn fan out into the communities to warn the people (WMO, 2009).

There are likely to be greater incentives for reducing risks associated with water-related hazards when such instruments address the needs of a number of stakeholders and competing priorities simultaneously; for example, if better water management not only addresses drought risk, but also increases hydro-energy generation, water-storage capacity for agricultural use, and the availability of domestic drinking water. In general, these incentives are stronger when reduction in risk to water-related hazards contributes visibly to improved economic and social well–being and choice for each citizen.

A number of countries, however, are now innovating and building approaches to reducing risk related to water-related hazards into existing development instruments – in areas such as public investment planning, ecosystem management, urban development and social protection (Box 27.6). While many of these innovations are still in their early stages, they hold the promise of exponentially increasing the impact of reducing risk related to water-related hazards. Importantly they also contribute to other social and economic development goals, which in turn feed back into reduced risk. The upgrading of inefficient, ageing water and drainage infrastructure, if planned from a risk reduction perspective, can reduce vulnerability to drought and floods, while improving the quality of water and sanitation.

This section of the report has presented different methods and tools to address water-related hazard risk and will be augmented in future with more systematic measures of effectiveness.

BOX 27.6

Micro-lending to assist watershed restoration and development in Maharashtra State, India

In the semi-arid region of Maharashtra State in India, the Watershed Organization Trust is assisting poor rural communities to increase their livelihood security by supporting watershed restoration projects. The combination of recurring droughts and human pressures on the surrounding land has degraded watersheds. This decrease in soil fertility and water availability has created drought-stressed communities vulnerable to the impacts of climate change.

Working on a micro-catchment basis, rigorous watershed restoration measures designed to regenerate and conserve micro-catchments have been undertaken, including soil, land and water management (e.g. trench building to control erosion, improve soil fertility and enhance groundwater recharge); crop management; afforestation and rural energy management (e.g. a ban on tree-felling, instead planting shrubs and grass to meet household fuel needs); and livestock management and pasture/fodder development (e.g. grazing restrictions leading to the natural regeneration of grass and shrubs). These projects have been supported by other measures, including micro-lending, training in new techniques and the formation of self-help groups, to diversify livelihoods.

Increased soil cover, improved soil moisture regimes, increased well water levels, biomass regeneration, and dramatic increases in fodder availability, milk production and vegetable farming are some of the results reported by participating villages. Coupled with micro-enterprise development and an increase in savings groups, these results have translated into more secure livelihoods, diversified asset bases and reduced exposure to climate-related shocks.

Source: IISD et al. (2003).

27.5 Emerging approaches to reduce flood and drought hazard risk

27.5.1 Land-use planning and building

The ways in which land is used in cities and how buildings, infrastructure and networks are designed and constructed have a decisive impact on exposure, and whether a country's accumulated risk increases or decreases. As such, land-use planning is a prime instrument for reducing risk related to water-related hazards. If existing and potential hazards are taken into account in land-use decisions, new risks could be avoided and existing risks reduced over time. Decisions on land use underpin most risk construction, given that once investments in infrastructure, housing and other facilities have been made in hazardous locations, the risk is locked in place for decades or more.

In a number of cities in Colombia, disaster risk reduction has been incorporated as an integral part of improvements in urban and local governance. In Manizales, an innovative cross-subsidized insurance scheme called Predio Seguro, supported by the city government, has enabled poor households to obtain catastrophe insurance cover. The city government, in partnership with women's groups in informal settlements, also invests in stabilizing slopes in landslide prone informal settlements (Cardona, 2009).

27.5.2 Ecosystem management

Protecting ecosystems that will, in turn, reduce the risk of natural hazards such as floods and drought, requires actions at different scales, the participation of a wide array of stakeholders, and different bodies of knowledge – scientific, technical, local and traditional.

Dense vegetation cover within upper watershed areas increases infiltration of rainfall as opposed to surface runoff, reducing peak flow rates except in the most extreme conditions when soils are already fully saturated. Vegetation also protects against erosion, thereby reducing soil loss and the transport of mud and rock that greatly increase the destructive power of floodwaters. Dense vegetation also protects riverbanks and adjacent land structures from erosion by floodwaters. Wetlands and floodplain soils absorb water, reducing peak flow rates downstream (World Bank, 2010).

A study around Mantadia National Park, Madagascar, concluded that conversion from primary forest to swidden (area cleared for temporary cultivation by cutting and burning the vegetation) can increase downstream storm flow by as much as 4.5 times (Stolton et al., 2008).

In the case of ecosystem restoration, the avoided costs may significantly exceed the restoration costs (Box 27.7). In Viet Nam, for example, the International Federation of Red Cross and Red Crescent societies (IFRC) planted and protected 12,000 ha of mangroves, an action that cost approximately US$1 million, but reduced the costs of sea dyke maintenance by US$7.3 million per year. Moreover, the co-benefits may also greatly exceed the opportunity costs. For example, the Millennium Ecosystem Assessment estimated that the value of healthy coastal mangroves as nurseries, pollution filters and coastal defences is US$1,000 to US$36,000 for mangrove value versus US$200 per ha for shrimp farming (MA, 2005). 'In Malaysia, the

BOX 27.7

Examples showing the value of ecosystem services to reducing disaster risk

- As coastal defences, mangrove forests in Malaysia have been estimated to have an economic value of US$300,000 per km based on comparison with engineered alternatives (ProAct, 2008).
- Since 1994, communities have been planting and protecting mangrove forests in northern Viet Nam to buffer against storms. An initial investment of US$1.1 million saved an estimated US$7.3 million a year in sea dyke maintenance and appeared to significantly reduce losses of life and property from typhoon Wukong in 2000, compared with other areas (WWF, 2008).
- In the Lužnice floodplain – one of the last floodplains in the Czech Republic with an unaltered hydrological regime – 470 ha have monetary values per hectare of US$11,788 for flood mitigation (water retention), US$15,000 for biodiversity, US$144 for carbon sequestration, US$78 for hay production, US$37 for fish production and US$21 for wood production (ProAct, 2008).
- The economic value of forests for preventing avalanches is estimated at around US$100 per ha per year in open expanses of land in the Swiss Alps, and up to more than US$170,000 per ha per year in areas with valuable assets (ProAct, 2008).
- A recent study on the role of wetlands in reducing flooding associated with hurricanes in the United States of America calculated an average value of US$8,240 per ha per year, with coastal wetlands estimated to provide US$23.2 billion per year in storm protection services (Costanza et al., 2008).

Source: World Bank (2010).

economic value of mangroves as coastal defences has been estimated at US$300,000 per km, taking into account the costs of hard engineering work to achieve the same protective effect' (UNISDR, 2009). In Switzerland, the economic value of forests in preventing avalanches is valued at US$100 per ha per year in open areas, but up to US$170,000 in areas with high-value assets (World Bank, 2010).

At the same time, ecosystems often provide important co-benefits if properly managed. Some of the most fertile agricultural land on the planet depends on regular flooding to recharge the soil with nutrients. Flooding can also recharge aquifers in semi-arid areas or transport vital sediments and nutrients to sustain coastal fisheries in other areas.

27.5.3 Social protection: Increasing resilience to disasters

There are two compelling reasons why social protection can be a strategic mechanism for the management of water hazards. First, social protection instruments (community cohesion, healthcare facilities, accommodation insurance, etc.) can be adapted to enhance the disaster resilience of individuals and households, as well as providing important benefits in terms of poverty reduction and human capital development. Second, many of these instruments are already being delivered on a large scale, which make them a powerful tool for reducing the risk associated with floods and drought. Existing mechanisms for social protection can thus usually be used to encompass large numbers of disaster-prone households and communities through relatively minor adaptations of targeting criteria and timeframes, and often with relatively low additional costs.

The countries best able to develop effective social protection for risk–prone households and individuals are those that already have requisite social policies backed up by a wide range of legislative provisions (ERD, 2010). They include labour market laws (including the regulation of unemployment benefits), health and safety regulations in the work place, basic entitlements and welfare payments, and the stipulation of affirmative action for marginal groups. Countries that have strongly developed social legislation, corresponding regulation, and up–to–date public registries find it easier to embed both targeted and universal social protection as an instrument for reducing water-related hazard risks.

27.5.4 Adapting to climate change

Climate change adaptation can be understood in terms of both (a) adapting development to gradual changes in average temperature, sea level and precipitation; and (b) reducing and managing the risks associated with more frequent, severe and unpredictable extreme weather events.

There is evidence that the momentum to develop country-level adaptation programming owes more to the perceived opportunity to access climate change funding mechanisms than to social demand for adaptation. But given that in practice most adaptation measures address disaster risks, adaptation provides an additional set of instruments and mechanisms for reducing water-related hazard risk.

As with disaster risk reduction, adaptation measures can generate benefits at the appropriate scale only when they are integrated into mainstream development planning and public investment decisions (ECA, 2009). Unfortunately, many climate change adaptation initiatives are still conceived of and implemented as stand–alone projects. Governments' failure to integrate efforts to reduce water-related hazard risk and climate change adaptation into national and sector development planning and investment perpetuates the misconception that climate change adaptation is predominantly an environmental issue, rather than a core component of development, and that reducing water-related hazard risk is limited to early warning insurance and disaster preparedness and response (Mercer, 2010).

The inability to recognize the links between adaptation, disaster risk reduction and development processes leads to an inaccurate understanding of climate-related risks. As a result, there is a tendency to emphasize the use of risk transfer measures for managing extreme events, rather than adopting a more comprehensive approach that also reduces the extensive risks upon which climate change will have the greatest impact in the short term.

27.6 Conclusions and required actions

27.6.1 Disaster trends

The exponential increase in the damage associated with highly localized flash and urban flooding, landslides, fires, storms and torrential rains in many low and middle-income countries provide a real-time indicator of the accumulation of risk (Box 27.1). Most of these losses disproportionately affect low-income households and communities and go largely unaccounted for. In other words, there is a social distribution of disaster loss.

In most of the world, the risk of being killed by a tropical cyclone or a major river flood is lower than in 1990. Countries are successfully strengthening their capacities for early warning, preparedness and disaster response. However, drought impact still goes largely unaccounted for and falls on poor rural households. As a result there may be little political or economic incentive to address it.

In most countries drought risk management is remedial, emphasizing early warning, response and insurance rather than policies that address the underlying risk drivers. Institutionally, drought risk reduction and management are rarely integrated into either national disaster risk reduction or other policy frameworks such as water management (e.g. IWRM). But given the evidence of rapidly increasing impacts and climate projections through the end of this century, the need to address drought risk and its underlying drivers will be fundamental to the sustainability of many countries and localities over the coming decades.

27.6.2 Integrated measures

A balanced portfolio of measures and investments that reduce flood and drought risk is likely to improve social and economic development. Such measures include development and land-use planning; targeted investments, for example, through retrofitting critical facilities such as schools and hospitals; risk transfer schemes to protect against the most intensive risks; and investment in social protection and disaster management. Thus, if on the one hand disaster risk reduction programmes improve development, on the other hand development programmes should integrate a disaster risk reduction aspect, including it into their portfolio. Perhaps the most strategic of these instruments is a country's national planning and public investment system (see Section 27.1.3).

Mainstreaming disaster risk reduction in national planning and public investment system decisions is a potentially very high impact strategy, particularly considering the scale and volume of public investment, infrastructure and public asset, particularly in middle-income countries. This include the incorporation of water-related disaster risk reduction into IWRM through the adoption of regulatory and other legal measures, institutional reform, improved analytical and methodological capabilities, appropriate technologies, capacity-building, financial planning, public education, community involvement and awareness-raising. This approach would also provide a cost-effective and first barrier against climate change impacts.

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CHAPTER 28

Desertification, land degradation and drought and their impacts on water resources in the drylands

UNCCD and UNU

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Acknowledgements Peer review was carried out by Zafar Adeel and Fabrice Renaud (UNU).

Water degradation in drylands will have detrimental effects for the people and the economy of dryland countries.

Although it is clear by definition that drylands are water-scarce, human drivers and climate change pose serious threats to water resources in drylands.

The impacts of desertification, land degradation and drought (DLDD) on water resources negatively affect development potentials in drylands.

Urgent and dedicated responses to protect drylands resources including water are needed to support sustainable development in dryland countries.

28.1 Introduction

The key challenges: desertification, land degradation and drought (DLDD) are specifically, but not exclusively, related to drylands. Drylands are by definition water limited environments. Water is a key resource that is under high pressure from increasing demand and decreasing quality. Productivity of drylands is determined by water availability and quality. Any further degradation of this essential resource will have detrimental effects for the people and the economy of dryland countries.

Drivers: DLDD are caused and exacerbated by different drivers, including (a) natural drivers, which are often related to the geographical situation and associated environmental and climatic settings of a site; (b) human drivers, related to unsustainable human development aspirations, which are often economic in nature and not attuned to the environmental frame conditions, and (c) climate change, which is a new, partially natural and partially human-induced driver.

Risks and uncertainties: There are various DLDD-related impacts on water, including: lower recharge of groundwater and runoff; water degradation, for example through pollutants, and changes in turbidity, sedimentation and siltation; and salinity. All these DLDD-related impacts have severe implications for the development potential in drylands. They negatively affect agricultural production, ecosystem health and the sustainability of industrial and energy projects and infrastructure. A major concern for sustainable development in drylands is the increasing threat of water scarcity (Figure 28.1). Water availability and quality are existing challenges to potential dryland development that are expected to be exacerbated by the impacts of climate change.

Hotspots: Geographic hotspots of intensified DLDD expand across the drylands of the world – countries with a low Gross Domestic Product (GDP) and a low Human Development Index (HDI) are particularly vulnerable, as interventions are costly. Dryland areas with high human populations or connected high density areas 'downstream' are prone to land degradation and associated negative water impacts.

Responses: A range of specific examples of strategic responses to the challenges exists and each has been tested and implemented on a pilot basis. However, these successes need to be scaled up in dryland areas, which often requires support actions (such as policy, financial and, structural and) and material resources. Generally three main areas of response are considered:

Innovations in water management and technology to cope with water scarcity, including concepts such as cost of and payment for water; investments for sustainable ecosystem services; investment in appropriate techniques, technologies and infrastructure; development of new water resources; and investments in water research, management and policy-making capacities.

Promoting water use efficiency by reducing water wastage and prioritizing water uses in the drylands.

Supporting policy changes needed in and for dryland countries, including policy changes in water demand management and food self-sufficiency versus food security, as well as global investments in long-term food security in water-restricted drylands.

A dedicated international framework to act upon the pressing issue of water scarcity in drylands as well as DLDD-related water and land issues is urgently required. The establishment of a 'Water Compact for Drylands' has been proposed as one such international priority action. Existing United Nations (UN) instruments – such as the UN Convention to Combat Desertification in those Countries Experiencing Serious Drought and/or Desertification, Particularly in Africa (UNCCD), the UN-Water and UN-Land initiatives, and the priority outcomes from the seventeenth session

FIGURE 28.1

The impact of desertification, land degradation and drought in Piali Village, India

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of the UN Commission on Sustainable Development – should be positioned to support and drive such work.

28.2 The challenge: Water as a key resource under pressure in the drylands

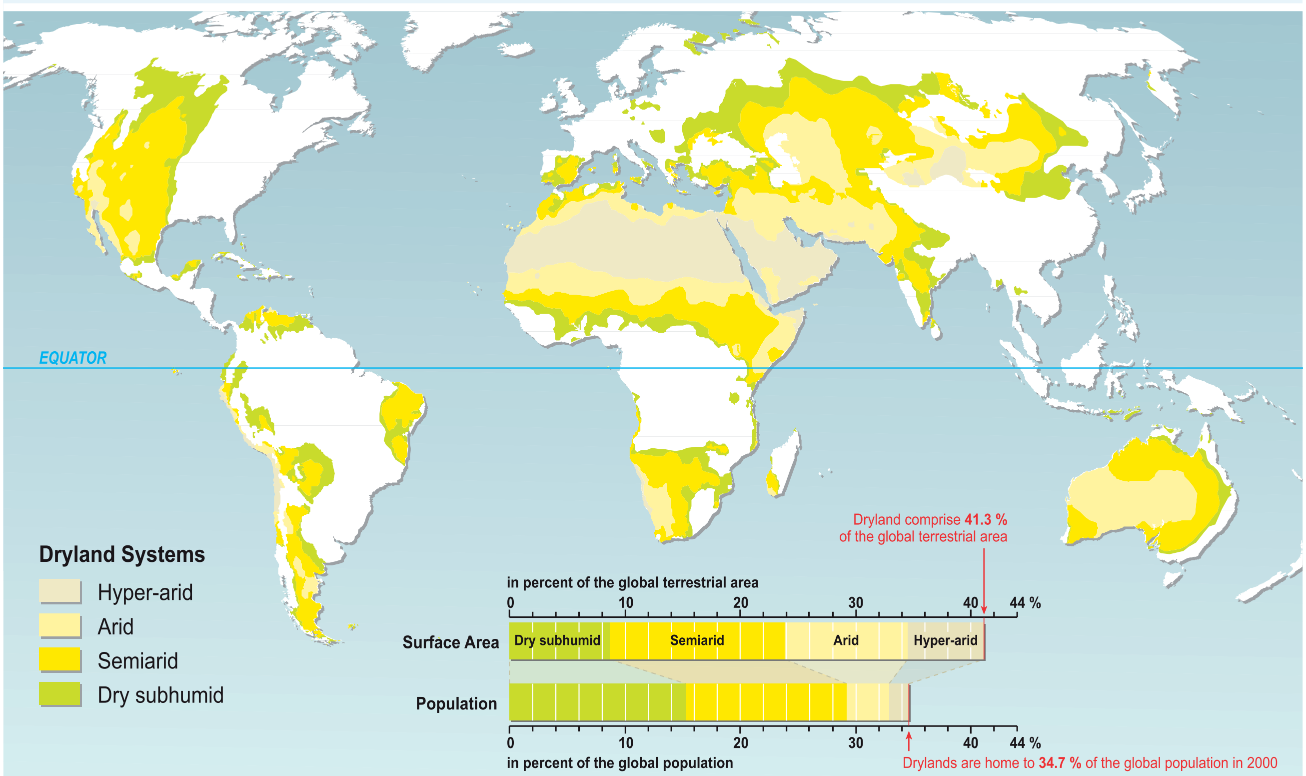
The growth in the use of this water resources has tended to be much greater than the growth in the number of people. For example, in the twentieth century, the world's population increased fourfold, whereas freshwater usage increased nine times over (Lean, 2009). In addition to this increased usage, DLDD means that natural recharge is reduced as the soil loses its water retention capacity (DG Environment – European Commission, 2007). and Rainfall is also reduced in times of drought. Consequently, a number of countries in the drylands are increasingly faced with water scarcity.

Water scarcity is the imbalance between available water resources and demands (UNCCD, 2010), occurring when water resources are insufficient to satisfy long-term average requirements. This long-term water imbalance is caused by a combination of low water availability and a level of water demand exceeding the natural recharge. Water scarcity frequently appears in areas with low rainfall but also in areas affected by DLDD, as well as in areas with high population density and intensive agriculture and/or industrial activity, particularly in the drylands. Large spatial and temporal differences in the amount of water available are observed across the drylands. Dryland problems of DLDD and water scarcity, among others, put immense pressure on the management of water resources.

Water scarcity, whether natural or human-induced, serves to trigger and exacerbate the effects of desertification through direct, long-term impacts on land and soil quality, soil structure, organic matter content, and ultimately on soil moisture levels. The direct physical effects of land degradation include the drying up of freshwater resources, an increased frequency of drought and sand and dust storms, and a greater occurrence of flooding due to inadequate drainage or poor irrigation practices. Should these trends continue,

FIGURE 28.2

The extent of dryland systems worldwide



Notes: Overall 41.3% of the global terrestrial areas are categorized as drylands and 34.7% of the global population lived in drylands in 2000. The long-term mean of the ratio of an area's average annual precipitation to its average annual potential evapotranspiration is the Aridity Index (AI). Source: Millennium Ecosystem Assessment (2005, appendix A, p. 23, from data sources cited therein).

it would bring about a sharp decline in soil nutrients, accelerating the loss of vegetation cover. This in turn leads to further land and water degradation, such as pollution of surface and groundwater, siltation, and the salinization and alkalization of soils.

28.2.1 An introduction to drylands of the world

Desertification is land degradation, resulting from various factors including climatic variations and human activities. DLDD are concepts mainly associated with, but not exclusive to, dryland areas around the world. Over 60 countries are characterized by dryland ecosystems (Table 28.1) – with prevailing hyper-arid, arid and dry subhumid climatic conditions. They are categorized using the Aridity Index (AI) which is the long-term mean of the ratio of an area's average annual precipitation to its mean annual potential evapotranspiration. For 17 of these countries, drylands account for more than 90% of their land area. Overall, 41.3% of the global terrestrial area is categorized as drylands and 34.7% of the global population lived in drylands in 2000 (Figure 28.2) (Millennium Ecosystem Assessment, 2005).

In drylands, water is usually the most important limiting resource – for both ecosystems and human and economic development. Poor management of drylands ecosystems leads to desertification and land degradation, and to increasing and long-term loss of productivity (UNCCD, 1994). Linkages with natural water limitation, unsuitable water management practices and negative feedback loops, as well as interconnectivity between land degradation and water resources, often exacerbate unsustainable use of water.

Although several dryland countries are counted as among the wealthiest globally, endowed as they are with non-renewable natural resources such as oil, diamonds and uranium, most dryland countries have a low GDP, and rank poorly in terms of their HDI (Table 28.1). The high dependence of drylands inhabitants on the natural resource base means that they are vulnerable to land degradation.

28.2.2 Water sources and their sustainability in the drylands

Sources of water in the drylands usually consist of surface water, groundwater (including fossil groundwater) and rainfall. Average annual rainfall in the drylands is relatively low in dry subhumid areas and is even lower for other drylands types. In hot arid climates, much of the precipitation is lost to evapotranspiration due to extremely high temperatures. For example, data collected in southern Africa suggest that less than 3% of precipitation actually contributes to ground or surface water recharge, less than 1% of precipitation contributes to aquifer and groundwater recharge, and approximately 2% contributes to surface water (perennial and ephemeral rivers, wetlands and dams) through runoff. Hence only a small percentage (approximately 17%) is productively used for ecosystem maintenance and rain-fed production systems (Heyns et al., 1998; Schlesinger, 1997).

As water demand in drylands usually exceeds water availability, local inhabitants depend largely on groundwater, obtaining their water supply through boreholes and wells, although small-scale rainwater harvesting also takes place. In areas where larger settlements and cities (with associated industries) are situated, water demand frequently exceeds availability. In such cases, groundwater availability determines whether local water supply is accessible and sustainable. In many instances excessive water mining has already taken place and existing sources of water have been depleted without replenishment. In certain countries, alternative water sources are sought from other areas, by pipeline, or through the desalination of sea water.

Water resources in various watersheds in drylands are already considered highly over utilized. An analysis projecting water supply data for the year 2025 in water catchments in drylands worldwide presents a disturbing picture. According to the analysis, seven major basins in the drylands – mostly in Asia, and one large basin in Africa and another in North America – are expected to experience water scarcity by 2025 (Figure 28.3) and fourteen major watersheds are projected to be water stressed by 2025. In total, half of the major watersheds investigated in the drylands are predicted to experience some type of water shortage in the coming years (White and Nackoney, 2003) exacerbated by the anticipated climatic changes in dryland areas around the world.

28.2.3 Primary human water requirement activities and limitations in drylands

The importance of access to safe water was confirmed in the 64th UN General Assembly resolution (UN, 2010), which explicitly recognized access to safe and clean water and sanitation as a human right. The primary human water requirement activities are for drinking water,

TABLE 28.1

Gross Domestic Product (GDP) per capita and Human Development Indices of countries with drylands areas

#	Country with dryland areas	Total land area (km^2)	Percentage of total dryland surface area (if exceeding 90%)[a]	GDP (PPP) per capita (US$)	HDI	Population
1	Afghanistan	647 500	94.0	$800	0.352	28 395 716
2	Albania	27 398		$6 300	0.818	3 639 453
3	Algeria	2 381 740		$7 000	0.754	34 178 188
4	Angola	1 220 000		$8 900	0.564	12 799 293
5	Argentina	2 736 690		$13 800	0.866	40 913 584
6	Armenia	28 454	98.1	$5 900	0.798	2 967 004
7	Australia	7 617 930		$38 911	0.970	21 262 641
8	Azerbaijan	86 100		$10 400	0.787	8 238 672
9	Botswana	585 370	100.0	$13 100	0.694	1 990 876
10	Bulgaria	110 550		$12 600	0.840	7 204 687
11	Burkina Faso	273 800	100.0	$1 200	0.389	15 746 232
12	Chad	1 259 200		$1 600	0.392	10 329 208
13	China	9 326 410		$6 600	0.772	1 338 612 968
14	Egypt	995 450		$6 000	0.703	78 866 635
15	El Salvador	20 720		$7 100	0.747	7 185 218
16	Eritrea	121 320		$700	0.472	5 647 168
17	Ethiopia	1 119 683		$900	0.414	85 237 338
18	Gambia	100 000	97.2	$1 400	0.456	1 778 081
19	Greece	130 800		$32 100	0.942	10 737 428
20	India	2 973 190		$3 100	0.612	1 156 897 766
21	Iran	1 636 000	90.2	$12 900	0.782	66 429 284
22	Iraq	432 162	99.9	$3 600	0.583	28 945 569
23	Israel	20 330		$28 400	0.935	7 233 701
24	Jordan	91 971		$5 300	0.770	6 269 285
25	Kazakhstan	2 669 800	99.1	$11 800	0.804	15 399 437
26	Kenya	569 250		$1 600	0.541	39 002 772
27	Kuwait	17 820	92.9	$54 100	0.916	2 692 526
28	Kyrgyzstan	191 300		$2 100	0.710	5 431 747
29	Lebanon	10 230		$13 100	0.803	4 017 095
30	Libya	1 759 540		$15 200	0.847	6 324 357
31	Macedonia	24 856		$9 000	0.817	2 066 718
32	Madagascar	581 540		$1 000	0.543	20 653 556
33	Malawi	94 080		$900	0.493	15 028 757
34	Mali	1 220 000		$1 200	0.371	13 443 225

#	Country with dryland areas	Total land area (km^2)	Percentage of total dryland surface area (if exceeding 90%)[a]	GDP (PPP) per capita (US$)	HDI	Population
35	Mauritania	1 030 400		$2 100	0.520	3 129 486
36	Mexico	1 923 040		$13 500	0.854	111 211 789
37	Moldova	33 371	99.9	$2 300	0.720	4 320 748
38	Mongolia	1 554 731		$3 200	0.727	3 041 142
39	Morocco	446 300	92.2	$4 600	0.654	31 285 174
40	Mozambique	784 090		$900	0.402	21 669 278
41	Namibia	825 418	90.8	$6 400	0.686	2 108 665
42	Niger	1 266 700		$700	0.340	15 306 252
43	Nigeria	910 768		$2 400	0.511	149 229 090
44	Oman	212 460		$23 900	0.846	3 418 085
45	Pakistan	778 720		$2 600	0.572	174 578 558
46	Romania	230 340		$11 500	0.837	22 215 421
47	Russia	16 995 800		$15 100	0.817	140 041 247
48	Saudi Arabia	2 149 690		$20 400	0.843	28 686 633
49	Senegal	192 000	94.1	$1 600	0.464	13 711 597
50	Somalia	627 337		$600	0.284	9 832 017
51	South Africa	1 219 912		$10 100	0.683	49 052 489
52	Spain	499 542		$33 700	0.955	40 525 002
53	Sudan	2 376 000		$2 300	0.531	41 087 825
54	Syria	184 050	98.0	$4 600	0.742	21 762 978
55	Tajikistan	142 700		$1 800	0.688	7 349 145
56	Tunisia	155 360	93.7	$8 000	0.769	10 486 339
57	Turkey	770 760		$11 200	0.806	76 805 524
58	Turkmenistan	488 100	100.0	$6 900	0.739	4 884 887
59	Ukraine	603 700		$6 400	0.796	45 700 395
60	Uzbekistan	425 400	99.2	$2 800	0.710	27 606 007
61	Venezuela	882 050		$13 100	0.844	26 814 843
62	Yemen	527 970		$2 500	0.575	22 858 238
63	Zimbabwe	386 670		$100	0.513	11 392 629

Note: Three countries have been added to the original listing: Senegal, Gambia and Tunisia.
[a] Data not available for countries with less than 90% dryland areas.
Sources: Updated and revised after Harrison and Pearce (2000) and White and Nackoney (2003). Updated and additional information: HDI (2007) from UNDP (HDI indices provided on Wikipedia); GDP per capita (2009 estimate) from CIA (n.d.); and population (2009 estimate) from CIA (n.d.).

agriculture (food production), industry and domestic use. Where water is a limiting resource, priorities need to be set among competing uses to meet the essential requirements. can be met. The following key requirement activities can be specified.

Drinking water

Water is required for humans, livestock and wildlife, and plant life (excluding crops and agricultural production). Livestock production is common in the drylands, where rangelands tend to support large herds of herbivores if there is sufficient drinking water.

Domestic water requirements

Basic human needs include clean and safe water for washing and sanitation. The health of people is directly linked to the availability of clean and safe water. Water scarcity in the drylands is a major limiting factor for human habitation and its unavailability leads to dehydration and ultimately the death of the affected people.

Agricultural water demand

In most drylands regions, food production for local consumption or trade at a household level depends largely on rainfed agriculture or small-scale irrigation based on rainwater harvesting technologies. Large-scale irrigation systems tend to be unsustainable in most drylands, depending on the source and management of water. Rainfed agriculture often performs poorly, with high production variability as determined by the highly variable rainfall patterns.

Industrial demand

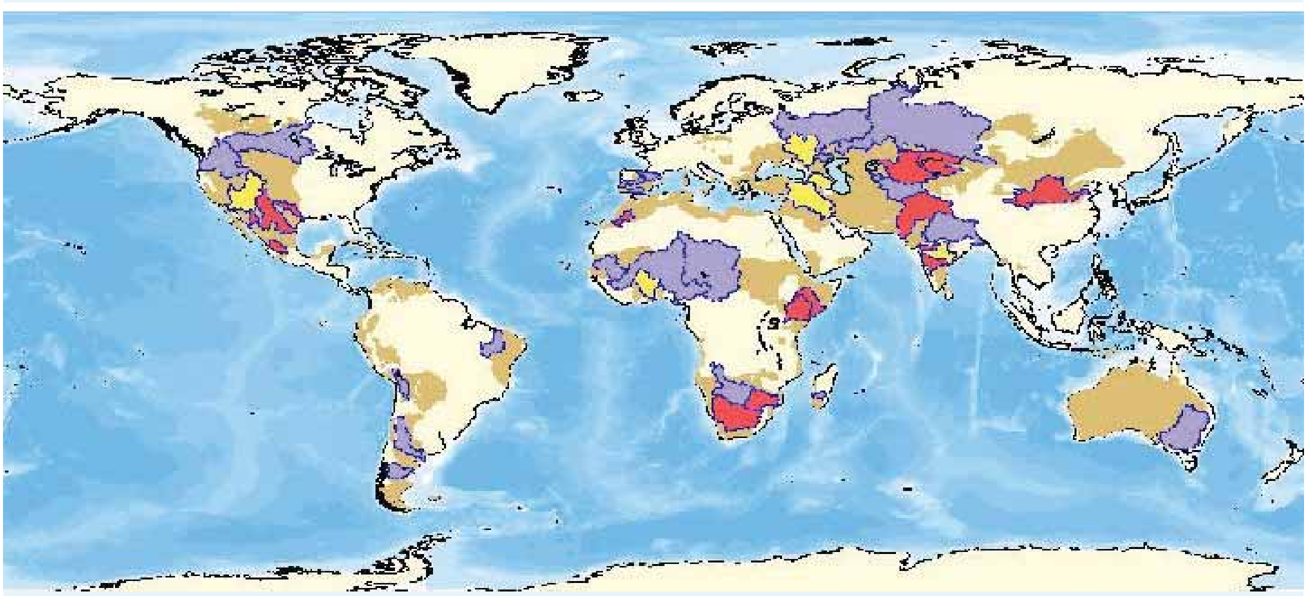
In general, water-dependent industries are not appropriate for the drylands, and this can have severe negative impacts on national economies. Given the prevalence of water scarcity in the drylands, promoting water-dependent industries becomes difficult, unless sustainable alternative sources of water can be accessed and managed in an efficient way without compromising domestic and agricultural water needs.

28.2.4 Global and regional water management policies in drylands

Water management is a critical aspect of dryland development. As the local and regional water cycles are extremely sensitive, the balance between demand and supply has often been disturbed and severe

FIGURE 28.3

Projected water supply in major watersheds in drylands by 2025: water scarcity will be exacerbated in many key dryland areas worldwide



Annual Renewable Water (m³/person/year)

< 1000 (Water Scarce) | 1000-1700 (Water Stressed) | > 1700 (Sufficient Quantity) | Drylands

Source: White and Nackoney (2003).

depletion of the water resources have occurred. Land and water use conflicts often arise. Where transboundary disagreements occur, capacity development in collaborative management of the scarce water resources is needed in order to avoid the potential escalation of these disagreements into major political crises.

Migration related to DLDD and water has already been observed and could potentially accelerate in the future. Water management must start at the local level. In drylands, priority should be given to strong investment in locally adapted technical and technological solutions, along with appropriate policy-making at national and international levels, to ensure improved water use efficiency. Water policies must be based on the availability of the resource, which has to be properly and economically valued. (See a more detailed overview of relevant policy instruments and examples of responses that help to reduce the impacts of DLDD on water resources and address water scarcity later in this chapter.)

Currently there are numerous regional and global water management policies in place. These policies often relate to transboundary agreements where watersheds reach across national borders (Figure 28.4). Also, projects such as 'Every River has its People' (KCS, n.d.) work with local communities on establishing basin management committees that also promote sustainable land management practices along the river to curb impacts of DLDD and its drivers (see Section 28.2 for further details).

28.3 Desertification, land degradation and drought: Drivers, risks and uncertainties, and hotspots

28.3.1 Drivers of desertification, land degradation and drought and water linkages

DLDD are caused and exacerbated by different drivers, relating to natural phenomena, human activities and climate change. The combined effects of desertification, land degradation and drought result in reduced water resources availability and accessibility. Both ground and surface water systems are affected.

Natural phenomena

It is important to recognize that certain geographic areas are naturally arid. It is normal for these areas to be exposed to highly variable and extreme climates,

FIGURE 28.4

World's major watersheds

Note: Watersheds that are situated in key dryland areas are indicated in yellow. Most of these watersheds are transboundary.
Source: World Resources Institute (http://earthtrends.wri.org/images/maps/P1_22_LG.GIF).

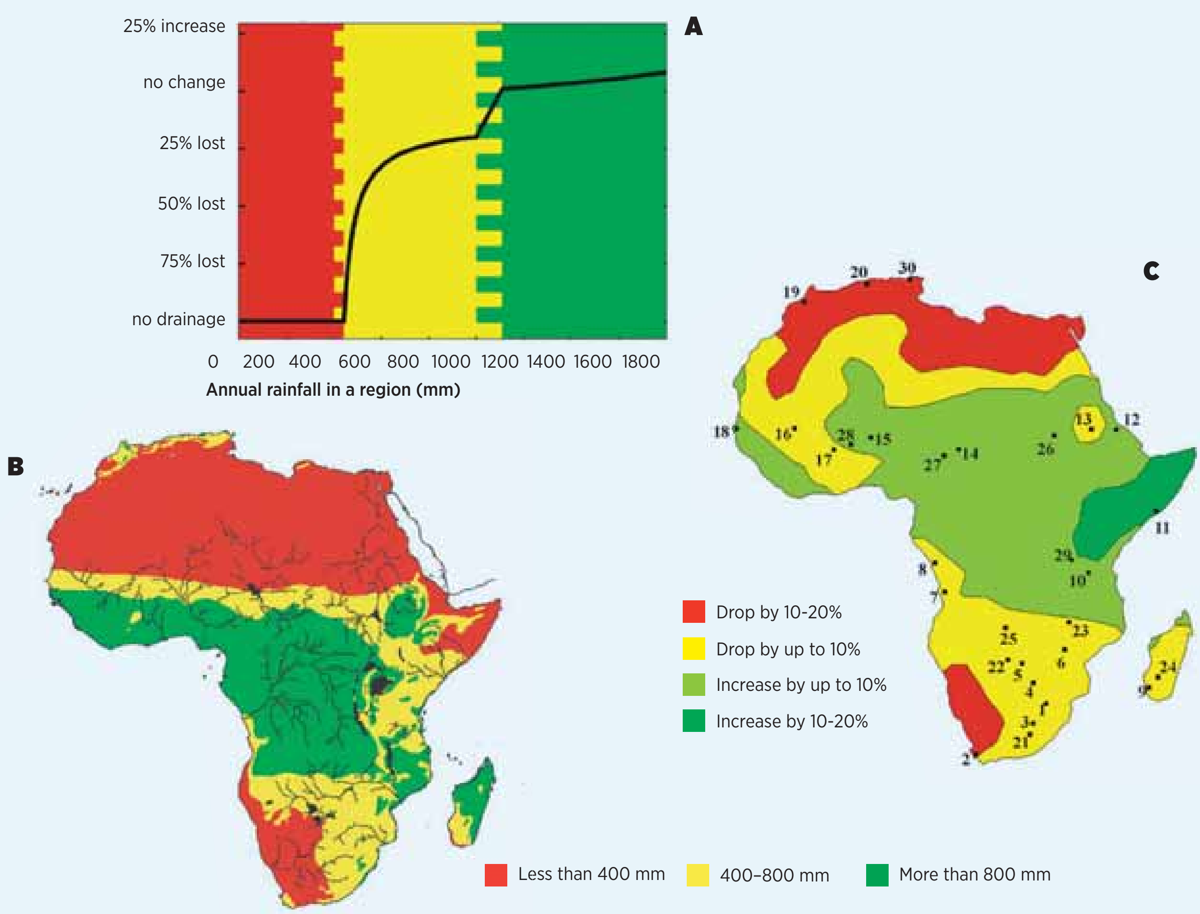
and droughts are a common phenomenon that results in water scarcity being experienced. Such dryland areas are limited in their production potential and have developed specific adaptive characteristics shaped by long-term climatic conditions, geomorphological circumstances and earth history, resulting in strong variations and shifts in the evolvement and geographic position of drylands being observed through the millennia.

Human activities

Many drylands have been characterized by a culture of human activities being in harmony with nature. However, high human-related pressure on natural resources has increasingly led to desertification and land degradation symptoms, which may be irreversible or may lead to the long-term loss of productive potential and increased water scarcity. Poor and inadequate land management practices, that are insensitive to the natural limitations and ecological processes of dryland ecosystems, coupled with frequent and often severe droughts, frequently lead to severe desertification and land degradation and hence water scarcity as the land loses its water retention capacity. This phenomenon also holds true for non-arid systems. Increased demands on the productivity of drylands – related to the development aspirations of local people and governments and increased populations who are dependent on the limited natural resource base – and the application of inefficient land management practices have led to drylands that are less and less inhabitable.

FIGURE 28.5

Projected impacts of climate change on perennial drainage density



Notes: Effects of a 10% reduction in rainfall on perennial drainage density by 2070–2099. (A) Rainfall regimes at the end of the twentieth century; (B) map of Africa showing predicted change in precipitation; and (C) numbers indicate selected locations for which the effect on perennial drainage density has been calculated.
Source: de Wit and Stankiewicz (2006), reproduced with permission from AAAS.

Climate change
Globally predicted climatic changes will pose differing risks and opportunities in different dryland regions of the world. In broad categories, climatic change will lead to either/and/or increases/decreases in temperatures and precipitation, affecting evaporation rates, water availability and tolerance levels of specific livestock, crop plants, and other elements of the natural ecosystems. The occurrence of more extreme weather events – such as prolonged and more severe droughts, unprecedented extreme flooding events in normally arid areas, and seasonal shifts of known weather patterns (for example changes to the onset of rainy seasons and shortening of growing seasons) – pose enormous challenges to ecosystems. Essential ecosystem services are affected by climate change, leading to DLDD. The difficulty of coping and adapting to climatic changes often worsens desertification and land degradation and poses a major management challenge. The impacts of climate change on water – that is, changes in groundwater recharge and runoff in catchment areas – are expected to be significant and lead to both the drying up of aquifers and/or flash floods and flooding in other areas. Major changes are predicted in the dynamics of perennial rivers in Africa (Figure 28.5), where major flooding disasters are already occurring more frequently, while elsewhere river courses are drying up.

28.3.2 Risks and uncertainties: The impact of desertification, land degradation and drought on water resources availability, quality and accessibility
DLDD directly affects and worsens already critical water resources, especially in drylands. Overuse and depletion of limited water resources are already an issue, but the direct effects of DLDD further negatively impact on the resource – bringing with it the risks and uncertainties described below.

Lower recharge of groundwater and changed runoff
Soil compaction and changes in soil, vegetation and soil faunal parameters directly affect the recharge rate of groundwater and water dynamics in ecosystems (FAO, 2002). It is well known that deforestation in catchment areas leads to altered runoff regimes, disturbing the natural water recharge and storage in ecosystems. On a smaller scale, water infiltration rates are disturbed by unsustainable land use practices, which have altered soil faunal associations and the balance of incorporating soil organic matter (SOM) back into soils, negatively affecting soil water holding capacities (Box 28.1).

The degradation of land by physical compaction of soils – for example through trampling by livestock, sealing of soil surfaces by buildings or industrial activities, or movements of tractors – all have negative effects on the percolation of water into the ground. Soil compaction creates more impervious surfaces that do not allow percolation of the water down through the soil into the aquifer. If the infiltration capacity of the soil is reduced or if vegetation has been removed on a large scale then peak flows or floods increase (Calder, 1998).

This reduction in soil infiltration capacity increases surface runoff. Surface runoff causes erosion of the earth's surface, including splash, gully, sheet or stream bed erosion. With increased runoff, water is instead forced directly into streams or storm-water runoff drains, reducing groundwater recharge, thus lowering the water table and making droughts worse,

BOX 28.1

Role of soil fauna in maintaining soil water holding capacities

DLDD often leads to a destruction of healthy soil biological properties, which in turn negatively affects the soil's water holding capacities. Water percolation and holding capacities of soils are essential for allowing rainwater to infiltrate into the ground and eventually contribute to groundwater recharge. The loss of biodiversity in soil fauna, through the occurrences of desertification and land degradation, leads to the disturbance of critical biogeochemical and physical soil processes such as soil water infiltration and holding capacity. Soil fauna improves physical soil properties such as macroporosity, thus increasing soil water infiltration capacity (Leonard and Rajot, 2001; Mando et al., 1999). For example, termites and ants, which dominate dryland soil macrofaunal invertebrates, translocate organic material such as pieces of grass stalks, leaves and wood into the soil, where these materials are broken down by various soil organisms into soil organic matter (SOM). SOM is critical for enhancing the water holding capacity of soils. Soil fauna modify the soil and litter environment playing a key role in SOM transformations and nutrient dynamics at different spatial and temporal scales thus affecting the soil's physical properties, nutrient cycling, water retention capacity and plant growth (Bhadauria and Saxena, 2010). If soil faunal assemblages are disturbed through DLDD-related impacts (e.g. overstocking, inappropriate use of insecticides) the soil's physical and chemical properties will be negatively affected resulting in negative impacts on water balances.

especially for farmers and others who depend on the water wells.

Degradation of water resources and the environment

DLDD can create important impacts on water quality, which in turn may have negative effects on downstream uses of water (FAO, 1993, 2002). These impacts can include changes in sediment load and the concentration of nutrients, salts, metals and agrochemicals; the influx of pathogens; and a change in the temperature regime. Where poor land management practices prevail, increased loads of nitrogen, phosphorus and related nitrate and phosphate concentrations result in severe eutrophication of water sources. Pathogenic bacteria in surface waters will increase as a consequence of riparian grazing or waste influx from livestock production. Pesticides and persistent organic pollutants may find their way into water courses in areas where DLDD effects are high, for example through soil erosion and increased runoff.

Turbidity, sedimentation and siltation

Soil erosion is a major manifestation of desertification and land degradation. Soil is transported by runoff or wind into water sources, such as rivers and the sea, causing the loss of valuable topsoil and adding sediment that can produce turbidity in surface waters. This soil loss and sedimentation, and the effects of turbidity such as limited penetration of sunlight, destroys the natural habitat of fauna and flora in the rivers (FAO, 2002), changing biodiversity patterns and leading to a loss of freshwater fish stocks. In extreme cases of changed climatic conditions combined with poor management of water resources and DLDD, the complete siltation and drying up of entire catchments and river systems has been observed.

Salinity

Salinization of soils and water resources is a major problem related to desertification and land degradation. An increase in salinity of surface and groundwater tends to have detrimental effects on downstream water uses such as irrigation or domestic water supply. Irrigation and drainage activities can lead to increased salinity of surface and groundwater as a consequence of evaporation and the leaching of salts from soils. This is of special concern in arid areas, where subsurface drainage water always has higher salt concentrations and higher sodium absorption rates than supply water for irrigation. Irrigation consequently leads to a surfacing and concentration of salts.

Water scarcity

Water scarcity poses a major threat to drylands. Drylands are water-constrained ecosystems where maintaining the balance between water demand and supply can be very challenging. When abstracting water for human use it is always important to allow for an ecological reserve – to retain sufficient water resources that are needed for maintaining underlying ecosystem services. In the event of water scarcity and the subsequent failure of water scarcity management plans, agriculture, which is often the largest consumer of water, is the most affected, translating into millions of dollars in lost income, particularly in economies that have a strong agriculture base. Simultaneously, with the failure of agricultural production, food security is threatened and hunger and malnutrition become inevitable in poor dryland countries.

28.3.3 Desertification, land degradation and drought hotspots and degradation of water resources in drylands

Geographic hotspots of DLDD are prevalent across the drylands of the world (Figure 28.2). Countries with low GDP and HDIs (Table 28.1) are particularly vulnerable because interventions are often costly. Dryland areas with high populations, or which are connected to high population density areas downstream, are prone to land degradation and the associated negative water impacts. Figure 28.4 displays major watersheds situated in dryland areas. According to White and Nackoney (2003), several of these major watersheds are already facing water scarcity (central and east Asia, southern and eastern Africa, central North America) and it is projected that in the future several of them will be further negatively affected by the impacts of climate change. For example, Figure 28.5 projects climate change induced impacts on drainage in Africa, negatively affecting at least 65% of the continent. Such projections overlay areas of DLDD in Africa, where severe interlinked impacts on ecosystems and ecosystem services, populations and economies can be foreseen.

It must be highlighted that, in addition to its scarcity, naturally available water resources in most drylands are often mismanaged. Exorbitant development expectations in such areas lead to unsustainable exploitation of existing water sources. Inappropriate land uses lead to DLDD and degradation of natural resources including water. Improving water use efficiency is a serious challenge. Seeking alternative water provision (e.g. large-scale desalination of sea water, long-distance transportation of water via canals and pipelines) has also led to an exacerbation of DLDD issues, promoting incompatible land uses such as overstocking of livestock leading to a change in vegetation cover and degradation of soils.

28.4 Potential responses to save the drylands and their populations

Current major drylands challenges include (a) poverty, (b) food crises (food insecurity and famine), (c) drought and water scarcity, (d) climate change, (e) loss of biodiversity, (f) deforestation, (g) energy challenges, and (h) environmentally forced human migration. In light of these challenges, one cannot fail to see that the need to address desertification and land degradation in the drylands is imperative. Indeed, where economic, social, political and geographic assets have become highly virtual, mobile and dynamic, it is easy to lose sight of the human interconnectedness of socio-economic assets such as land and water resources. Water scarcity in the drylands has an inevitable negative impact on sustainable development, hampers local governance and exacerbates social conflicts.

The future productivity and development options of the drylands are dramatically affected by both the low and further diminishing water resources in drylands and the DLDD impacts exacerbating water scarcity and quality. These effects are discernible on the environment, social systems and economies of the drylands. Although expected climate change impacts may improve water balances in some regions, other dryland areas will certainly have to deal with worsening water situations, and all regions will have to be able to manage change through numerous strategic response options to the water challenges. Some of these options are outlined in the following sections.

28.4.1 Strategic approaches

Securing water resources in the drylands requires an integrated approach to the management of the natural environment and associated natural resources, which takes into account all factors influencing decisions on land and water resources use at local, national and regional levels. It requires partnership building between different sectors of governments and societies, international agencies, scientific communities, non-governmental organizations, bilateral agencies, and others to tackle the complexity of securing water resources. In tandem, a number of policies and technological measures and innovations should be employed to mitigate water scarcity in the drylands.

Innovations in water management and technology to cope with water scarcity

Cost of and payment for water

The tradition of having free or heavily subsidized water for livestock, irrigation and domestic use has wrongly created the impression that water is plentiful and of low value. This brings about a need to reduce the excessive demand and improve water use efficiency through promoting efficient water use practices and proper resource use planning and management, and through the proper costing and valuation of this limited resource. Paying for water is an increasingly accepted concept, even in rural communities (see Chapter 23, ‘Valuing water’). Costs usually cover the delivery and supply of water. External costs, such as costs associated with the sustainability of the resource, are often not fully incorporated into existing pricing systems. Opportunity costs, a third category of costs, refers to the fact that we have conflicting water use demands and certain people/industries may lose the opportunity to do something because the limited water has been used in other ways.

Development of new water resources

Innovation in terms of developing and negotiating new water resources is important for the dryland countries. Whilst investments in desalination plants and improved transfers from other areas (e.g. by pipelines) are one avenue, others include improved recycling and improved transboundary management of existing resources. Some impressive examples of technological solutions come from the Middle East, and models of collaboration and application of new technologies are available from elsewhere, for example Germany and other EU-countries.

Desertification, land degradation and drought – investing in sustainable ecosystem services

Valuation of ecosystem services has proven to be a reasonable concept although it is not yet fully embraced by most water providers and users (Box 28.2; see also Chapter 21, ‘Ecosystems’). Placing an adequate value/price on ecosystem services is critical to ensuring long-term sustainable use and management of finite resources such as water (Emerton and Bos, 2004; Smith et al., 2006). In the DLDD context, maintenance of critical ecosystem services such as those provided by watersheds and associated vegetation and soil interactions must be fully considered. Relevant investments to curb the negative effects of DLDD on water resources need to be made and fully incorporated into such valuations. Ecosystem values then need to be translated into water management decision-making. For example, economic valuation (of ecosystem services) is best applied to an incremental change and within a policy context such as DLDD. To date there is mainly access to case study materials that illustrate methods and actual values. Investment in policy-relevant research is needed in most countries to inform decision-making.

BOX 28.2

Approaches to introducing payment for ecosystem services – examples from Kenya

According to Engel et al. (2007), payment for environmental services (PES) is an innovative market-based mechanism. It is based on twin principles that those benefiting from environmental services should pay for their provision and that those who provide environmental services should be compensated for doing so. The Pro-poor Rewards for Environmental Services in Africa initiative supported by the World Bank (www.worldbank.org) with the World Agroforestry Centre (ICRAF) and partners is working with communities and governments on introducing PES approaches including for watershed management and conservation. Various examples of projects in their early stages exist. In Kenya, Nairobi relies on distant forested catchments for its water supplies, like other major cities in Africa. One such catchment is the Sasumua watershed, which supplies 15% of Nairobi's water demand. Land use changes in upstream areas of the Sasumua watershed have led to increased sedimentation and water contamination (Porras et al., 2008). Ensuring proper hydrological functioning of the watershed is of critical importance to the future water supply of Nairobi. Baseline studies have recently been undertaken that will guide decision-making and the establishment of the PES mechanism in the watershed (Vågen, 2007). Learning from experiences in other countries such as Costa Rica and Columbia, which have already established very advanced PES mechanisms for water systems, is essential (Porras et al., 2008).

One PES mechanism that has been tried is the green water credits (GWC) concept. GWC offer a tried and tested means of providing Kenya with food, water and power security. GWC are payments or rewards for water and land management services provided by farmers, which in turn benefit downstream users by providing them with better-quality water and a more reliable supply.

Investing in appropriate innovations, technologies and infrastructure

Enhancing environmental flow and thus curbing the negative impacts of DLDD on water availability is one aspect of new technology and infrastructure development. For example, South Africa introduced the Working for Water programme (http://www.dwaf.gov.za/wfw/), where scientists and field workers use a range of methods to control aquatic invasive alien plants. This programme is one example a technological intervention. Another example is the construction of dams, either for water storage or energy generation. A wide range of innovations are available today that reduce water use and/or loss, as well as improve the soil's moisture balance due to their improved designs. Drylands countries experiencing water scarcity need to invest in water use reduction techniques, technologies and infrastructures. These include household appliances such as sanitation installations that should be researched, developed and preferentially marketed. Incentive measures that promote the development and use of such innovations must be rigorously supported.

Apart from investment in water-use-reduction technologies, investments in innovations that curb DLDD, particularly in drylands, must be made to reduce negative impacts on the water base. Regularly cited examples are the development of agricultural systems, such as improved irrigation systems, and improved water and soil management technologies at the farm level. The appropriate management of water disposal and sanitation is another important issue, which can also lead to efficient use of water through highly advanced recycling technologies.

Investing in water and production system research, management and policy-making capacities and addressing the linkages to desertification, land degradation and drought

Many dryland countries are developing nations where capacity development is a critical issue – as is strongly reflected in the UNCCD ten-year strategy. In addition to the need for technical capacities, which promote advances in technical and technological development, capacities should be developed at all levels to implement and act on water and DLDD-related issues. There is a need to build or strengthen national water and other related institutions with adequate support and decentralizing. There is also a need for local level institutions to act on immediate water management requirements on the ground (Iza and Stein, 2009). Many countries are devolving water management structures and institutions – structures that are charged with managing demand, maintaining infrastructure, and coordinating payment schedules (see chapters 25, 'Water and institutional change: Responding to present and future uncertainty' and 26, 'Developing knowledge and capacity'). These structures should also address land management and DLDD-related water issues. For example, village societies in India often address integrated agendas and more recently have also dealt with climate change risk and possible adaptation measures (Box 28.3). It is clear that similar capacities need to be built in other related sectors and production systems, such as agriculture and forestry. Crop research, for example, needs to shift from conventional agriculture to a more conservation-effective agriculture, such as adopting an eco-agriculture or agro-ecosystems approach.

Irrespective of the measures, it is critical to recognize that outreach and engagement of the local farmers and natural resource managers is imperative for the success of any intervention (see Box 28.3). Adoption pathways for technologies as well as implementation of policies depend on the end user, and sufficient effort must be made to include such users in the design and development of solutions. It is clear that such outreach is resource-intense, however without this extra effort, limited progress can be made.

BOX 28.3

Participatory watershed management: A case from India

A watershed can be defined as a catchment area from which all water drains into a common area, making it a suitable target for technical efforts to manage water and soil resources (Shiferaw et al., 2008). A watershed connects various communities sharing a specific water resource depending on their specific position within the catchment. In the long run this creates interdependency in both the watershed resources and user communities.

Water scarcity and land degradation resulting from overgrazing was already a problem in Sukhomajri village in India in the 1970s. Local villagers, with institutional support, established a village society that was responsible for planning and implementing conservation activities in the village and later in surrounding areas, leading to the rehabilitation and more effective use of the farmland. Participatory decision-making and the establishment of formal governance structures in the village and later in the greater watershed area have been identified as key instruments for success. Evidence and information-based decision-making is promoted and villagers are directly involved in adaptive management. In this village, sustainable land management (SLM) practices were integrated with water management practices from the beginning.

Source: Centre for Science and Environment (1998); Porras and Neves (2006); and Porras et al. (2008).

Water use efficiency

Water use efficiency in drylands should consider rehabilitation of degraded lands and conservation of water catchment areas, including reducing losses by lining channels, avoiding direct evaporation and avoiding runoff and percolation losses due to over-irrigation. Evaporation from the bare soil should be reduced by appropriate practices, such as mulching and applying weed control measures. Enhancement of crop growth by implementing sustainable land management practices is also important, such as choosing suitable and marketable crops, considering optimal timing for planting and harvesting, applying optimal tillage and green manures, and appropriate drainage systems.

Reducing water wastage

A vital contribution to managing water wisely is the reduction of water losses. At all levels of governance it is important that leakages are reduced or prevented. This includes support and know-how for local communities to implement integrated strategies and for using water resources efficiently and maintaining wells, taps and water points in good working conditions. On a larger scale, national water carriers, storage dams and other infrastructure need to be well maintained, and systems that help detect unaccounted-for water losses must be established. Innovative recycling and integrated multiple use systems especially for larger industries need to be designed and implemented.

Sustainable land management practices in the drylands

Poor and unsustainable land management techniques tend to worsen land and water resources degradation. Recent estimates indicate that nearly 2 billion hectares of land worldwide – an area twice the size of China – is already seriously degraded, some of it irreversibly (FAO, 2008). Over-cultivation, overgrazing and deforestation put great strain on water resources by reducing fertile topsoil and vegetation cover, and lead to greater dependence on irrigated cropping. Observed effects include siltation and reduced flow in rivers that feed large lakes such as the Aral Sea and Lake Chad, leading to the alarmingly fast retreat of the shorelines of these natural reservoirs in central Asia and northern Africa, respectively.

It is fundamental therefore to promote soil, water and vegetation conservation and to enhance measures that rehabilitate, conserve and protect the natural environment. Sustainable land management is one of the few options for sustaining livelihoods and generating income without destroying the quality of the land and the water resources which are the basis of production (Figure 28.6).

The essence of a sustainable land management approach finds expression in the coordination of the sectoral planning and management activities concerned with the various aspects of land, land use and water resources (UNEP, 2007). Initiatives for sustainable land management are particularly significant for dryland ecosystems, where the majority of people are still engaged in primary agriculture, livestock production, forestry and fishery, and their livelihood and options for economic development are directly linked to the availability and quality of the land and water resources.

Examples of sustainable land management practices for drought and water scarcity mitigation and adaptation are presented in Box 28.4.

BOX 28.4

Using sustainable land management practices to adapt to and mitigate the effects of drought and water scarcity

Sub-Saharan Africa is predicted to be highly affected by drought and water scarcity in the face of climate change. Existing environmental problems – such as desertification, land degradation, floods and droughts – are expected to worsen with climate change. This will be a challenge to farmers and communities to adjust their production systems. Sustainable land management (SLM) strategies and practices enable farmers and communities to become more resilient to drought and water scarcity by increasing food production, conserving soil and water, enhancing food security, and restoring productive natural resources. Integrated land and water resources management tend to prevent land degradation, restore degraded lands, and reduce the need for further conversion of natural forests and grasslands to agricultural production (Woodfine, 2009), as well as enhancing the soil water retention capacity.

Other SLM practices that are relevant to mitigating drought and water scarcity include: crop diversification/intercropping; conservation tillage and conservation agriculture; organic agriculture; integrated plant nutrient management; and integrated plan and pest management, zero tillage farming, crop rotation, mulching and crop residues utilization and fallowing.

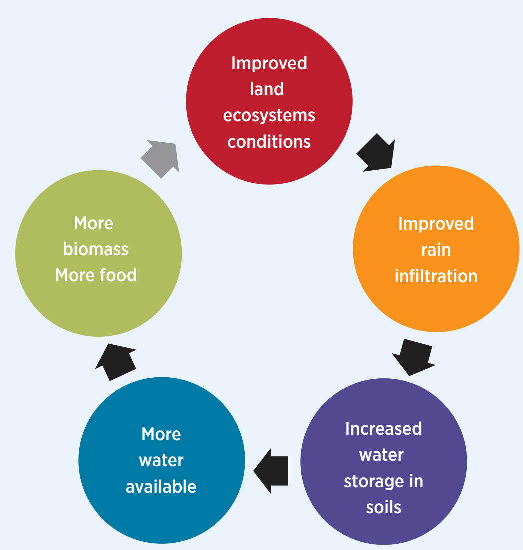
Sustainable land management makes it possible to minimize conflicts and make the most efficient trade-offs, and to link social and economic development with environmental protection and enhancement, thus helping to achieve the objectives of sustainable development.

Prioritizing the use of water in drylands

The careful prioritization of water use is more important in the drylands than in any other ecosystems. Different land uses place different demands on water and other natural resources and ecosystem services. Based on the valuation of these resources, in-country policy decisions for water allocation, provision and pricing have to be made. Examples from Israel and Namibia calculate water use efficiency in terms of economic output per cubic metre of water consumed. It is clear in both countries that irrigated agriculture consumes the majority of water supplied (in Namibia 44%, in Israel 70%), while the economic returns measured in contribution to the gross national product or income generated are extremely low (Heyns et al., 1998). It is

FIGURE 28.6

The sustainable land management virtuous circle of improvement starts with land condition improvement



Source: UNCCD (2010).

notable that Israel is regarded as having one of the most efficient irrigation systems in the world and yet does not reap significant economic returns on water investments.

Policy changes needed in and for dryland countries

A variety of solutions and strategies have been developed to mitigate the impacts of water scarcity. These include empowering of existing institutions cooperating on transboundary river basins with the required authority to address water scarcity impacts, through opening consultations, pooling knowledge and initiating joint action. For years the integrated land and water resources management (ILWRM) principles have been promoted to enhance sustainable management of water resources. Management of the full cycle of water, where groundwater and surface water are linked with land management, has also come into the fold, with decentralization and the full participation of all stakeholders in the water sector considered imperative.

The major goal is to ensure the delivery of enough water to all communities. Therefore, sets of policy tools are needed to help decision-makers design tailored programmes to deal with water scarcity. For example, in countries where demand is driven largely by growth in the agricultural sector in the face of population growth, the most cost-effective policy solutions should be dominated by agricultural measures, both in irrigated and rainfed crop production. In countries where agriculture is expected to account for less water demand however, while household and industry demand account for higher consumption, the most cost-effective policy solutions will include some agricultural policy measures, but also a range of industrial efficiency measures and common household measures.

Water demand management

Water demand management is part of an integrated approach towards the sustainable development and use of water resources. This involves planning and establishing policies for efficient use of water, economic efficiency and environmental sustainability. Managing water demand can reduce water consumption, delay the implementation of additional water supplies and infrastructure, and conserve scarce water resources.

A special dryland debate: Food self-sufficiency versus food security

As food and water needs continue to rise, it is becoming increasingly difficult to supply more water to farmers. The supply of easily accessible freshwater resources is limited both locally and globally. In arid and semi-arid regions, in densely populated countries and in most of the industrialized world, competition for water resources has set in. In major food-producing regions, scarcity of water is spreading as a result of climate change and increased climate variability. In the light of demographic and economic projections, the freshwater resources not yet committed are a strategic asset for development, food security, the health of the aquatic environment and, in some cases, national security (Koohafkan and Steward, 2008).

Many dryland countries still pursue national policies for food self-sufficiency. Developing dryland countries in particular are exposed to great difficulties when it comes to assuring food-security, especially for rural communities threatened by frequent droughts and the impacts of DLDD. Although these communities live largely traditional lifestyles, which are often very well adapted to the prevailing climatic conditions (including nomadic/migratory lifestyles), modern aspirations and sometimes controversial government policies (e.g. forced settlement policies) have left such communities extremely vulnerable. Relevant alternatives and tools for planning are needed to assist with the prioritization and selection of the most appropriate and sustainable water and resource allocations. Under the projected medium and long-term climate change risks for dryland areas around the world, debates on food self-sufficiency or food security are gaining new significance and must be addressed more analytically to avoid entire nations facing aggravated DLDD and eventually famine, deteriorating development potential and increasing poverty.

Global investments in long-term food security in drylands with water scarcity

How to address food security in drylands experiencing water scarcity is a complex issue, and countries are confronted with difficult policy and development options. However as water availability, quality and accessibility are at the heart of local food production potential – and DLDD threats – it becomes imperative to explore and support promising alternatives. Many countries have been advised to promote and develop secondary and tertiary industries, a process that is often a very difficult undertaking in already marginalized and poor countries. While it is difficult enough to build up alternative production industries in developing countries with low human capacities, it is also difficult to secure reliable and equitable international food and commodity trade conditions that are conducive to the requirements of developing nations. Relevant in-country and international responses should be promoted to assist dryland countries in developing long-term food security strategies – at the same time curbing the threats of DLDD and worsening water scarcity conditions.

In tandem, meeting food security targets in the drylands requires the implementation of sustainable agricultural policies from which local populations would benefit most. As current irrigated cropping systems require the greatest share of water in most countries and demand is expected to rise 14% in the next 30 years (UNCCD, 2010), adaptation to this increase is vital and will require variability and flexibility. Changes to land use and cropping patterns are one option for adaptation. Less water-demanding and drought tolerant crops could also be an alternative. No-tillage, which is the practice of leaving residue of the previous season's crops on farmland, can increase water infiltration while reducing evaporation as well as controlling wind and water erosion. The use of other soil fertilization and techniques such as biochar – which simultaneously increases retention of soil moisture associated with carbon sequestration – is also promising.

Switching from annual to permanent or semi-permanent crops could be another option. The advantages of such farming include reducing tillage energy requirements, limited topsoil disturbance and soil erosion prevention. Multi-annual crops also bring the benefits of easy access to water and soil nutrients in deep soil layers. Land use changes should be considered where current agricultural patterns are no longer sustainable in terms of water consumption. Rehabilitation and conversion of marginal agricultural lands into suitable alternatives, such as forests or grassland, can prevent further land degradation and enhance soil water retention capacity and regeneration of the long-term farming potential of the land.

28.4.2 An international framework on land and water

The need to address pressing dryland-specific water issues is urgent. The impact of DLDD on water resources is a major problem and the associated water scarcity in the drylands is of overriding concern, especially in the context of the projected changes in climatic conditions. While a number of expert institutions within the UN are dealing with relevant individual issues (water, land, food security, etc.), there is a pressing need for cooperation and agreements at the international level to address the problems of water scarcity specifically in the drylands. Addressing and coordinating such specific needs through establishing, for example, a water compact for drylands and a related multi-stakeholder dialogue can be useful.

The importance of multi-stakeholder coordination has been recognized within the UN system, both for effective agenda setting and for the coordination of interconnected issues such as effective water and land management for sustainable development.

Several relevant coordination mechanisms have been launched over the past years including UN-Water (www.unwater.org), which was established in 2003. UN-Water strengthens coordination and coherence among UN entities dealing with issues related to all aspects of fresh water and sanitation. Similar to the UN-Water approach, member governments called for a coherent UN system-wide response to the land challenges (UN-Land). A UN Issue Management Group (IMG) on land was established in September 2009 for a period of two years. The IMG proposed options for a coherent UN system-wide contribution to land challenges, including the implementation of the ten year strategic plan of the UNCCD. The IMG also prepared a UN system-wide rapid response report on drylands highlighting the importance of key emerging issues on the global agenda, including climate change, food security and human settlements. In addition, the IMG presented options for follow-up action on all issues that were included as priorities in the outcomes of the 17th session of the UN Commission on Sustainable Development.

Conclusions and recommendations

Water scarcity in the drylands is an increasingly pressing issue that needs to be recognized and addressed on the international agenda. It is exacerbated by the negative impacts of DLDD on the availability, quantity and quality of water resources. As DLDD imperatives take their toll, water crises and scarcity are expected to continue raising ethnic and political tensions, contributing to conflicts where water resources straddle or delineate country borders. In some countries, desertification, land degradation and the associated water scarcity inevitably exacerbates internal migrations, forcing whole villages to flee their farms and move to already overcrowded cities. In the next ten years, 50 million people are at risk of displacement if desertification is not checked. Implementing sustainable land and water management policies would help to overcome the challenge of these increasingly extreme situations.

The impact of water scarcity varies from region to region and from country to country. Countries that have the technical and financial capacity to deal with the effects of water scarcity tend to experience less severe impacts compared to poorer countries. The impacts of water scarcity are also experienced differently depending on whether the scarcity is chronic and long-term, periodic and unpredictable, or regional and local. Clear support mechanisms are required to aid the drylands countries, especially those with already vulnerable economies and development challenges, to address and invest in measures that can alleviate water scarcity in the future. Projected climate change impacts will pose an increasingly serious threat to human beings and development prospects in certain drylands areas. Hotspots in which worsening climatic conditions are expected to affect already vulnerable water resources must be identified and recognized, and urgent support measures must be put into place to address the water crises in such regions.

DLDD impacts on water resources are evident and must be addressed in an integrated manner with ongoing SLM activities. ILWRM is a key to achieving longer-lasting development advancements. The UN system can play a major role in establishing and coordinating multilateral action on the water crises in the drylands. The UNCCD is proposing establishing a 'Water Compact for Drylands', which could be a suitable tool to generate the necessary support for addressing this priority issue – water scarcity.

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CHAPTER 29

Africa

WWAP, in consultation with UN Water/Africa, AMCOW and UNECA

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Authors Albert Wright, Kodwo Andah and Michael Mutale

Acknowledgements Daniel Adom, Roberto Chionne, Christine Young Adjei and Stephen Max Donkor (review)

After decades of poor economic growth, Africa is now experiencing prospects of robust growth. But without innovative and concerted efforts, this will not be able to be sustained.

As a result of natural and man-made challenges, the region's water resources are vastly underdeveloped.

Although sub-Saharan Africa uses barely 5% of its annual renewable freshwater, access to improved water supply in both urban and rural contexts is still the lowest in the world. Lack of sanitation facilities is an even greater challenge to water management in Africa. If MDG Target 7c on drinking water and sanitation is to be achieved, the number of people served must more than double, from 350 million in 2000 to 720 million in 2015.

If governments do not take immediate and radical action, the urban slum population in sub-Saharan African countries is expected to double, from 200 million in 2005, by 2020.

The lack of access to adequate and safe drinking water and food security is not necessarily tied to the availability of water itself but rather to low adaptive capacity, lack of effective development strategies, lack of effective regional and subregional institutional frameworks, and economic and financial constraints.

Transboundary river basin management must find ways of turning potential conflicts into constructive cooperation and 'zero-sum predicaments' – in which one party's gain is another's loss – into win–win situations.

29.1 Regional issues and recent developments

Africa is home to 54 countries. It is a region characterized by transboundary waters, with international river basins covering about 62% of its land area. The region is also endowed with precious industrial and strategic minerals. Yet these resources remain largely under-exploited, leaving Africa as one of the poorest and least developed regions of the world. In fact, economic performance from the mid-1970s to the early 1990s was so poor the period was dubbed the 'lost decade'.

However, in recent years this situation has changed for the better. Analysis by *The Economist* (2011) reveals that in the first decade of the new millennium, leading up to 2010, ten of the fastest growing economies in the world were in Africa. There are also positive indicators showing that far-reaching economic reforms adopted across the region have begun to yield positive results in many of its countries. Negative GDP growths have given way to progressively increasing growth across the region, averaging around the mean figures for developing countries (Figure 29.1). In terms of per capita GDP growth, however, Africa is still far behind all other regions (Figure 29.2).

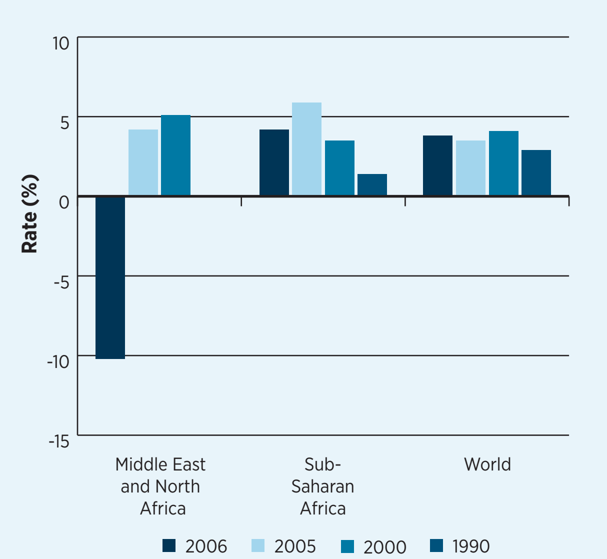
Hence, in its Outlook for Africa document *Africa's Pulse*, the World Bank (2011) reports that, prior to the present worldwide economic crisis, more than a decade of steady growth and debt relief had strengthened African countries' fiscal balances. By 2008, 72% of African countries had positive primary fiscal balances compared with 28% in the early 1990s. Figure 29.3 shows the dynamics of economic growth in the region, and, as depicted in Figure 29.4, among the 15 fastest growing economies of the world, 12 are in Africa. All this shows that in spite of the perturbations in the global economy, as well as drought in the eastern parts of the continent, Africa's growth prospects for the forecast horizon remain robust.

> Africa appears to be endowed with abundant water resources. It has 17 rivers with a total estimated catchment area of over 100,000 km², 160 lakes larger than 27 km². It has vast wetlands and a limited but widespread groundwater resource. In addition, it has a huge potential for energy production through hydropower production... [However], there are natural and man-made challenges that make it difficult to capture the inherent benefits and the full potential in Africa's water resources to support sustainable developments in Africa. (SARPN, 2002, p. 13)

As is the case with other natural resources in the region, the water resources of Africa are vastly underdeveloped; however, it is now generally recognized

FIGURE 29.1

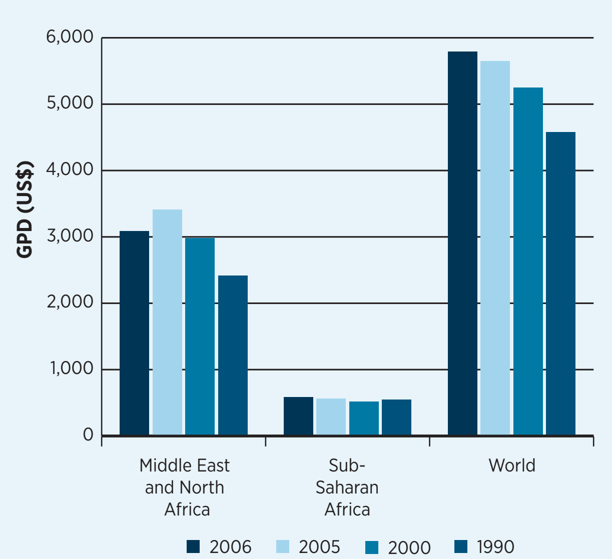
Annual GDP growth rate



Sources: Prepared by K. Andah from data from World Bank (2008) and the EarthTrends database (no longer active) from the World Resources Institute.

FIGURE 29.2

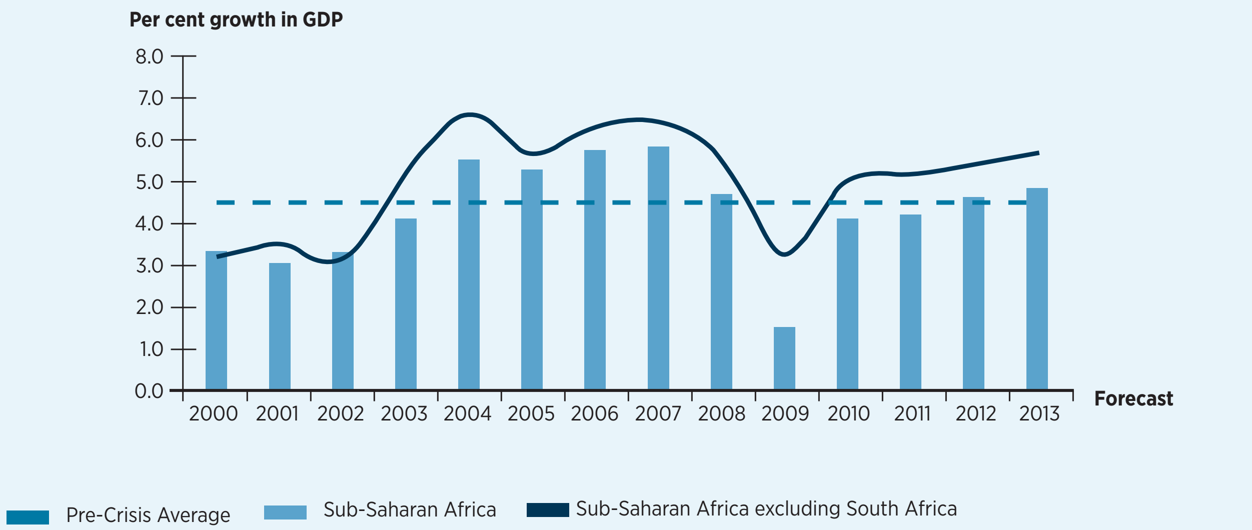
Per capita GDP (constant $US)



Sources: Prepared by K. Andah from data from World Bank (2008) and the EarthTrends database (no longer active) from the World Resources Institute.

FIGURE 29.3

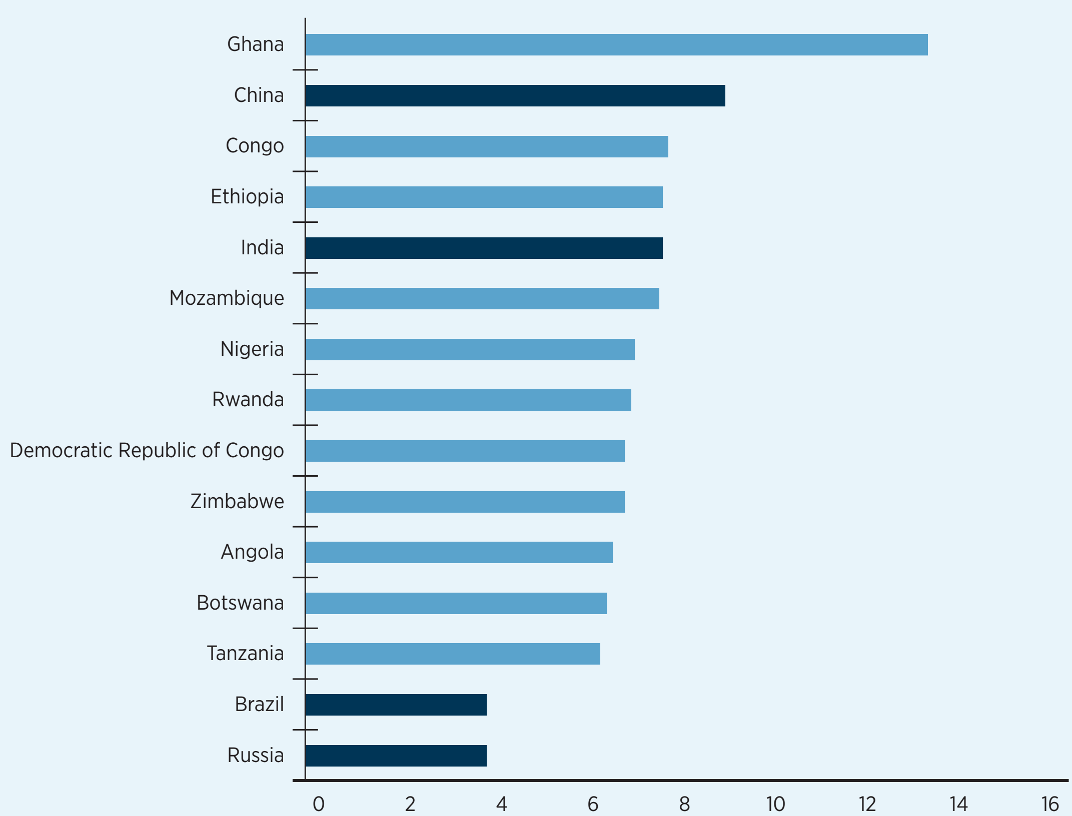
Dynamics of sub-Saharan Africa economic growth



Source: World Bank (2011, fig. 2, p.3).

FIGURE 29.4

Fastest growing economies of sub-Saharan Africa



Source: World Bank (2011, fig, 3, p. 3).

that water has a vital role to play in the development agenda for the region. It is understood that although water can become an instrument for sustainable development, it can also become a constraint, 'capable of wiping away the gains of development either progressively or overnight, as happened in Mozambique in the floods of 2000' (SARPN, 2002, p. 2). Its improper management can result in degradation of productive soils, as has been happening in the Sahel region; or in the loss of valuable ecosystem use, as is occurring in the Lake Chad basin. In addition, unless appropriate approaches are followed, economic and social development could negatively impact on the availability and quality of water resources, thereby limiting their value for future development. There is therefore a concerted effort to address challenges that may hamper the effective development and management of the region's water resources. These efforts are enshrined in the African Water Vision 2025, which was endorsed by the African Union in 2004 and serves as the basis for water development and management by the African Ministers' Council on Water (AMCOW), the African Development Bank (AfDB) and the UN system organized as UN Water/Africa.

This chapter reviews some of the drivers and challenges being encountered in water resources management in the region. It reviews the risks and uncertainties they pose, and presents some of the response measures being followed.

29.2 External drivers

29.2.1 Climate change

> Africa is characterized by extreme climatic zones; from humid equatorial and tropical zones through the semi-arid to the arid North, creating about seven distinct hydro-climatic zones. The distribution of rainfall over Africa therefore exhibits extreme unevenness, both spatially and temporally. (UNECA, 2001, p. 1)

On a continental basis, Africa has a relatively plentiful supply of rainwater: a total of 20,359 km^3 per year or 678 mm per year (FAO, 2005). The variation in precipitation is determined by climate variability, which is in turn driven by the movement of the Inter-Tropical Convergence Zone (ITCZ). Average precipitation is distributed over the continent from the equator towards the northern and southern fringes in a diminishing manner. Risks due to uncertainties inherent in movement of the ITCZ are manifested in high seasonality in rainfall, uncertain timing of the onset and duration of the rainfall season, and frequent hydrometeorological extremes of floods and droughts.

> Rainfall anomalies, both positive and negative, are very frequent over the continent. Most freshwater comes from seasonal rains, which vary with the climatic zone. The greatest rainfall occurs along the equator, especially the area from the Niger Delta to the Congo River Basin. The Sahara Desert has virtually no rain … Southern Africa receive[s] 12% … of the region's rainfall (FAO, 1995). In Western and Central Africa, rainfall is exceptionally variable and unpredictable. (UNECA, 2001, p. 3)

Several factors influence climate variability in the region. The most dominant is the El Niño-Southern Oscillation (ENSO), which is responsible for inter-annual climate variability over eastern and southern Africa. The 1997–1998 ENSO event resulted in extreme weather conditions over eastern Africa; and the 1999–2000 La Niña is suspected to have caused the devastating floods in Mozambique. In the Sahel, ENSO appears to influence annual variation and reduces rainfall. Rainfall variability in the area is also influenced by factors like sea surface temperature (SST) and atmospheric dynamics. Across western Africa, the Atlantic Ocean plays a key role in year-to-year changes in seasonal climatic variations.

The climate in the region also displays high interdecadal variability. It appears that aerosols and dust may also play important roles in modulating climate variability in the region, indicating the presence of extremely dense and deep dust layers in the Sahel/Sudan area (reaching several kilometres) during the main Harmattan or dust season from November to April.

29.2.2 Transboundary water basins

Transboundary water basins cover two-thirds of the total land area in the region. They are 'home to three-quarters of the entire African population and account for a staggering 93% of the total surface water resource base of the continent' (Turton et al., 2006, p. 23). Some of them are shared by as many as ten countries.

> The continent has over 80 major river/lake basins, some of which are among the largest in the world. About 55 of the world's 200 major international rivers are in Africa – a number greater than in any

> other continent. ...The political boundaries of fourteen African countries almost entirely fall within the catchment areas of one or more transboundary river systems. (UNECA, 2006, p. 201)

Ten major river basins are shared by more than four African countries:

> The Nile Basin, for instance, has 10 riparian countries [9 within sub-Saharan Africa]; the Congo has 9, the Niger has 11, and the Zambezi has 9. The Volta has 6 and the Chad has 8. Then there are countries through which several international rivers pass. One extreme case is Guinea, which has 12 such rivers.

> Water interdependency is accentuated by the fact that high percentages of total flows in downstream countries originate from outside their borders. For example, ... in Mauritania and Botswana, the corresponding figures are 95% and 94%, respectively; in the Gambia it is 86% and in the Sudan it is 77%. (Mwanza, 2005, p. 99)

Of great importance is the transboundary Nubian Sandstone Aquifer System beneath the north-eastern Sahara, with a total extension of over 2.2 million km^2. This is shared between four countries: Chad, Egypt, Libya and Sudan. It is the world's biggest repository of fossil water with a volume estimated from 150,000 km^3 to 457,550 km^3. The most important sub-basins are the western Kufra Basin and the eastern Dahkla Basin. Actual withdrawal rates by the main riparian countries have been estimated (Bakhbakhi, 2004) as:

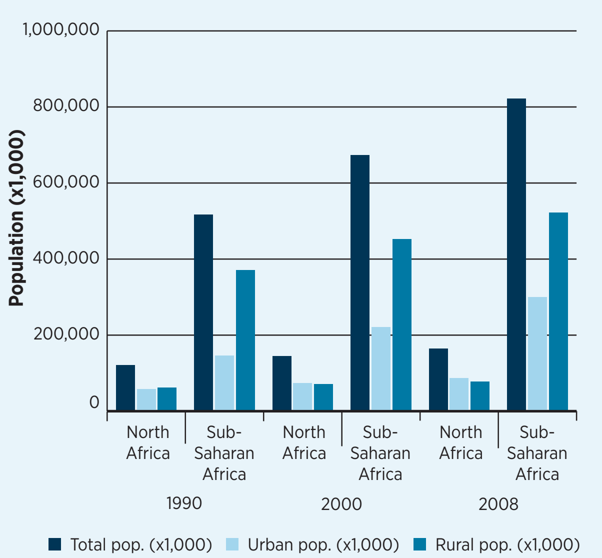
- Egypt: 1,029 mm^3 per year
- Libya: 857 mm^3 per year
- Sudan: 407 mm^3 per year
- Chad: very low rate

29.2.3 Demographic pressures

Pressures emanating from the region's population dynamics, especially rapid rural migration into peri-urban areas, constitute a major challenge to the provision of water and sanitation services, coupled with fast growing urban centres. An estimated 61% of the region's population lives in rural areas, exceeding the world average of 50%, and the average population density is 29 inhabitants per km^2, with very high variations at national and subregional levels. The region's urban population grew at 3.4% between 2005 and 2010, which is 1.1% faster than the rural population growth rate (UNEP, 2010). The urban slum population in African countries is expected to double by 2020, from 200 million in 2005, if governments do

FIGURE 29.5

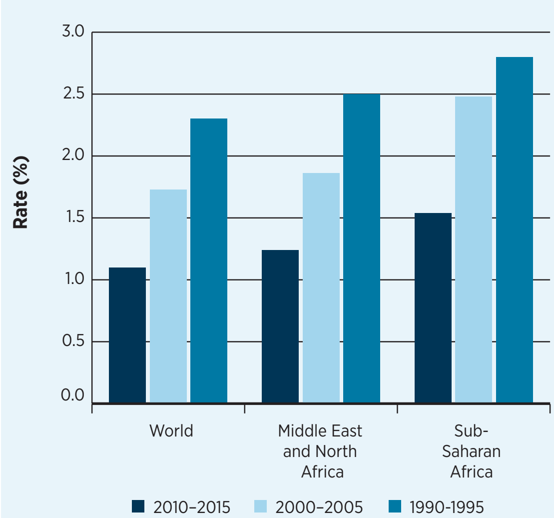
Population distribution in Africa



Sources: Prepared by K. Andah from data from WHO/UNICEF (2010), UNDESA (2007), and the EarthTrends database (no longer active) from the World Resources Institute.

FIGURE 29.6

Comparative population growth rate



Sources: Prepared by K. Andah from data from UNDESA (2007) and the EarthTrends database (no longer active) from the World Resources Institute.

not take immediate and radical action (UN-Habitat, 2005). However, urban slum populations are highly mobile and the numbers are difficult to assess. It is clear, though, that improvements are not keeping pace with the rapid urbanization of slum populations (UN-Habitat, 2010). This rapid and poorly managed growth of urban areas, especially in peri-urban slums, has overwhelmed most municipal water services and constitutes a major challenge to water and sanitation development.

In 2004, Africa's population was estimated at 868 million inhabitants, representing about 14% of the world's population. At the time that total population growth in Africa appeared to be stabilizing (Figure 29.5), the global population growth rate was progressively decreasing, from about 2.8% in 1990–1995 to a projected value of about 2.3% in 2010–2015 (Figure 29.6). This trend, coupled with an increasing trend of economic growth, is likely to contribute to increased prospects for socioeconomic development.

29.3 Principal risks, uncertainties and opportunities

29.3.1 Principal risks

Principal risks in Africa include water scarcity, extreme hydrological events, water quality degradation, and loss of water-related ecosystems.

Water scarcity

Although blessed with an abundant water supply, Africa is the second driest continent in the world, after Australia. It is estimated that around 200 million people in sub-Saharan Africa face serious water shortages, and that by 2025 nearly 230 million will face water scarcity (UNEP, 2008). One of the consequences of this is the prevalence of aridity and drought conditions. About 16% of the population in the region lives in semi-arid areas. In Niger, severe drought resulted in famine in 2005, causing food insecurity for 2.5 million people (WFP, 2005). According to Sharma et al. (1996) eight countries in sub-Saharan Africa were suffering from water stress or water scarcity in 1990, and the World Bank estimates that by 2025, the number of countries experiencing water stress will rise to 18, affecting 600 million people.

There are many contributing factors to the increase in water scarcity in the region. Climate change is a major factor. In the case of the long-term drought that afflicted the Sahel from the 1960s to the 1990s, and caused widespread disasters, sea surface temperature changes were implicated. Other likely contributing factors were under-investment in water storage infrastructure, use of inefficient systems, rapid population growth, expanding urbanization, and increased economic and industrial development. Additional factors include changes in lifestyles, as well as poor and unsustainable land management practices like over-grazing, over-cultivation and deforestation.

In addition to drought and aridity, risks from water scarcity include conflict between sectors and between countries, land and water quality degradation, eutrophication, siltation, salination, alkalinization of soils, reduced flows in rivers and adverse impacts on business.

29.3.2 Uncertainty

The two basic sources of uncertainty in water resources management in Africa are natural variability in physical phenomena and incomplete knowledge.

An example of natural variability is the distribution of rainfall, which exhibits extreme unevenness, both spatially and temporally over the region (see Section 29.2.1). As regards incomplete knowledge, the major cause in the region is two-fold, namely inadequate historical hydrometeorological data, and lack of scientific understanding of the nature of the physical phenomena and processes. Inadequate past investment in hydrometeorological data collection and analysis has led to hydrological, hydraulic and structural uncertainties. This, combined with the lack of scientific understanding of the systems and processes taking place, has resulted in inadequate knowledge about the present and past states of the resource being managed. There is also a lack of knowledge about how the water resource systems will change over time. In effect, it is impossible to adequately model current situations and predict future conditions, or to construct appropriate probabilities necessary to understand the nature of the hazards facing vulnerable groups so that appropriate strategies for addressing the risks they face can be developed. As a result of the complexity of the physical phenomena, both types of uncertainties are expected to remain in the foreseeable future. This highlights a need for water resources management, including integrated water resources management (IWRM) practices, to adapt to reflect these uncertainties.

29.3.3 Opportunities

> Some of these transboundary water basins in the region hold tremendous potential for mutually beneficial uses, including cross-boundary hydropower generation, large-scale multi-country irrigation schemes, inter- and intra-country navigation, joint inland fisheries development, joint water supply projects, environmental protection, wildlife conservation, recreation and eco-tourism development. The Congo River Basin alone holds almost 30% of Africa's total fresh surface water reserves and the world's largest hydropower potential in any one single river basin [an estimated 100,000 MW of power production capacity] ...
>
> The main thrust of the management of transboundary river basins is to find ways of turning potential conflicts into constructive cooperation, and to turn what is often perceived as a zero-sum predicament – in which one party's gain is another's loss – into a win-win situation. (UNECA, 2006, pp. 201–4)

The challenge is to adopt a paradigm shift from water sharing to benefits sharing.

> Integrated development of these transboundary natural resources will not only contribute significantly to the socio-economic development of the Riparian countries sharing these rivers and lakes, they will also promote and enhance sub regional and regional cooperation for economic integration in Africa. However, integrated development of these resources on the basis of win-win principles needs enhanced and concerted cooperation among the Riparian countries sharing these resources. (UNECA, 2006, pp. 202)

The SADC example

As a vivid example, under the auspices of the Southern African Development Community (SADC), falling within the framework of the Revised Protocol on Shared Water Courses in SADC, South Africa has entered into various cooperation agreements on multilateral projects with relevant riparian countries on subregional integration, including the following (Turton et al., 2006):

- The Lesotho Highlands Water Project, comprising dams, tunnels and pipelines for transferring water from rivers in Lesotho, through the divide onto the Vaal river catchment in South Africa
- The Komati River Development Project, consisting currently of the Maguga and Driekoppies Dams for storing water mainly for irrigation development in Swaziland and South Africa
- The Noord-Oewer Irrigation Project, which uses South African infrastructure for a development in Namibia
- The Barberton Water Supply Project, which draws water from the Lomati River in Swaziland for use in South Africa
- The Phongolo Poort Dam where Swaziland has granted South Africa a storage servitude
- The Gaberone Water Supply Project, which transfers water from South Africa to the capital of Botswana

The most pressing challenge is the lack of complete, reliable and consistent data about the transboundary water resources, especially groundwater; followed by weak institutional frameworks. Thus, there is the potential for conflicts over these waters. Nevertheless, there are also over 90 international water agreements to help manage shared water basins on the African continent (UNEP, 2010).

Inter-basin water transfer schemes

The Lesotho Highlands Water Project (LHWP), listed above, is an example of an inter-basin water-transfer scheme. The Congo Cross-Border Water Pipeline Project (CWPP) is another such example. As envisaged, the latter project will involve diverting water from one of the river's southern tributaries by pumping it over the Angolan highlands to boost the flow of a tributary of the Kavango River. The CWPP is expected to be the biggest water project in sub-Saharan Africa. It is estimated to cost US$6 billion and will generate thousands of jobs for local economies in Angola, Botswana, Central African Republic, the Democratic Republic of the Congo (DRC), Namibia and the Sudan. It will also generate huge business opportunities such as electricity and communications supplies resulting from the fibre optics that will be positioned along the pipelines.

> Namibia sees the water from Congo as an ideal opportunity to have 'irrigation schemes in the Namib Desert, modelled on similar projects undertaken by Sahara desert countries'. To do that, however, Namibia will pump the water from the Kavango River (250 km) to deliver it to the capital, Windhoek. Botswana, on the other hand, intends to pump the water from the Kavango Delta (300 km) to the nearest agricultural area, or a further 700 km to its capital, Gaborone. (Ngurare, 2001; Tennyson, n.d.)

29.4 Geographical hotspots

29.4.1 The Sahel

One of the hotspots in Africa is the Sahel. The term refers both to an eco-climatic zone and to a geopolitical entity. The eco-climatic zone refers to the semi-arid transition region between the Sahara desert and the wetter regions of equatorial Africa. It extends from the Atlantic to the Indian Ocean, and it is characterized by dryness, intense heat and sporadic irregular rainfall, as well as periodic flooding and prolonged droughts that are often accompanied by widespread famine and large-scale deaths as well as the displacement of people and livestock.

Rainfall records, archaeological and other forms of evidence suggest that drought and floods, as well as consequent famines and other forms of widespread devastation that are characteristic of the Sahel in our time, are not a recent phenomenon. On the contrary, they have been a recurring feature in the region from time immemorial; what is more, they seem to be recurring with increasing intensity and frequency.

A major drought occurred in the Sahel from June to August 2010. There was also a major drought during the early 1970s, which caught the world unprepared and resulted in disasters of major proportions and resulted in costly international interventions. The nature of this experience raised questions about how best to coordinate the multitude of assistance efforts by donors and recipients. It also raised questions about the optimal balance between relief, recovery and development.

Consideration of these questions led to the establishment of a new organization in 1973 by heads of state and governments of countries in West Africa that have parts of their territories falling within the Sahel region. This organization is known as the Permanent Inter-State Committee for Drought Control in the Sahel (CILSS). The part of the broader eco-climatic Sahel zone that falls within the territorial boundaries of member states of the CILSS is what constitutes the geopolitical 'Sahel' region of West Africa.

There are nine Member States in the CILSS of which four are coastal countries (The Gambia, Guinea Bissau, Mauritania and Senegal), four are landlocked countries (Burkina Faso, Chad, Mali and Niger), and one is an island state (Cape Verde).

There are approximately 58 million people in the CILSS countries, which cover an area of 5.7 million km^2. In addition to having similar climatic conditions – the Sahel climate – the people of these countries:

> have a lot in common in terms of cultures and livelihood systems. These livelihood systems include agriculture, livestock herding, fishing, short and long-distance trading, and a variety of urban occupations. Dryland crops such as millet, sorghum and cowpeas constitute the staple foods of the populations while groundnut and cotton are the major cash crops. Farming in this region is almost entirely reliant on three to four months of summer rainfall, except along the banks of the major rivers, lakes, and other seasonal water courses, where some irrigation activities are undertaken. Livestock herding is a very important aspect of life in the region, and constitutes the major source of income in some areas. (UNEP, 2006, p. 2)

The mandate of CILSS is to invest in research in food security and in the fight against the effects of drought and desertification. Recognizing the crucial role water plays in its mandate, the members of CILLS have decided to form a complementary global coalition on water to address specific problems at a local level.

29.4.2 Lake Chad

Lake Chad is the fourth largest lake in Africa, after lakes Victoria, Tangayika and Nyasa. It is a very shallow freshwater lake, averaging about 1.5 m deep even in normal years. Its four riparian countries are Cameroon, Chad, Niger and Nigeria, who collectively comprise the original members of the Lake Chad Basin Commission (LCBC). The Central African Republic (CAR) became a member in 1994, Libya joined in 2008, and Sudan and the Republic of Congo were accepted as observer countries. The basin extends over an area of 2,397,423 km^2 distributed over eight countries as follows: Chad (46.3% of the basin), Niger (28%), CAR (9.1%), Nigeria (7.5%), Algeria (3.7%), Sudan (3.4%), Cameroon (1.9%) and Libya (0.1%).

The lake, first surveyed in 1823, is believed to be a remnant of a former inland sea that has grown and shrunk with changes in climate over the past 13,000 years. In 1964, when the LCBC was established, the lake covered an area of 25,000 km^2. Today, it covers an area of less than 1000 km^2 during the annual lowest water levels in the region.

The shrinkage has been attributed to many causes such as overgrazing in the area surrounding the lake, which triggers a process of desertification and the decline of vegetation. Some have placed the blame on human water use such as irrigation; others highlight climate change as a key factor.

The shrinkage is also reported to have given rise to disputes between countries over rights to the remaining water. Violence is also emerging between farmers and herders over the use of water.

> [The lake is] fringed by a zone of swampy vegetation dominated by reeds (*Phragmites spp.*), papyrus (*Cyperus papyrus*) and cattail (*Typha australis*) ... There are many small islands formed by the invasion of moving sand dunes near the northeastern coast; some of them are inhabited or utilized as bases for fishing. Besides the products of agriculture, livestock grazing and fishery, the drainage basin of L. Chad is known for its yield of natural soda, an activity that contributes to keeping the lake water fresh. (ILEC, n.d.)

The lake is home to many flora and fauna including over 44 species of algae, and has large areas of swamp and reed beds covered with *Yaere* grassland of *Echinoclora pyramidalis*, *Vetiveria nigritana*, *Oryza longistminata* and *Hyparrhenia rufa* varieties. Its floating islands host a wide variety of wildlife and large communities of migratory and near endemic birds. It is feared that the shrinking of the lake is threatening nesting sites of the Black Crowned Crane (*Bolearica pavonia pavonina*). The lake is also a good source of fish.

Environmental problems

A transboundary diagnostic analysis conducted in 1989 and 2007 by LCBC identified the following seven regional environmental problems (LCBC, 2008):

- Variability of the hydrological regime and availability of freshwater
- Water pollution
- Low variability of biological resources
- Loss of biodiversity
- Destruction and modification of ecosystems
- Sedimentation of rivers and water courses
- Invading species

They were all determined to be products of the combined effects of global climate change and the use of unsustainable practices and resources by the ever-growing basin populations.

Saving the lake and its basin

The LCBC has launched a programme to save the lake. A key feature of this effort is the Inter-Basin-Water Transfer Project (IBWT). This entails the transfer of water from the Congo/Oubangui Rivers into Lake Chad. Member States of the LCBC have already contributed the US$6.07 needed for the project's feasibility study. A complementary effort includes the following:

- The 2008 adoption by the LCBC Council of Ministers of a Strategic Action Plan developed within the framework of a GEF project. The aim of this Action Plan is to reverse the general ecosystem degradation trends in the area.
- The development of national action plans to meet the priorities of the national portions of the lake.

The proposed inter-basin water transfer project is envisaged as the solution to the problems of underdevelopment, food insecurity and poverty in the West and Central African subregion.

29.4.3 The Horn of Africa: Macroeconomic effects of drought

In addition to the turmoil in the global economy, parts of Africa are facing specific challenges, the most severe of which is the drought in the Horn of Africa – the worst in over 50 years. The most affected economy is Somalia, but parts of Ethiopia, Eritrea, Kenya and Tanzania are also suffering from poor rains and dry weather conditions. An estimated 13.3 million people are in need of humanitarian assistance across the Horn. With agriculture accounting for about 20% to 40% of GDP in most African countries, and with about 93% dependent on good rains, the impact of poor rains on GDP growth in sub-Saharan African economies can be significant.

Initial estimates suggest that in the average sub-Saharan African economy, every percentage decline in growth in the agricultural sector cuts GDP growth by 0.26 percentage points. However, the decline in GDP will differ by country, depending on the size of the agricultural sector in the country's economy and the strength of the agricultural sector's linkages with the rest of the economy. First quarter 2011 GDP figures for Kenya already show that growth in the agriculture sector slowed down to 2.2% compared to 5.7% over the same quarter in 2010. Coffee delivery fell by some 28%

in the first quarter of 2011 in Kenya and, for the first half of 2011, tea production fell by 16% (year-on-year) on account of the unseasonal hot and dry weather conditions and poorly distributed rainfall in tea-growing areas.

A simulated 10% reduction in crop and livestock production in the pastoralist areas in Ethiopia – the areas most affected by the current drought – shows agricultural growth declining by 0.6 percentage points and industry and services sectors by about 0.2 percentage points (for 2010–2011). The overall effect would be to dampen GDP growth by 0.4 percentage points. Households directly impacted by drought-related production shocks are likely to be severely affected as they lose income and livelihoods. To the extent that these shocks are reflected in prices at the local and national level, net consumers of food in both rural and urban areas lose. Persistence of drought or worsening of the severity of the drought would have more adverse effects. For example, a shock simulating three years of drought (i.e. through 2012–2013) would shave 0.3 percentage points off GDP growth in 2012 and 2013. Poor rains would reduce hydroelectric power generation in an environment where lack of adequate power supply is already a binding constraint on economic activity. Tanzania has carried out extensive power rationing in 2011. Some 90% of large firms in the country have their own generators which, being much more expensive, significantly reduce the profit margins of firms. In Tanzania, growth forecasts have already been lowered by some 0.3% on account of the lower rains, power outages and higher inflation rates.

There has also been some power rationing in Kenya. The Kenya Manufacturers Association estimates that generator power costs alone could account for some 40% of overall costs. The estimated impact of the drought and high food and fuel prices, combined with below normal rainfall, is a 1 percentage point reduction in GDP growth in Kenya. The GDP impact of the drought does not adequately capture the effects on households. In general, droughts affect poorer households disproportionately. For instance, in Kenya where some 3.8 million people are estimated to have been affected, the poverty head count in the drought-affected areas averages 70% compared with a national poverty rate of 47%. Similarly, in Ethiopia the majority of the 4.8 million people affected by the drought live below the poverty line. In both countries, cereal prices have risen sharply, significantly reducing the purchasing power of poor households, who spend 60–70% of their incomes on food (World Bank, 2011).

29.5 Response measures

Using the Africa Water Vision 2025 as the regional policy framework, a number of initiatives have been undertaken since 2000 to respond to these regional challenges. They include initiatives at regional level (by such organizations as the African Union, the UN Economic Commission for Africa, AfDB, UN Water/Africa, AMCOW, the Africa Water Task Force, the New Partnership for Africa's Development [NEPAD] and the Africa Water Facility); initiatives at basin level (by various water basin authorities) and actions at country level. Other responses include collaborations between regional and international water resources agencies like the Global Water Partnership (GWP)/AMCOW programme to support climate change adaptation in Africa region. In addition, a number of special and regular meetings on water have been introduced. These include the annual Africa Water Week series, AfricaSan meetings, and the Sharm el-Sheikh and Sirte Summits of the African Union, dedicated to discussion of water and agriculture, respectively.

29.5.1 Concerted African response to regional and international commitments

Political and institutional perspectives increasingly acknowledge that regional and subregional concerted efforts can go a long way to ensure that African countries can face the challenging task of mobilizing their water resources for sustainable development in the face of climate variability and change and other uncertainties. It is therefore important to pool all human and institutional resources at local, national, subregional and continental scales to tackle the common challenges by improving:

- Understanding and quantitative knowledge of the various sources of uncertainty
- The way in which this is communicated to water resource managers and other stakeholders
- The way in which uncertainty is incorporated into water resource management decision-making (Hughes, 2008)

The challenges include the need for early warning systems for the prediction of:

- Onset and duration of rainfall seasons
- Intra seasonal dry spells
- Rainfall anomalies based on inter-hemispherical teleconnections
- Lead time of impacts of El Niño and La Niña

African Union initiatives, AMCOW, the African Water Facility and the increasing role of the AfDB in water resources development and management, with special reference to the rural water and sanitation sector, all testify to ongoing high commitments to water resources development and management. The meetings of the 2nd Extraordinary Session of Heads of State and Governments of the African Union, in Sirte, Libya in 2004 dedicated to agriculture, and the African Union Summit of Heads of State on Water and Sanitation held at Sharm el-Sheikh, Egypt in 2008, in particular, reflect political support at the highest level. The annual Africa Water Week series, held under the auspices of AMCOW and launched in 2007, have added further impetus to the platform for information sharing and awareness on water resources development and management. There is now an urgent need for wider international cooperation to augment regional and subregional efforts. This can be through collaborative efforts such as the EU-Africa Strategic Initiative and others to be developed with other development partners, such as the growing relationships with developing Asian partners, in particular Japan.

These continental and subregional institutional frameworks are necessary for 'strengthening specialized institutional capacities in order to provide useful and reliable data-information-knowledge and services in support of more effective development policies, economic plans, socio-economic activities and investments across the African continent' (UNECA, 2010, p. 2), which take into account the uncertainties in climate change. For example:

> African climate institutions like the African Centre for Meteorological Applications for Development (ACMAD), the IGAD Climate Prediction and Applications Centre (ICPAC), the SADC Drought Monitoring Centre (SADC-DMC) have worked on the CRM [Climate Risk Management] approach in conjunction with the International Research Institute for Climate and Society (IRI) and are building capacities for its smooth integration within sectoral decision-making processes, such as agricultural production, food security, water resource management, health protection and disaster risk management. (UNECA, 2010, p. 3)

They can also facilitate the harmonization of legal frameworks at the regional level for protecting shared water resources and for making their use sustainable through a benefit-sharing paradigm. Feasible arrangements can also be made for inter-basin water transfer schemes that involve saving dying water ecosystems such as Lake Chad, and initiating transfers from water-rich basins to drier zones like the Sahel. Many such projects are being studied across the continent (UN Water/Africa, 2007).

29.5.2 Implementation of targets under the African Water Vision and the MDGs

During 1999–2000, the Organisation of African Unity (OAU) (now the African Union), together with the United Nations Economic Commission for Africa (UNECA), GWP branches in Africa and the AfDB mobilized human and material resources for the drafting and adoption of the African Water Vision 2025 along with its Framework for Action, and towards Africa's full participation in the 2nd World Water Forum in The Hague in 2000. Financed by the secretariat of the 2nd World Water Forum, the final document was published by UNECA. Implementation of the provisions of the Vision include: the Accra conference on Sustainable Development in 2002, the first Pan African Water Conference in 2003 (Box 29.1), the development of the Africa Water Facility in 2004, and the publication in 2006 of the first edition of the *African Water Development Report* (Box 29.2).

The Accra Conference on Sustainable Development

The first, most significant activity to flow from the Africa Water Vision was the Accra Conference on Water and Sustainable Development, held in April 2002. The conference was organized by the Africa Water Task Force (AWTF) with financial support from the Government of the Netherlands. Its success was followed by the organization of the Water Dome event by the AWTF during the World Conference on Sustainable Development, held in Johannesburg later in 2002. The Water Dome enabled all water-related activities to be conducted at a single venue during the conference.

African Water Facility

The African Water Facility (AWF) is an initiative developed by AWTF, and developed under the leadership of AMCOW and AfDB. It is hosted by AfDB, at the request of AMCOW, and is designed to mobilize resources to finance water resources development activities in Africa within the framework of building African capacity for effective water resources project development, preparation and implementation.

Within this context it has been estimated 'that on aggregate, US$20 billion per year will be required to achieve the targets of the African Water Vision 2025' (NEPAD, 2006). Out of this amount, it is estimated that about US$10 billion is required to meet urgent water needs. The AWF therefore focuses its operational support on the attainment of the following main strategic objectives:

- Strengthen water governance
- Mobilize and apply resources to meet urgent water and sanitation needs
- Strengthen the financial base
- Improve water knowledge

Since it became operational in 2006, the AWF has approved 66 projects at a total investment of €79 million.

The African Water Information Clearing House (AWICH)

UNECA has been entrusted by UN Water/Africa with setting up an information clearing house for water-related issues in Africa. A technical group was created to discuss in detail the modalities and technicalities of the clearing house. The African Water Information Clearing House was finally established in 2005 as part of the UNECA website, and covers the following water and environmental components:

- Rainfall and climatic data
- Environment
- Rivers
- Lakes
- Groundwater
- Seas/oceans
- Water quality

BOX 29.1

The Pan African Water Conference

The first Pan African Implementation and Partnership Conference on Water was convened by AMCOW, UN-Water/Africa and the AfDB and was held at the United Nations Conference Centre in Addis Ababa from 8–13 December 2003. The second was held in November 2009 at Addis Ababa.

'The [first] Conference attracted more than 1400 delegates and 45 ministers in charge of water, environment and housing. The participants included national delegates, key stakeholders, intergovernmental organizations, co-operation development partners and non-governmental organizations (NGOs)' (UNECA, 2006, p. 293). The Conference confirmed the determination of African countries in 'confronting issues of integrated water resources management (IWRM) and in meeting the targets of the Millennium Development Goals (MDGs), both at national and subregional levels, and also through partnerships at the international level, by placing water and sanitation at the centre of their strategies for socio-economic development. … The Conference provided a platform for African countries, the international community and UN agencies to reaffirm their commitment to solving Africa's water crisis and to collectively implement the actions envisaged in the African Water Vision 2025, the Water Agenda of the New Partnership for Africa's Development (NEPAD), the World Summit on Sustainable Development (WSSD) targets and the MDGs on water.… The thematic sessions were dedicated to the challenge areas, including: water, sanitation and human settlements; water and food security; protecting ecosystems and livelihoods; water and climate; financing water infrastructure; integrated water resources management (IWRM); water allocation; water wisdom; and water governance. Each session came out with recommendations, which were discussed at a joint ministerial and stakeholders plenary sessions. One of the main outcomes of the Conference was the presentation and adoption of subregional project portfolios to the ministerial segment. These projects have been prepared through national and subregional consultations and meetings, addressing the implication of the outcomes of the WSSD on regional water initiatives and setting up a concrete agenda in implementing the targets of the African Water Vision and the MDGs, with special emphasis on water supply and sanitation and the strategic application of IWRM.' (UNECA, 2006, pp. 293–4)

BOX 29.2

The African Water Development Report (AWDR)

Due to the particular problems of water resources development and management in Africa, the Inter-Agency Group on Water in Africa (now referred to as UN Water/Africa), decided in April 2001 in Niamey to develop an *African Water Development Report* (AWDR). It was conceived along the framework of the *World Water Development Report* (WWDR), and is intended to serve as an input to the preparation of the WWDRs. The first edition was published in 2006 and launched at the 4th World Water Forum in Mexico under the aegis of AMCOW. The aim of the AWDR is to afford African countries and other stakeholders the necessary tools and skills to monitor the goals and targets of the African Water Vision. The World Water Assessment Programme (WWAP), UN Water/Africa and AMCOW initiated contact in 2011 to revitalize this report as a part of a broader monitoring and assessment effort.

UN Water/Africa

In 1992, the United Nations (UN) family organizations operating in the water and environmental sectors in Africa decided to pool resources together under the name Inter Agency Group on Water (IGWA), with the objective of placing Africa at the forefront of international water concerns. The Secretariat is provided by UNECA in Addis Ababa, Ethiopia. Other strategic partners do participate in meetings of UN Water/Africa, and take part in some of its initiatives. These include: AMCOW, the NEPAD Secretariat, inter-governmental bodies such as subregional economic groupings (ECOWAS, IGAD, SADC, etc.), and reputable research institutions, centres and networks.

The principal objective of UN Water/Africa is to contribute to the UN system-wide response to the challenges and opportunities connected with pursuing the MDGs, and participation in the World Summit on Sustainable Development (WSSD) and other major inter-governmental conferences and summits through technical support to the African Union. Specifically, UN Water/Africa seeks to facilitate:

> (i) The adoption of effective national and regional policies and institutional frameworks based on the principle of integrated water resources management (IWRM); (ii) the establishment of collaborative framework on agreements to facilitate the management and development of shared water resources; (iii) capacity building; and the urgent need for improved water wisdom. (NEPAD, 2006, p. 4)

Conclusion

Africa has made significant progress in mobilizing its vast water resources potential. The nature of these resources is influenced by natural and human external drivers that are complex and characterized by inherent uncertainties. The uncertainties arise from both natural variability and lack of knowledge. Good progress has been made in resolving the current uncertainties. New ones are likely to emerge so coping strategies should

BOX 29.3

Financing water: The role of AfDB

The African Development Bank has placed high priority on the water sector as a way of assisting Regional Member Countries (RMCs) to achieve the objectives of poverty reduction and economic growth because of the unique potential of this sector to contribute to achieving the other MDGs on poverty, health, education and gender. The Bank's portfolio of interventions in the water and sanitation sector spans drinking water supply, water resources management, sanitation and hygiene, capacity building and policy reform among others. The Bank is currently financing more than 50 active projects in 29 countries amounting to about US$2 billion.

The Bank aims at significantly increasing its interventions in rural water supply and sanitation while continuing to support urban and peri-urban water supply and sanitation, and promoting integrated management of water resources. In summary, the strategy seeks to:

- Increase water supply and sanitation financing
- Focus primarily on poorest 65% of population living in rural areas
- Provide some support for peri-urban areas, small and medium towns; and specifically for urban sanitation
- Promote transboundary water resources management
- Support the enabling environment to attract more resources

Moreover, the AfDB is also hosting a number of complementary initiatives which together enhance the effectiveness of the Bank's work and provides vital resources for scaling up and for promoting innovation and supporting knowledge management activities. The four main initiatives underpinning the Bank strategy in the water sector are the:

- Rural Water Supply and Sanitation Initiative (RWSSI)
- African Water Facility (AWF)
- NEPAD Water and Sanitation Programme
- Multi-donor Water Partnership Programme (MDWPP)

Source: Reproduced from AfDB (2011).

be flexible and adaptive in design, and approaches need to be modified to benefit from adaptive strategies. At present much action is taking place to address the problems in the water resources management area and in meeting the urgent needs defined in the African Water Vision 2025. To be fruitful, coping strategies should emphasize the importance of addressing knowledge gaps but most importantly the mobilization of sustainable financing to achieve the target of the African Water Vision 2025.

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CHAPTER 30

Europe and North America

UNECE

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Specific water quality and quantity problems arise from pressures placed on water resources by agriculture, manufacturing industries, and sewerage and wastewaters. Climate change and economic development aggravate these pressures. Distinct subregional water problems (e.g. in Central Asia, Western Europe and North America) need tailor-made solutions. Although many issues are yet to be solved, over the last two decades the status of water resources has been improved and integrated water resources management plans have been developed at local, national and transboundary levels.

The region's surface waters and groundwaters contain pollutants, such as nutrients, metals, pesticides, microbes, industrial chemicals and pharmaceutical products. These have adverse effects on freshwater ecosystems. Prevention, control and reduction of water pollution are of utmost priority. Pollution sources are extremely diverse and vary considerably over river basins. Agriculture and urban sources (e.g. industries, urban wastewaters) contribute most of the freshwater pollution.

Climate change is projected to increase the risks of floods and droughts in many areas of the region. Costly water infrastructures designed to serve for decades in stationary climatic conditions are vulnerable to climate change. Concern over water scarcity is also increasing. Citizens and economic sectors are directly affected by abstraction pressures to satisfy urban needs and needs for irrigated agriculture, and especially in arid and semi-arid areas by diminishing water availability due to climate change.

Re-naturalization of watercourses is a challenge. Past structural measures (e.g. building dams and reservoirs for hydropower generation and irrigational water supply, constructing dykes, straightening waterways and enforcing river banks) have caused significant hydro-morphological changes in river basins in Europe and North America.

Insufficient wastewater treatment and its adverse effects on sources of drinking water and recreational waters are further priorities for action. The health impact of floods and heat waves add to the burden of water-related diseases.

Due the large numbers of transboundary rivers, lakes and groundwaters in the region, there is an understanding that transboundary cooperation for their management is necessary. This has led to strengthened bilateral and multilateral cooperation on shared waters, supported by bilateral and multilateral agreements, in many cases underpinned by UNECE Water Convention.

National and international response measures have been agreed upon, including European Union (EU) environmental legislation and United Nations Economic Commission for Europe (UNECE) conventions and protocols, supplemented by recommendations and guidelines for action. EU assistance programmes and bilateral assistance programmes for countries in Eastern Europe, the Caucasus and Central Asia are important for putting in place legal and other response measures, and contribute to strengthening water management.

30.1 Introduction

More than 1.2 billion people live in the 56 countries of the UNECE region (Table 30.1).[1] Western and Central Europe is one of the most densely populated areas of the world, with an average of nearly 110 people per km^2. This is in contrast to the relatively small populations in other parts of the world, where the average density is below 20 people per km^2. Between 1960 and 2000, Central Asia (more than 120% population increase) and the Caucasus (60% increase) have experienced considerably higher growth rates than other countries. For most countries in Western and Central Europe and in North America, there is a trend towards stable or even declining populations.

Migration of people has been increasing since the 1990s, including migration along gradients of political stability or economic prospects, in-country migration from rural to urban areas and seasonal migration of workers and retirees. These are among the reasons for increased abstraction pressure to satisfy water needs in major Western cities. Migration along gradients of economic prospects also gives rise to a mostly unconsidered effect on data about domestic water consumption and sanitation figures: the water statistics in some countries is based on the number of people officially registered to apartments and not the number of people actually living there – as in Armenia, Georgia, Kyrgyzstan and the Republic of Moldova, many residents of which work for most of their time abroad.

Economic development is also highly diverse in the region. Some of the countries are among the richest in the world, while others, particularly those whose

TABLE 30.1

Grouping of the 56 United Nations Economic Commission for Europe (UNECE) Member States

Group	Subgroup	Countries
EU countries		Austria, Belgium, Denmark, Finland, France, Germany, Greece, Ireland, Italy, Luxembourg, Netherlands, Portugal, Spain, Sweden, United Kingdom, Bulgaria, Cyprus, Czech Republic, Estonia, Hungary, Latvia, Lithuania, Malta, Poland, Romania, Slovakia, Slovenia
Western Europe		Andorra, Austria, Belgium, Denmark, Finland, France, Germany, Greece, Iceland, Ireland, Italy, Liechtenstein, Luxembourg, Monaco, Netherlands, Norway, Portugal, San Marino, Spain, Sweden, Switzerland, United Kingdom
	EU-15 countries	Austria, Belgium, Denmark, Finland, France, Germany, Greece, Ireland, Italy, Luxembourg, Netherlands, Portugal, Spain, Sweden, United Kingdom
Central and Eastern Europe		Albania, Bosnia and Herzegovina, Bulgaria, Czech Republic, Croatia, Cyprus, Estonia, Hungary, Latvia, Lithuania, Malta, Montenegro, Poland, Romania, Serbia, Slovakia, Slovenia, The former Yugoslav Republic of Macedonia, Turkey
	Countries that became EU Member States in the course of the EU enlargement process	Bulgaria, Cyprus, Czech Republic, Estonia, Hungary, Latvia, Lithuania, Malta, Poland, Romania, Slovakia, Slovenia
Eastern Europe, Caucasus and Central Asia		Armenia, Azerbaijan, Belarus, Georgia, Kazakhstan, Kyrgyzstan, Republic of Moldova, Russian Federation, Tajikistan, Turkmenistan, Ukraine and Uzbekistan
	Caucasus	Armenia, Azerbaijan, Georgia
	Central Asia	Kazakhstan, Kyrgyzstan, Tajikistan, Turkmenistan, Uzbekistan
Pan-European region		UNECE countries, except Canada, Israel and the United States
North America		Canada, United States

economies have been in transition since the 1990s, are still catching up. Per capita levels of gross domestic product (GDP) vary widely, from well over US$20,000 reported in EU-15, the United States, Canada, Norway, Switzerland and other countries, to less than one-eighth of this figure in the Caucasus and Central Asia. By 2009, two decades after the transition period began, some countries in Eastern Europe, the Caucasus and Central Asia had increased their per capita incomes approximately 50% above their 1989 levels, most had only returned to something similar to their 1989 level, while a few economies (Georgia, the Republic of Moldova, Serbia, Tajikistan, and Ukraine) remained 30% or more below this earlier level (UNECE, 2010).

Demographic patterns and migration, economic development and – as analysed further below – climate change are key external drivers in the UNECE region (EEA, 2007; EEA, 2010*a*; EEA, 2010*b*; UNECE, 2011*b*). National legislation (e.g. the US Clean Water Act), EU legislation and UNECE environmental conventions and protocols are designed to counteract the many adverse effects of external driving forces, prevent water pollution and the degradation of ecosystems, and mitigate climate change. A large number of states are bound by UNECE environmental conventions and protocols, and half of the Member States are under the obligations of the EU legislation. International assistances rendered under national and EU assistance programmes are decisive for achieving response measures and contribute to strengthening water governance.

A particular challenge stems from the large number of transboundary waters, whose status is comprehensively assessed on a regular basis by UNECE in collaboration with governments and international organizations (UNECE, 2007*a*; UNECE 2011*b*). More than 100 first-order transboundary rivers, with a basin area of over 1,000 km^2 and many of their tributaries run along or cross the border between two and more states. One of these rivers, the Danube, has 19 countries in its basin. Around 40 large lakes are shared by two countries (e.g. Lake Geneva, Lake Peipsi, the Great Lakes) or even three countries (e.g. Lake Constance), and over 100 transboundary groundwater aquifers have been identified. This has led to strengthened cooperation, supported by bilateral and multilateral agreements in Europe and North America.

30.2 Water management and response measures

The key external drivers in the region lead to pressures on water resources, influence in a multifaceted way the status of water bodies, impact on human health and call for response measures. Tables 30.2 and 30.3 summarize the relative importance of pressures on water resources over typical subregions and provide response measures depending on external drivers (UNECE, 2007*a*; UNECE 2011*b*). With the revival of economy in Eastern Europe, the Caucasus and in Central Asia, a shift in the relative importance of some pressure factors might occur.

TABLE 30.2

Main pressures on water resources in order of priority (from high to low)

Countries in Eastern Europe, Caucasus and Central Asia	EU-15 countries and North America
Pressures on water quality	
Municipal sewage treatment, non-sewered population, old industrial installations, illegal wastewater discharges, illegal disposal of household and industrial wastes in river basins, tailing dams and dangerous landfills	Agriculture and urban sources
Abstraction pressures	
Agricultural water use	Agricultural water use (particularly in Southern Europe), major urban centres
Hydromorphological alterations	
Hydropower dams, irrigation channels, river alterations	Hydropower dams, river alterations
Other pressures	
Agriculture (with a trend to become more severe), mining and quarrying	Selected industries discharging hazardous substances, mining and quarrying

30.2.1 Water and agriculture

Agricultural practice in the region has changed considerably over the past four decades: mechanization, increased use of fertilizers and pesticides, farm specialization, growth of farm size, land drainage and developments in animal husbandry have led to adverse impacts on the aquatic environment with some specific subregional differentiation of water use and water pollution. Water use for crop and animal production, for example, in Central Asia, Greece, Italy, Portugal and Spain accounts for 50–60% of the total use. In other countries, agriculture only accounts for around 20%, while the bulk is used by manufacturing industries and for cooling purposes.

In many river basins, nitrogen and phosphorus from fertilizers as well as pesticides are often detected at excessive levels and give rise to detrimental impacts on the aquatic environment (e.g. eutrophication) and human health (UNECE, 2011*b*). *Campylobacter* and *Cryptosporidium* excreted by livestock grazing next to waterways make waters unfit for recreation or contaminate sources of drinking water. Certain features of the rural landscape, such as small ponds, brooks and wetlands, have disappeared, thus one of their important roles in the water cycle – attenuation of pollutants – has been lost because of intensified agricultural production. In some basins, particularly in Central Asia, the predominant consumptive water use (i.e. irrigation) has also led to problems, such as salinization of soils and high mineral salt contents in water bodies.

The legal framework to cut down pollution from agriculture was established in the 1990s (e.g. EU Nitrates

TABLE 30.3

Selected water management issues and responses

Main issues	Possible water management responses[a]
Pressures by nutrients and pesticides from agriculture with economic development as main driver	Coordination of objectives, coordination of measures and combined approach for pollution control from agriculture (e.g. good agricultural practice, payments for ecosystem services)
Pressures by specific substances from manufacturing industries with economic development as main driver	Inventory of existing and potential polluters, coordination of objectives, coordination of measures and combined approach for pollution control from industrial installations (e.g. best available technology for hazardous substances, pollution reduction through installation of closed water systems)
Pressures by organic matter and bacteriological pollution with economic development, demographic patterns, and migration as main drivers	Inventory of existing and potential polluters, coordination of objectives, coordination of measures and combined approach for pollution control from municipal wastewater treatment plants (at least biological treatment or equivalent processes)
Flooding with climate change and economic development as main drivers	Climate change adaptation, holistic approach to flood management (combination of non-structural and structural measures)
Pressures due to hydromorphological alterations with economic development as main driver	Re-naturalization of small and medium-sized rivers, payment for ecosystem services
Water scarcity and/or abstraction pressures with economic development, demographic patterns, migration and climate change as main drivers	Climate change adaptation, conjunctive management of surface waters and groundwaters, licensing groundwater use
Water management in a transboundary context with political transitions and security concerns, economic development, demographic patterns, migration and climate change as main drivers	Transboundary cooperation as stipulated by applicable bilateral and multilateral agreements, implementation of the UNECE Water Convention (UNECE, 1992) and its Protocols

[a] Terminology according to the Water Framework Directive (European Commission, 2000) and UNECE (2007*a*, 2007*b*, 2009*d*).

Directive and national legislation in EU countries, Norway and Switzerland, Canada and the USA) and good practice guidance to control water pollution by fertilizers and pesticides in agriculture is broadly available and applied. However, agriculture remains a major concern as the relative importance of agricultural pollution over industrial pollution grew, mainly from cutting down of pollution by industrial enterprises in many countries over the last three decades. In EU countries located in the drainage basins of the Mediterranean Sea, the East Atlantic Ocean, the Baltic Sea and the Black Sea, the impact of agriculture on the quality of water resources is still striking, mostly because the implementation of the above-mentioned pieces of legislation and recommended practices as well as the recovery of water bodies takes more time than expected (UNECE, 2011*b*). Experience has also shown that 'command and control' approaches promulgated through legislation need to be supplemented by voluntary measures and innovative financing schemes, such as payments for ecosystem services (UNECE, 2007*b*).

In Eastern Europe, the Caucasus and Central Asia, if diffuse pressures from the use of pesticides and fertilizers in agriculture increase in the future alongside the revival of countries' economies, their use will be much higher than in the last decade and will cause growing negative effects on national and transboundary waters and human health.

Apart from the implementation of legal–regulatory, institutional and management measures, it is important to focus on education, training and advice to promote understanding of good agricultural practice and respect for existing legislation by various economic entities. The establishment of Nitrate Vulnerable Zones and the implementation of action programmes in areas where agricultural sources of nitrates have led to excessive concentrations in freshwater are other positive examples from Western Europe. The idea of conservation agriculture, developed under the auspices of Food and Agriculture Organization (FAO) is another example that should be taken up in the agricultural practices of Central Asia and other countries.

BOX 30.1

Water quality of rivers and lakes in the United States

In the United States, the National Water Quality Inventory Report to Congress (USEPA, 2009*a*; the next report was due in 2011) covers 16% of the total river length and 39% of the lakes areas (with the exception of the Great Lakes). In general, the inventory shows an improvement of the water quality: the waters were generally suitable for irrigation, supplying drinking water, and domestic and recreational uses. However, the report also stated that about half of the assessed stream miles and 64% of assessed lake acres (see the first table) were still not clean enough to support uses such as fishing and swimming, and require enforcement of existing legal requirements and improvement of management practices, awareness raising and training.

Leading causes of impairment in assessed watercourses	
Rivers	Lakes and reservoirs
Pathogens	Mercury
Habitat alterations	PCBs
Organic enrichment	Nutrients

Leading causes of impairment included pathogens, mercury, nutrients, and organic enrichment/low dissolved oxygen. The main pressure factors were agriculture and hydromorphological modifications. In areas with significant agricultural and urban development, the quality of surface waters and groundwaters has been degraded by contaminants such as pesticides (insecticides in urban areas, herbicides in agricultural areas), nutrients, metals, and gasoline-related compounds. However, concentrations of contaminants in water samples from wells were almost always lower than current Environment Protection Authority drinking water standards.

Water body	Assessed	Conditions (% of assessed water bodies)		
		Good	Good but threatened	Impaired
Rivers	16%	53	3	44
Lakes	39%	35	1	64

30.2.2 Industries and municipal wastewater treatment

Most water pollution problems in the region seem to originate from the great number of small and medium-sized industries, and small municipal wastewater treatment plants, rather than big undertakings, mostly equipped with modern pollution abatement technologies.

The biggest area of concern is Eastern Europe, the Caucasus and Central Asia. The aftermath of the economic decline in the 1990s, which often caused a breakdown of essential infrastructure, is still visible, despite many assistance programmes from Western European countries. Apart from some major enterprises, wastewaters are usually discharged into collective sanitation systems for treatment at municipal wastewater treatment plants, which do not operate according to standards, as the infrastructure is worn out. In addition to pollution by heavy metals, phosphorus and nitrogen, a few watercourses show increased levels of pollution by oil products, specifically discharges from oil refineries and surface runoff from refinery sites. Accidental pollution from industrial installations and unauthorized discharges of hazardous substances (mostly at night and during holidays) are still major concerns. Illegal waste disposal along rivers, as well as old and uncontrolled waste disposal sites in many transboundary river basins are additional pollution sources.

Regarding pressures from industries in basins in Western Europe and North America (Box 30.1), a particular challenge that needs proper response measures is the control and reduction of pollution by new substances produced by the chemical industry, including new pharmaceuticals – which are difficult to eliminate in wastewater treatment processes – as well as the control of pollution by priority substances given provisions of the Water Framework Directive and other applicable directives of the EU (EEA, 2010*b*) and other relevant regulation.

In most of the countries that became EU Member States in the course of the enlargement process (e.g. Bulgaria, Poland, Romania, Slovakia) as well as in transboundary and national rivers draining to the East Atlantic Ocean, untreated or insufficiently treated industrial wastewater remains a concern and breakdowns of municipal wastewater treatment systems result in significant discharges of polluted waters into rivers (UNECE, 2007*a*; UNECE 2011*b*).

30.2.3 Abstraction pressures, water scarcity and droughts

Over-abstraction, water scarcity and drought have a direct impact on citizens and economic sectors, and large areas of the UNECE region are already affected. There are three principal areas of concern in the region: abstraction pressures to satisfy urban needs (Box 30.2); growing abstraction pressures from irrigated agriculture in many Southern European countries, Ukraine, Russia, in Central Asia and parts of Canada and the United States; and reduced water availability and increased pressure on water resources because of anticipated climate change. A particular challenge for countries in Eastern Europe and Central Asia is water use efficiency in irrigated agriculture (Box 30.3). Abstraction of water for industrial use has largely decreased over the last three decades in parts of the region, partly from a general decline in water-intensive heavy industry in Western Europe and North America, partly from an increase in water use efficiency.

BOX 30.2

Abstraction pressure to satisfy water needs in major cities

In the past, with growing populations and increasing demand for water, Europe's larger cities have relied on the surrounding region for water. Athens, Paris and Istanbul have all developed wide water networks for transporting water, often over more than 100–200 km. Growing urban populations, improved lifestyles, reduced water availability due to climate change and the introduction of drinking water quality standards (the water around large cities is often polluted and cannot be used for drinking water) are all factors that should be taken into account when seeking to reduce the vulnerability of large cities to water stress.

In dry years, there have been problems supplying sufficient water to the 12 million people living in Istanbul and the four million Ankara, and water supplies have been rationed. During the 2008 drought, Barcelona turned off civic fountains and beachside showers, brought in hosepipe bans, and banned the filling of swimming pools. In the same year, Cyprus applied emergency measures that included cutting water supply by 30%; and households were supplied with water for around 12 hours a day, 3 times a week (EEA, 2007; EEA, 2010*b*).

In a growing number of cases, such severe restrictions in emergency situations became part of a consultative process with stakeholders; this was also influenced by the requirements of the Aarhus Convention (UNECE, 1998).

Abstraction for cooling water has also decreased, given advanced cooling technologies.

A comparison of the impacts of droughts in the EU area between 1976–1990 and 1991–2006 has both shown a doubling in the affected area and a doubling in the number of affected people. For example, an intense drought throughout the Iberian Peninsula in the hydrological year 2004–2005 led to a 40% average decrease of cereals production and hydroelectric power production was heavily impacted. During summer 2006, rainfall in Lithuania was only half the long-term average and agricultural production fell by 30% with an estimated loss of around €200 million. Increasing water scarcity also limits access to water for sanitation purposes and hygiene, which may result in increased adverse health impacts, and water scarcity is reducing the self-purification capacities of water bodies (EEA, 2010*b*).

BOX 30.3

Agriculture in Central Asia

In Central Asia, the agricultural sector ensures livelihoods of half of Central Asia's population. Agriculture consumes more than 90% of surface water and 43% of groundwater. It produces US$13.54 billion of the annual domestic product and plays a critical role in the generation of Central Asia's total gross domestic product of US$58.5 billion (Stulina, 2009).

Despite what was learned from the Aral Sea disaster, the use of water resources is still geared to meet the water requirements of agriculture and hydropower generation without paying proper attention to the needs of other sectors and nature. As a result, drinking water quality and health of local population are deteriorating; land productivity and crop yields are decreasing; and poverty, unemployment, migration, and risks of conflicts are rising (GWP/CACENA, 2006).

Measures are being progressively implemented to reduce water losses by redesigning irrigation systems, improving irrigation techniques, and applying technologies for the reuse of drainage water. However, scarce financial means often delay the implementation of measures. Therefore it was recognized that in addition to the implementation of technical measures, a major objectiveshould be the involvement of stakeholders and relevant sectors in negotiations (coordinating water allocation) and development of acceptable for all rules for water allocation. The Interstate Commission for Water Coordination (ICWC) of Central Asia is the regional institution responsible for water allocation between the countries.

Drought management has become an essential element of water resource policy and strategies, and drought management plans (European Commission, 2009) were already drawn up or are under preparationin, for example, Spain, Portugal, England and Wales, Finland and the USA to mitigate the consequences of droughts and water scarcity. To address the impact of drought and water scarcity on human health, UNECE and WHO/EURO have developed specific guidance and recommendations, which include adaptation measures for drainage, sewerage and wastewater treatment (WHO, 2010).

30.2.4 Hydromorphological alterations

Structural measures (e.g. building dams and reservoirs for hydropower and irrigational agriculture, constructing dykes, straightening waterways and enforcing river banks) have caused significant hydromorphological changes in the UNECE region. This includes changes in the hydrological regime of many rivers, interruption of river and habitat continuity, disconnection of rivers from adjacent wetlands and floodplains, and change of the erosion process and sediment transport. For many rivers, restoring former floodplains and wetlands would both reduce flood risk and improve their ecological status (Box 30.4). At the same time, however, many European countries are still developing plans and studies for new dams, reservoirs and small hydropower projects.

30.2.5 Floods

Since the beginning of this century, more than three million people have been affected in the UNECE region by floods – almost two million in Eastern Europe alone – exposing people to various health hazards and causing deaths, displacement of people and large economic losses. Major floods have included those along the Danube in spring 2006 and in summer 2009 in rivers shared between Romania and Ukraine, and the Republic of Moldova and Ukraine; and in 2010 in the Oder basin, Southern France, and the Prut River (Romania and the Republic of Moldova). In the USA, significant flood events during the twentieth century were comprehensively documented (Perry, 2000). The recent floods include those in 2008 in Nebraska, Indiana and Illinois and the June 2010 flood in Arkansas.

In the region, the costs of floods have increased rapidly. Flood damage is mostly attributed to socio-economic factors, such as an increase in population, urbanization in flood-prone areas, and to unfavourable changes in land use such as deforestation and loss of wetlands.

BOX 30.4

Hydromorphological alterations in the Danube Basin

Like many other European rivers, the Danube is heavily influenced by human activities, such as intensive navigation and hydraulic engineering. On many stretches the natural structure of the river has been changed, including its depth and width, flow regime, natural sediment transport and fish migration routes. Dams have been built in mountain areas and some lowland regions of the Danube basin; and navigation channels, dykes and irrigation networks are widespread along the middle and lower reaches of the Danube:

- More than four-fifths of the Danube is regulated for flood protection, and about 30% of its length is impounded for hydropower generation.
- About half of the Danube tributaries are used to generate hydropower of around 30,000 MW.
- More than 700 dams and weirs have been built along the main tributaries of the Danube.

The Danube River Basin Management Plan addresses hydromorphological alterations. Basin-wide objectives by 2015 include the construction of fish migration aids and other measures to achieve and improve river continuity in the Danube River and in respective tributaries to ensure reproducing and self-sustaining of sturgeon species and specified other migratory species, as well as the restoration, conservation and improvement of habitats and their continuity for sturgeon species and specified other migratory species in the Danube River and its tributaries (ICPDR, 2007).

In Western Europe, initiatives to enhance the natural environment and improve its capacity to perform ecosystem services have been brought forward under the Water Framework Directive (e.g. the Dutch 'Room for the River' programme, the Spanish 'National Strategy for Restoring Rivers') or under national legislation (e.g. the Swiss 'Guiding Principles for Sustainable Water Management'). An innovative approach in the UNECE region is 'payment for ecosystem services' (PES), which is widely used in Latin America (Wunder, 2005) and explored in the UNECE region (UNECE, 2005). Prominent examples from the UNECE region (UNECE, 2007*b*) include the water supply of New York City (Catskill/Delaware basin management programme), the nitrate strategy of Switzerland, agro-environmental measures as part of the EU Common Agricultural Policy, and the management of natural mineral water springs in France (Nestlé/Vittel). Under the UNECE Water Convention, pilot projects on payments for ecosystem services have been carried out in Kyrgyzstan (Lake Issyk Kul basin) and in Armenia.

However, floods are natural phenomena that can also bring benefits: seasonal floodplain inundation is essential to maintaining healthy rivers, creating new habitats, depositing silts and fertile organic material, and sustaining wetlands. Therefore, an integrated approach to flood management – one that recognizes both the opportunities provided by floodplains for socio-economic activities and that manages the associated risks – is being implemented in many countries (e.g. Austria, Czech Republic, Germany, France, the Netherlands, Slovakia and Switzerland). The lessons learned from these events, particularly related to transboundary watercourses, have recently been summarized by UNECE and the World Meteorological Organization (UNECE, 2009*e*) and are now in pilot applications in in transboundary river basins such as the Dniester, shared by Ukraine and the Republic of Moldova.

30.2.6 Impact on human health

In parts of the region, inadequate sanitation, improper wastewater treatment, unsafe disposal methods for chemicals, and fertilizers and pesticides that leak into sources of water supply threaten human health. Microbial contamination of the sources of drinking water and water used for recreational purposes is one of the consequences as it is the case with man-made chemical pollution of the sources of drinking water supply; in some cases the natural background pollution causes immense problems, for example, in Hungary (naturally occurring arsenic) and the Caucasus (relatively high background concentration of some metals due to the weathering of rocks).

One hundred and twenty million people[2] in the European region do not have access to safe drinking water. Even more lack access to sanitation, resulting in water-related diseases like diarrhoea, typhoid fever (170,000 reported cases in 2006, which is probably an underestimate) and hepatitis A. In Eastern and South-eastern Europe, the Caucasus and Central Asia, access to improved sources of drinking water and improved sanitation is particularly inadequate in rural areas. In Western Europe and North America, outbreaks of water-related diseases occur occasionally despite state-of-the-art of water purification and wastewater treatment technology. For example, the USA reported that chemicals (16%), viruses (6%), bacteria (18%), and parasitic protozoa (21%) were identified as causes of outbreaks whereas in the remaining 39% of cases, it was not possible to identify the exact source (Greer *et al.*, 2008; Centres for Disease Control and Prevention, 2011).

During floods, people may be exposed to health hazards, such as freshwater pollution (particularly the contamination of the sources of drinking water by pathogens and waste), lack of household hygiene, and reduction of food safety. Water supply and sanitation utilities are also key health determinants during heat and cold waves.

The safety of the water supply and sanitation sector clearly relies on close inter-sectoral cooperation; however, it was not until the end of the 1990s before Governments in the region undertook concerted international action to prevent, control and reduce water-related diseases, including response systems to counteract health hazards due to incidents and outbreaks of water-related diseases. These international efforts culminated in the Protocol on Water and Health to the UNECE Water Convention. It is the first international agreement, which – by linking water management and health issues – aims to ensure the adequate supply of safe drinking water and adequate sanitation for everyone. It complements the UNECE Water Convention with further measures to strengthen the protection of public health, particularly at the national level, for example, by establishing or maintaining comprehensive national and/or local surveillance and early warning systems to prevent and respond to water-related diseases. From its entry into force in 2005 until now, it has already yielded positive results: the parties to the Protocol not only strengthened their measures to achieve the water-related and health-related MDGs, but also initiated measures to achieve water supply and sanitation for everyone beyond 2015 (UNECE, 2010; UNECE, 2011*a*). International assistance through *inter alia* providing access to sources of finance for infrastructure projects is also part of this instrument, and is already being rendered for the Republic of Moldova and Ukraine.

30.3 Uncertainties and risks

Water management adapts continuously to uncertainties and responds to risks that are posed by external driving forces and/or political, economic and technical responses. This requires new kinds of action from all stakeholders, including national and local governments and, for transboundary waters, from the parties to agreements.

30.3.1 Non-climatic drivers

The fact that many water bodies cross boundaries between two or more states means that challenges and risks are shared and that solutions need to be coordinated. Since the 1970s and early 1980s, countries have been engaging in a growing number of multilateral and bilateral agreements to regulate the use and protection of transboundary waters, and since the 1990s, the countries that evolved after the dissolution of the former Soviet Union have been taking measures to establish transboundary water cooperation. Many have joined international conventions and agreements and/or have entered into new bilateral and multilateral agreements and established joint bodies (e.g. river or lake commissions, meetings of plenipotentiaries) to facilitate transboundary water cooperation. As a result, the status of many watercourses in the region has been considerably improved and there are far fewer disputes over shared waters compared to the earlier 1990s (UNECE, 2009*b*; 2011*b*). The UNECE Convention on the Protection and Use of Transboundary Watercourses and International Lakes (UNECE Water Convention) adopted in 1992 and entered into force in 1996 (UNECE, 1992) has played an important role in this process.

However, a few first- and second-order transboundary rivers and many transboundary aquifers (UNECE, 2011*b*) in Eastern Europe, the Caucasus and Central Asia, as well as in South-Eastern Europe are not yet covered by agreements, and in some cases existing agreements and joint bodies do not effectively address such current challenges as economic development. In addition, some states – either inside the region or bordering it – resist participating in agreements on transboundary watercourses, whether framework agreements or those for specific watercourses. This leads to uncertainties and risks in transboundary water management where there are no formal channels for joint action.

While a prerequisite for effective cooperation is political will, joint bodies must also have, from the onset, the right structures and mechanisms to effectively address their tasks. To cope with uncertainties and risks in transboundary cooperation, the many existing joint bodies in countries in transition improve their activities by strengthening institutional mechanisms. This implies achieving better representation of national authorities in the joint body and improving coordination at the national level, and eliciting greater financial commitments by riparian states to cover implementation of joint programmes and expenses of organizational structure.

Insufficient access to, and cumbersome conditions for, the exchange of water quality and water quantity data and information in a transboundary context as well as information about drivers and their impact on water management also pose uncertainties and risks. In some cases, official communication lines go through the ministries of foreign affairs, although the environment ministries or state water committees are increasingly empowered with transboundary data exchange. In recent years, joint bodies established by countries in Eastern Europe and Central Asia have taken some steps towards improving access to information and stakeholder participation. Participation of non-governmental organizations and other stakeholders in the activities of joint bodies exists for many joint bodies in North America and Western Europe (e.g. the International Joint Commission (Great Lakes, North America) and the Rhine, Meuse and Scheldt river commissions). At the end of 2007, the plenipotentiaries of the Republic of Moldova and Ukraine adopted a Regulation on Stakeholder Participation. This is the first example of formalized procedure for the dissemination of information and promotion of public participation in the activities of the joint bodies in Eastern Europe, the Caucasus and Central Asia. Lack of finances is often one of the barriers to broadening access to information and public participation.

Coping with the increasing water demands of different sectors of economy poses particular challenges and has led or may lead to uncertainties about proper response measures. An example is water allocation among riparian countries, as disagreement remains over use quotas for the upstream and downstream users belonging to different states, as it is the case for some rivers in the discharge area of the Caspian Sea. A similar issue arose in water allocation between different sectors of economy, such as the 'classical conflict' between hydropower production (high releases of water during winter to produce energy often associated with man-made flooding of downstream areas) and irrigated agriculture (with high water demands in the growing season when the upstream reservoirs are being filled up), which is particularly obvious in Central Asia (Amu Darya and Syr Darya basins). This has not yet been solved satisfactorily; however, the existing joint bodies, under the umbrella of International Fund for Saving the Aral Sea (IFAS) (Box 30.3), are now approaching the problem as the water demand from other sectors is also growing (including an expected growth of water demand in Afghanistan – an upstream country outside the UNECE region) over the next two decades, and in the Aral Sea basin a reduction from around 2,500 m^3 per capita and year to 1,800 m^3 or even 1,300 m^3 depending on development scenarios.

Other examples of uncertainties and risks refer to the conflict between water use for economic activities and water for the maintenance of aquatic ecosystems. Lake Balqash, located in Kazakhstan and mainly fed by the transboundary river Ili with its source in China, may suffer the same fate of the Aral Sea if Kazakhstan and China fail to agree on sustainable water use and pollution control. The joint Kazakhstan–China Commission has recognized this issue and is approaching a solution to the problem with extreme caution owing to the many (scientific) uncertainties involved about the impact of response measures on the aquatic ecosystem of the Lake.

Growing abstraction pressures, including from groundwater aquifers, is another concern of transboundary cooperation. The work of many joint bodies in the area of transboundary groundwaters is still insufficient; this applies across the region, perhaps with some exemptions in Western Europe and North America. The staffs of joint bodies, often trained in the management of surface waters rather than groundwaters, do not supervise water supply from groundwaters and the licensing of groundwater abstraction.

In some countries, the aftermath of the political changes of the 1990s and the 2008–2009 global economic crisis continues to impact the stability and security situation, even today, with adverse effects on water and the environment as well as international cooperation on transboundary waters (Box 30.5).

In areas that witnessed armed conflicts, infrastructure was destroyed, causing pollution, and internally displaced people and refugees have put additional pressure on water supply and sanitation. Examples include the armed conflicts in the Balkans (1990s) and in the Caucasus (Armenia and Azerbaijan in the 1990s; Georgia and the Russian Federation in 2009). The internal political conflicts and ethnic tensions in Kyrgyzstan in the summer of 2010, causing death among its own population and large numbers of refugees, poses uncertainties and risks: it may not only have negative effects on transboundary water management in the Ferghana Valley (Aral Sea basin) as it was the case with the country's rural water supply and sanitation systems, but also negatively impact the solution of transboundary issues in the entire basin.

30.3.2 Climate change

The need to address climate change is a major concern as the entire UNECE region accounts for approximately one-half of the global greenhouse gas emissions. Climate change impact will vary considerably from region to region and even from basin to basin. These will include increased risk of inland flash floods, and more frequent coastal flooding, intensified erosion and extensive species losses (EEA, 2008; UNECE, 2009*a*, UNECE, 2011*b*); it may also affect hydropower, shipping, tourism and recreation, shoreline structures and human health (Greer et al., 2008; USEPA, 2007).

Governments in Europe (EEA, 2010*a*) are at different stages of preparing, developing and implementing national adaptation strategies, and the United States Environmental Protection Agency released in 2008 the National Water Programme Strategy with specific actions to adapt programme implementation in light of climate change (USEPA, 2009*b*). The adaptation strategies depend on the magnitude and nature of the observed and predicted impacts, assessments of current and future vulnerability and the countries' capacity to adapt. In addition, some actions and measures are increasingly being taken at regional and local levels. However, the strategies are long-term programmes whose immediate effects are difficult to assess.

Ensuring adequate financial means to implement adaptation measures is an important precondition for success; however, there are still many uncertainties about the ability of a number of countries to adapt water management to climate change. For example, in Eastern Europe, the Caucasus and Central Asia, uncertainties remain as to investment and funding for adaptation measures and there is a lack of capacity (including human resources) for adaptation. Widespread poverty in these countries also limits their adaptive capacity. Moreover, policy makers are not used to uncertainty and risk considerations when taking decisions related to water management, water supply and sanitation.

There is another challenge for water managers (UNECE, 2009*a*): climate mitigation measures may produce adverse side-effects for water management. One example is 'water for food production versus water for bio-energy crops'. Large-scale biofuel production may increase water demand and may contaminate freshwater from enhanced leaching of pesticides and nutrients, and in conflicts with food production. Hydroelectric power plants adversely affect the existing river ecosystems and fisheries, for example, due to changes in flow regime, water temperature regime, and oxygen concentrations. Conversely, they help to regulate flow and are needed for irrigation.

Another example is inland waterway transport, which plays an important role in the transport of goods in Central Europe and is generally seen as more environmentally friendly than road transport. However, navigation activities and infrastructure works are typically associated with a range of hydromorphological changes with potentially adverse ecological consequences. Thus, despite the advantage of mitigation policies for society and for reducing greenhouse gas emissions, there is a need to strike a balance between the benefits and the impacts on the ecological status of water bodies, adjacent land ecosystems and wetlands.

Many river basins that are already stressed due to non-climatic drivers are likely to become more stressed

BOX 30.5

Impact of the 2008–2009 global economic crisis

The Emerging Europe and Central Asia region[3] was the most affected by the global financial and economic crisis beginning in mid-2008, with declines in economic output in 2009 averaging about 6%. The economic declines had major socio-economic implications, for example, the number of unemployed during the first six months of 2009 grew by almost half in Russia and Turkey compared to the same period in 2008. As most countries can expect at best a mild growth in the coming years, the crisis will continue to hinder the achievement of the Millennium Development Goals (MDGs) and human development in the region. In particular, there are limited prospects for increasing social protection because of the expected weakness of the economic recovery and the accumulation of public debt (UNECE, 2010). The financial crisis presents risks to further developing the water sector; however, it also provides opportunities to reinforce commitments to invest in water services and infrastructure as part of fiscal stimulus packages. The European Union and United Nations Economic Commission for Europe (UNECE) Member States play a crucial role in these policy areas, using public spending and grants to create and maintain necessary infrastructure, promote technological innovation, support behavioural change and render further assistance to countries in transition (OECD, 2009).

because of their vulnerability to climate change. Of particular relevance is the vulnerability to climate change of costly water infrastructures (e.g. flood defence structures, water supply and sanitation infrastructure), which have to serve for decades but were designed on the assumption of stationary climatic conditions. Moreover, policy tools such as land planning are based on stable 'old' climate scenarios, which did not take into account variability and change. Other uncertainties related to climate change include the still insufficient knowledge base.

Uncertainties of climate predictions and predictions of precipitation patterns at the river-basin scale make scenario development particularly difficult for smaller river basins (UNECE, 2011*b*). Pilot projects were recently initiated, with finance from donor countries from Western Europe, in the Chu-Talas basin (Kazakhstan/Kyrgyzstan) and the Sava basin (Bosnia and Herzegovina, Croatia, Serbia, Slovenia). Other joint bodies, such as those for the Rhine, Meuse, Scheldt and Danube, also challenge the basin countries to develop a more coordinated approach and address the effects that pose the highest risk and uncertainties to human health and water management, and to develop appropriate adaptation measures to new risks as they become better understood.

30.4 Water governance

Water governance is well recognized in the UNECE region as a means for effective water management at the local, national and transboundary levels. Strategies, policies, legislation and assistance initiatives – designed as response measures – are at the same time 'political drivers' to achieve water governance.

Problems remain: in many countries in Eastern Europe, the Caucasus and Central Asia, capacities of institutions tend to be weak due to the institutional collapse and economic dislocation that marked the early years of the transition. While many of these countries have made great strides in reforming public administration and developing a dynamic civil society, the new institutions are not yet stable or well-rooted, nor have they completely moved away from the old mode of functioning. The political will to finance environmental protection is also weak; regular cuts in budgetary funding indicate that environmental protection receives little attention, and sometimes, the allocated funds are not even enough to ensure the normal functioning of state agencies. Moreover, it is difficult to recruit highly qualified staff because salaries are low and public authorities are not held in high esteem (UNECE, 2007*c*; Mott MacDonald, 2010).

The new EU Member States have accomplished greater progress in building new institutional structures. They were assisted on multiple fronts by the acceptance of the European model offered by EU membership as a powerful incentive for collective action, and by massive financial and knowledge assistance (UNECE, 2010). Notwithstanding the focus of UNECE and the European Commission on water governance in countries in transition, there are also challenges in governance in other countries, particularly those with a federal structure (e.g. Germany, USA) with multiple actors within each jurisdiction (Rogers and Hall, 2003; Moss, 2004; Norman and Bakker, 2009; and Cohen, 2010).

30.4.1 Legislation and assistance initiatives

The EU legislation is an important response measure to the external drivers and addresses *inter alia* water problems in the EU area and beyond. A comprehensive range of legislation has been established for this purpose, including Directives related to urban wastewater treatment (1991), to control and limit nitrate pollution from agriculture (1991), to regulate the quality of drinking water (1998) other areas related to water-and-health issues. The most important piece of legislation is the Water Framework Directive (WFD), concluded in 2000 (European Commission, 2000). This Directive expands the scope of water protection to all waters, and requires the achievement of a 'good status' for all waters in EU countries by 2015. The WFD is a direct response of the European Communities and the Member States to fulfill their obligations under international conventions on water protection and management, particularly the UNECE Water Convention (UNECE, 1992). The WFD includes a strong economic component: it requires that EU Member States implement full recovery of the environmental and resource costs of water services; and water pricing policies are to be established that provide adequate incentives for the efficient use of water resources. More recently, 'daughter' directives, such as those on environmental quality standards, floods and groundwaters, supplement the WFD.

Apart from its effect to improve water management in EU countries, the application of principles of the WFD is of immense importance to improving water management and cutting down pollution in countries at the Eastern border of the EU (Belarus, the Republic of

Moldova, Ukraine, Armenia, Azerbaijan and Georgia). This is the reason for the EU (European Commission, 2007) to support these countries under the European Neighbourhood and Partnership Instrument (ENPI).

UNECE Environmental Conventions and Protocols are another response to the external drivers to resolve national and transboundary issues of water management, air pollution, industrial accidents, impact assessment and public participation. For what concerns water management, the central aim of the 1992 UNECE Water Convention is to strengthen local, national and regional measures to protect and ensure the quantity, quality and sustainable use of transboundary waters. It stipulates managing shared waters in a reasonable and equitable manner and calls for action guided by the precautionary principle and based on the polluter-pays principle. The Convention requires parties to enter into specific bilateral or multilateral agreements and to create institutions – joint bodies such as river and lake commissions – to meet these responsibilities.

The Environment for Europe process, including its ministerial conferences, became another prominent response measure to the external drivers in the region. UNECE Member States, UN system organizations and other intergovernmental organizations represented in the region, regional environment centres, non-governmental organizations, the private sector and other major groups act in partnership to help countries in transition to raise their environmental standards towards a common regional benchmark, provide access to sources of finance, and share experience and good practice.

30.4.2 National Policy Dialogues

International support to strengthen water governance should be a process that involves and supports two distinct levels of decision-making: decision-making on technical and managerial issues and decision-making on policy issues. This gave rise to the National Policy Dialogues on integrated water resources management, water supply and sanitation as part of the EU Water Initiative, launched at the World Summit on Sustainable Development in Johannesburg in 2002, which covers nine of the 12 countries in Eastern Europe, the Caucasus and Central Asia.

On the one hand, technical assistance programmes by the EU and Western European Countries enhance the expertise of staff in the water–environment ministries and improve legislation, institutions and management practices. On the other, National Policy Dialogues – led by the ministers for environment – enhance the political support of water management by key ministries such as economy, finance, justice, emergency situations, and foreign affairs, and involve additional stakeholders (e.g. academia, non-governmental organizations, parliamentary bodies responsible for environment, and international organizations and financial institutions). The production of highly policy-relevant outputs, such as new pieces of legislation (Box 30.6) in line with the principles of the UNECE Water Convention, the Protocol on Water and Health, the EU Water Framework Directive and other UNECE and EU instruments, the strong country commitment and the cooperation with other international organizations are among the strengths of the National Policy Dialogues in the region, and a means to strengthen water governance.

BOX 30.6

Wastewater treatment infrastructure in the Republic of Moldova

Of the 623 municipal wastewater treatment plants constructed in major cities and other settlements in The Republic of Moldova, only 24% were operational in 2010. This has led to a growing amount of untreated wastewater being discharged into the river system and only 4% of plants treat wastewater according to existing legal requirements. In addition, sanitation is unsatisfactorily in rural areas, where 70% of houses are not connected to the sewerage system.

An assistance programme is being developed, supported by European Union (EU) funds, and funds provided by other West European countries, to rehabilitate infrastructure in municipalities and improve sanitation in rural areas. New wastewater treatment legislation, modeled on the basis of EU legislation, was drawn up under the National Policy Dialogue process and entered into force in October 2008. This new legislation provides a sound basis for the rehabilitation of existing and the construction of new municipal wastewater treatment plants, as it no longer relies on the outdated Soviet-style requirements. Thus, the treatment performance of the state-of-the-art Western treatment technology no longer clashes with former Soviet-style Moldovan standards and no longer forces the Minister for Environment to apply to the Government for exceptions from the law to install these technologies (UNECE, 2011*a*).

Notes

1 Eight hundred and seventy million people live in the 'pan-European region', a term which does not include North America and Israel. The USA has a total resident population of about 310 million; Canada 34 million and Israel 7 million (UNECE Statistical Division Database at http://www.unece.org and UNECE, 2010).

2 North America is not included in these figures, which were compiled by the Regional Office for Europe of the World Health Organization (WHO/EURO)

3 Countries in Eastern Europe, the Caucasus and Central Asia and South-Eastern Europe, including Turkey, and the new EU Member States (Table 30.1).

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CHAPTER 31

Asia and the Pacific

UNESCAP (Energy Security and Water Resources Section, Environment and Development Division)

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Acknowledgements Inputs were provided from Felix Seebacher on wastewater management, Salmah Zakaria on climate change adaptation and Marina Korzenevica on country-specific policies.

Trends and major challenges

Millions of people in the Asia-Pacific region are still not connected to improved water infrastructure for personal and productive uses, placing them in a state of human insecurity. In 2008, about 480 million people lacked access to improved water resources, while 1.9 billion had no access to improved sanitation facilities.

Population size, rapid urbanization, industrialization and economic development put pressure on freshwater resources. The region's water resources are also increasingly vulnerable to and threatened by natural disasters and pollution.

Natural water-related disasters such as floods and droughts undermine economic development. Coastal and flood-prone areas, where much economic growth is generated, are often struck by typhoons and rainstorms.

Of all wastewater generated, only 15–20% receives some level of treatment before discharge into water resources. The total volume of domestic wastewater currently produced in urban areas is a particular concern, estimated to be between 150 and 250 million cubic metres per day. This wastewater either is discharged directly into open water bodies or leaches into the ground.

Richer, urban households are in a better position to secure safe water and adequate sanitation. Inequalities in access to water between rich and poor households are evident all over Asia, but for sanitation, the inequality is more striking.

Emerging needs

Providing water and sanitation services to all requires sizeable financial resources – US$59 billion to meet the Millennium Development Goal of access to water and $71 billion to provide access to sanitation. If investment needs for all water services are included, the total annual investment costs for water infrastructure could reach $180 billion, of which $100 billion is needed in developing countries.

Extremes of flood and drought are expected to increase in both magnitude and frequency as a result of climate change.

Policies and solutions

To address the lack of adequate financing, time horizons of investment assessment need to be expanded. Environmental costs should be factored into prices charged for water and sanitation services. Governments need to create the market conditions for the development of sustainable and eco-efficient infrastructure.

Integrated stormwater management can prove invaluable during floods, as clean water bodies minimize spreading of polluted water and disease. Integrated rainwater harvesting, thanks to advances in technology, is also viewed as an integral part of water cycle management.

Central sewage treatment plants require a very large space, and are costly and difficult to maintain. Technology for compact small wastewater treatment plants has improved and offers many advantages.

Certain water-related challenges, such as stagnant access to sanitation, deteriorating water quality, and climate-related risks, are common in Asia-Pacific countries. Targeted, urgent action is needed to break the developmental deadlock that many countries find themselves in due to poor water resources management. Promoting household water security, recognizing the need to adapt to climate change threats and initiating a 'Wastewater Revolution' are proposed priorities for regional cooperation.

31.1 Introduction

'Asia and the Pacific' and 'ESCAP region' refer to the group of members and associate members of the Economic and Social Commission for Asia and the Pacific (ESCAP) that fall within the region. The geographical description of the region used in this chapter includes 55 member states of ESCAP in the five subregions: Central Asia, North-East Asia, the Pacific, South Asia and South-East Asia, as shown in Table 31.1.

31.1.1 General trends in the Asia-Pacific

The Asia-Pacific region has the largest share of renewable freshwater resources in the world, at 21,135 billion m^2. This endowment is coupled with high water utilization rates. On average, the region withdraws 11% of its total renewable resources, second in the world after the water-scarce Middle East and on par with European utilization rates (ESCAP, 2009*a*).

Despite some progress, millions in the Asia-Pacific remain disconnected from improved water infrastructure for personal and productive uses, forcing them into insecurity. In 2008, about 480 million people lacked access to improved water resources, while 1.9 billion had no access to improved sanitation facilities (WHO and UNICEF, 2010b).

The future is also uncertain. Population size, rapid urbanization, industrialization and economic development are placing pressure on freshwater resources. Water resources are also increasingly vulnerable and threatened by natural disasters and pollution. The Asia-Pacific is the world's most vulnerable region with respect to natural disasters. Pollution from industries, agriculture and households further jeopardize future water availability.

31.2 Issues

31.2.1 Meeting or missing the MDG target on drinking water and sanitation

Between 1990 and 2008, significant achievements were made towards meeting the Millennium Development Goals (MDG) target on access to safe drinking water. Asia, and the Pacific as a whole, is an early achiever for halving the proportion of people without access to safe drinking water, but not sanitation (ESCAP, ADB and UNDP, 2010). Between 1990 and 2008, the proportion of the region's population with

TABLE 31.1

Member states of the Economic and Social Commission for Asia and the Pacific (ESCAP) in the five subregions

Subregion	ESCAP member states
North-East Asia	China, Democratic People's Republic of Korea, Japan, Mongolia, Republic of Korea, Russian Federation
Central Asia and the Caucasus	Armenia, Azerbaijan, Georgia, Kazakhstan, Kyrgyzstan, Tajikistan, Turkmenistan, Uzbekistan
South-East Asia	Brunei Darussalam, Cambodia, Indonesia, Lao People's Democratic Republic, Malaysia, Myanmar, Philippines, Singapore, Thailand, Timor-Leste, Viet Nam
South and South-West Asia	Afghanistan, Bangladesh, Bhutan, India, Iran (Islamic Republic of), Maldives, Nepal, Pakistan
Subregion	**ESCAP member states**
	Sri Lanka, Turkey
Pacific	American Samoa, Australia, Cook Islands, Fiji, French Polynesia, Guam, Kiribati, Marshall Islands, Micronesia (Federated States of), Nauru, New Caledonia, New Zealand, Niue, Northern Mariana Islands, Palau, Papua New Guinea, Samoa, Solomon Islands, Tonga, Tuvalu, Vanuatu

Source: CARE (2009).

access to improved drinking water sources increased from 73 to 88 %, a 1.2-billion people increase (including population size increase). The access rate increased in all Asia-Pacific subregions, except for Central Asia and the Pacific region, where it stayed the same.

Compared with water supply, sanitation coverage is in a dire state. Only around 53% of the region's population has access to improved sanitation. Access to sanitation also varies considerably between subregions. The most rapid progress has been in South-East Asia where the increase was 22 percentage points, and in North-East Asia which between 1990 and 2008 increased access by 12 percentage points. The progress in South and South-West Asia was even weaker. Although the number of people with access doubled since 1990, by 2008 the average coverage was only 38% and the number of people without access was higher than it was in 2005.

Poor drinking water quality and inadequate sanitation threaten human health and productivity. According to the World Health Organization (WHO), 88% of diarrhoea incidents are attributed to poor sanitation and dirty water (WHO and UNICEF, 2010*a*). In South and South-East Asia, diarrhoea is responsible for up to 8.5% of all deaths, which is the highest rate in the world, followed by Africa, where it is responsible for 7.7% of deaths (WHO, 2010c). These numbers reveal a grim reality, which because of lack of access to basic infrastructure perpetuates poverty and poor health, and conceals the region's vast hidden potential for development.

32.2.2 Stretched carrying capacity

Water availability

In the ESCAP region, high total and internal renewable resources stand in sharp contrast with the per capita availability, which is the second lowest in the world at 5,224 m^2 per capita and far below the world average of 8,349 m^2 per capita – a result of the population size (Figure 31.1).

Physical water scarcity is only one part of the equation. Water allocation is another matter. The share of domestic water withdrawal over total withdrawal in Asia and the Pacific, the most populated region in the world, is the lowest at 7.7%, compared with Africa at 10%. Agriculture is the principal user of water, claiming around 70% of all withdrawals. The region's main staple food, rice, requires two or three times more water for cultivation than other cereals. In many countries, agricultural practices are characterized by free-of-charge water abstraction, poorly managed irrigation schemes, outdated and damaged technological infrastructure, and production of water-intensive crops in dry regions. Many examples of over-abstraction of ground and surface water exist. The threat of disappearance of the Aral Sea, mainly from intensive irrigation upstream, demonstrates that even the biggest lakes of the world can be seriously affected (ESCAP, 2008).

Overall water availability for development across the region is on a steep decline. Some countries, like Uzbekistan and Tajikistan, withdraw very close to, or even more than, their total surface and groundwater combined (116 and 99.6% of the total renewable water respectively) (ESCAP, 2009*a*). Although critical conditions of freshwater availability appear localized in a number of countries, analysing existing data from a new, development angle reveals wider critical trends.

Water quality

The ecological carrying capacity of the region is further affected by the deteriorating water quality of water bodies. Of all wastewater generated worldwide, and in the region, only 15–20% receives some level of treatment before discharge into water resources; the remainder is discharged with its full load of pollution and toxic compounds (UNEP, 2002).

Domestic sewerage is of concern, as it affects ecosystems close to densely populated areas. The total volume of wastewater produced in urban areas is estimated at 150–250 million m^2 per day (UNEP, 2002). This wastewater is either discharged directly into open water bodies or leaches into the subsoil. In addition, most industries in the region continue to generate water pollution, as enforcement of relevant regulations lags behind.

Even relatively water-rich countries, such as Malaysia, Indonesia, Bhutan and Papua New Guinea, now face water supply and quality constraints in their major cities because of population growth, growing water consumption, environmental damage, harmful agricultural activities, poor management of water catchment areas, industrialization, and groundwater overuse.

Countries that are relatively less well-endowed with water, in Central Asia and in South and South-West Asia, are even more severely affected when water quality deteriorates. Countries with the least available water per person also tend to have poor water quality. Kazakhstan, Uzbekistan, Kyrgyzstan, Georgia, Myanmar, the Islamic Republic of Iran, the Maldives, Nepal, Tajikistan, Azerbaijan, Turkmenistan, Democratic People's Republic of Korea, Bhutan, Papua New Guinea and Mongolia are countries in which water quality pressures are strong.

31.2.3 Natural disasters

Asia-Pacific is a diverse region covering almost all of the different types of climatic regions, from tropical rain forest to more temperate areas; and from land-locked, mountain regions of the Himalayas to island states in the Pacific and Indian Oceans. Precipitation in many countries in the region is heavily influenced by the monsoon climate.[2] Some subregions, like South-East Asia, suffer from both floods and droughts at the same location, but at different times of the year.

Natural water-related disasters, such as floods and droughts undermine economic development. Coastal and flood-prone areas, where much economic growth is generated, are often struck by typhoons and rainstorms. Striking and sustaining an optimal balance between the developmental needs of many Asian developing economies (especially influenced by population growth, food and energy security issues) and the risks associated with the use of flood-prone land is a challenge, given uncertainties concerning the future state of the water regime.

Between 2000 and 2009, an average of 20,451 people were killed each year by water-related disasters, excluding tsunami disasters, in the region. World's annual average was 23,651 deaths for the same period (Center for Research on the Epidemidiology of Disasters, 2009). Unprecedented floods in Pakistan killed 1,974 people, damaged 1.65 million houses, and destroyed 2.24 million hectares of crop land in 2010 (ESCAP, 2010*b*).

Extreme weather conditions also jeopardize gains in access to water and sanitation. Droughts reduce drinking water availability and floods and storms can damage basic water infrastructure and spread disease.

31.3 Emerging drivers

Asia-Pacific is an incredibly dynamic region. Rapid urbanization, economic growth, industrialization, extensive and intensive agriculture development, as well as climate change, have resulted in increasing and exponential demand for water. Emanating from these trends are the following drivers shaping the region's capacity to meet its water needs.

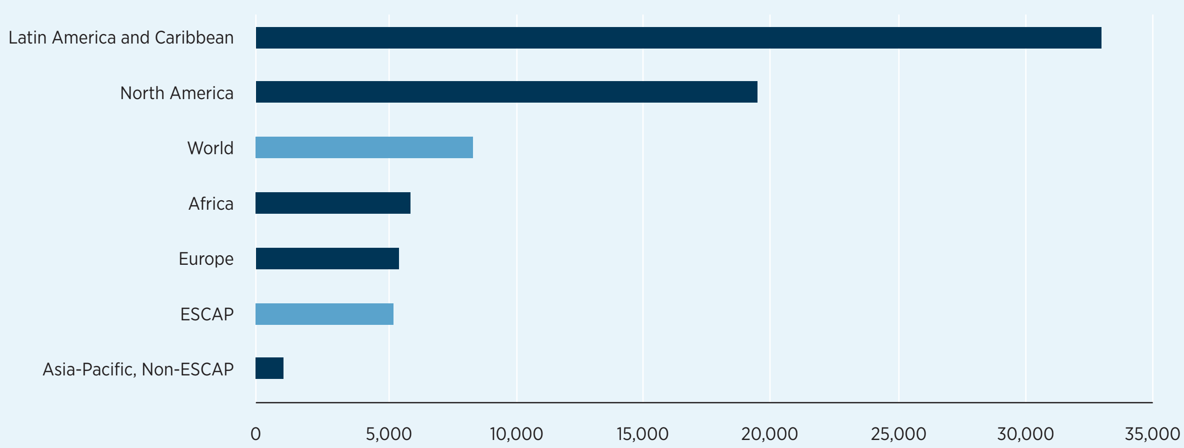
31.3.1 Economic and social drivers

Inequality in access to drinking water and sanitation

Despite impressive growth in gross domestic product (GDP) rates and substantial improvements in access to drinking water and sanitation, income and gender inequalities persist. A basic typology analysis undertaken by ESCAP showed that richer, urban households are in a better position to secure safe water

FIGURE 31.1

Total renewable water per capita (total renewable/population), global regions (2007)



Source: ESCAP (2009a, fig. 28.4, p. 206).

supply and adequate sanitation. Inequalities in access to water between rich and poor households are evident all over Asia, but for sanitation, the gap is even bigger. The largest discrepancies between access of rich and poor people are in urban environments, particularly in smaller cities (MEASURE DHS, 2004–2008; UNICEF, 2004–2008).

Sex-disaggregated data on access to water and sanitation is not available at the international level. However, the Convention on the Elimination of All Forms of Discrimination Against Women (CEDAW) Committee has underlined that the health of rural women often depends on adequate and non-discriminatory access to water (UN Women, 2010). Provision of segregated toilets in schools is a necessity to increase school attendance by girls because gender inequalities in access to water and sanitation affect women disproportionally (Burrows et al., 2004).

The unfulfilled potential of women hampers progress. ESCAP research reveals that women invest more of their money in the health of their family, including water and sanitation, than men. The argument can also be made that women value access to water more than men. In national surveys from countries as diverse as Armenia, India, Indonesia, Lao People's Democratic Republic, Kazakhstan, Mongolia, Tajikistan and Viet Nam, female-headed households consistently had better access to improved water and sanitation than male-headed households (Table 31.2) (MEASURE DHS, 2004–2008; UNICEF, 2004–2008). However, in male-dominated environments, women's role in household decisions on water and sanitation remains marginal.

Infrastructure development and investment

Providing water and sanitation services to everyone requires sizeable financial resources. For all of Asia and the Pacific, it is estimated that US$59 billion is needed to meet the target of access to drinking water and a total of US$71 billion is needed to provide access to sanitation according to the MDG target (ESCAP, 2010*a*). If investment needs for all water services are included, the total annual investment cost for water infrastructure could reach US$180 billion, including about US$100 billion for all developing countries in the region (ESCAP, 2006*b*). Poor water quality requires vast investments, and increases in water treatment and distribution costs.

The coordinated drive to achieve the MDGs by governments, civil society and donors has boosted performance in related indicators over the past few years. In response to international calls for increased financing for water, the Asian Development Bank (ADB) launched the Water Financing Program (WFP) to double investments in the sector between 2006 and 2010 and established the Water Financing Partnership Facility (WFPF) to mobilize co-financing and investments from development partners, with some US$65 million reached as of December 2008 (Asian Development Bank, 2011).

Data from seven South-East Asian countries (Cambodia, Indonesia, Lao People's Democratic Republic, the Philippines, Thailand, Timor-Leste, Viet Nam), one country from Central Asia (Kazakhstan), one country from North-East Asia (Mongolia) and two countries from South Asia (Bangladesh, Nepal) indicated a diverse level of institutional engagement in water and sanitation planning. Countries like Cambodia, Lao People's Democratic Republic, Nepal and Thailand have adequate policies and institutions, while Cambodia and Lao People's Democratic Republic lack human resources and financial planning for implementation.[3] The Philippines, Cambodia, Timor-Leste, and Viet Nam also lagged behind in financial planning and resources, with Viet Nam indicating the best future potential for scale-up of resource allocation in meeting water and sanitation goals (UN-Water, 2010).

However, even if access to adequate water and sanitation systems is established, it is important to ensure that the built systems are financially sustainable, functional, reliable, affordable, responsive to needs, socially acceptable for both genders, and appropriate for children and adults. Often sanitation facilities are incompatible with women's needs, while the size of basic facilities is improper and even dangerous for children.

Wastewater treatment facilities in the region are also generally lacking. In cities, many small waterways are covered to allow more space for roads or commercial areas, put into concrete beds, used mostly to facilitate storm runoff or simply used as open sewers. Irrigation facilities in the region are often old and in poor condition, partly because of extremely low water prices and poor management of the facilities. Many governments have subsidized the construction of inefficient irrigation systems, along with fuel and electricity supplies. This has weakened price signals, tempting farmers to withdraw too much water from rivers, over-pump groundwater and waste freshwater resources (ESCAP, 2008).

Water for food

The changing economic, demographic and climatic backdrop is exacerbating difficult conditions for food production. Producing each calorie of food requires approximately 1 L of water. To provide each consumer with 1,800 calories per day, by 2050 Asia and the Pacific would need an additional 2.4 billion m^2 of water per day. Food security concerns aggravate the harm inflicted on those who lack basic water access, whether small-scale or large-scale producers.

31.3.2 Policies, law and financing drivers

Water management capacity

Countries that withdraw water very close to their internal renewable sources may face difficulties in supporting development trends in the long-term. Over-exploitation can modify water distribution and cause water crises in parts of the region. Many countries in the region have moved, with various levels of

TABLE 31.2

Percentage of male and female-headed households with access to safe drinking water

Country	Year	Male-headed (%)	Female-headed (%)	How much more women value access to water (% points)
Armenia	2000	93.8	95.4	2
	2005	95.8	96.4	1
Bangladesh	2007	97.0	97.6	1
India	1999	80.4	78.8	-2
	2006	87.7	89.2	2
Indonesia	1997	73.9	77.5	4
	2003	71.8	72.1	0
Kazakhstan	1999	92.5	96.2	4
	2006	94.0	95.9	2
Kyrgyzstan	2006	88.9	93.3	4
Lao PDR	2005	58.6	70.4	12
Mongolia	2005	65.3	76.3	11
Nepal	1996	76.9	78.5	2
	2006	82.3	80.3	-2
Philippines	1998	85.4	87.4	2
	2003	83.2	85.4	2
Tajikistan	2000	56.1	65.8	10
	2005	70.0	78.3	8
Thailand	2005	96.0	96.1	0
Uzbekistan	2006	89.5	95.9	6
Viet Nam	1997	71.5	78.6	7
	2000	76.1	83.1	7
	2002	77.1	84.4	7
	2006	87.7	92.2	4

Source: ESCAP analysis based on Demographic and Health Surveys (DHS) and Multiple Indicator Cluster Survey (MICS) from the period 1999–2008.

on-the-ground-success, to adopt Integrated Water Resources Management (IWRM). Tables 31.3 and 31.4 provide some examples of regional and country-level initiatives.

Water disputes and conflicts

Despite increased awareness and implementation of IWRM principles, the rapid economic growth of the region's developing countries, accompanied by high intensity of the use of natural resources, especially water, has led to a rapid increase in conflicts over water. This poses a threat to stability and development.

Over the past two decades, the number of reported water-related incidents has risen. Conflicts within countries are dominating the picture, particularly since 1990 (Table 31.5). In China alone, the number of disputes related to water reached over 120,000 during the 1990s, according to official sources.[4] In India, efforts and resources in water management are often focused on conflict management between different states. Allocation of increasingly scarce water resources has become the principal cause for water conflicts. Direct conflicts are most likely to occur at the local level over an ill-thought dam, ambiguous withdrawal rights or deterioration of water quality. Against the context of development, the biggest challenges are balancing the different uses of water and managing their economic, social and environmental impacts.

31.3.3 Technological drivers

Advances in technology are also changing the landscape of options for the region on water resources management to meet its needs for water supply and wastewater treatment coverage and socio-economic development.

TABLE 31.3

Regional Integrated Water Resources Management (IWRM) initiatives

Region	IWRM initiative
Central Asia	Aral Sea Basin: framework for subregional dialogue (October 2008)
	Aral Sea Basin: Executive Committee of the International Fund for Saving the Aral Sea (EC-IFAS)
	Global Water Partnership Central Asia and Caucasus (GWP CACENA): support for IWRM
South and South-West Asia	South Asian Association for Regional Cooperation (SAARC): Disaster Management Center
	SAARC: Comprehensive Framework on Disaster Management
	Global Water Partnership (GWP) – South Asia: support for IWRM
	South Asia Water Forum (SAWAF): directions for transboundary water management
	National Adaptation Plan of Action (NAPA) in all countries
	Political commitment for sanitation (SACOSAN)
	Water Utility Network –South Asia (SAWUN)
South-East Asia	Mekong River Commission establishment (1995)
	Mekong River Commission: IWRM-based Basin Development Strategy
	ASEAN: Working Group on Water Resources Management and IWRM
	GWP-SEA: support for IWRM
Pacific Islands	Pacific Wastewater Policy Statement
	Pacific Wastewater Framework for Action (2001)
	Pacific Regional Action Plan on Sustainable Water Management (2002)
	Drinking Water Quality and Health Framework for Action (2005)
	Pacific Islands Applied Geoscience Commission (SOPAC)

Source: Jin Lee, Ti LeHuu and Salmah Zakaria, Energy Security and Water Resources Section, Environment and Development Division, ESCAP, Status of IWRM Implementation in the Asia-Pacific Region (unpublished report), December 2009, in cooperation with Torkil Clausen, GWP.

Modular structures for water supply and wastewater
The advent of efficient modular design of water treatment using recent advances in technologies, such as membrane technology, allows effective decentralized water supply and wastewater management. Technology for compact, small wastewater treatment plants (or units) has improved significantly and the requirement for space has been reduced, allowing introduction of these units even in crowded urban areas.

TABLE 31.4

Country-specific Integrated Water Resources Management (IWRM) initiatives

Country	IWRM initiative
Armenia	New Water Code with IWRM principles
Bangladesh	IWRM and Water Efficiency Plan, water codes
Cambodia	Law on Water Resources Management (2007)
	National Water Resources Strategy (2004)
China	District management guided by IWRM
	GWP and provincial GWP partnerships supporting IWRM
	Water Law integrating river basin management
Indonesia	Government Regulation on Groundwater (2008)
	Government Regulation on Water Supply System Development (2006)
	National Water Resources Council (2008)
	Revision of Government Regulation on Irrigation (2006)
	Revision of Government Regulation on Water Resources Management (2008)
Japan	Revised Basic Environment Plan (2000)
	Water management includes environmental sustainability
Kazakhstan	New Water Code with IWRM principles
Kyrgyzstan	New Water Code with IWRM principles
Lao PDR	Water Resources and Environment Administration
Malaysia	National Water Services Commission (2007)
	Water Services Industry Act (2006)
Mongolia	Water Authority supports IWRM through river basin councils
Myanmar	Conservation of Water Resources and Rivers Law (2006)
	National Commission for Environmental Affairs (2008): effluent standards for factories
Nepal	IWRM and Water Efficiency Plan, water codes
Pakistan	IWRM and Water Efficiency Plan, water codes
Philippines	Water Resources Commission to act as economic regulatory body
Republic of Korea	Comprehensive River Basin Plan revitalizes 12 rivers
Sri Lanka	IWRM and Water Efficiency Plan, water codes
Tajikistan	New Water Code with IWRM principles
Viet Nam	River basin management by Ministry of Natural Resources and Environment (2007)
	Water sector reform (2006–2008) separates water resources from water use management

Source: Jin Lee, Ti LeHuu and Salmah Zakaria, Energy Security and Water Resources Section, Environment and Development Division, ESCAP, Status of IWRM Implementation in the Asia-Pacific Region (unpublished report), December 2009, in cooperation with Torkil Clausen, GWP.

Water-sensitive urban design

Water-sensitive urban design is the cumulative process of designing urban environments to accommodate human and environmental needs for water, while respecting and supporting the natural water cycle. The design incorporates the basic water supply access and security; public health protection (e.g. through sewers); flood protection through drainage systems; environmental protection by rehabilitating waterways; protection of natural resources through the water cycle, paying specific attention to intergenerational equity and resilience to climate change (Brown et al., 2008).

Storm water management

Extremes of floods and droughts are expected to increase in magnitude and frequency as a result of climate change. Natural water bodies can turn into water supply sources during droughts, if rehabilitated. Integrated storm water management (ISWM), already implemented in the more developed countries of the region, can prove invaluable during floods, as clean water bodies minimize spreading of polluted water and disease.

Rainwater harvesting

TABLE 31.5

Chronology of major recent water conflicts in Asia, 2000–2008

Date	Countries involved	Description of conflicts or potential conflicts
2000	Central Asia: Kyrgyzstan, Kazakhstan, Uzbekistan	Kyrgyzstan cuts off water to Kazakhstan until coal was delivered. Uzbekistan cuts off water to Kazakhstan for nonpayment of debt. (Pannier, 2000)
2000	Afghanistan: Hazarajat	Violent conflicts broke out over water resources in the villages of Burna Legan and Taina Legan, and in other parts of the region, as drought depleted local resources. (Cooperation Center for Afghanistan, 2000)
2000	India: Gujarat	Water riots were reported in some areas of Gujarat to protest against failure of the authority to arrange adequate supply of tanker water. Police shot into a crowd at the village of Falla near Jamnagar, killing three people and injuring 20 others following protests against the diversion of water from Kankavati Dam to the town of Jamnagar. (FTGWR, 2000)
2001	China	In protest to the destruction of fisheries from uncontrolled water pollution, fishermen in northern Jiaxing City, Zhejiang Province, dammed for 23 days the canal that carries 90 million tonnes of industrial wastewater per year. The wastewater discharge into neighbouring Shengze, Jiangsu Province, killed fish and threatened people's health. (China Ministry of Water Resources, 2001)
2002	India: Kashmir	Two people were killed and 25 others injured in Kashmir when police fired at a group of villagers in Garend in a dispute over sharing water from an irrigation stream. (The Japan Times, 2002)
2002	India: Karnataka, Tamil Nadu	Continued violence over the allocation of Cauvery River between Karnataka and Tamil Nadu. Riots, property destruction, more than 30 injuries, and arrests occurred through September and October. (The Hindu 2002a,b, The Times of India 2002a)
2004	China	Tens of thousands of farmers staged a sit-in against the construction of Pubugou Dam on Dadu River in Sichuan Province. Riot police were deployed to quell the unrest and one person was killed. Some residents were killed. (See China 2006 for follow-up) (BBC, 2004b; VOA, 2004)
2007	India	Thousands of farmers breached security and stormed the area of Hirakud Dam to protest allocation of water to industry. Minor injuries resulted from the conflict between the farmers and police. (News Service, 2007)

Source: Gleick (2008).

Due to advances in rainwater harvesting technology, integrated rainwater harvesting is increasingly viewed as an integral part of water cycle management. Rainwater can be captured at the city level. In Singapore little rainwater is wasted. Rainwater is collected wherever it can - in streets and ponds, even on tall buildings and bridges - before being taken by drains to reservoirs, and then to treatment plants where it is cleaned to drinking water standards. The catchment area is being increased by the creation of a pair of reservoirs. The first of these reservoirs, will expand the rainfall-catchment acreage to two-thirds of the island's total land area (*The Economist,* 2010).

Domestic rainwater harvesting systems are also simple to install and operate. Their decentralized nature allows owners to benefit from direct management of demand and supply. With support technologies (modern and indigenous), rainwater harvesting is cost-effective, and can release capital in times of disaster. (Stockholm Environment Institute and UNEP, 2009).

31.4 Principal risks and uncertainties

31.4.1 Climate change

Hydrological extremes have increased in the Asia-Pacific as well as around the globe. Countries in the region are expected to be severely affected by increased climate variability. For example, in the Mekong River, the maximum flow is projected to increase by 35–42% in the basin and by 16–19% in the delta. In contrast the minimum flow is estimated to decline by 17–24% in the basin and by 26–29% in the delta, suggesting possible water shortages in the dry season. Heavily populated mega deltas in South-West, East and South-East Asia are expected to be at greatest risk of increased river and coastal floods. The interaction of climate change impacts with rapid development is expected to affect growth, including MDG gains (IPCC, 2007).

In addition to floods and droughts, saltwater intrusion in estuaries is expected to move further inwards. Snow melt and glaciers, as well as rising snow lines, could also be unfavourable for downstream agriculture in South and Central Asia. North-western China is projected to experience a 27% decline in glacier areas. Changes in runoff could impact power output from hydropower generating countries such as Tajikistan and increase demand for agriculture water in arid and semi-arid regions of Asia.

31.4.2 Hotspots

The many threats to water resources paint a complex picture. To better focus and prioritize regional action, ESCAP has identified hotspots of multiple challenges. Hotspots are countries, areas or ecosystems with overlapping challenges of poor access to water and sanitation, deteriorating water quality, limited water availability and increased exposure to climate change and water-related disasters. All or some of these challenges may be of concern (Table 31.6).

As shown in Figure 31.2, countries in South-East Asia are at a crossroads of development. High growth rates provide financing for better water resources management, but development priorities ignore the risks from disaster, climate change and poor household water and sanitation access. Uzbekistan and India are also facing exceptional circumstances because of little preparedness for natural disasters and climate change (India), and unsustainable patter of water use (Uzbekistan). Basic access to sanitation remains a determining concern for Bangladesh.

31.5 Achievements through policy-making

After decades of high economic growth, the region is now facing severe environmental risks. Water insecurity is one manifestation of the unfolding environmental damage. Informed policy-making is the only tool to enhance resilience while sustaining growth.

31.5.1 Policy options

Pricing in costs to the environment

The Asia-Pacific development pattern has relied primarily on cheap natural and human resources. This, however, has created economies that run in two speeds: one of rapid advances in economic performance, and another of persisting poverty and environmental degradation. To promote more balanced growth, prices of production factors need to reflect the real cost, including costs to the environment and ecosystem services. This shift has important implications for water resources management, including expanding time horizons of investment assessment to more adequately incorporate benefits of access to water, sanitation, and wastewater treatment; and factoring environmental costs into water and sanitation service charges. Payments for Ecosystem Services (PES) is one way of determining the value and paying a price for these services (Box 31.1).

Eco-efficient water infrastructure development

Eco-efficient water infrastructure aims to harmonize water infrastructure within the environment and can be envisaged in urban and rural contexts. Eco-efficient urban solutions include river rehabilitation, storm water management, decentralized wastewater treatment, and water re-use and recycling while rural options include modern irrigation practices, decentralized water and sanitation systems, water reuse and re-cycling, as well as rainwater harvesting.

Many countries such as Cambodia, China, Malaysia, and the Republic of Korea have already been pursuing eco-efficient water infrastructure development. Although specific examples of large-scale eco-efficient water infrastructure are difficult to find, some governments are already discussing and integrating these terms in their national planning. Indonesia integrated the eco-efficiency concept into its five-year National Development Plan for 2010–2014, and the Philippines adopted the eco-efficiency dimensions into its Mid-Term National Development Plan.

To support this process, ESCAP has developed eco-efficiency water infrastructure guidelines and completed capacity-building initiatives in several developing countries, including support to the development of guidelines for Eco-efficiency in Water Infrastructure for Buildings in Malaysia, recommended to be implemented in all public sector buildings; the implementation of a pilot project on an ISWM system in the Philippines; and a river rehabilitation programme for a tributary of the Brantas River in Indonesia.

Sustainable consumption and production

Water resources management is shifting from supply-side to demand-side management and this is increasingly recognized in the region. Non-revenue water averages 30% of production in Asian cities, but ranges from 4 to 65% (McIntosh, 2003). Approximately half of this loss is from leaking distribution networks. There are many examples of implementation of demand-side management measures across the region and interest

TABLE 31.6

Basic framework for defining water hotspots

Challenge	Measures available*	Countries at risk
Water availability	Water utilization level (Threat* 1) Index of Water Available for Development (IWAD**) (Threat 2) Water quality (Threats 3 and 4)	Afghanistan, Azerbaijan, Bhutan, Democratic People's Republic of Korea, Georgia, India, Indonesia, Kazakhstan, Kyrgyzstan, Malaysia, Maldives†, Mongolia, Myanmar, Nepal, Pakistan‡, Papua New Guinea, Philippines, Tajikistan, Thailand, Turkmenistan, Uzbekistan‡
Vulnerability and risk	Frequency of floods (Threat 5) Frequency of cyclones (Threat 6) Frequency of droughts (Threat 7) Climate change pattern (Threat 8)	Australia, Bangladesh‡, Cambodia‡, China‡, DPRK, India‡, Indonesia‡, Iran, Kazakhstan‡, Kyrgyzstan, Lao PDR‡, Myanmar, ‡ Malaysia‡, Maldives†, Nepal, Pacific Islands†, Pakistan, Papua New Guinea‡, Philippines‡, Republic of Korea, Sri Lanka, Thailand‡, Timor-Leste‡, Turkmenistan, Uzbekistan‡, Viet Nam‡
Household water adequacy	Access to water (Threat 9) Access to sanitation (Threat 10) Disability adjusted life-years (DALY) from diarrhoea	Afghanistan†, Bangladesh, Cambodia†, China, India, Indonesia, Lao PDR†, Mongolia, Nepal, Pacific Islands, Papua New Guinea†, Timor-Leste
Human development	Life expectancy at birth Inequalities in access People living in poverty	Cambodia, Democratic People's Republic of Korea, Indonesia, Lao PDR, Myanmar, Pacific Islands, Papua New Guinea, Philippines

**. The 'Threat' numbers refer to columns in Figure 31.2 and measures that were actually used to estimate water hotspots.*
***. The Index of Water Available for Development (IWAD) examines the current trends of rapidly increasing water withdrawal in relation to the limited amount of renewable freshwater resources.*
†. Challenges exist in two of the indicated measures. IWAD is defined as an index measuring the balance between the total internal renewable water resources and total water withdrawals in a particular year against the base line of 1980 of this balance.
‡. Challenges exist in more than two of the indicated measures.
Note: Data not used for hotspot identification.
Sources: Compiled from Dilley et al. (2005); ESCAP (2009a).

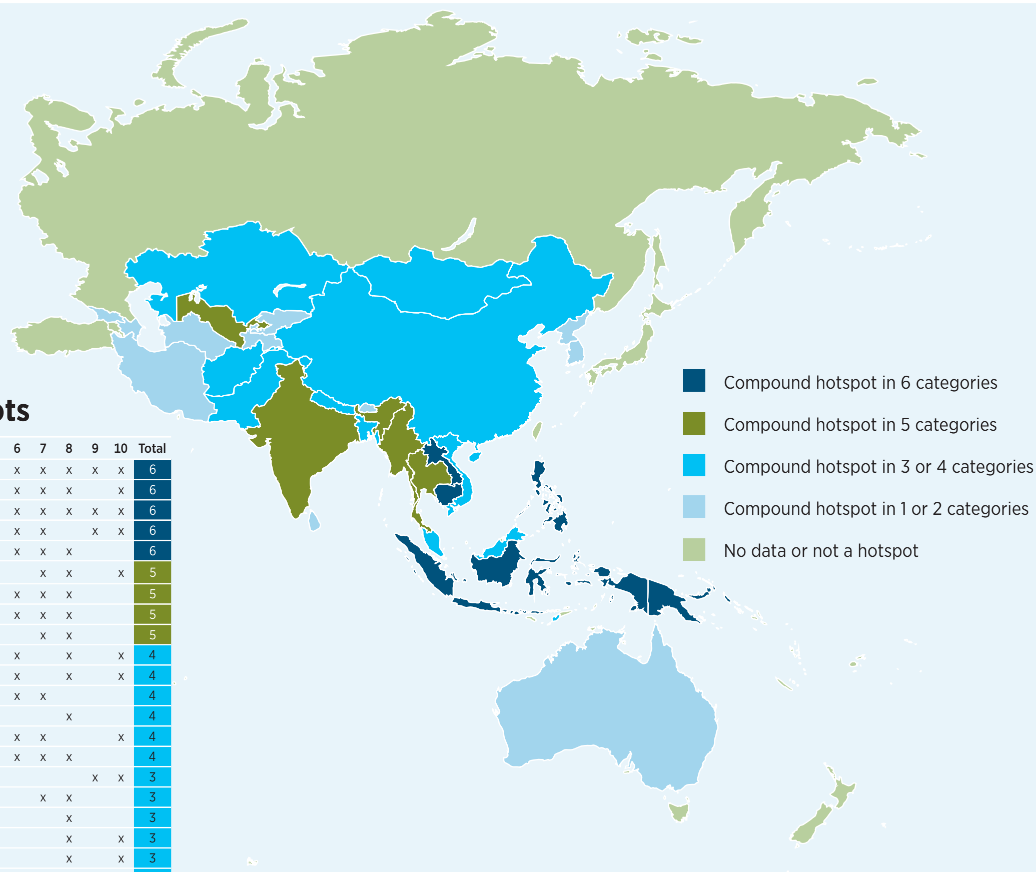
in improving water use efficiency is growing. Bangkok and Manila leak detection programmes have lowered estimated Uncounted-for-Water (UFW), thus postponing the development of new infrastructure (Molle et al., 2009). Since 2008 Sydney Water in Australia has provided homes in the Hoxton Park area with two water supplies: recycled water and drinking water (dual reticulation) (Sydney Water, 2011).

Singapore has reduced urban domestic water demand from 176 L per person a day in 1994 to 157 L in 2007 through the comprehensive policy, based on three principles: voluntary, pricing and mandatory (Kiang, 2008). To apply these principles, several actions were taken: water tariffs and water conservation tax were restructured, maximum allowable flow rates were set, public education and awareness campaigns were launched, and water audits to large customers were implemented as a part of the market-oriented programme to obtain industry feedback. As a result, Singapore now has one of the lowest UFW rates in the world (below 5%) (Kiang, 2008).

In Hamirpur district of India, the Department of Rural Development and the Department of Agriculture have embarked on a programme of Soil and Water Conservation to reduce runoff, create 'high efficiency life-saving irrigation' and promote groundwater

FIGURE 31.2

Asia-Pacific water hotspots



Compound hotspots

	1	2	3	4	5	6	7	8	9	10	Total
Cambodia					x	x	x	x	x	x	6
Indonesia			x		x	x	x	x		x	6
Lao PDR					x	x	x	x	x	x	6
Papua New Guinea				x	x	x	x		x	x	6
Philippines	x		x		x	x	x	x			6
India	x				x		x	x		x	5
Myanmar				x	x	x	x	x			5
Thailand			x		x	x	x	x			5
Uzbekistan	x	x		x			x	x			5
Bangladesh					x	x		x		x	4
China					x	x		x		x	4
Malaysia			x		x	x	x				4
Pakistan	x	x	x					x			4
Timor-Leste					x	x	x			x	4
Viet Nam					x	x	x	x			4
Afghanistan	x								x	x	3
Kazakhstan				x			x	x			3
Maldives	x			x				x			3
Mongolia				x				x		x	3
Nepal				x				x		x	3
Pacific Islands						x		x		x	3
DPRK				x	x						2
Kyrgyzstan				x			x				2
Tajikistan				x			x				2
Turkmenistan				x			x				2
Australia							x				1
Azerbaijan				x							1
Bhutan				x							1
Georgia				x							1
Iran								x			1
Republic of Korea					x						1
Sri Lanka								x			1
Prevalence (countries affected)	6	2	5	14	15	13	17	19	4	12	

Legend

1	Increasing water scarcity threat
2	High water utilization
3	Deteriorating water quality
4	Poor water quality and low water endowment
5	Flood-prone countries
6	Cyclone-prone countries
7	Drought-prone countries
8	Elevated ecosystem/Climate change risk
9	Poor access to drinking water
10	Poor access to sanitation

Sources: Compiled from Dilley et al. (2005); ESCAP (2009a); FAO (2010) (AQUASTAT).

recharge. The goal of the Himachal Pradesh Mid-Himalayan Watershed Development Project is to combine protection of natural resources with rural household income increase. The project also intends to harmonize watershed development projects and policies across the state in accordance with best practices (Asian Development Bank, 2010*b*).

31.5.2 Country responses

BOX 31.1

Payments for Ecosystem Services (PES) in Asia and the Pacific

Innovative policies to support payment for ecosystem services have been established, or are under consideration, in some countries in the region, including Viet Nam, Indonesia, the Philippines and Sri Lanka.

An example of an innovative policy to support payment for ecosystem services is the ecosystem service fee collected from water users by the district water utility on the island of Lombok, Indonesia, as prescribed by local government regulations. A water utility in the water catchment in which the provincial capital of Aceh is located has agreed to pay two local communities for securing the watershed. The fee is paid to targeted communities that can impact water quality and supply and who then have a contractual obligation to sustainably manage their land. Five million Rp will be paid every year, for three years and will be managed by a community forum. The agreement will be expanded if both sides fulfil their commitments and improvements in water quality and quantity are achieved. The result is that water users enjoy cleaner water and more sustainable supply. The payment for ecosystem services mechanism was seen as a way to address escalating conflicts over water use.

ESCAP and the World Wide Fund (WWF) have been supporting action by BAPEDAL (Badan Pengendalian Dampak Lingkungan [Environmental Impact Management Agency]), Aceh to lead a Payments for Ecosystem Services project in Aceh, Indonesia for Nature Aceh programme and other partners. Under this project, a PES arrangement has been agreed to in the Krueng Aceh watershed area and is being implemented. A community forum (FORSAKA) has been established to develop and implement an agreement between the water utility and three communities, under which the water utility will pay for enhanced protection against illegal logging. Sustainable management arrangements will follow in subsequent phases of the project, as trust is built and implementation arrangements are refined. A pilot project in the Krueng Peusangan watershed area is also being developed by WWF (ESCAP, 2009*b*).

Integrated planning approach

Water resources management traditionally has been compartmentalized in government policy-making, with different water users – agriculture, industry, domestic water supply and sanitation, environment – falling in the jurisdiction of different line ministries and institutions. Over the past few decades, the momentum has picked up across the region for introducing and implementing IWRM policies.

An indicative profile report on the current status of IWRM implementation in the region was presented at the 5th World Water Forum held in March 2009. A proposed framework to facilitate IWRM implementation and monitoring at the country level has also been developed (Lee, 2009).

There are many country-specific examples that showcase the importance of IWRM. To address the problem of poor management of water resources and high withdrawal for agricultural needs, Kazakhstan launched a water resources management project in 2008 aiming to strengthen water management organization and institute the practice of IWRM. Stakeholders forums with experts and the public took place to draw feedback from major water users and providers. As a result, River Basin Councils were established in all the eight river basins of the country to implement national water policy (GWP, 2010).

Decentralization and inclusiveness

Decentralization of the planning and decision-making process for water resources management, together with enhancement of public participation is essential for introducing sustainable solutions.

Inclusiveness in decision-making is also a prerequisite for buy-in on water-related policy and investment decision-making. For example, in the state of Victoria, Australia, the Department of Sustainability and Environment in partnership with rural and urban water corporations, catchment management authorities, key regional stakeholders, interest groups and communities has developed long-term sustainable water strategies in the Our Water Our Future action plan. Every strategy aims to secure water for local growth, as well as regulate water systems and protect rivers and other water sources; therefore in each case, water-related risks are evaluated and analysed, and appropriate action is taken (Government of Australia, Department of Sustainability and Environment, 2010).

31.6 Sectoral priorities and regional initiatives

The identification of hotspots revealed that certain water-related challenges are common in Asia-Pacific countries. Among the most prominent challenges are stagnant access to sanitation and sometimes drinking water, deteriorating water quality, and climate-related risks. These sectoral priorities require targeted, urgent action to unblock the developmental deadlock that many countries find themselves in, due to poor water resources management.

31.6.1 Household water security

Meeting the MDG targets remains a priority for the region, but the benefits of access to water and sanitation expand beyond the basic need for life. Adequate water and sanitation are linked to various desirable developmental outcomes, such as healthy ecosystems and productive livelihoods and also linked to GDP growth through increase in tourism, foreign direct investment, labour productivity and agricultural outputs. A study of four South-East Asian countries estimated the total economic benefits of achieving universal access to sanitation at between US$5.4 billion and US$27 billion (Hutton et al., 2008). The narrow definition of access to drinking water and sanitation facilities is thus expanded to accommodate a broader concept of household water security linked to socio-economic development.

Better monitoring and assessment of achievements is required to inform policy-making. The question remains whether recent progress, particularly with respect to water targets, represents a one-time event or a real take-off for the Asia-Pacific.

To improve water and sanitation services in the second largest city in the country, Chittagong, the Government of Bangladesh recently initiated the Chittagong Water Supply Improvement and Sanitation Project with the support from the International Development Association. The project supports institutional development by enhancing the services provided by Chittagong Water Supply and Sewerage Authority and will focus on formulating a sewerage and drainage master plan for Chittagong. The project targets the poor, particularly those in urban slums, where piped distribution networks are not available (WaterWorld, 2010).

Cambodia's Phnom Penh Water Supply Authority (PPWSA) is unlike typical water utilities in Asia. It has an efficient service and an increasing consumer base. With the assistance of external funding agencies, particularly the Asian Development Bank, and through internal reforms, PPWSA transformed itself into an efficient, self-financed, autonomous organization in a city still recovering from many years of war and civil strife. Today, PPWSA is a model public sector water utility that provides drinking water to Phnom Penh 24 hours a day. The main factors behind the Authority's success are streamlining the organization's workforce; improving collection levels (e.g. installing meters for all connections, computerizing the billing system, updating the consumer base, and confronting high-ranking nonpayers and cutting off their water if they refuse to pay); rehabilitating the whole distribution network and the treatment plants; minimizing illegal connections and unaccounted-for water (e.g. setting up inspection teams to stop illegal connections, penalizing those with illegal connections, and giving the public incentives to report illegal connections); and increasing water tariffs to cover maintenance and operating costs by proposing a three-step increase in tariffs over seven years, although the third step was ultimately not required because revenues began to cover costs (Asian Development Bank, 2007).

Sanitation is also increasingly understood as expanding beyond toilets. There is a need for behavioural change and for institutional reforms to address sanitation in its broader interpretation, which includes hygienic disposal of human excreta and grey water management. The momentum of the International Year for Sanitation (2008), for example, urged regional leaders to assert that sanitation improves not just human health (access to toilets), but also environmental health, as domestic wastewater is a major contributor of bacterial contamination to groundwater supplies and rivers across the region (Asian Development Bank, 2010*c*).

Dhaka Water Supply and Sewerage Authority has been implementing the Dhaka Water Supply and Sanitation Project for Bangladesh through rehabilitating and strengthening sewerage systems and stormwater drainage, as well as implementing environmental and social safeguards. It has been also planned to provide local communities with services after strengthening institutional capacity and extending mainstream services (World Bank, 2011*a*).

Governments and international organizations need to work together to generate demand and ultimately willingness to pay for these services. For the poorest, governments need to step in and subsidize a transition to sustainable, adequate, eco-efficient infrastructure. An example of potential demand generation initiative can be found in Cambodia. The Ministry of Rural Development and the Government of Cambodia have acknowledged that the market can play an important role in sanitation improvements. In the new Sanitation Marketing Project (launched in 2009), market forces and demand creation activities have been widely used to install 10,000 toilets in rural village households. Unlike previous projects, the focus is on changing behaviour within communities to create demand for sanitation facilities. As part of the market-based solutions, an affordable and simple latrine core was designed and branded as Easy Latrine, and introduced to the market through local producers. The innovative pour-flush latrine sells for as low as US$25, and producers are receiving training in sanitation and hygiene education, latrine production, and basic business and sales management (Water and Sanitation Program, 2011). An additional example of market creation for water and sanitation activities is the WaterSHED programme (Box 31.2).

31.6.2 Green growth and wastewater revolution in the Asia-Pacific

Water quality in the region is at a critical stage as more wastewater is continuously being released into the natural environment. The wastewater revolution initiative, which was begun and promoted by the UN Secretary-General's Advisory Board on Water and Sanitation's (UNSGAB) with the launching of Hashimoto Action Plan II (HAPII) in late January 2010 looks at the rapidly deteriorating water environment in the Asia-Pacific and the need to revolutionize the way wastewater is being handled and treated.

Recognizing the critical stage of water pollution challenges, ESCAP convened the Regional Dialogue on Wastewater Management in Kuala Lumpur, held on 15–16 June 2010, within the context of eco-efficient water infrastructure development of the Green Growth approach in the region. The Regional Dialogue reviewed regional experiences and issues related to wastewater management and various initiatives and recent developments, including decentralization efforts and advances in technologies.

In Malaysia, the Government has introduced new wastewater regulations. Taking into account shortcomings in the 1979 Regulations, a comprehensive review was initiated and culminated in the enforcement of three new sets of regulations on 10 December 2009: Environmental Quality (Industrial Effluents, Sewage, Control of Pollution from Solid Waste Transfer Station and Landfill) Regulations 2009 (Lee, 2010).

The National Ganga River Basin Authority in India, with the financial support of the World Bank, launched a programme in 2009 to clean the Ganges, to ensure that 'no untreated municipal sewage or industrial effluents would be discharged into the river by 2020'. Previous action plans did not improve the health of the river, in which almost 95% of the pollution is caused by sewers and open drains (World Bank, 2011*b*). This time the governmental approach has moved from a town-centric approach to a broader river basin approach, focussing on strengthening the newly formed National Ganga River Basin Authority, and financing the estimated US$4 billion needed to stop all discharge of untreated sewage and effluent into the Ganges by 2020 (World Bank, 2009).

Finally, the Regional Dialogue recommended support for the Wastewater Revolution in Asia of UNSGAB, to be implemented in collaboration with the Green Growth initiative of ESCAP. The regional initiative was subsequently presented at the Sixth Ministerial Conference on Environment and Development (MCED-6) in 2010, and included the Regional Implementation Plan of the MCED-6 as part of the Astana Green Bridge Initiative of Kazakhstan.

31.6.3 Adapting to climate change

The Asia-Pacific region is home to two-thirds of the world's poor, and as the poor are generally the least resilient to and least prepared for climate change impacts, the region faces challenges in achieving its MDG targets, as well as the potential for some erosion of its past MDG achievements. Despite efforts to understand the extent of climate change impacts, effective adaptation and adaptive capacity in developing Asian countries will continue to be limited by various ecological, social and economic, technical, institutional and political constraints.

To address this multitude of problems, a knowledge hub on climate change was recently established within the framework of the Asia-Pacific Water Forum (APWF) to promote more effective regional cooperation, including more targeted research to identify types of vulnerability, appropriate policies, strategies, and action plans on adaptation. It is expected that the knowledge hub would promote the mainstreaming of these policies and strategies into national development agendas and enhance the needed capacity building.

Bhutan has been developing mitigation and adaptation policies, while incorporating them in strategies for economic growth and national plans. For many years the main tool for mitigation of climate change has been hydropower, which is also the largest driving factor of the country's pro-poor economic growth, as it accounts for 25% of GDP and more than 40% for national revenues. Adaptation strategies have been included in the government's 10th Five-Year Plan (2008–2013) with the special note for potential adverse impacts on hydrological flows for power plants and irrigation, which may affect national energy and food security, and flood hazards, such as glacial lake outburst floods (GLOF). Climate change risks are additionally addressed in the Disaster Risk Management Framework (Asian Development Bank, 2010*a*). Formulation of the Water Act following principles of IWRM has been at the core of these strategies. Despite this effort to address climate change-related risks, Bhutan does not have a comprehensive climate change policy (National Environment Commission Royal Government of Bhutan, UNEP, 2009).

Several globally sponsored adaptation projects were recently initiated in Bhutan. The GLOF Risk Reduction Project focused on the development of a regional GLOF database and risk management strategies in the Himalayan region for climatic and meteorological risk reduction and mitigation (UNDP, 2010). International partners are helping Bhutan reduce GLOF risks arising from climate change in the Punakha-Wangdi and Chamkhar valleys including plans for an early warning system for the Punakha-Wangdi Valley (UNDP, 2011). A midpoint assessment in 2010 showed that mitigation action so far focused on lowering the water levels of the Thorthormi Lake, to reduce the risk of glacial floods in the valley resulting in lowering the water level by 67 cm while the aim is to lower it by 5 m (Meenawat and Sovacool, 2010). Early warning systems have also improved: while previously only one warning station was operated manually by two employees, in 2010 representatives of 21 vulnerable communities were

BOX 31.2

WaterSHED: Using markets to bring water, sanitation, and hygiene to Asia's poor

Water, Sanitation, and Hygiene Enterprise Development (WaterSHED) is a USAID-funded project implemented in Cambodia, Lao People's Democratic republic and Viet Nam as a public–private partnership led by the University of North Carolina at Chapel Hill in the United States. The programme is designed to bring effective, affordable water and sanitation to poor and disadvantaged consumers in Asia. Providing affordable and desirable water and sanitation products increases consumer demand and encourages adequate use among the poor. Using proven market-based principles, WaterSHED leverages the power of private enterprise to bring water, health, and wealth to the poor.

An enterprise development programme supports the market creation initiative. The enterprise development programme focuses on manufacturing, marketing, and distributing household water treatment and storage products, as well as hygiene and sanitation products, such as latrines. This 'business incubator' approach aims to create private, for-profit companies and develop a well-functioning supply chain to ensure programme sustainability long after the development dollars are gone.

The success behind such programmes relies on two main business principles: (a) offering products consumers want at prices based on full cost and (b) selling to local retailers and consumers at full cost, instead of providing free or subsidized products, which can distort the natural business environment.

A second factor of success is building on the existing efforts of nongovernment organizations to develop transformational technologies, provide training and education, and drive demand for clean water solutions. The for-profit business model needs to be driven by sustainability and efficiency rather than being based on permanent donor funding. By creating new distribution channels for clean water products, such as microfranchises, the overall supply chain is strengthened and local entrepreneurs are empowered to determine community-specific needs. Engaging local microfinance institutions is also crucial, as these provide finance options for consumers, allowing for monthly payments (over 12–24 months) on the part of creditworthy borrowers whose cash flow patterns do not allow them to incur a single lump expense.

Through this programme, WaterSHED has provided water filters to over 100,000 people and new latrines to over 25,000. In addition, design innovations include a low-cost aspirational water filter and a low-cost, build-it-yourself latrine costing less than US$100.

Source: Adapted from USAID (2010).

provided with mobile phones to contact national authorities in case of flood events. The replacement of the manual system by gauges and sensors for monitoring glacial lake depth and rivers is planned.

In 2009, India embarked on the National Water Mission as a part of the National Action Plan on Climate Change (2008), identifying several strategies to tackle climate change and achieve water-related goals. The main goals are to create a comprehensive water database and proper public awareness and education campaigns, shift focus on overexploited areas, increase water use efficiency by 20% and promote IWRM on a basin level. Key strategies include regulatory mechanisms with differential entitlements and pricing, promotion of environmentally friendly solutions and behavioural change, efficiency improvement of existing facilities, and implementation of programmes for groundwater recharge (Box 31.3) (Government of India, Ministry of Water Resources, 2011).

Notes

1 The views expressed herein are those of the authors and do not necessarily reflect the views of the United Nations.

2 Affected by the oceanic air current in summer and controlled by the continental air current in winter, resulting in dry winter and wet summer.

3 Kazakhstan is a very low performer in all categories, possibly because of the scarce and limited data provided through the survey.

4 For the purpose of this analysis, conflict is not limited to armed conflict, but includes all water-related disputes that have necessitated mediation. Whether violent or not, these disputes have threatened the stability of the socio-economic development process.

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CHAPTER 32

Latin America and the Caribbean

UNECLAC

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till taught by pain, Men really know not what good Water's worth
— *Don Juan*, Lord Byron

There is a long tradition of water management in Latin America and the Caribbean, and it has gone through many changes. In the 1960s and 1970s, water resources development was among the leading development priorities with projects such as dams for hydroelectricity generation and irrigation.[1] These developments slowed with the serious economic crisis that affected most countries in the 1980s. More recently the emphasis in water management has changed as the priorities of governments have changed. The focus of the governments of the countries of the region is now primarily on fulfilling the Millennium Development Goals (MDGs) for the reduction of poverty, which for water management translates to a concentration on improvements in drinking water supply and sanitation, as exemplified by such major projects as the Water for All Programme in Peru. Water supply and sanitation are not, however, the only concern: there is a growing preoccupation with improving water governance as well with strengthening the role of water management in environmental protection. The concern for governance, in particular, is based on the perception that water management remains fragmented and inadequate and this could jeopardize progress in the reduction of poverty and in the achievement of sustainable development.

As in almost every other area of economic activity and social conditions, there are both marked contrasts as well as many commonalities in the water sectors of the countries of the region. Commonality can be seen in the advances that have occurred in water management in all countries, and in the fact that these advances have not yet translated into universal increases in water use efficiency, any overall change in the levels of water quality, or region-wide sustained increases in the contribution of water to social and economic development. Local advances can be observed in many aspects of water management. A few countries have undertaken large-scale reforms of their water management institutions, notably Mexico and Brazil, but these efforts have so far had only partial success.[2]

The main issues facing the countries of the region in water management have not changed significantly over the last two decades. There has been a widespread inability to establish institutions that are able to deal with water allocation issues under conditions of scarcity and conflict. Various segments of the water sector still exhibit many examples of poor management, and there is a general absence of self-financing and a consequent dependence on fluctuating political support. In general, there is an inability to respond to crises. Despite much improvement, reliable information is often missing, including on the resource itself, on the infrastructure, on institutional responsibilities, and especially on water uses and users and on future needs.

Contrasts also abound in the region, however, and are not just due to variations in climate and hydrology or to the scale at which water management must operate – Brazil is 10,000 times the area of Dominica, for example. Equally or more so the contrasts are due to differences in the nature, stability and potency of institutional systems, dissimilarities in the distribution and demographic structure of the population, and sizeable variations in levels of income. Some impressive advances in specific water management activities – such as the substantial, sustainable and nationwide development of urban water supply, sewerage and wastewater treatment in Chile – have also contributed to the differences among the countries.

The issues that water management in Latin America and the Caribbean has had to confront do not all come from within the 'water box'. There have always been strong external drivers or forces affecting both the water resource and its management. The more significant of these come from general social change, but they also include macroeconomic policies, often a negative influence, stemming from abrupt changes in domestic policies and from outside (such as the global financial crisis of 2008–2009), but they are sometimes positive: macroeconomic administration has improved domestically and globally, as with the recent expansion of participation in world markets and adoption of countercyclical macroeconomic policies. Political instability – for example the turmoil in Honduras in 2009 – can hamper the sustainability of water management policies. There are also important, if subtle, pressures on the sector produced by gradual economic and social change that can produce issues difficult for water managers to resolve. Extreme climatic events, especially hurricanes in the Caribbean, have long had a negative influence on water management, particularly the destruction of infrastructure. Recently, the complex of uncertainties related to and derived from climate change has become a looming challenge.

This chapter will examine the risks, uncertainties and opportunities offered by the most important contemporary external drivers, as well as focus on a number of areas of particular concern within water management itself. The examination will be illustrated by references to both positive and negative experiences in the region.

32.1 External drivers and their effects

Only those external influences or drivers with the most significant influence on water management are discussed here. Naturally, there are others that may have influence on occasion – particularly events stemming from the endemic political instability in many countries. A more permanent negative driver is the inefficiency and weakness in the wider public sector, which can hamper seriously even well-planned and well-managed water management policies and projects. The influence of the state of the wider public sector can be seen in many of the examples of innovative policies and programmes cited here.

32.1.1 The changing economic and social environment

Obviously, there are consequences for water use and the demand placed on the water resource as the economic and social environment, in which water management is immersed, changes. The influence of economic and social change goes beyond the short-term effect of global financial crises, such as that of 2008–2009, and national crises, such as the Mexican peso crisis of 1994 or the collapse of the Argentinean economy in 2001 (Klein and Coutiño, 1996). Crises can and do interrupt ongoing programmes, but they rarely have more than short-term consequences. Of more far-reaching influence has been the historical volatility in the rates of economic growth in the region (Figure 32.1).

Fortunately, volatility has markedly lessened recently and the trend in rates of growth has been positive. The greater stability in the general economy has permitted more sustainable water management, but also has resulted in the emergence of new demands for water-related services as growth has wrought notable changes in the economic and social structure of Latin American and Caribbean societies. The growth and greater stability in the economies of the countries of the region has caused many apparently disparate changes in demand for water services, such as that for tourism in the Caribbean and for energy almost everywhere, both of which tend to be closely related to per capita income within the countries themselves and in the rest of the world.

Poverty and the related unequal distribution of income remain unresolved issues in all countries of Latin America and in most of those of the English-speaking Caribbean. Although one-third of the population is estimated to still be living in poverty – some 180 million people – the average rates of poverty have fallen steadily over the past 20 years (ECLAC, 2009*c*). Less progress has been made in reducing income inequality. The water resource sector has a major role to play in poverty reduction programmes through the provision of drinking water supply and sanitation services, which governments have increasingly recognized. Demands for improved services can be expected to continue to increase between now and 2015 as the countries of the region attempt to meet the MDGs for poverty reduction.

As levels of poverty have declined there has been a large increase in that part of the population that can be considered to be middle class due to increasing

FIGURE 32.1

Latin America and the Caribbean: GDP at constant 2005 prices, 1951–2010 (variation rates)

Source: From ECLAC CEPALSTAT ((http://www.eclac.cl/estadisticas, accessed in 2011).

levels of income and some improvement in the very unequal income distribution characteristic of the region.[3] One consequence of this emergence of a larger middle class has been the increasing demands to give more emphasis to the resolution of environmental issues, illustrated by the controversies arising from dam construction or over the construction of pulp mills on the River Uruguay. There are a number of examples in the region related to the increasing concern for the social and environmental repercussions of water projects, particularly the construction of large hydroelectricity generation plants, such as the controversies surrounding the decision of the Brazilian government to approve the building of the Belo Monte Dam on the Xingu tributary of the Amazon and over the proposed construction of hydroelectricity generation plants in the Río Baker basin in Chile.[4] Overall, there has been an abandonment of reservoir-based hydroelectricity generation plants in favour of run-of-the-river plants.

A subtler example of the influence of rising expectations among the new middle class can be deduced from the popular acceptance in Chile of a very significant increase in water supply and sewerage tariffs. Tariffs were increased substantially following the decision of the government to place greater emphasis on health and environmental concerns as well as to protect the export of agricultural products through the development of an ambitious programme for the treatment of domestic sewage discharges. By 2010, almost 90% of urban sewage was receiving treatment (SISS, 2011).

32.1.2 External demands for natural resources

With the exceptions of Mexico and some of the small countries of Central America, the countries of Latin America base their economies on the export of natural resources. The global demand for these products, whether minerals, food crops or other agricultural products, timber, fish or tourism, has increased notably in recent years. Moreover, much of the production of these goods and services is financed by external capital and many of the facilities are foreign owned. The result is that the major engine of economic growth in the region, with heavy demands on the water resource, is subject to factors outside the direct control of the governments of the countries of the region. This is so even when the producing companies are locally owned, as it is the world markets that determine demand.

For water management, the dependence on natural resources is complicated by the physical location of many of the activities to obtain them. For example, the expansion of copper and gold mining in Chile and Peru has mainly occurred in arid areas and has led to competition for scarce water resources both with export agriculture dependent on irrigation, and with the needs of the indigenous population. Tourism demand has increased water stress on many Caribbean islands as tourists consume far more water than local residents. Coffee production uses large quantities of water and can seriously affect water quality. One potential future demand for irrigation could come from the production of biofuels. However, in Brazil, the only current significant producer in the region,[5] sugar cane production is rain fed and only 3.5% of irrigation demand at present is used for biofuel production (de Fraiture et al., 2008).

The uncertainty in the level of demands of the global market and the changing nature of these demands have always considerably complicated water management decision-making in the region as local economies expand and contract according to the demands of the global economy.

32.1.3 Macroeconomic policies

'Macroeconomic policy has a pervasive influence on the structure of incentives and performance in the entire water sector' (Donoso and Melo, 2004, p. 4): this has been very evident in the countries of Latin America and the Caribbean. For example, high rates of inflation can destroy any attempts to develop effective charging systems for water use or to protect water quality.

Successful macroeconomic policies leading to high rates of growth, as in Chile in the 1990s and in Argentina and Peru more recently, also impose challenges on water managers as new demands can emerge more rapidly than water management policies can be adapted.

At the same time, rapid economic growth offers many opportunities. Strong water institutions can attract investment not just for expansion of and improvement in water-related infrastructure, but also for water management itself. There are examples of this in Brazil, Mexico and Chile where, as the respective economies have grown, the political decision has been taken to strengthen water management institutions.

What is required most of all, however, is not just periods of economic growth, but stability in policies over time. Many water management programmes can take decades to mature. For example, the current urban drinking water supply and sanitation system in Chile grew out of decisions taken in the mid-1970s, and the regional environmental authorities (CARs) in Colombia were first created in 1961.

32.1.4 Social policies

In recent years most governments in Latin America and the Caribbean have placed great stress on improving the social conditions of their populations. The programmes and projects carried out under their policies are of the most diverse nature, but many have direct bearing on water management and on decisions made within the water sector. This is obvious with the recent stress on policies to increase the provision of drinking water supply and sanitation services. However, it is not always obvious what the impact of any set of social polices might be. For example, efforts to extend coverage of drinking water supply and sanitation may raise issues related to water quality at both ends of the pipe. The need can arise to protect all water sources – whether streams and lakes or groundwater – while at the same time there is the need to protect drinking water sources from pollution caused by the disposal of untreated wastewaters. This is, perhaps, a fairly obvious external driver on water management. An example of a less obvious driver is the results of the improvement in living standards. In resort areas close to major population centres, this has generated both increased wastewater flows and demands for greater pollution control. Protecting popular beaches from pollution has driven a number of decisions to develop sewage treatment, including the Clean Beaches programme in Mexico (CONAGUA, 2009). In Uruguay, protecting beaches of the La Plata estuary was a major driver of the decision to build sewage treatment plants in Montevideo (IDB, 2010).

Housing policies too can provide a different kind of boost for the water sector. Improving housing means not only providing drinking water and sanitation, but can also lead to the adoption of programmes to control urban flooding in the new residential areas. Urban flooding remains a perennial problem in all large urban areas in Latin America, often worsened by the building of informal residential developments in flood-prone areas sometimes in areas set aside for flood mitigation.

32.1.5 Extreme events and climate change

Any impact of climate change on the water resources will be conditioned by their abundance in Latin America and the Caribbean. About 35% of the world's continental waters (freshwater) are found in the region, but the distribution within and across countries is highly variable. Many areas (e.g. northern Mexico, North eastern Brazil, coastal Peru, northern Chile) have great difficulty meeting their water needs. Moreover, large portions of Argentina, Bolivia, Chile, Peru, north eastern Brazil, Ecuador, Colombia, and central and northern Mexico are semi-arid and subject to wide variations in rainfall. Often, as in Peru, much of the population and economic activity is concentrated in water-scarce areas. For the region as a whole it is estimated that 30% of the population live in arid or semi-arid areas.

Water managers in Latin America and the Caribbean have long faced the challenges posed by increased climate variability and change and related extreme events, such as the extreme events recurrent in Haiti and the annual havoc caused by hurricanes in the Caribbean, Central America and Mexico.

Examples include tackling the problems associated with El Niño/La Niña-Southern Oscillation (ENSO) events in Peru and with the cycle of dry and wet years in the drought polygon of North Eastern Brazil, dominated by a large semi-arid expanse, the *sertão*, which encompasses about 900,000 km^2. The *sertão* is subject to recurrent droughts, which are often followed by floods. These events may not affect the entire semi-arid region at any one time, but have been of sufficient recurrence, intensity and magnitude to warrant permanent protective policies and programmes, not just emergency measures.

32.1.6 Demographic change

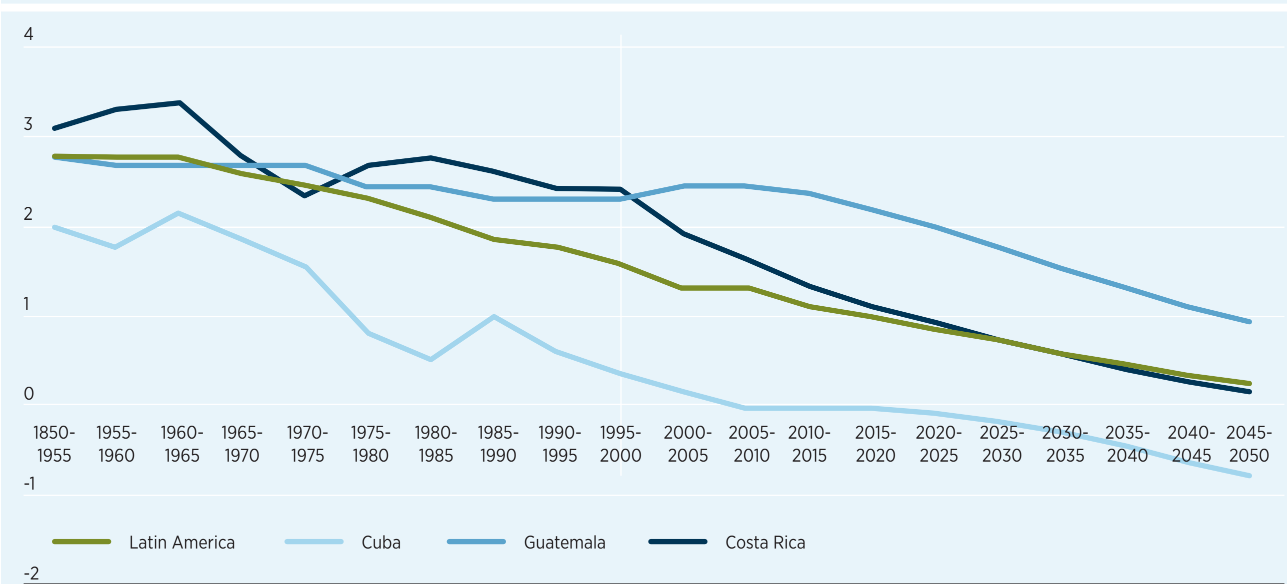
The countries of Latin America and the Caribbean are going through a new period of rapid demographic change. Following the great migration to the cities in the 1960s and 1970s, the last major demographic event, the main characteristic of the current demographic situation in the region is a rapid decline in birth rates resulting in a rapidly slowing rate of population growth: 1.3% in the 1980s and expected to fall to a rate, for Latin America as a whole, of less than 0.5% by 2050 (Figure 32.2). The region has a relatively clean energy matrix due to its high share of hydroelectricity, which at 11% of total primary energy supply almost doubles the world average. In terms of carbon dioxide emissions from fossil fuel combustion per capita, Latin America and the Caribbean is still four times bellow the OECD average and less than half that of China although slightly above the level of India. The decline is so great that if current trends continue, the population will begin to fall absolutely in some countries, notably in Cuba and Uruguay (CELADE, 2007).

The decline in birth rates also means that, even if the total national population remains stable, many regions will lose population, especially rural and isolated ones. Maintaining services for smaller populations raises new issues. In the case of water supply and sewerage it can also mean that facilities may end up over-designed, hampering their operations and undermining financial stability.

The fall in birth rates has been accompanied recently by an even faster increase in longevity. It is estimated that the number of people over the age of

FIGURE 32.2

Annual average rate of population growth for Latin America and selected single countries (1950–2050)



Source: CELADE (2009).

65 in Latin America and the Caribbean will triple by 2050 (CELADE, 2007); again, this can be expected to change the nature of the demand for many services related to water, such as increased recreational demands and lower water supply demands as a higher proportion of the population live in apartment complexes.

Latin America is already the world's most urbanized developing region, with more than 80% of the population living in towns and cities (ECLAC, 2010). There has been a massive shift of population from rural to urban areas and increasingly large inter-city migratory flows, resulting in the establishment of an urban system characterized by a high percentage of large cities (with more than one million inhabitants) and by a high concentration of the population in some countries living in the largest (or two largest) cities. However, urbanization is not the only significant characteristic of changes in the spatial distribution of the population. There has also been the progressive – and sometimes aggressive – settlement of what has historically been sparsely populated land in the heart of the region, particularly in the Amazon and Orinoco river basins. These changes have played their part in the new priorities of the governments of the region. The emphasis on urban water problems has arisen from the heavy weight of the urban populations in the political process and, in general, their more active role in politics. In Brazil, the growing economic importance of settlements in the Amazon basin is playing and expected to continue to play a crucial role in the policies adopted towards the development of the basin. In fact, the die has probably been already cast in the decision between development and conservation to the advantage of the former, as the rate of growth of population in the basin accelerates.

BOX 32.1

Latin America and the Caribbean and the global financial crisis

Given the magnitude of the global financial crisis, the Latin American and Caribbean region has not been spared its impacts. Yet this crisis has differed from those the region has experienced in the past, not only because the epicentre lay in developed countries, although this played no small part in accounting for recent economic trends, but, above all, because of the juncture at which the crisis broke out in the region and how the region was affected. The combination of highly favourable external conditions and more prudent management of macroeconomic policy have enabled the region to reduce its outstanding debt and to renegotiate it on advantageous terms, while also building up international reserves. The Latin American economies thus went into the crisis with unprecedented liquidity and solvency. The countries' financial systems have not deteriorated and there has been no flight from local currencies, which has helped to maintain calm in the region's currency markets. However, a number of Caribbean countries are carrying hefty external debts and facing rather more complex exchange rate situations. Also unlike the situation during previous crises, the broadened macroeconomic policy space in many of the region's countries has given them substantial capacity for anti-crisis policy-making.

Although poverty levels in the region have remained high, and the impact of the crisis on social variables was predictably negative, the deterioration was not as great as had initially been projected. The rise in social spending in the past few years and the increase in the number and effectiveness of social programmes played an important role in containing the social costs of the crisis. Learning the lessons from previous crises, the countries in the region have sought to maintain – and expand – the coverage of these programmes, even in the context of a gradually tightening fiscal space.

Source: ECLAC (2009b).

32.2 Risks, uncertainties and opportunities

The most significant risks and uncertainties facing water management in Latin America and the Caribbean appear likely to stem from global economic events, climate change and domestic demands for continuing improvement in the provision of water services – all three will provide significant challenges for water managers and decision makers in the broader frames alike. Moreover, there is a complex inter-relationship among them. One obvious example: global economic events will play a large part in guiding development and associated domestic prosperity (or not) in the countries of the region which, in turn, through changes in income, will influence the demands for water-related goods and services, and consequently water management. Another example: climate change will introduce a basket of unexpected factors – directly through its impact on the water resource and indirectly through its influence on many aspects of the economy.

32.2.1 Global economic events

The recent global financial crisis noticeably affected the economies of the countries in the region, but compared with similar occurrences in the recent past, the countries withstood the problems well (Box 32.1). Moreover, the economies are now recuperating fairly rapidly and seem set to resume the period of rapid expansion that the crisis interrupted. This will provide a positive environment for investment in the region. This investment, given the structure of the economies of the countries of Latin America and the Caribbean, will increase water demands. In continental Latin America, however, overall demand on the regions' water resources remains low and spatially very concentrated. It is estimated that water abstractions amount to only about 1% of available water; in contrast, in the Caribbean, 14% of the available water is abstracted. This compares with a world average of some 9% (United Nations, 2010). However, there are significant restrictions on access to this abundance, as the location of the population and economic activities in the region does not coincide with plentiful water sources: approximately one-third of the population live in arid and semi-arid areas.

The Copiapo valley in northern Chile provides an example of the potential conflicts that can arise from large-scale investments related to serving global markets in areas of water scarcity. This is a region that produces large volumes of export crops, particularly table grapes, but at the same time the valley is the site of an increasing number of copper and other mines. The surface waters of the valley have long been committed and increasing reliance is placed on groundwater. The result has been the drilling of increasingly deeper wells by the fruit farmers and consequently the mining of the groundwater as rates of extraction have exceeded any capacity for recharge (*El Mercurio*, 2010). This problem has arisen despite the generally high level of governance in Chile and the existence of water markets. Deficiencies in the definition of water rights and weakness of water management institutions, have contributed to the current over-exploitation of water resources in the region.

32.2.2 Climate change

The region makes only a minor contribution to global greenhouse gas emissions (GHG): in 2008, Latin America and the Caribbean accounted for 8.6% of the world's population, 8.2% of global gross domestic product (GDP) and 7.6% of global GHG emissions, excluding those from changes in land use (Figure 32.3). However, on a per capita basis and when emissions from land use changes are included, the region contributes more GHG emissions than do all other developing countries, including China and India. The main source of emissions comes from deforestation, accounting for almost half of total emissions (WRI, 2009). Vast forest areas, equivalent to 4 million hectares per year since 2000, are being lost in the region as the agricultural frontier expands, and many forest areas remain under threat despite the efforts that are being made to control deforestation (FAO, 2010). Efforts to address changes in land use and reduce the emissions from deforestation are a priority for the region as a contribution to the global effort to reduce greenhouse gases.

At the same time, many parts of the region are highly vulnerable to the adverse consequences of climate change, and climate change threatens the progress made in recent decades in development and in the achievement of the MDGs.

The countries estimated to be in areas of high or extreme risk from global climate change are often the poorest countries of the region – those in Central America, the Caribbean and the Andes. It is in these countries with relatively weak water management capacities that the greatest challenges will be faced.

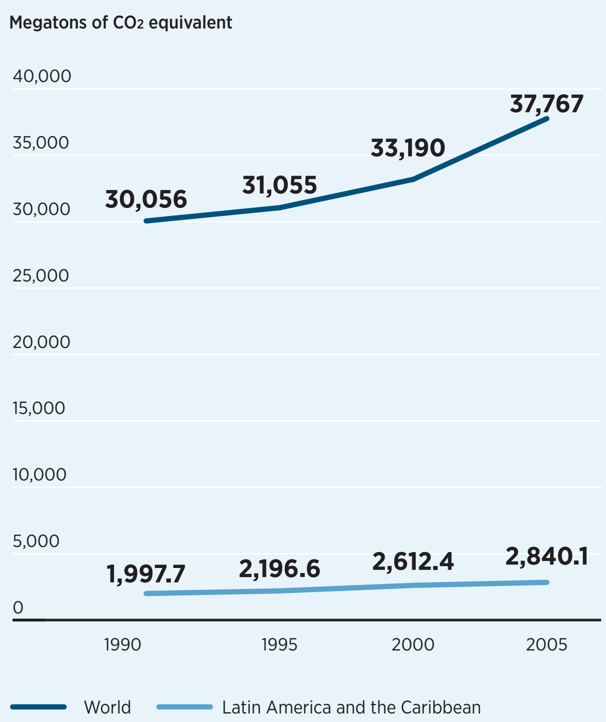
The most serious challenges arising from climate change for the management of water resources in Latin America and the Caribbean can be expected to lie in the following areas:

- Significant deterioration in the quality, quantity and availability of water for all uses in many areas.
- Damage to coastal areas owing to a potential rise in sea levels, which in turn will affect river regimes.
- Increased economic damage from the greater intensity and frequency of hurricanes and tropical storms due to higher ocean surface and air temperatures (ECLAC/IDB, 2010).

Climate change will also bring significant opportunities for the wider application of imaginative innovations in many aspects of water management, particularly in hydrometeorology. There are already examples of successful innovation, such as the development of a national meteorological system providing local forecasts specifically directed at agriculture in Chile, and the use of weather forecasts in Peru to counteract the negative

FIGURE 32.3

Greenhouse gas emissions from Latin America and the Caribbean as a share of the global total (1990–2005)



Note: Emissions include CO_2, CH_4, SF_6, N_2O, PFCs and HFCs, but exclude those from land use changes.
Source: WRI (2009).

consequences of El Niño events (Box 32.2). While, as yet, there is little sign of major changes in water management policies in Latin America because of the perceived consequences of climate change, there is more realization of the potential negative effects among the governments of the islands of the Caribbean and Andean countries, as in Bolivia and Peru, particularly in relation to urban water supply.

32.2.3 The demand for better water management

It is very likely, given the economic and social environment in many countries of the region, that pressure to improve water management as a result of changing social priorities and alterations in patterns of water availability and use will increase. New demands and priorities can be expected to arise, including the need to protect the increased investment in urban infrastructure from flooding; improve the efficiency of water use in irrigation farming; address the greater use of water resources for recreation; respond to awareness of environmental issues and conflicts over greener energy and construction of dams; and improve water pollution control. Many countries are discussing the reform of water laws, some have already changed them or adopted new ones (as for e.g. Brazil, Chile, Honduras, Mexico, Nicaragua, Peru and Paraguay), virtually all have reformed drinking water supply and sanitation sector legislation, and some are modifying it again. Only in few cases have these changes already produced extensive innovation in practice (Solanes and Jouravelev, 2006).

Rising expectations for better water management create risks and pose challenges, but also offer great opportunities. In many areas, there has been noticeable improvement in irrigation efficiency, as the area under irrigation has slowed its expansion, through the adoption of advanced irrigation techniques (drip irrigation, for example) and the use of new crop varieties that demand less water; however, more than 95% of the cultivated area remains under surface irrigation (FAO, 2009). There remains, therefore, much room for better, more efficient irrigation. This is especially so given the intention announced by a number of countries to play a major role in satisfying the increased global demands for food and biofuels.

Water issues are not well understood by the public at large. Prominent examples of improved water management, such as the construction of large dams in the 1960s and 1970s or the recent clean-up of the Mapocho River in Santiago, Chile, have not been sufficient to raise public awareness of the importance of water management over the long term.

Traditionally, there has been a widespread political interference in water management affecting even technical decisions. There are favourable signs of attempts to isolate water institutions from political interference as seen in the institutional design of the National Water Agency (ANA) in Brazil.

32.3 Areas of particular concern

Within Latin America and the Caribbean, there are major areas of concern that affect all countries in the region and touch on all issues likely to face the water sector in the near future, but there are also geographical areas with their own particular water management scenarios. Some of these follow.

BOX 32.2

Use of weather forecasts in Peru

In Peru, since 1983, forecasts of the upcoming rainy season have been issued each November based on observations of wind and water temperatures in the tropical Pacific region and the output of numerical prediction models.

Once the forecast is issued, farmer representatives and government officials meet to decide the appropriate combination of crops to sow to maximize the overall yield. Rice and cotton, two of the primary crops grown in northern Peru, are highly sensitive to the quantities and timing of rainfall. Rice thrives on wet conditions during the growing season followed by drier conditions during the ripening phase. Cotton, with its deeper root system, can tolerate drier weather. Hence, a forecast of El Niño weather might induce farmers to switch from rice to cotton or vice versa.

Source: NOAA (2010).

- Around 80% of the population of Latin America and the Caribbean lives in cities and almost half in cities of more than one million inhabitants. Many of these large urban conglomerations have precarious drinking water supply and sewerage networks and nearly all lack sewage treatment. There is also little regulation or control of industrial waste discharges and many urban areas are subject to episodic flooding.
- The poorer countries of Central America, many of the smaller islands of the Caribbean, and Bolivia and Paraguay face grave problems of water management and are among the most exposed to the negative consequences of climate change. They tend to have only a limited capacity to respond to challenges due to weak institutions and a lack of financial resources and trained personnel.
- Latin America and the Caribbean is the world's most humid region, but, as already mentioned, there are large arid and semi-arid areas in northern Mexico, Peru, Chile, Argentina and Northern Brazil that will likely be the most susceptible to any negative repercussions from climate change.
- The shrinking of glaciers and the reduction of available water resources represent a major concern for the Andean countries. This will have considerable effects on the region's water sources, hydroelectric power and agriculture, as well as the conservation of natural ecosystems – in the Amazon in particular.

32.3.1 Improving water governance

The Economic Commission for Latin America and the Caribbean (ECLAC) has long maintained that any 'reference to a water shortage in our region in the absolute physical sense is not very appropriate … There is no denying, however, that water management systems are often poorly organised if not non-existent' (ECLAC, 1997, p. 1), so that in Latin America and the Caribbean the 'water crisis' is more an institutional one than one of water scarcity (ECLAC, 2001). All the countries of the region will continue to face constant challenges in water management and, therefore, need to find legislative and institutional answers that can help prevent and resolve growing conflicts over water use, as well as mitigate extreme natural phenomena. Regional associations and the interaction of motivated and informed professional groups may prove decisive in improving sector governance problems and in giving technical viability to proposals for change. Fundamental is the dissemination and opening up of the debate to the public and a wide range of decision-makers. In Brazil, the discussion process leading to the National Water Act of 1997 was opened to different sectors of society. Organizations of water professionals played a key role in leading the discussion (Porto et al., 1999). For instance, the Brazilian Water Resources Association produced formal statements, approved by its members that helped introduce novel concepts into the discussion of the law. The Brazilian example shows the significance of the existence of a basic consensus if solid progress is to be made in governance.

It can be very difficult to implement reform even when it receives widespread political support and is legally enforced. For example, in Brazil, one of the central features of the 1997 water law was establishing user fees for water use, but these are not being collected on a regular basis (Benjamin et al., 2005); in Colombia, the collection of fees from polluters by CARs has been hampered by the reluctance of municipalities to pay; and in Mexico, few of the new river basin agencies created under the *National Water Law* of 2004 are fully functioning.

Poor governance in many countries of Latin America and the Caribbean runs from the top to the bottom of the sector. It is not restricted to the management of the water resource but is rife in the management of most water-based services (Solanes and Jouravlev, 2006).

A serious constraint on improving management stems from the absence of any large-scale formal education for water management at either the university or technical level. There is a plentiful supply of well-educated water professionals in most fields of a more technical nature and many courses in almost all countries to prepare them. However, there is little offered for the formation of professionals with a wider and integrated view of the water management process. The training of professionals with such skills remains largely a process of learning through experience. There have been a number of attempts by international agencies, including ECLAC, to establish water management training programmes, but these have tended to be short lived. A number of institutions, such as the Tropical Agricultural Research and Higher Education Center (CATIE) in Costa Rica, offer regular short courses to reinforce the work experience of water management professions, but these by their very nature can only offer a relatively general review of the knowledge available. A few universities do offer programmes, for example, the masters' degree in integrated river basin management at the University of Querétaro in Mexico and the similar degree programme at the Universidad de La Plata, Argentina. A growing number of Latin American professionals have studied the concepts and skills of integrated river basin management outside the region, but any regular and accessible means of obtaining the necessary knowledge within the countries of Latin America is still absent.

32.3.2 Water supply and sanitation

Over the past two decades there has been a slow but steady increase in most countries of Latin America and the Caribbean in the provision of both drinking water and sanitation. By 2008, piped water supply was available to more than 90% of the urban population and almost 60% of the rural population, exceeding the MDGs at the regional level (WHO/UNICEF, 2010). These aggregate statistics, however, do not show the variations in the quality of the services. In many countries, water supply and sanitation services are plagued by what has been defined as a vicious circle of low quality. Political interference, poor management and low tariffs all conspire to produce low levels of coverage, low quality services and poor maintenance leading to constant interruptions in supply, as well as periods of low pressure leading to contamination within the drinking water supply system. A large number of wastewater treatment plants have been abandoned or function precariously. All produce a high level of dissatisfaction in the populations served (Corrales, 2004).

The overall national statistics also hide the large regional variations in access within countries. For example, in central and southern Mexico, Honduras and Nicaragua, there are many municipalities where less than 10% of the population has access to drinking water. In water supply and sanitation, the definition of what constitutes improved access, used in compiling international statistics, is very general and lax, so the published statistics provide little guidance to the real situation in many countries of the region (ECLAC, 1999; Jouravlev, 2009; United Nations, 2010).

Undeniably, there has been an expansion of water supply and sewerage networks in most countries, but this in turn has brought to the fore other issues.[6] It is estimated for the region as a whole that at most only 28% of sewage is treated before discharge - which constitutes very significant progress in comparison with the situation of only a decade or two ago - leading to serious contamination of watercourses, including the sea, from both sewage outfalls and industrial discharges from urban areas (Lentini, 2008). Too often the introduction of measures to control pollution has produced mixed results due to political and technical complexity. For example, it is not clear that the introduction of charges for wastewater discharges in Colombia has been the sole or the main determining factor in reducing water pollution (Box 32.3).

There remain many problems to be resolved in water supply and sanitation, including the recurring issue of the failure to ensure adequate and sustainable financing for utilities, so that any gains in provision are negated, or at least reduced, by lack of maintenance and through low levels of operating efficiency. Lack of maintenance leads to large losses in piped water systems; for example, in Cuba, losses in distribution are estimated to amount to at least half the water leaving the treatment plants (Business News Americas, 2010). Even in Chile, few systems have unaccounted for water under 30 % (SISS, 2011).

32.3.3 Climate change and natural hazards

According to a recent ECLAC study, between 1970 and 2008 extreme hydro-meteorological events likely to be exacerbated by climate change (storms, floods, drought, landslides, extreme temperatures and forest fires) cost the region over US$80 billion (Samaniego, 2009). If the region fails to take action to mitigate the impact of extreme events, many of which are water related, costs could rise to as high as US$250 billion in 2100 or 1% of the regional GDP (ECLAC/IDB, 2010).

Estimates of what repercussions climate change may have on economic activity vary widely and depend crucially on factors such as the discount rate applied to estimates of future costs, the sectors considered, and the methodology and assumptions used in developing climate scenarios. The Intergovernmental Panel on Climate Change (IPCC) estimates that freshwater systems in Latin America and the Caribbean are potentially very sensitive to climate change and vulnerable to inter-annual fluctuations in climate, such as those associated with the ENSO phenomenon.

BOX 32.3

The Colombian experience with wastewater discharge fees

Various regional authorities in Colombia have used discharge fees for more than 30 years, but it was Law 99 of 1993 that established the present national discharge fee system. It mandated the 33 regional environmental authorities (CARs) to develop comprehensive inventories of all organic waste discharges and to estimate baseline quantities. Each CAR was to map major basins and set five-year targets for reduction in discharges and then charge each polluter a fee for each unit discharged.

Despite the efforts of the environmental ministry the implementation of the programme encountered a number of obstacles:

- Only nine of the CARs had fully implemented the programme by 2003 and eleven had not even begun to collect fees
- On average only half of the dischargers were being charged
- Fee collection rates were low: on average, only 27% were collected
- There was consistent non-compliance by municipal sewage agencies, which caused many basins to be unable to meet reduction targets

Even with these problems, between 1997 and 2003 discharges dropped significantly in many river basins. The reasons for this seem to have been the existing pollution controls based on a command and control approach; the need to catalogue dischargers; the fact that the programme demanded greater transparency and accountability; and the fact that the CARs kept the fees, which gave them an economic incentive to make the programme work.

Source: Blackman (2006).

Excess rainfall is already a common problem, particularly in Central America and the Caribbean, which are subject to tropical storm and hurricane events. One specific issue that plagues most large metropolitan areas is flooding due to the lack of storm sewers, except in the older central parts of cities. In Rio de Janeiro, Brazil, more than 200 people died as a result of a rainfall induced landslide in March 2010. But flooding is a severe problem even in relatively flat cities, such as Buenos Aires, Argentina. If climate change leads to higher rainfall or more concentrated storms, urban flooding can only become more common and more costly.

The ability of water management to react to the challenge of climate change will be hampered by the inadequate hydrological and meteorological observation networks of most countries in Latin America and the Caribbean. Large, sparsely or uninhabited areas have no surface observation systems, and the densities and operational practices of existing networks – which were very negatively affected following the 1980s economic crisis – generally do not meet the recommended international and regional standards.

32.3.4 Water pollution and water quality

The region has a major deficit in water pollution control and overcoming this involves implementing successful institutional arrangements for the setting of standards, creating control and inspection mechanisms, and mobilizing significant financial resources, which may have alternative social or economic destinations. The failure is evident in the case of pollution from urban wastewater discharges where only a minor portion of wastes are treated and where it is difficult to place emphasis on waste treatment when so many people lack connection to sewage systems. Similarly, it has proved difficult to impose controls on industrial pollution, especially on small or medium-sized industries with low levels of technological development. Other difficulties in building effective governance in water pollution control include administrative limitations for dealing with matters such as monitoring watercourses, controlling and supervising clandestine dumps (especially concerning discharge into aquifers) and controlling diffuse non-point source pollution.

The implementation of water pollution control and water quality policies is an expensive process, involving far more than the direct control and regulation of water pollution, and, if water quality is to be improved, the funding issue must be resolved (Box 32.4).

32.4 The challenge ahead

The greatest challenge for water management in Latin America and the Caribbean is without any doubt to continue to improve overall governance. The needs are many, including establishing a clear separation of policy and regulatory activities from day-to-day operations, improving incentives for efficiency, formalizing water institutions, strengthening their operational capacity, improving management training, adopting greater transparency in decision-making, and developing better systems for conflict resolution through a clear deliberative framework while increasing the participation of stakeholders in management decisions.

Among the major drivers or exogenous factors that will condition challenges in water management, the water sector can only hope to influence directly its weight in the definition and implementation of national development strategies. The others are likely to remain beyond any direct influence from water management institutions. The water sector must continually adjust to taking these major external drivers into account as it defines water strategies, and make a maximum contribution to more rational economic policies and to the improvement of institutional quality, governance and transparency while reducing corruption.

Challenges do not end with being prepared to tackle the most significant external drivers. There is a great deal to be done to improve management and governance within the 'water box' itself but there are no simple and universal ways to do this. One limitation that all water management systems seem to share is a notorious lack of operational capacity, due to a variety of factors, including the well-recognized limited financial, legal and human resources and, too often, the lack of importance given to the role of regulation and management in water resource policies. For example, a recent article on irrigation management in Latin America concluded that 'large amounts of water are inefficiently supplied to farmers because the right tools are not available for irrigation managers that allow them to schedule water deliveries and satisfy crop water requirements in an effective way' (de Oliveira et al, 2009, p. 13).

One emerging issue is the need for the management of transboundary water resources. Few of the river basins that are shared have formal agreements that regulate their use or active institutions to focus on issues arising from this situation. In the case of groundwater, the countries sharing the immense Guarani Aquifer (Argentina, Brazil, Paraguay, Uruguay), have recently entered into a binding agreement regulating some key aspects of management and protection of this resource, setting an unprecedented example at the global level.

The size of the challenges ahead, however, should not deter water managers from confronting them and making every effort to further strengthen management within the sector. There have been a number of interesting experiences in the region over the past few decades regarding the establishment of water institutions outside sector ministries. For example, in Mexico, water resources are managed by the National Water Commission (CONAGUA) and in Brazil, the National Water Agency (ANA) was set up in 2000 with the principal objective of achieving the sustainable use of water by overcoming traditional conflicts and limitations imposed by a system in which water had been under the responsibility of functional ministries. Other examples of institutions that are not linked to specific sectors of water use include the Ministry of Environment, Housing and Territorial Development in Colombia, the Water Resources Authority in Jamaica, the Ministry of Environment and Natural Resources in Venezuela, and the General Water Directorate of the Ministry of Public Works in Chile.

BOX 32.4

Investment in sanitation infrastructure in Chile

The total investment in sanitation infrastructure in Chile between 1999 and 2008 has been estimated at more than US$2.8 billion in the water supply and sanitation sector alone – in addition to huge investments in industrial pollution control and separated storm drainage networks. The investment can be estimated to equate to more than US$2,000 per capita. Yet even before 1999, the provision of sanitation in Chile was above the regional average.

Source: Yarur (2009).

These initiatives provide examples of attempts at reform in water management. However, it would be a mistake to think that complex problems can be resolved only by top-down initiatives, through the mere creation of new organizations, or by extrapolating from the experience of effective legislation and organizational structures that were achieved elsewhere only after a significant effort of coordination and capacity building. One of the most powerful is to introduce charges for water use or for waste disposal. The imposition of charges has been a part of reforms in a number of countries, including through the ANA in Brazil, the CARs in Colombia and CONAGUA in Mexico. One interesting new proposal is the trust fund established for water conservation and protection in Quito, Ecuador (FONAG). The idea behind FONAG is to create a system of payment for environmental services to be placed in a capital fund for water protection (ECLAC, 2009*a*).

If reform is to be placed on the political agenda it is not sufficient to have proposals that are supported only by experts – it is essential that any initiative have the widest public support. This means opening up decision-making processes to wide participation among stakeholders, but this has to be done in a meaningful manner so as not to drown the possibility of reaching decisions. Mechanisms, as proposed in much recent legislation, should be developed within the water sector to allow the creation of a consensus on the direction to be followed. If such a consensus does not exist, no true climate of confidence can be created for reform and any proposed reform, or even adopted legislation, will never produce results. The challenge is to open water management to society as a whole. In doing so the water sector can build on its previous achievements to continue to make a sustainable contribution to the betterment of society in all countries of Latin America and the Caribbean.

Notes

1 The World Bank had no active loans for large dams in Latin America and the Caribbean in the first decade of the twenty-first century (Independent Evaluation Group, 2010).

2 The objective of the reforms in Brazil is to establish autonomous river basin agencies that will have both stakeholder representation and their own sources of revenues from charges for bulk water abstraction. However, the restricted legal nature of the river basin agencies has hindered the introduction of charging in most states (Porto and Kelman, 2000).

3 ECLAC estimates that in Uruguay, Chile and Costa Rica 60% or more of the population is not vulnerable to poverty – that is, they have incomes 1.8 times the poverty level – and a number of other countries have over half their population with this level of income (ECLAC, 2009*c*, p.35).

4 There is strong opposition in Chile, with wide international support, to the building of hydroelectricity generation plants on the Río Baker and its tributaries in Chilean Patagonia, a popular area for adventure tourism (Chilean Patagonia Without Dams!, http://www.patagoniasinrepresas.cl/final/)

5 In 2007, 98.6% of biofuel production in Latin America and the Caribbean was in Brazil (OLADE, 2008).

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CHAPTER 33

Arab region and Western Asia

UNESCWA

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The Arab region is facing multiple water challenges due to population growth, food security, overconsumption of water resources, climate change, extreme weather events, damage to water infrastructure caused by regional conflicts, and risks posed by the potential for conflict over shared water resources.

Arab countries have responded to these challenges by improving water resources management, increasing access to water supply and sanitation services, strengthening resilience and preparedness, and expanding the use of non-conventional water resources. However, these measures are insufficient to overcome water scarcity constraints facing most countries in the region.

33.1 Regional developments

The 22 countries of the Arab region,[1] which include the 14 member states of the United Nations Economic and Social Commission for Western Asia (ESCWA),[2] are among the most water-scarce countries in the world. At least 12 Arab countries suffer from acute water scarcity with less than 500 m^3 of renewable water resources available per capita per year (FAO, 2011). Arab countries that are relatively better endowed with water resources are either least developed countries or countries in crisis.

While the Arab region has long suffered from water scarcity, several drivers and challenges have increased strains on freshwater resources over recent decades, including population growth, migration, changing consumption patterns, regional conflicts, climate change and governance. These pressures have increased risks and uncertainty associated with water quantity and quality, as well as the realization of policies seeking to promote rural development and food security objectives.

In recognition of these challenges, and the need to address them in a coordinated and regional manner, Arab governments established the Arab Ministerial Water Council (AMWC) under the auspices of the League of Arab States. At its first session in June 2009, the AMWC responded to the request of heads of state convened at the Arab Economic and Social Summit (Kuwait, January 2009) to prepare an Arab strategy to help confront current and future challenges needed to ensure water security and sustainable development in the region.

The resulting Arab Water Security Strategy (2010–2030) was adopted in June 2011 and proposes a series of measures to respond to these challenges, and is complemented by a set of implementation projects focused on water use efficiency, non-conventional water resources, climate change, integrated water resources management, and water security. Arab countries are also seeking to reduce risks at the national level by developing water sector strategies, incorporating water considerations into national development plans, pursuing institutional and legal reforms, and addressing uncertainties related to the management of shared water resources.

This chapter examines some of the drivers and challenges raised in the Arab Water Security Strategy in view of identifying the risks and uncertainties they pose for the management of water resources, and elaborates on selected response measures and approaches adopted to overcome these challenges in the Arab region.

33.2 Drivers

33.2.1 Demographics, migration and urbanization

The total population of the Arab region stood at 352 million in 2009, and it is expected to reach 461 million by 2025 (UNESCWA, 2009*a*). Rapid population growth for the last a few decades has increased the demand for freshwater as well as water stress in urban and rural areas. Over 55% of the region's population lives in cities, with rural-to-urban migration trends observed in Egypt, Lebanon, Morocco, the Syrian Arab Republic and Tunisia (UNDESA, 2007) largely due to reduced income and employment opportunities in the agricultural sector and the burgeoning youth demographic. To stem this tide, Arab governments have pursued rural livelihoods policies that link agricultural production to rural development, even though this has skewed the allocation of water resources to the agricultural sector in most of the region.

Demand for water services has also grown in urban centres from migration associated with economic development and the movement of displaced persons due to regional conflicts, while adequate water services are not provided in several countries facing intermittent water supplies (Box 33.1). Displaced Iraqis led to an unanticipated spike in new housing development in Jordan and the Syrian Arab Republic, and increased pressures on already strained water networks and freshwater resources. Interregional and intraregional labour migration to otherwise sparsely populated countries of the Gulf Cooperation Council (GCC) is influencing water supply and sanitation decision-making, particularly in view of the aggressive investments being made to stimulate economic growth.

Additionally, most urbanization in the Arab region is concentrated along the coastline, which is vulnerable to floods, sea level rise, and saltwater intrusion into coastal aquifers. Urbanization is fuelling settlement in reclaimed deserts, expanded coastlines and urban peripheries, with new satellite cities emerging around Cairo, Abu Dhabi and along the Red Sea. This has increased public and private sector investment in non-conventional water resources, particularly desalination, to ensure adequate access to water.

BOX 33.1

Access to Water Supply and Sanitation in the Arab Region

According to the World Health Organization and United Nations Children's Fund Joint Monitoring Programme (WHO/UNICEF JMP) for Water Supply and Sanitation, Arab countries are generally on track to meet the Millennium Development Goal (MDG) targets on water supply and sanitation, with the exception of the region's least developed countries and countries in conflict.

However, field assessments reveal that these figures do not adequately reflect that state of access to water services in the region. For instance, while access to an improved water source in Jordan and Lebanon is reported to be 100% and 96% respectively (WHO/UNICEF JMP for Water Supply and Sanitation, 2010), many consumers only receive water once or twice a week and rely heavily on bottled water and the delivery of water through tanker trucks to meet basic needs. Palestinian achievements towards the MDG targets are now mitigated by damage, destruction and the inability to install or maintain water infrastructure due to the ongoing conflict and Israeli security restrictions (World Bank, 2009).

The Arab Ministerial Water Council (AMWC) accordingly mandated the United Nations Economic and Social Commission for Western Asia (ESCWA) to establish a regional mechanism to identify and report on the two MDG 7 targets and an additional set of water supply and sanitation indicators to determine the actual quantity and quality of water services available in the Arab region. ESCWA is implementing this MDG+ initiative in collaboration with the Arab Countries Water Utilities Association (ACWUA), the Arab Water Council (AWC), the Center for Environment and Development in the Arab Region (CEDARE), the Arab Network for Environment and Development (RAED), and WHO, with support provided by the Swedish International Development Cooperation Agency (SIDA).

33.2.2 Water consumption trends

Water consumption levels in ESCWA countries is largely tied to gross domestic product (GDP), as illustrated in Figure 33.1, although this is only possible due to the heavy reliance on desalination. In other parts of the Arab region, water consumption is largely tied to the agricultural sector, which only contributes marginally to GDP.

Domestic water demand in GCC countries is significant and increasing, largely due to changing lifestyles resulting from high economic growth rates, proliferation of real estate development projects, and availability of energy for desalination. Meanwhile, tourism growth is creating seasonal peaks in water demand in the Gulf and Arab Mediterranean countries. The Environmental Agency of Abu Dhabi reports that the United Arab Emirates water usage is 24 times greater than its total annual renewable water resource availability (Al Bowardi, 2010). While Dubai signalled in 2011 that there would be no changes to its water or electricity tariffs in the coming years, graduated water tariffs have been instituted in Jordan and Tunisia, and revisions to tariff schedules are under way in Egypt and Lebanon to stem excess consumption and generate revenue to improve water services.

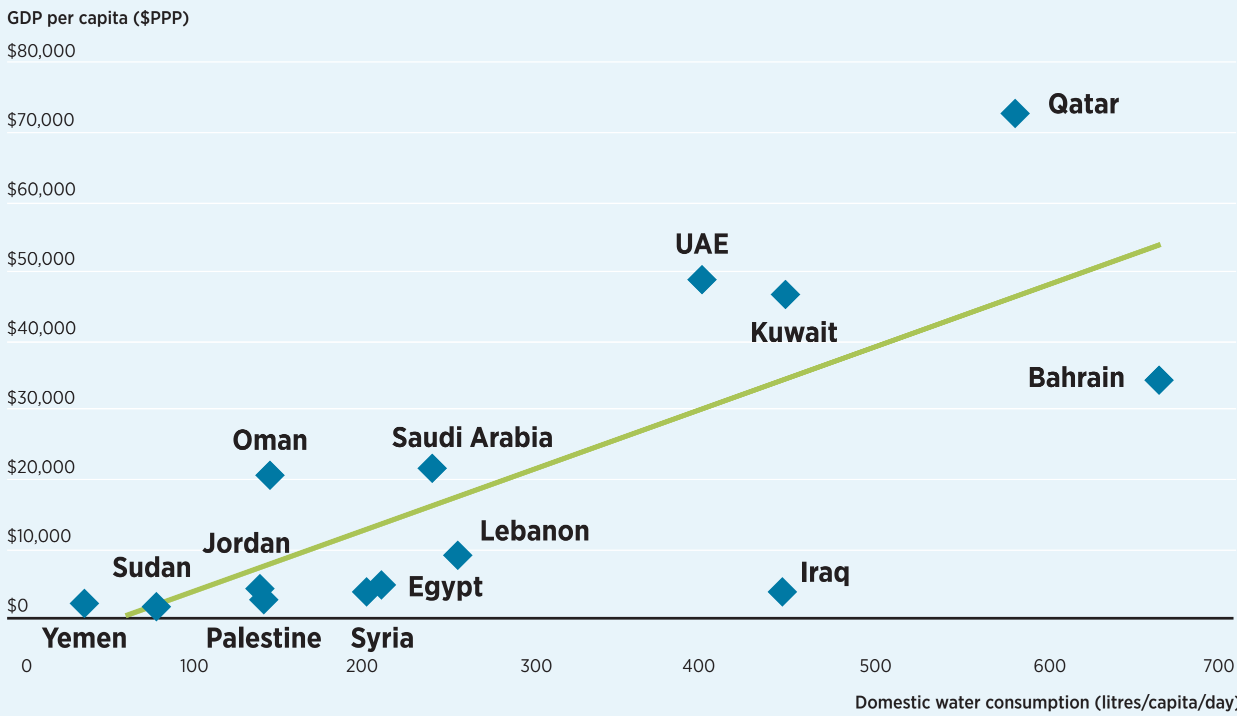
Agricultural water consumption is characterized by low productivity in the region, while drought has plagued agricultural heartlands in recent years. Irrigated agriculture has led to the exploitation of deeper groundwater resources at a cost to sustainability and income. Small-scale farmers in South Lebanon pump groundwater from a depth of over 350 m to irrigate patches of land that have become parched from shifts and reductions in seasonal precipitation patterns; 4–6.5% of gross revenues are allocated to cover the cost of diesel to operate pumps, which has reduced net income in rural areas not connected to irrigation networks (UNESCWA, 2010*a*). Increased exploitation of non-renewable aquifer systems is also witnessed in the Disi Aquifer, shared by Jordan and Saudi Arabia, as well as in the North Western Sahara Aquifer System, shared by Algeria, Libya and Tunisia where 80% of withdrawals are used for agricultural purposes (Sahara and Sahel Observatory, 2011). This is raising concerns about the depletion of fossil aquifers, and the trade-offs to consider when balancing food security, food self-sufficiency, regional cooperation and rural development priorities.

33.2.3 Regional conflicts and the Arab Spring

Cycles of conflict manifested by instability, civil strife, war and occupation have characterized the Arab region for decades. This has generated large numbers of internally displaced persons and increased migration at national and regional levels. As a result, 36% of displaced persons in the world are now found in the ESCWA region (UNESCWA, 2009*c*), imposing additional demands on water networks and on already strained freshwater resources. For instance, most of

FIGURE 33.1

Domestic water consumption relative to gross domestic product (GDP) per capita



Source: UNESCWA (2009b, p. 7), based on data on domestic water consumption from FAO AQUASTAT and GDP per capita data from the United Nations Population Division.

Iraq's two million refugees found safe haven in Jordan and the Syrian Arab Republic, although Amman and Damascus already suffer from high rates of unaccounted-for water and intermittent water supplies. Crippling drought in Somalia led to a flood of refugees into neighbouring countries, including Djibouti and Yemen, despite civil strife in Yemen and projections that Sana'a will become the first capital city in the world to run dry. Women and children are among the most vulnerable in Sudan's internally displaced communities, and are not able to access clean water despite the wealth of freshwater resources in Sudan and its southern neighbours.

Ongoing conflicts and instability are also reversing progress towards water supply and sanitation targets. For instance, despite being once the most water- and oil-rich countries in the region, Iraq experienced water shortages in displacement camps (IRIN, 2007) and water services remain intermittent in urban centres and peripheries. Reduced surface water flows in the Tigris, Euphrates, Karoun and Karkeh rivers from growing demand and diversions upstream in Iraq, the Islamic Republic of Iran, the Syrian Arab Republic and Turkey have increased saltwater intrusion through the Shatt al-Arab and reduced freshwater outflows to the Gulf (UNESCWA-BGR, 2012). This has affected water supply in Basra where water salinity – even after filtration – now exceeds drinking water standards. Increasing salinity in the Gulf also affects desalination operations and fisheries, and may contribute to renewed tensions between Iraq, Kuwait and nearby countries.

Water infrastructure is also damaged or destroyed by violent conflicts. Israel cut off water supplies to Beirut during the siege of 1982, while Iraq destroyed much of Kuwait's desalination capacity as it withdrew from Kuwait in 1991. A damage assessment after the 2006 Israeli offensive into Lebanon estimated US$80 million worth of damage to the water sector (Council for Development and Reconstruction, 2006). The ongoing blockade of the Gaza Strip has prevented the entry of materials and expertise needed to maintain water pumps and installations, and is affecting the ability of donors to invest in a new desalinization plant that is considered a strategic project for cooperation by the Union for the Mediterranean.

Meanwhile, Palestinian refugees are scattered in camps throughout the region with inadequate water supply and sanitation, and limited prospect for improvement.

Concurrently, the public uprisings that have swept through the Arab region since December 2010 offer opportunities to revisit water governance structures and foster greater consultation at the community level. While a relatively recent phenomenon driving change in the region, government officials in Tunisia and Egypt are already engaging with water user associations and local constituencies in renewed dialogue aimed at fostering greater public participation in planning and decision-making related to the water sector.

33.3 Challenges, risks and uncertainties

Four major challenges affect water resources management in the Arab region: water scarcity, dependency on shared water resources, climate change and food security. Financial and technical constraints, as well as poor access to and availability of reliable data and information on water quality and quantity are cross-cutting factors that increase risks and uncertainty associated with managing these challenges.

33.3.1 Water scarcity

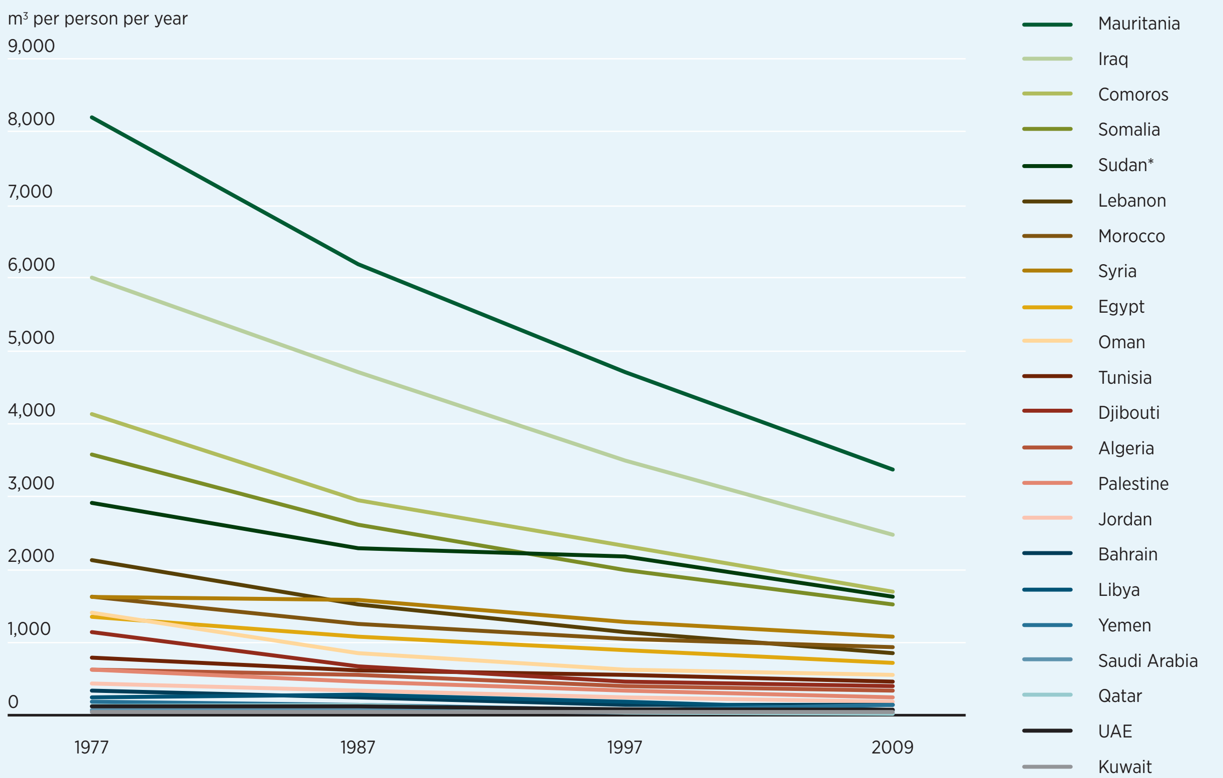
Nearly all Arab countries can be characterized as water-scarce, while those formally endowed with rich water resources have seen their total annual per capita share of renewable water resources drop by half over the past four decades (Figure 33.2). This declining trend presents the most significant challenge to the water sector in the Arab region.

Water quantity

As the availability of freshwater resources in the region has become scarcer relative to its population, efficient and integrated management of water resources has become more critical. Risks and uncertainties associated with the management of surface and groundwater resources must thus be considered jointly and based on local circumstances. For instance, countries with

FIGURE 33.2

Renewable water resources in the Arab region per capita



*Note: *Area covering South Sudan and Sudan.*
Source: Based on FAO AQUASTAT data (2011).

perennial rivers in which surface water constitutes the primary conventional source for freshwater and over 70% of the renewable water resources include Egypt, Iraq, Lebanon and Sudan (FAO, AQUASTAT, 2011). In other Arab countries, groundwater constitutes at least one-third of the total volume obtained from conventional sources, but surface water remains the primary source of freshwater, such as in Oman, Saudi Arabia, UAE and Yemen; ironically these four water-scarce countries are also characterized by intermittent rivers, or *wadi* systems, and are subject to seasonal flash floods. Some countries are thus considering ways to recharge aquifers with these floodwaters to increase the quantity of water available during dry periods.

As surface waters can no longer satisfy water needs in some parts of the region, the extraction of groundwater has increased and is threatening the sustainability of many national and shared aquifer systems and increasing the risk of conflict (UNESCWA, 2007*a*). However, as some groundwater resources are non-renewable, their very use challenges frameworks that seek their sustainable management. An integrated management framework is necessary where conventional and non-conventional approaches are applied to address water scarcity constraints in the region. Non-renewable shared aquifers that include fossil water include the Nubian Sandstone Aquifer shared by Chad, Egypt and Libya; the North Western Sahara Aquifer shared by Algeria, Libya and Tunisia; and the Basalt Aquifer underlying Jordan and Saudi Arabia. Additional deep non-renewable aquifers underlie Kuwait, Iraq and Saudi Arabia; Iraq and Jordan; and Iraq and the Syrian Arab Republic (UNESCWA, 2009*d*).

Water quality

Differences in freshwater regimes influence the response patterns of governments to water-scarce conditions and how countries consider water quality a priority. Coastal aquifers pose a major challenge for many Arab countries due to seawater intrusion resulting from over-pumping of groundwater for domestic or agricultural use. This is evident along the northern coast of Egypt, the Lebanese coastline, in the Gaza Strip and around several coastal cities along the eastern Gulf. Sea level rise is expected to increase stresses on coastal aquifers and river outlets, such as the Nile Delta and at the Shatt Al-Arab, increasing the salinity of these freshwater resources.

Pesticides and fertilizers mixed with agricultural runoff are contaminating surface and groundwater resources in rural and peri-urban areas, and have even become a source of contention in some shared surface water systems in the region, such as between Turkey and the Syrian Arab Republic. Post-harvest processes associated with agro-industries, garments production (leather tanneries and textiles) and domestic sewage pollute surface and groundwater resources throughout the region. For instance, river disposal of olive residues (Lebanon), sugar beet pulp (Morocco and the Syrian Arab Republic) and sugar cane (Egypt, Sudan) increases biological oxygen demand (BOD) levels and eutrophication of some inland water bodies causing fish kills. Nutrient pollution from sewage has reduced fish stocks in Lake Tunis in Northern Tunisia (Harbridge et al., 2007). Untreated effluents released in Cairo have affected aquaculture and agriculture in the Nile Delta. Oil production pollutes freshwater resources in the region, although marine ecosystems are more frequently affected by oil spills.

Watershed protection and management challenges are exacerbated by unregulated urban development, poor sanitation and sewage infrastructure, and the rapidity with which urban expansion is taking place. Inadequate urban planning and enforcement fuelled by bifurcated water governance structures and overlapping jurisdictional mandates between ministries and municipal bodies involved in permitting, testing and compliance contribute to the difficulty of protecting water resources in the region.

33.3.2 Dependency on shared water resources

A big challenge to water resources management in the Arab region is that the major international river systems in the region are shared by two or more countries. The challenge is magnified where institutional regimes are not in place to reduce the risk and uncertainty associated with the management and allocation of water resources under water-scarce conditions at the basin level. The major shared surface water systems in the region include the (a) Tigris and the Euphrates river basin, shared by the Islamic Republic of Iran, Iraq, the Syrian Arab Republic and Turkey; (b) Orontes (or *Al-Assi*) river, shared by Lebanon, the Syrian Arab Republic and Turkey; (c) Jordan (including the Yarmouk) river, shared by Jordan, Lebanon, the Occupied Palestinian Territory, the Syrian Arab Republic and Israel; (d) Nile river basin covering

11 countries, of which Egypt and Sudan are Arab States; (e) Senegal River with four riparian countries, including Guinea, Mali, Mauritania and Senegal; and (f) Lake Chad, with eight riparian countries namely Algeria, Cameroon, Central African Republic, Chad, Libya, Niger, Nigeria and Sudan.

The Arab Water Security Strategy estimates that 66% of surface water resources in the Arab region originates outside of the region and enters through the Euphrates, Nile, Senegal and Tigris rivers. This has become at times a source of political conflict with the upstream countries. There are also many smaller surface water resources (rivers, streams, seasonal spate flows) that cross into the region and between Arab countries on a regular and intermittent basis, which have sparked localized disputes regarding water resources and fuelled border tensions. For instance, reduced flows from intermittent rivers originating in the Islamic Republic of Iran affect border communities and agriculture in eastern Iraq. Many Arab countries have thus turned to groundwater to complement dwindling domestic freshwater supplies and increase water for irrigation and development. However, with shallow aquifers under threat of total exploitation, countries are exploring possibilities to develop deeper and farther aquifers, which, in many cases, are part of more extensive regional cross-boundary aquifer systems.

Additionally, water conflicts can also exist at the subnational level between administrative districts, communities and tribes. Tensions emerge in water-scarce environments and stakeholders with competing interests, which are then manifested through local level conflicts, such as in Yemen (Box 33.2).

BOX 33.2

Water conflicts in Yemen

With acute water scarcity in Sana'a and Taiz, access to water has become an issue of survival.

Stresses on the delivery of water service come from water scarcity, the dependent relationship between water and energy resources for service delivery, internal strife manifested in urban–rural divides, and tensions over scarce resources. Challenges in balancing socio-economic priorities with sustainable water allocation for the agricultural sector complicate decision-making in this least developed country under conflict.

Source: UNESCWA (2010b).

In recognition of the importance of reducing conflict, countries in the region have tried to conclude international agreements and establish shared water resources institutions. However, despite efforts to establish formal agreements, those that exist require increased capacity and improved institutional and legal frameworks to support the integrated management of shared water resources, particularly when political will and commitments are absent or insufficient. Prevailing political tensions and ongoing conflicts also frustrate efforts to collaborate at the technical level. For instance, despite years of efforts to strengthen cooperation in the Nile River basin, countries have failed to reach agreement on a common management scheme. The establishment of the Republic of South Sudan in July 2011 increases to 11 the number of countries requiring agreement on this shared resource.

However, while water scarcity and ongoing conflicts are key drivers influencing shared water resources management, opportunities for collaboration can still emerge. For instance, the divergent interests of riparian countries in the Senegal River basin allowed for constructive compromise, mutual benefits and the prevention of a potential conflict. The resulting establishment of the Organization for the Development of the Senegal River in 1972, the adoption of the Senegal River Charter in 2002, and the tie-in to a financing mechanism for ensuring the generation of revenues and benefits among the four basin countries has reinforced confidence in cooperation and generated income and energy for development.

33.3.3 Climate change and climate variability

Although climate change is a global phenomenon, its impacts are felt differently throughout the world. The Arab region is particularly sensitive to climate change and variability as it already suffers from water scarcity; small changes in climate patterns can thus result in dramatic impacts on the ground. Climate scenarios predict an increase in temperature in the region, which several impact assessments expect to contribute to increased aridity, lower soil humidity, higher evaporation–transpiration rates and shifts in seasonal rainfall patterns. Reduced snowfall and snow melt is projected in the High Atlas Mountains and Anti-Lebanon Mountains. Reduced surface water runoff and sea level rise is expected to reduce groundwater recharge rates and increase the salinity of coastal aquifers, respectively.

Some climate scenarios also anticipate increased climate variability and more frequent extreme weather events, such as floods and droughts. As a transitional climate zone, precipitation has already been fluctuating significantly in Morocco and Tunisia to the west, and Lebanon and the Syrian Arab Republic to the east. Evidence that climate change is affecting freshwater quantity and quality in the region is becoming stronger, although the expected intensity of these changes remains uncertain.

Droughts and land degradation

The increasing frequency of drought in the Arab region is a very important challenge facing the Arab region. Algeria, Morocco, Somalia, the Syrian Arab Republic and Tunisia have experienced significant droughts over the last 20 years, and the frequency and intensity of these events seem to be increasing. In Morocco, the drought cycle changed from an average of one year of drought in every five-year period before 1990, to one year of drought for each two-year period in the following decade (Karrou, 2002). The Horn of Africa is experiencing one of the worst droughts in decades.

Despite repeat experience, Arab countries remain vulnerable to drought. Socio-economic vulnerability to drought in ESCWA countries has intensified due to demographic and economic growth, increasing water scarcity, unsustainable water consumption patterns and land use practices (UNESCWA, 2005). The vulnerability of some Arab countries to droughts comes from their high dependency on agriculture, and particularly rainfed agriculture, as a main contributor to GDP and employment. An extended hydrological drought in north-eastern Syria from 2006 to 2009 drove an estimated one million people to abandon their homes and seek refuge in larger cities. A former Syrian Deputy Prime Minister has attributed this mass migration to having set in motion the popular uprisings initiated in Syrian secondary cities in 2011 (A. Dardari, personal communication, November 2011). In Somalia, where large segments of the population are economically dependent on pastoral and subsistence farming, prolonged drought has decimated families and caused widespread famine displacing communities in a conflict-ridden country that has faced droughts of varying intensity every year for over a decade.

Drought also contributes to increased land degradation and desertification, which is a regional phenomenon poignantly witnessed in Mauritania when it faced repeated cycles of drought during the 1960s, 1970s and 1980s. Dams erected along the Senegal River helped mitigate the effects of drought and introduce more certainty in water availability for development. Nevertheless, drought in the Sahel region in 2009 and 2010 has reduced water availability for agriculture and again increased food insecurity levels in Mauritania (CILSS et al., 2010).

Floods and extreme events

Extreme weather events have increased in the region, including greater frequency and intensity of flooding. In January 2010, heavy rainfall caused flash floods in Egypt in the Sinai Peninsula, Hurghada, and Aswan along the Red Sea – resulting in 12 deaths, the evacuation of over 3,500 people and the destruction of electricity towers, telephone lines and roads (DREF operation, 2010). The same storm caused flooding in the area of Wadi Gaza in the Gaza Strip, where the floods cut off roads and the bridge connecting Gaza City with southern parts of the Gaza Strip, causing a state of emergency.

Cyclone activity is also intensifying in the region. The three strongest tropical cyclones recorded in the Arabian Sea have occurred since 2001 (*Gulfnews*, 2010). Super Cyclonic Storm Gonu was the strongest and hit Oman, Yemen and Somalia in August 2007. Storm surges caused coastal damage and *wadi* flooding as rainfall reached 610 mm; the high water mark peaked at Ras al Hadd at the eastern tip of Oman and exceeded 5 m in what is normally an arid area. The cyclone resulted in an estimated US$4 billion worth of damage and at least 49 deaths, and is considered the worst natural disaster in the history of Oman. Saudi Arabia suffered devastating floods in Jeddah in November 2009 which killed 100 people and caused mortalities in Rabigh and Mecca (BBC News, 2009). Yemen has been experiencing landslides and rock slides caused by increasingly intensive seasonal flash flood events through mountainous valleys.

These high-consequence flood events are not only due to the increasing intensity of rainfalls, but also to the rapid and often haphazard development of high-risk areas such as *wadis* which are natural drainage areas for flash floods. Lax building codes and infrastructure standards, as well as weak regulation and enforcement, also permit the construction of buildings and infrastructure that are ill-prepared to sustain damage during major floods, such as those in Jeddah in 2009 (Assaf, 2010). These extreme events, however, led to increased public investment in storm water systems and preparedness planning that reduced risks in subsequent years.

33.3.4 Food security

Agricultural cultivation consumes the largest share of water in the Arab region and is a primary source of water stress. While per capita arable land and permanent croplands account for a small share of land in most ESCWA member countries, agriculture accounts for over 70% of total water demand; in Somalia and Yemen, the share exceeds 90% of total water demand (FAO, AQUASTAT, 2011).

Despite high usage rates, Arab countries are not able to produce sufficient quantities of food to meet basic needs. Accordingly, ESCWA member countries import 40–50% of their total cereal consumption, and this rate reaches up to 70% in Iraq and Yemen, despite the significant size of their agricultural sectors (UNESCWA, 2010*b*). This situation is likely to worsen with climate change.

Agricultural export bans have also been instituted in response to the recent food crises in an effort to increase domestic food security, prevent hording for sale in international markets and reduce price inflation for basic foodstuffs at the national level, such as in Egypt with rice exports. The fluctuations in the global cereal market during the past few years, and the instability of supplies, witnessed when Russia banned the export of grains in August 2010, proved problematic for the region as Egypt and the Syrian Arab Republic imported approximately half of their total wheat imports from Russia in 2008 and 2009. However, wheat and barley imports have become a necessity as the region does not have enough water to meet growing demand. Globalization, trade dependency and the global food crisis have thus added new dimensions to the food security challenge in the Arab region.

Further, the Arab region has a vulnerable social structure. While there is a concentration of wealth in some countries, a large share of the population is clustered around the poverty line, with many people living well below the poverty line in the Comoros, Djibouti, Mauritania, Somalia and Yemen. Increased drought frequency, complemented by dependency on food imports and population growth, leaves the Arab region highly vulnerable to food insecurity.

To address the challenge, Arab countries initially tried to increase domestic cereal production and encouraged cultivation in strategic commodities through subsidies and guaranteed price supports (Egypt, Jordan, Saudi Arabia). Investments in irrigation networks and reservoir capacity increased (Lebanon, Syrian Arab Republic), as well as the pumping of groundwater resources for the production of cereals (Morocco, Saudi Arabia). Intraregional agricultural trade was encouraged through the Greater Arab Free Trade Agreement. However, limited agricultural productivity, continued land degradation and water scarcity made food self-sufficiency goals unachievable at the national or regional level. As a result, Arab food self-sufficiency policies shifted towards a broader concept of food security. Governments with the financial resources have been able to pursue alternative measures within the global marketplace to achieve this goal, while others are re-examining their development and trade policies. Some have also turned to emergency relief to overcome food crises, such as those experienced in the Horn of Africa and Sahel due to drought.

Biofuels

Global research and development has demonstrated that biofuels provide opportunities for increased energy security and rural development through a reliable market for certain agricultural commodities. Investors encouraged by the emerging biofuel market have thus sought to cultivate jatropha in Egypt and Sudan, as it is a drought-resistant non-food crop that can be grown in saline soils. However, a range of stakeholders have expressed concern that Arab farmers might shift cultivation to more profitable commercial biofuel crops instead of food crops, despite growing water scarcity and food insecurity in the region.

Arab governments responded by encouraging the development of second-generation biofuel instead. The Arab Ministerial Declaration on Climate Change (CAMRE, 2007, p. 4) warns of the 'consequences of the encouragement of developed countries to developing countries to cultivate agricultural crops that produce bio-fuel instead of food; while encouraging its production from bio-waste'. Meanwhile, the Strategy for Sustainable Arab Agricultural Development for the Upcoming Two Decades (2005–2025) adopted through the Arab Organization for Agricultural Development recognizes the added value for farmers of using agricultural residues for biofuel production and the positive impact this will have on the environment and on securing fuel. Assessments have also found the potential for expanding second-generation biofuel production in Egypt, Lebanon, Morocco, the Syrian Arab Republic and Sudan from residues resulting from sugar cane, sugar beet and olive processing, as well as from the livestock and dairy sectors (UNESCWA, 2009*e*).

33.3.5 Data and information

The difficulty of collecting consistent and credible data and information on water resources in the Arab region impedes accurate analyses and well-informed decision-making processes. It also prevents the establishment of coherent and cooperative policy frameworks for shared water resources management as well as observing changes and assessing progress.

Several initiatives have been launched to increase the knowledge base of water resources in the region, including intergovernmental processes tied to statistical reporting at the global level, and others at the regional and national levels through regional reporting mechanisms or as academic initiatives.

However, the difficulty of reducing the gaps and uncertainty associated with the knowledge base rests with the political sensitivity and national security considerations that are sometimes tied to this information. This results in a patchwork of information from different sources that is used by the research and professional community, while official data remains a coveted resource that is sometimes reserved for use by certain governmental institutions.

33.4 Response measures

In view of these drivers and challenges, Arab countries are seeking to improve water resources management and capacity, strengthen resilience and preparedness, and expand the use of non-conventional water resources as a means to ensure a water-secure future.

33.4.1 Improving water resources management

At the regional level

Arab countries clearly recognize the need for a common approach towards water resources management to achieve sustainable development of the region. This led to the adoption of the Arab Water Security Strategy by the AMWC in 2011. The strategy lays out key issues facing the Arab region and identifies various priorities for action focused on:

- *Socio-economic development priorities* – namely access to water supply and sanitation, water for agriculture, finance and investment, technology, non-conventional water resources and Integrated Water and Resources Management (IWRM);
- *Political priorities* – related to the management of shared water resources and the protection of Arab water rights, particularly those under occupation; and
- *Institutional priorities* – associated with capacity building, awareness raising, research, and participatory approaches involving civil society.

Regional institutions and initiatives launched in recent years respond to these priorities. For instance, the Arab Countries Water Utilities Association (ACWUA) established its secretariat in 2009 and provides a platform for dialogue and capacity building on water supply and sanitation for public and private sector operators on various topics, including unaccounted-for water, tariffs and benchmarking. The Center for Water Studies and Arab Water Security, affiliated with the League of Arab States, convenes intergovernmental meetings on agreements and resolutions on shared water resources and Arab water rights. This includes deliberations on a legal framework on shared waters in the Arab Region, which the Center, and UNESCWA drafted at the request of the AMWC (2010) in consultation with Arab governments and with support provided by the Bundesanstalt für Geowissenschaften und Rohstoffe (Federal Institute for Geosciences and Natural Resources, BGR, Germany). The legal framework seeks to foster consensus on a core set of principles that can support bilateral and basin-level agreements on water resources shared by Arab countries (UNESCWA, 2011). The framework draws upon a vision that fosters cooperation and participation; equitable, reasonable, and sustainable use; and conflict prevention and resolution through peaceful means (UNESCWA and BGR, 2010). Regional capacity-building programmes have also been conducted in response to the strategy, such as training on negotiations by the Arab Water Academy and workshops on water governance by the AWC and CEDARE.

At the national level

At the national level, different ministries and authorities are responsible for managing water resources and delivering water services in Arab region. Only a handful of joint committees or units have been established to support shared water resources. However, efforts to improve institutional and legal frameworks in the water sector have been enacted or are under way, and are increasingly incorporating issues previously limited to IWRM planning.

For example, Law 10-95 in Morocco sets forth an institutional framework for managing water resources, with a view towards environmental protection as well as monitoring and responding to extreme events, such as droughts (Makboul, 2009). Egypt prepared a 2005 National Water Resources Plan, which includes many institutional procedures aimed at decentralization, public–private partnerships and engaging water users in water system management. A new draft water law seeks to empower the Egyptian Water Regulatory Agency (EWRA), differentiate between social and economic tariffs, and establish a set of performance indicators for utilities. Yemen devised a national strategy and investment programme for the water sector (2005–2009), which addresses water resource management, water and sanitation in urban areas, water and sanitation in rural areas, irrigation management, and the environment. Palestine is working to integrate water resource management into development planning, and examined the implications of climate change for groundwater resources as a means to inform the process. Jordan developed a national strategy that includes policies on groundwater management, irrigation, infrastructure, sanitation, water resource management and investment (UNESCWA, 2007*b*). Lebanon prepared a new National Water Sector Strategy focused on water supply and sanitation that is supported through a Water Sector Coordination Group that contributed social impact analysis, health assessments and climate change impact scenarios to the preparatory process. Nevertheless, there remains a need to strengthen legal and institutional frameworks and inter-ministerial coordination for IWRM to push forward progress in this area throughout the region.

33.4.2 Strengthening resilience and preparedness

Improving food security

As with most countries in the world, Arab countries seek to ensure their food security through trade, investment and contractual arrangements with other countries. Long-term leasing of agricultural land in other countries has emerged as another tool for overcoming shortcomings and shortfalls in domestic agricultural production due to water, land, energy or technological constraints. These investments are designed to ensure access to staple commodities and reduce exposure to global food price fluctuations and export bans, which often occur during food crises. Through these arrangements, investors reduce risk by leasing land to grow needed primary commodities in countries with suitable land and water resources, while host countries secure investments over an agreed time horizon that can allow for the development of transport, water and energy infrastructure in the targeted area. Employment and income generation is also fostered through primary and secondary agro-industries (fertilizers, packaging, shipping) given that these investments tend to be large in size. However, while these contracts offer the opportunity for mutual benefits, the operationalization of these investments has been controversial where indigenous communities and pastoralists have traditionally used the lands that are being opened to joint ventures or leased to investors by central governments or absentee landowners.

Several Arab countries are engaged in agricultural investments and land deals with other Arab countries and in neighbouring regions, and their numbers have increased in recent years as water scarcity and land degradation have become more evident. Jordan engaged in land deal talks with Sudan for livestock and crop cultivation (Hazaimeh, 2008), and the Abu Dhabi Fund for Development invested in the cultivation of 28,000 ha of farmland in Sudan (Rice, 2008). The King Abdullah Initiative for Saudi Agricultural Investment Abroad was established to maintain food security in the Kingdom given the Government's decision to reduce price supports for domestic wheat production and other commodities because of water constraints. The initiative encourages the private sector to invest in agriculture abroad and received its first rice imports in 2009. Staple goods are targeted, particularly wheat, barley, corn, sorghum, soybeans, rice, sugar, oil seeds, green fodder, livestock and fishery goods, which are all water-intensive products (Al-Obaid, 2010); Egypt, Sudan, Turkey, Ethiopia, the Philippines, and Brazil among other countries are targeted for investments. One study reports that five African countries (Ethiopia, Ghana, Madagascar, Mali and Sudan) approved a total of 2,492,684 ha of land for foreign investments in agriculture since 2004, excluding allocations below 1,000 ha and pending land applications, and that Arab countries contribute significantly to this total (Cotula et al., 2009).

Sovereign wealth funds, like the Qatar Investment Authority and Kuwait Investment Authority are engaged in these types of investments directly or through state-owned enterprises in Arab and South East Asian countries (Reuters, 2008*a*). The private sector is also engaged. Jenat, a consortium of Saudi agricultural companies, produces wheat, barley and livestock feed in Egypt, and announced plans to invest in Sudan and Ethiopia (Reuters, 2008*b;* 2009). Private investment funds, such as the Abu Dhabi-based Al Qudra Holding are also active in this sector (Blas, 2008). This demonstrates the market's recognition that investments abroad will help satisfy growing food demand given the lack of opportunity to invest in this sector at home because of increased natural resource constraints.

Nevertheless, the rapid rise of foreign land acquisitions in developing and least developed countries has raised concern that they may further reduce food security in these countries in face of global food crises, particularly among the least privileged and marginalized communities. As a consequence some Arab countries such as Qatar are now targeting more developed countries with significant food surplus for their agricultural investments (Reuters, 2010), while others are also supporting food programmes in countries under stress, such as Saudi Arabia through its donations to Somalia, Sudan and Mauritania.

Pursuing climate change adaptation and disaster preparedness

The Arab Ministerial Declaration on Climate Change (2007) expresses Arab commitment to move towards climate change adaptation and mitigation, and was followed by the preparation of the Arab Framework Action Plan on Climate Change for 2010–2020. Arab countries have concurrently sought to assess the impact of climate change on national water resources to inform their national adaptation plans and communications to the Intergovernmental Panel on Climate Change (IPCC). In view of providing a unified assessment for informing regional policies on climate change adaptation, the Regional Initiative for the Assessment of the Impact of Climate Change on Water Resources and Socio-Economic Vulnerability in the Arab Region was launched as coordinated UN-LAS effort under the umbrella of the AMWC and the UN Regional Coordination Mechanism.

Risks and uncertainty associated with climate change and extreme weather events have pushed forward national and regional efforts in the area of disaster risk reduction, planning and preparedness. The Arab Strategy for Disaster Risk Reduction 2020 was adopted in 2010 and is being supported by the United Nations International Strategy for Disaster Reduction (UNISDR) and partners through the preparation of national disaster inventories, regional platforms, and capacity-building programmes aimed at improving land use planning, regulatory frameworks, financing and access to user-friendly information and communication tools.

Arab countries are also responding to climate change nationally. For example, a drought insurance programme based on rainfall contracts in Morocco is an important climate change adaptation measure that has the potential to reduce the effect of drought hazards and has helped to safeguard the production of cereals (Medany, 2008). Programmes to implement no-regret measures are also proliferating in water use efficiency and non-conventional water resource management.

Management strategies focused on dam construction and aquifer recharge are increasingly visible in the region as a way to respond to flood risk and store water for future use. During the flash floods that hit Egypt in January 2010, the Government reported that the dams established in Sinai and Aswan played a positive role in protecting Na'ama Bay, Nuweiba'a and Dahab, while also allowing for the storage of storm water in aquifers; this raised the groundwater table along the coastline and has helped prevent saltwater intrusion and contributed to improving water quality in those areas (Government of Egypt, 2010). Dams built around Jeddah helped minimize damage caused by the floods and associated landslides in the city in 2009 (Saud, 2010).

While dams can have both positive and negative impacts on natural and urban ecosystems, some Arab countries have increased their total dam capacity. Egypt stands at the forefront with a capacity of at least 169 km^3 since 2003. However, total dam capacity in Iraq almost tripled from 50.2 km^3 to 139.7 km^3 between 1990 and 2000. Syrian dam capacity increased from 15.85 km^3 in 1994 to 19.65 km^3 in 2007, with new dams under development along the Al-Assi River to help regulate river flow and reduce flood risk. Lebanon is proposing a series of new dams in its National Water Sector Strategy.

Managed aquifer recharge is also being considered more closely, for two reasons: (a) to stave off saltwater intrusion into coastal aquifers from over-pumping and sea level rise, which affects Mediterranean and Arabian Gulf coastlines; and (b) to store excess production of desalinated water as a risk buffer to prepare for future peaks in demand or desalination plant failures in GCC countries.

33.4.3 Expanding use of non-conventional water resources

Non-conventional water resources have become a mainstream response to water scarcity in the Arab region. Desaliniation is the primary source of water in GCC countries, while the reuse of wastewater is common practice in Jordan and the UAE. Nevertheless, the sustainability of these measures requires further action by Arab Governments as they pursue research and investment in new non-conventional water resources under development.

Desalination

Growing water demand has increased investment in desalination throughout the Arab region. Saudi Arabia has the greatest desalination capacity in the world and produces over 10 MCM per day, while the UAE is the second largest producer; jointly their desalination capacity accounts for over 30% of global freshwater production (UNESCWA, 2009*b*). Outside of the GCC, desalination represents a growing share of water supply in Algeria, Egypt, Iraq and Jordan, with efforts to expand capacity in Palestine underway. Tourism growth along the Egyptian coastline is dependent upon desalination, as pipelines transferring Nile River water to the Red Sea coast are no longer sufficient to satisfy needs.

Co-generation is also expanding in the Gulf, where power and desalinated water are produced at a joint facility. For instance, in 2011, the Power and Water Utility Company for Jubail and Yanbu (Marafiq) in Saudi Arabia started construction on Yanbu 2, which aims to produce 850 MW of electricity and 60,000 m^3 of desalinated water per day (Zawya, 2011). However, desalination and co-generation are not cost-effective solutions in energy-poor countries and poses a problem for climate change due to their energy intensity. Universities and research centres in the region are thus piloting renewable energy desalination facilities based on solar or wind energy (UNESCWA, 2009*b*), which are gaining currency in Algeria, Morocco, Tunisia, Saudi Arabia and the UAE. Prospects for nuclear desalination are also being advanced in Jordan, Morocco, Saudi Arabia and the UAE.

Desalination also emerged as a local response and community-based resilience scheme in the the Occupied Palestinian Territory, where access to water is limited and groundwater has become increasingly saline. Driven by the private sector, small reverse osmosis desalination units can now be found in about 100,000 households in the Gaza Strip, as a secondary source of drinking water when municipal supplies are not delivered (World Bank, 2009). However, a new challenge has been the false sense of security that these small household desalination units provide as the units continue to be used despite the difficulty of securing replacement filters, which has resulted in associated health risks and challenges caused by continued use of systems that require maintenance.

Reuse of wastewater

The reuse of domestic wastewater for urban landscaping and greenbelts to combat land degradation and desertification has been practiced in Arab countries for decades. Some Arab countries adopted quality standards to regulate wastewater reuse for certain purposes (WHO-EM/CEH, 2006). However, increasing water scarcity and development pressures have increased interest in the use of treated sewage. As a result, treated wastewater is now used in the urban, agricultural, industrial and environmental sectors.

Jordan, Kuwait, Saudi Arabia and the UAE produce a relatively large amount of treated wastewater, with direct use of treated wastewater representing nearly 1% and 3% of total water withdrawal in Saudi Arabia and Oman respectively in 2006,and nearly 9% and 10% of total water withdrawal in Jordan and Qatar respectively in 2005 (FAO, 2011). Jordan and the UAE have established classification systems for regulating the reuse of treated wastewater for different purposes, including the cultivation of food and non-food products. Bahrain Airport uses treated grey water for cooling and landscaping. Abu Dhabi contracted Veolia Water to tertiary treat sewage from its capital city at a desert location, where the treated wastewater will be used to green the desert and support the establishment of a new community and biodiversity reserve. The use of treated wastewater is also being considered as part of managed aquifer recharge schemes in some Gulf countries. However, increased investment in sanitation, sufficient access to energy to fuel tertiary treatment facilities, and the adoption of harmonized quality standards and classification systems are needed to generate further benefits from treated wastewater re-use in the region.

Water harvesting and fog collection

Water harvesting has been up-scaled and expanded in the Arab region based on traditional practices. Household and farm level rainwater collection is already common practice in the Occupied Palestinian Territory, Tunisia and Yemen, and is usually captured in storage tanks and reservoirs for watering residential gardens or meeting domestic water needs. Water harvesting through condensation by forests has been piloted to facilitate groundwater recharge in Oman, while other methods are in place to recharge aquifers along the northern coast of Egypt. Fog collection is another option. In Yemen, 25 large fog collectors were constructed in 2004 with an area of 40 m^2 each, estimated to provide 4500 L of drinking water per day during the dry winter season (Schemenauer et al, 2004). In 2006, three standard fog collectors spanning 1 m^2 each were installed in the south-western region of Saudi Arabia. During the winter season, the best average daily water production of 11.5 L/m^2 was obtained, which encourages the development of further application of this technology in the region (Al-Hassan, 2009). However, fog collection facilities need to be carefully introduced based on comprehensive feasibility studies as they only work where certain weather conditions are met.

Pilots and prospects for new non-conventional water resources

While cloud seeding became popular after its successful demonstration by China prior to the 2008 Beijing Olympic Games, several Arab countries, including Algeria, Libya, Morocco, Jordan, Iraq, Saudi Arabia, the Syrian Arab Republic and UAE have been piloting cloud seeding programmes since its introduction (Al-Fenadi, n.d.). Between 2001 and 2002, the UAE conducted cloud seeding field programmes and found that the characteristics of clouds differ from season to season; new cloud seeding experiments were successfully conducted by meteorological authorities in the UAE in 2008 (*Gulfnews*, 2008). However, cloud seeding has fostered debate in the region regarding who owns the clouds, particularly when they cross between countries (Majzoub et al., 2009).

Capturing freshwater from newly identified underwater springs in the region offers another way to overcome water deficits thanks to the introduction of advanced remote sensing techniques (Shaban, 2009). However, this may introduce new territorial conflicts regarding sea and submarine resources shared by countries, and may potentially affect salinity levels needed to maintain coastal marine ecosystems.

Conclusion

Despite the risks and uncertainties discussed in this chapter, water flows at the core of Arab culture and consciousness. A national Egyptian holiday commemorates the flooding of the River Nile every spring, even though seasonal flooding has stopped since the Aswan Dam was built in the 1950s. Most Arabs live in cities situated along the coastline or a riverbed. Islamic cleansing with water is practiced by millions of Arabs every day prior to prayer, while threats to Arab water rights remain a touchstone for solidarity throughout the region.

Nonetheless, water scarcity, population growth, food security, climate change, extreme weather events, regional conflicts and the potential for new conflict over shared resources influence the ability to manage surface water and groundwater resources in the Arab region. The future will show how assessing these risks and engaging stakeholders in constructive and participatory processes will stimulate action at the national and regional levels to overcome these challenges despite continuing conditions of uncertainty.

Notes

1 The 22 countries of the Arab region are identified as those that are members of the League of Arab States, namely Algeria, Bahrain, the Comoros, Djibouti, Egypt, Iraq, Jordan, Kuwait, Lebanon, Libya, Mauritania, Morocco, Oman, the Occupied Palestinian Territory, Qatar, Saudi Arabia, Somalia, Sudan, Syrian Arab Republic, Tunisia, the United Arab Emirates and Yemen.

2 The 14 ESCWA member countries are Bahrain, Egypt, Iraq, Jordan, Kuwait, Lebanon, Oman, the Occupied Palestinian Territory, Qatar, Saudi Arabia, Sudan, Syrian Arab Republic, United Arab Emirates and Yemen.

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CHAPTER 34

Water and health

WHO and UNICEF

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The global drivers predicted to have the greatest effect on disease rates via the water environment are population growth and urbanization, agriculture, infrastructure, and global climate change. Trends in these drivers directly and indirectly affect the global burden of disease, largely adversely, and increase the overall uncertainty in future human health.

There are numerous non-water-related environmental determinants of health, as well as non-environmental determinants of health, that make the identification of trends and hotspots in water and health challenging.

By outlining the environment–health nexus for each of the major water-related disease groups, five key solutions were identified: access to safe drinking water and sanitation, improved hygiene, environmental management and the use of health impact assessments. Implementation of these actions serves to reduce the burden of multiple diseases and improve quality of life for billions of individuals.

In-depth studies are required to more accurately identify the risks and opportunities related to water and health, such as The 2030 Vision Study which determined the major risks, uncertainties and opportunities related to the resilience of water supply and sanitation in the face of climate change.

Protection of human health requires collaboration among multiple sectors, including those in non-water and non-health sectors.

34.1 Introduction

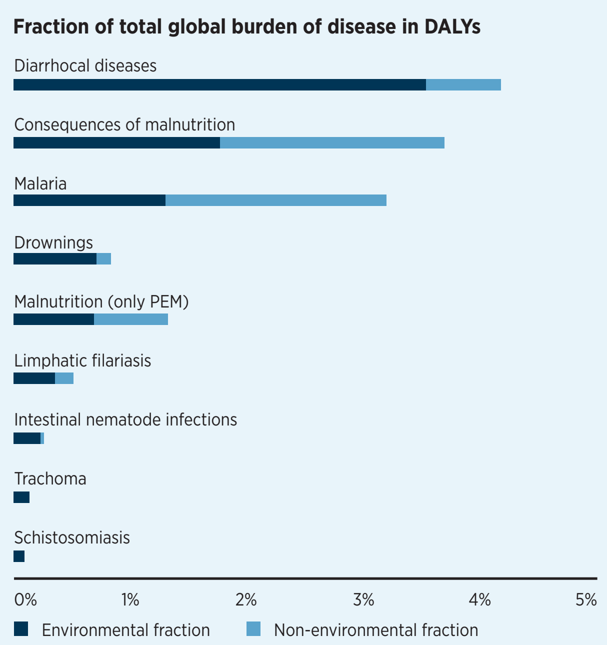
Improving water resource management, drinking water supply, sanitation and hygiene has the potential to prevent 9.1% of the global disease burden or 6.3% of all deaths (Prüss-Üstün et al., 2008). Understanding the nature and magnitude of the burden of water-associated diseases provides the basis for effective interventions.

This report examines the diseases that contribute significantly to this global burden (in disability-adjusted life years, or DALYs, a weighted measure of deaths and disability; see Figure 34.1) and that are realistically preventable using available technologies, policies and public health measures.

Mapping the environment–health causal pathway provides insights that inform effective public health interventions. The driver, pressure, state, exposure, effect and action (DPSEEA) model, developed by the World Health Organization (WHO) provides a simple illustration of the way in which the environment influences health and how the environmental state is influenced by higher causes (Kjellström and Corvalán, 1995). The model allows for a clear understanding of the factors contributing to the burden of disease and supports the development of effective intervention strategies. Yet this process is complicated by the fact that each disease is associated with a variety of economic, societal and natural driving forces. We have used the DPSEEA model to determine the linkages for the disease groups, defined by Bradley (2008) as waterborne diseases, water-washed diseases, water-based diseases and water-related insect vector diseases.

FIGURE 34.1

Diseases with the largest water, sanitation and hygiene contribution in 2000



Note: DALY, disability-adjusted life year (which measures the years of life lost to premature mortality and the years lost to disability); PEM, protein-energy malnutrition (which is malnutrition that develops in adults and children whose consumption of protein and energy is insufficient to satisfy the body's nutritional needs).
Source: Prüss-Üstün et al. (2008).

34.2 Water-related disease groups, environment–health pathway and promising interventions

34.2.1 Waterborne diseases

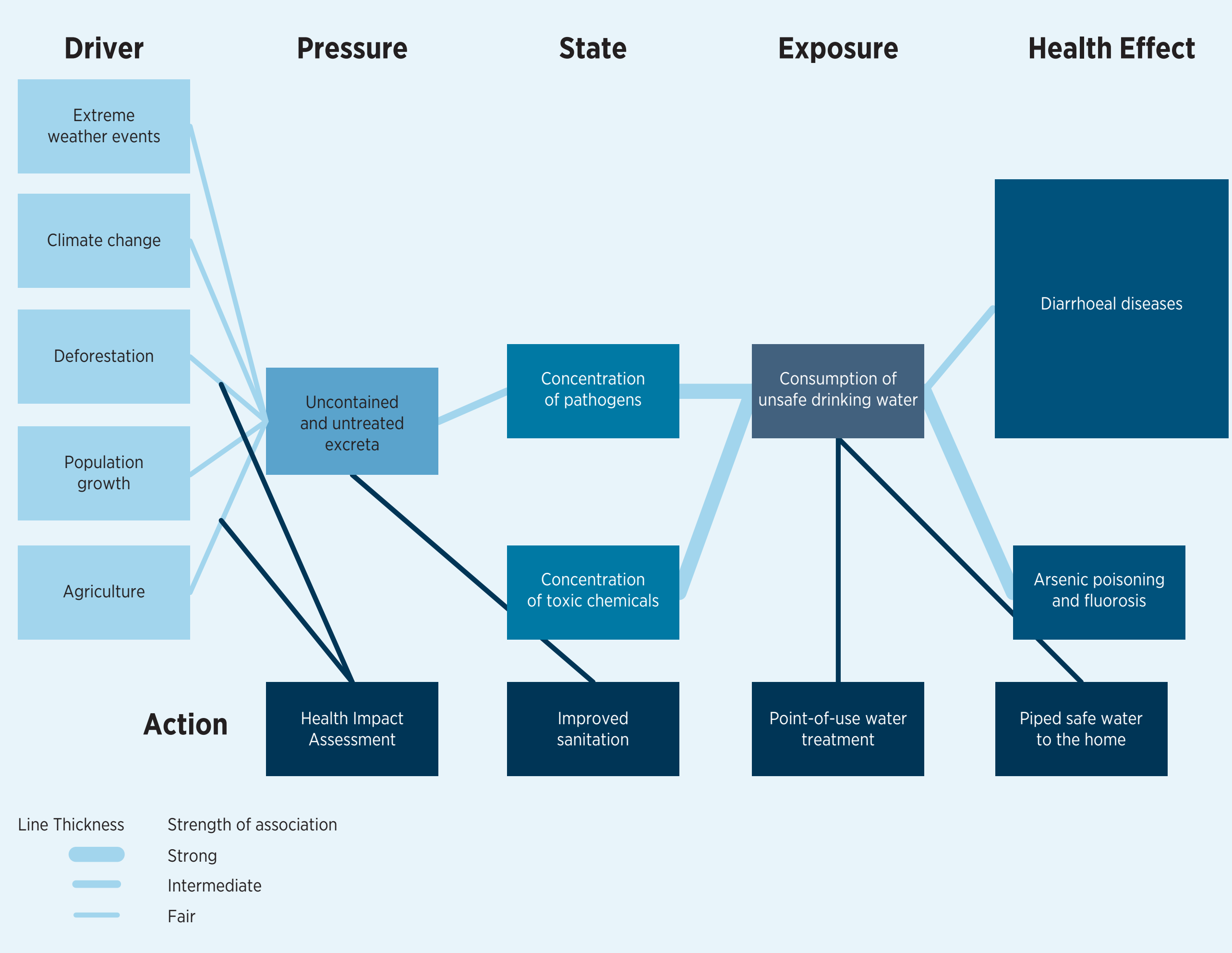
Waterborne diseases are contracted by drinking contaminated water. The most predominant include diarrhoeal disease, from which over 2 million people die every year (WHO and UNICEF, 2010), and arsenic and fluoride poisoning, for which the global impacts are unknown. These diseases are driven by fluctuations in extreme weather events (e.g. inland flooding), climate change, deforestation, population growth and agriculture, as shown in Figure 34.2 which outlines the environment–health pathway for waterborne diseases. Promising interventions for waterborne diseases include the provision of safe drinking water (Box 34.1), improved sanitation (Box 34.2) and health impact assessments (Box 34.3).

Access to safe drinking water can prevent waterborne diseases by avoiding consumption of unsafe drinking water. Some strategies for providing access to safe drinking water are given in Box 34.1.

Access to water via a piped infrastructure can lead to substantive reductions in mortality due to diarrhoeal disease and arsenic and fluoride poisoning. Studies from the United States (Cutler and Miller, 2005; Watson, 2006) and India (Jalan and Ravallion, 2003) have shown that combined improvements in water access and quality can have enormous health returns. As the proportion of the global population that relies on improved sources of drinking water (including piped systems) increases, the quality of water received from these sources will become increasingly significant for health. Piped water is not necessarily safe – for example,

FIGURE 34.2

Driver, pressure, state, exposure, effect and action (DPSEEA) model for waterborne diseases



Note: The size of the health effect boxes varies with the corresponding global burden of disease in disability-adjusted life years: diarrhoeal diseases, 52,460,000 (including waterborne and water-washed diarrhoeal disease); arsenic poisoning and fluorosis, unknown (disease burden estimates from Prüss-Üstün et al., 2008).

BOX 34.1

Safe drinking water strategies for reducing waterborne disease

Safe drinking water, as defined in the third edition of the WHO guidelines for drinking-water quality, does not represent 'any significant risk to health over a lifetime of consumption, including different sensitivities that may occur between life stages' (WHO, 2008*b*). Solutions for providing safe drinking water include piped water infrastructure (through standpipes and household connections), wells and point-of-use (PoU) water treatment. Piped water supply has been shown to drastically reduce child mortality (Cutler and Miller, 2005; Watson, 2006). However, piped water services to some, especially dispersed rural, populations may not be readily achievable. The majority (84%) of the global population who do not have an improved drinking water source resides in rural areas (WHO and UNICEF, 2010), despite an increased rural coverage from 64% in 1990 to 78% in 2008. In rural regions, drinking water access is often outside the home, such as communal taps, wells and protected springs. Such protected sources may make water available closer to the home, but quantities transported are moderate, and water is readily and frequently contaminated. PoU water treatment and improved water storage practices can reduce pathogen contamination. Numerous PoU technologies are available, including chlorination, the use of flocculants, adsorption, filtration, boiling or solar disinfection.

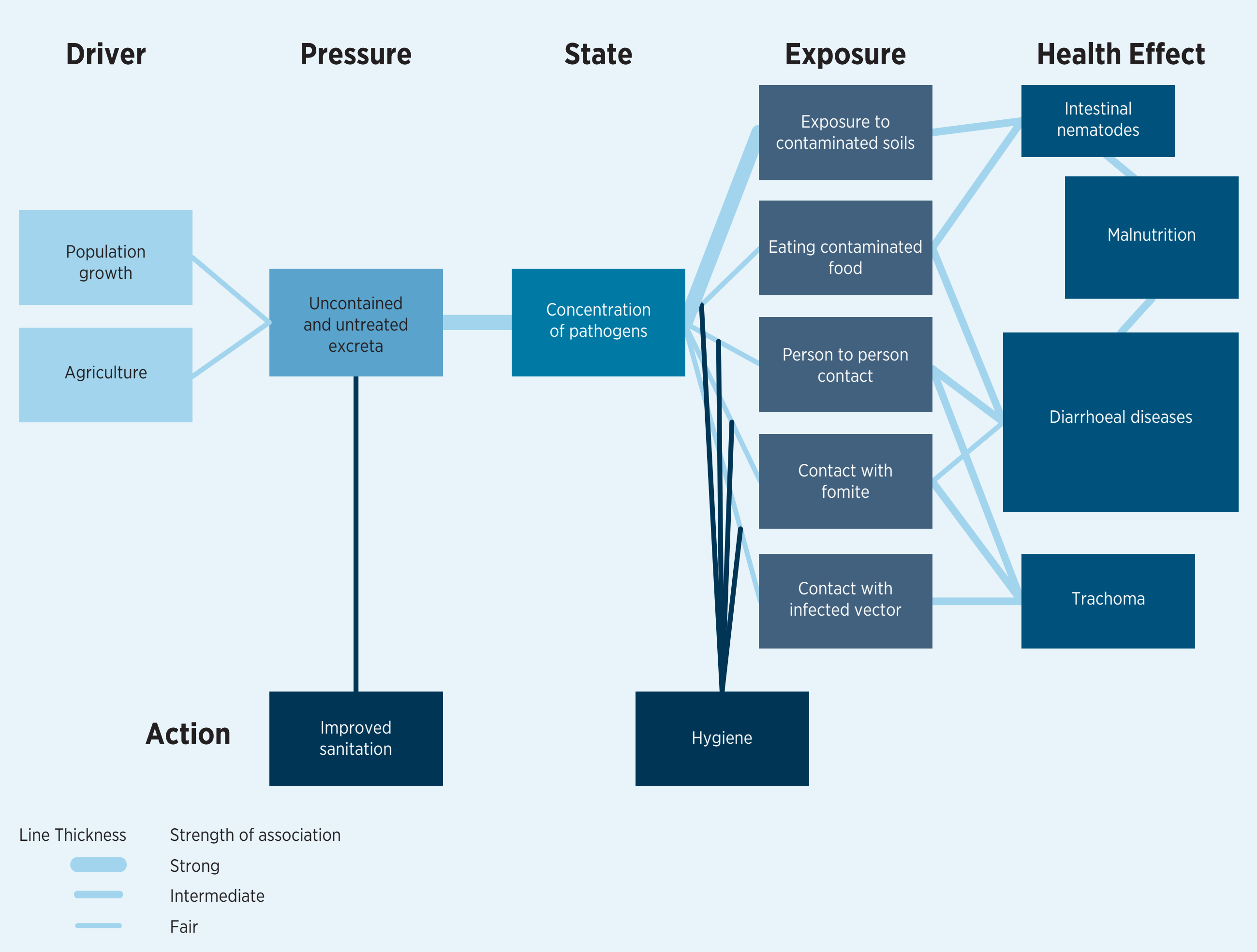
insufficient treatment and interruptions to treatment and service can result in the consumption of unsafe water (Hunter et al., 2005). In aging systems, failure will likely become a principal risk related to water and health issues (USEPA, 2007) (see Chapter 24 for infrastructure tools and options).

Conversely, studies report little evidence for substantial health effects from rural water infrastructures (Esrey, 1996; Fewtrell et al., 2005). Small, especially rural, systems are frequently contaminated and improperly maintained. Water carried into the home frequently becomes contaminated in transport and storage (Wang and Hunter, 2010). Countless anecdotes exist about infrastructures that are poorly constructed, improperly maintained and eventually abandoned.

Point-of-use (PoU) water treatment is a promising way to counter contamination of water during transport and storage. Some evaluations of PoU water treatment systems found reductions of 20–30% in diarrhoeal incidence at the household level (Quick et al., 1999; Reller et al., 2003). Some PoUs remove arsenic and fluoride. Nevertheless, health benefits of PoU treatment depend on individual decisions to adopt and consistently adhere to certain behaviours. The introduction of water treatment technology without consideration for the sociocultural aspects of the community and without behavioural, motivational, educational and participatory activities within the community is unlikely to be successful or sustainable (as reviewed in Sobsey, 2006). Determining effective promotion strategies and

FIGURE 34.3

Driver, pressure, state, exposure, effect and action (DPSEEA) model for water-washed diseases



Note: The size of the health effect boxes varies with the burden of disease in disability-adjusted life years: diarrhoeal diseases, 52,460,000 (including waterborne and water-washed diarrhoeal disease); intestinal nematodes, 2,948,000; malnutrition, 35,849,000; trachoma, 2,320,000 (disease burden estimates from Prüss-Üstün et al., 2008).

BOX 34.2

Sanitation strategies for disease prevention

Sanitation is the safe disposal of human excreta (WHO and UNICEF, 2010), where 'safe disposal' means that excreta is contained or treated to avoid adversely affecting the health of the individual or that of other people (Mara et al., 2010). Improved sanitation can prevent disease by eliminating the source of contamination, by preventing pathogen spread by flies, and by preventing exposure to pathogens in contaminated fields. Most (99%) people in developed countries have access to improved sanitation, while only 53% have access in developing countries (WHO and UNICEF, 2010). Two-thirds of the approximately 2.6 billion people who lack access to improved sanitation live in Asia and sub-Saharan Africa, and approximately 1.2 billion people, over half of whom live in India, defecate in the open (WHO and UNICEF, 2010). Most of those lacking improved sanitation in developing countries are located in rural areas: urban sanitation coverage is 71% in developing countries, while rural coverage is only 39% (WHO and UNICEF, 2010). Sewerage systems, septic tanks with drainage beds, pour-flush latrines and pit latrines can effectively prevent disease if maintained and used consistently (WHO and UNICEF, 2000).

how to sustain behavioural changes should be a priority in PoU initiatives.

In addition to safe drinking water, actions to combat waterborne diarrhoeal disease include sanitation (eliminating the source of pathogen contamination of drinking water – see Box 34.2); hygiene improvements (see Section 34.2.2); and health impact assessments (HIAs) (to evaluate the potential health effects of projects or policies before they are built or implemented to provide recommendations to minimize adverse health outcomes – see Box 34.4).

34.2.2 Water-washed diseases

In contrast to waterborne diseases, water-washed diseases are transmitted when the quantity of water available is insufficient for washing and personal hygiene. Predominant water-washed diseases include diarrhoeal diseases (which are also waterborne – see Section 34.2.1), intestinal nematodes and trachoma. Intestinal nematode infections – including ascariasis, trichuriasis and hookworm – cause approximately 2 billion infections and affect one third of the world's population (de Silva et al., 2003). Approximately 40 million people are infected with *Chlamydia trachomatis*, the etiologic agent of trachoma, and 8.2 million have blinding trachomatous trichiasis (Mariotti et al., 2009). Figure 34.3 outlines the environment–health pathway for water-washed diseases. The dominant drivers are population growth and agriculture. Improved sanitation (Box 34.2) and hygiene (Box 34.3) would serve to significantly reduce the disease burdens.

BOX 34.3

Hygiene promotion

Hygiene refers to practices that prevent the spread of disease-causing organisms. Means to achieve hygiene include cleaning, such as hand washing, which removes infectious microbes in addition to dirt and soil. Along with improved sanitation and storing and using safe drinking water, washing hands correctly and at the right times is a key behaviour for reducing the spread of pathogens (EHP, 2004).

Hygiene promotion is 'a planned approach to preventing … diseases through the widespread adoption of safe hygiene practices. It begins with, and is built on what local people know, do and want' (UNICEF, 1999, p. 10).

These interventions contribute to reducing childhood undernutrition, as diarrhoeal diseases and intestinal nematode infections are closely tied to childhood undernutrition (Figure 34.3). Repeated diarrhoea and intestinal nematode infections are responsible for approximately half of all childhood underweight or undernutrition. Approximately 70,000 children under five years old die annually from malnutrition, and an additional 790,000 die from infectious diseases to which they are more vulnerable because of their nutritional status. Thus repeated diarrhoea or intestinal nematode infections are responsible for 860,000 deaths due to malnutrition per year in children under the age of five (Prüss-Üstün et al., 2008).

Sanitation interacts with both waterborne and water-washed disease groups and is a necessary component of effective prevention of the associated disease burdens, especially diarrhoea. Improved sanitation has been shown to reduce diarrhoeal disease rates (Fewtrell et al., 2005; Moraes et al., 2003), intestinal nematode transmission (Moraes et al., 2004) and trachoma prevalence (Emerson et al., 2004).

Hygiene reduces diarrhoeal disease (e.g. Luby et al., 2004) and trachoma (West et al., 1995), and is promoted as a public health intervention (Box 34.3).

BOX 34.4

Health impact assessments promote health across diverse sectors

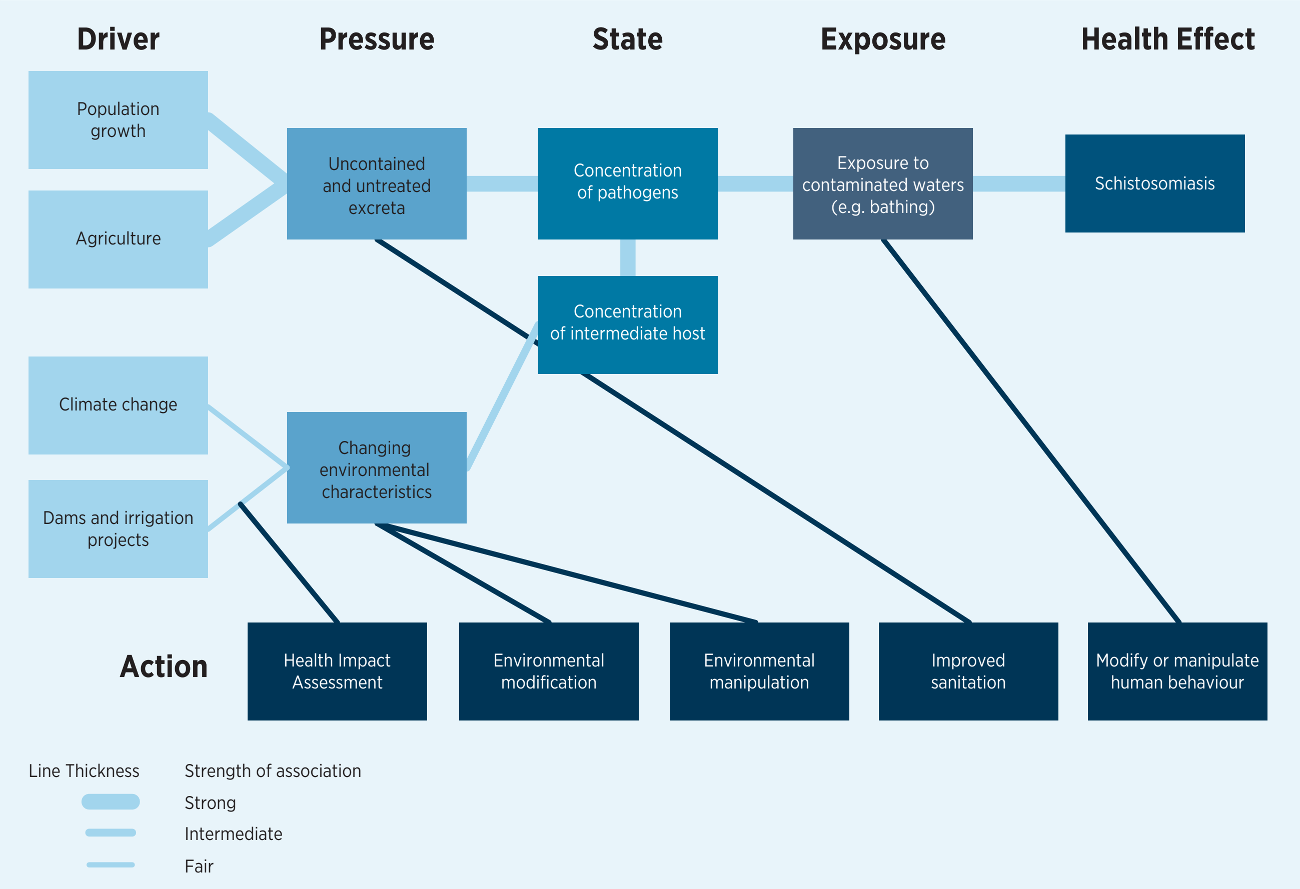
A health impact assessment (HIA) 'is a combination of procedures, methods and tools by which a policy, program or projects may be judged as to its potential effects on the health of a population, and the distribution of those effects within the population (WHO, 1999, p. 4).

An HIA objectively evaluates the potential health effects of a project or policy before it is built or implemented and can identify means to increase positive health outcomes and minimize adverse health outcomes. The HIA framework brings potential public health impacts and considerations to the decision-making process for plans, projects and policies that fall outside traditional public health arenas, such as transportation, agriculture, land use and construction. These activities can greatly affect disease transmission, but are often planned without public health consequences in mind. Cooperation between health, agricultural and development sectors can lead to reduced pathogen transmission.

The major steps in conducting an HIA include:
1. Screen – identify projects or policies for which an HIA would be useful
2. Scope – identify which health effects to consider
3. Assess risks and benefits – identify which people may be affected and how they may be affected
4. Develop recommendations – suggest changes to proposals to promote positive or mitigate adverse health effects
5. Report – present the results to decision-makers
6. Evaluate – determine the effect of the HIA

FIGURE 34.4

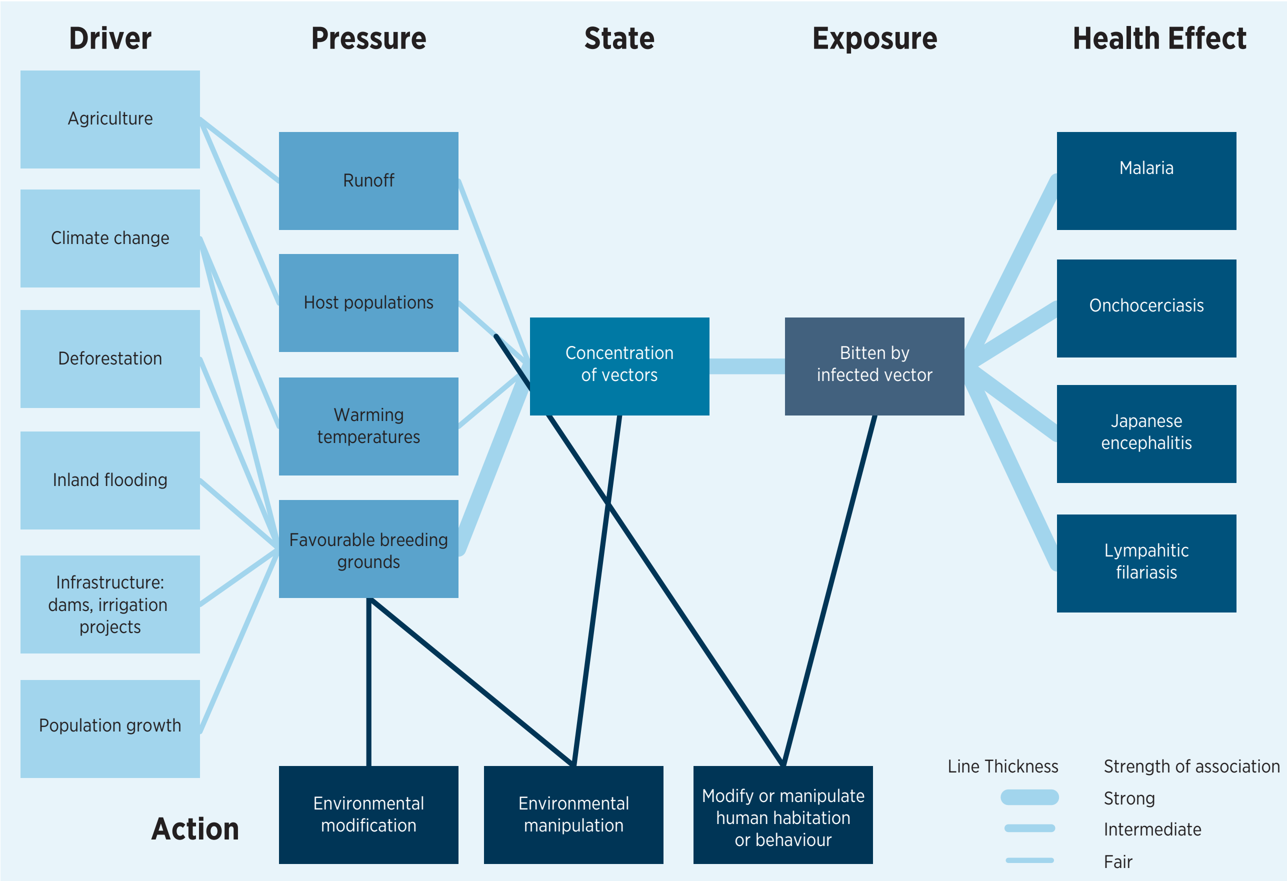
Driver, pressure, state, exposure, effect and action (DPSEEA) model of water-based diseases



Note: The size of the health effect box varies with the corresponding global burden of disease in disability-adjusted life years: schistosomiasis, 1,698,000 (disease burden estimates from Prüss-Üstün et al., 2008).

FIGURE 34.5

Driver, pressure, state, exposure, effect and action (DPSEEA) model of the water-related insect vector diseases malaria, onchocerciasis, Japanese encephalitis and lymphatic filariasis in Africa



Note: The size of the health effect boxes varies with the corresponding global burden of disease in disability-adjusted life years: malaria, 19,241,000; onchocerciasis, 51,000; Japanese encephalitis, 671,000; lymphatic filariasis, 3,784,000 (disease burden estimates from Prüss-Üstün et al., 2008).

34.2.3 Water-based diseases

Water-based diseases are transmitted by hosts that live in water or require water for part of their life cycle. Schistosomiasis has the largest disease burden of these diseases; at any one given time, approximately 200 million people are infected with the trematodes of the species *Schistosoma*, which cause schistosomiasis. Schistosomiasis is principally driven by population growth, agriculture, climate change, deforestation and infrastructure such as dams and irrigation projects (Figure 34.4).

Effective interventions include sanitation (Box 34.2), environmental management (Box 34.5) and the use of HIAs (Box 34.4). Sanitation can reduce schistosomiasis prevalence by 57–87% (Esrey et al., 1991). Environmental management reduces transmission by eradicating host snail populations (e.g. by eliminating marshes and ponds, draining irrigation areas, cleaning and removing vegetation from canals, introducing predators and pathogens, or using molluscicides) and by limiting human contact with infested waters. HIA applied to the design and planning of irrigation or dam projects enables incorporation of preventative safeguards rather than retrofitting responses.

34.2.4 Water-related insect vector diseases

Water-related insect vector-borne diseases (VBDs) are spread by insects that breed or feed near water. The major water-related insect VBDs (malaria, onchocerciasis, Japanese encephalitis, lymphatic filariasis and dengue) are responsible for more than 1.5 million deaths per year. Drivers of these diseases include agriculture, climate change, deforestation, inland flooding, infrastructure projects such as dams and irrigation projects, and population growth (Figures 34.5 and 34.6).

Historically, some of the most effective public health measures against water-related insect VBDs have been targeted at the vector (to interrupt transmission), particularly for diseases lacking vaccines such as malaria and dengue (Gubler, 1998). Such programmes are regaining favour due to environmental problems with chemical insecticide programmes and insecticide resistance. Environmental management of water-related insect VBDs is promoted by the WHO (Box 34.5).

Environmental management has been used to successfully control the transmission of malaria (Baer et al., 1999; Dua et al., 1997; Heierli and Lengeler, 2008),

BOX 34.5

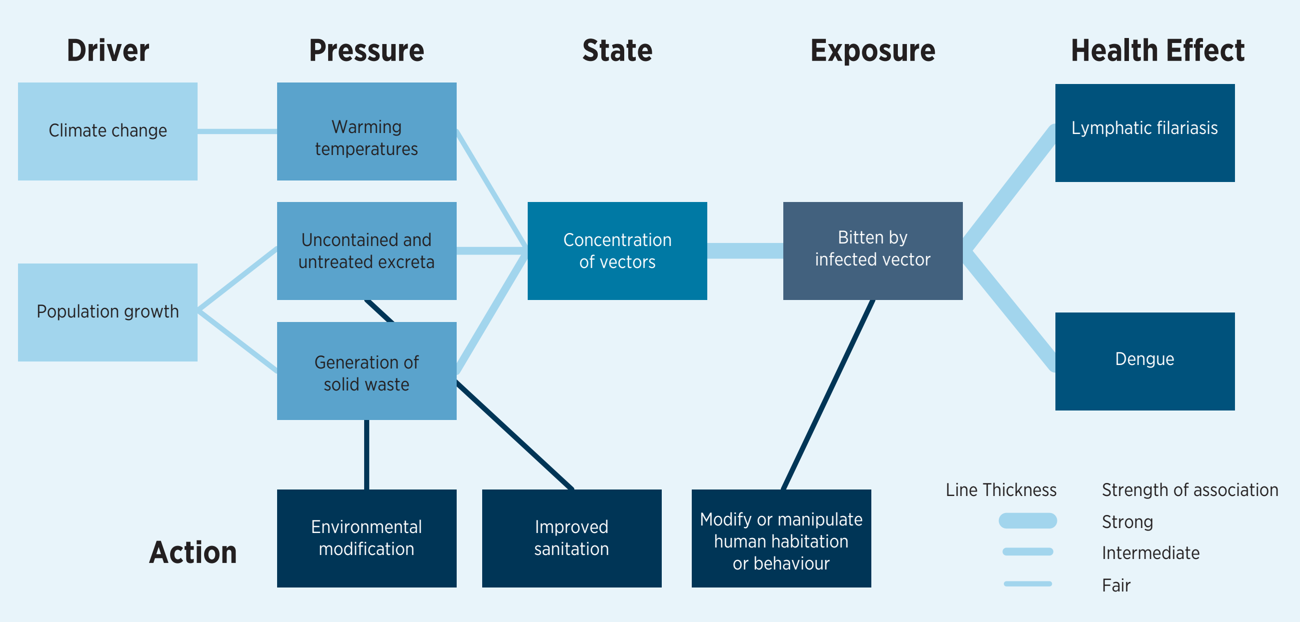
Environmental management strategies to reduce and prevent vector-borne diseases

Environmental management for vector control is 'the planning, organization, carrying out and monitoring of activities for the modification and/or manipulation of environmental factors or their interaction with man with a view to preventing or minimizing vector propagation and reducing man-vector-pathogen contact' (WHO, 1980, p. 9). The three strategies are:

1. Modification of the environment: permanently changing land, water or vegetation conditions to reduce vector habitats, often using infrastructure. Examples include draining or filling-in water bodies or depressions; modifying river boundaries; lining canals; designing small dams as cascading systems; and covering overhead tanks and other water storage structures (Fewtrell et al., 2007).
2. Manipulation of the environment: recurrent activities, often with community involvement, to create temporarily unfavourable conditions for vector propagation. Examples include removal of aquatic plants from water bodies where mosquito larvae may find shelter (de-weeding); alternate wetting and drying of irrigated fields (intermittent irrigation); periodic flushing of waterways where mosquito breeding occurs in standing pools; screening or fitting household water storage containers with proper lids to exclude mosquitoes; and introduction of predators such as larvivorous fish (Fewtrell et al., 2007).
3. Modification or manipulation of human habitation or behaviour: reduce contact between humans and vectors. Examples include vaccination; zooprophylaxis; vector trapping and collection; bednets; door and window screens; and better housing construction.

FIGURE 34.6

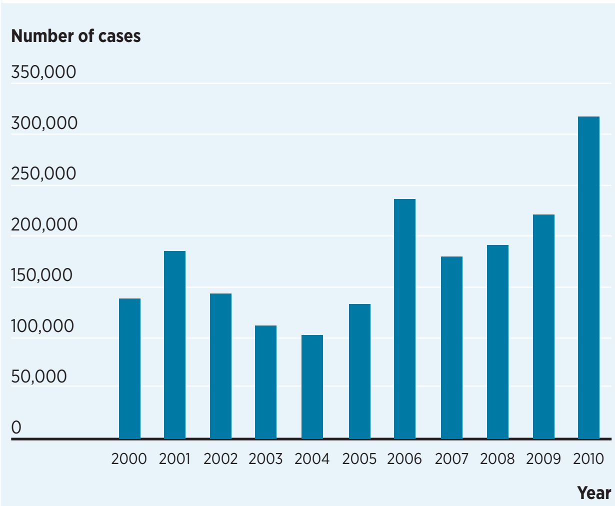
Drivers, pressure, state, exposure, effect and action (DPSEEA) model of the water-related insect vector diseases lymphatic filariasis (Asia and the Americas) and dengue



Note: The size of the health effect boxes varies with the corresponding global burden of disease in disability-adjusted life years: lymphatic filariasis, 3,784,000; dengue, 586,000 (disease burden estimates from Prüss-Üstün et al., 2008).

FIGURE 34.7

Cholera cases reported to the World Health Organization between 2000 and 2010



Source: Adapted from WHO (2011a).

onchocerciasis (Walsh, 1970), Japanese encephalitis (Keiser et al., 2005), dengue and lymphatic filariasis. Sanitation and drinking water also contribute to water-related insect VBD control. In urban areas of south and South-East Asia and the Americas, the mosquito vector of lymphatic filariasis breeds in organically-polluted water, including open sewerage drains and wastewater treatment ponds (Erlanger et al., 2005; Meyrowitsch et al., 1998). Piped water supplies contribute to dengue control by eliminating the need for water storage containers in which the mosquito vector breeds.

34.3 Trends and hotspots

Identifying trends and hotspots in water and health is challenging. There are difficulties in monitoring and reporting; information on determinants is lacking; and the interplay between environmental and other determinants is insufficiently understood. Current monitoring and reporting limitations make it impossible to quantify the water-related disease burden in most countries. Reporting constraints include a lack of reliable morbidity and mortality data; variations within and between countries in the coverage and quality of case reporting; as well as variations in access to health care services and the thoroughness of disease surveillance. There are also multiple environmental determinants concurrently affecting human health within the social, economic and physical environment. These include access to and quality of health care, nutrition, education, governance, socio-economic status and resource availability. Non-environmental determinants of health – a person's individual characteristics and behaviours – also determine disease trends. Some characteristics, including age and sex, can be easily obtained. Others, such as health status and genetic make-up, are not readily available.

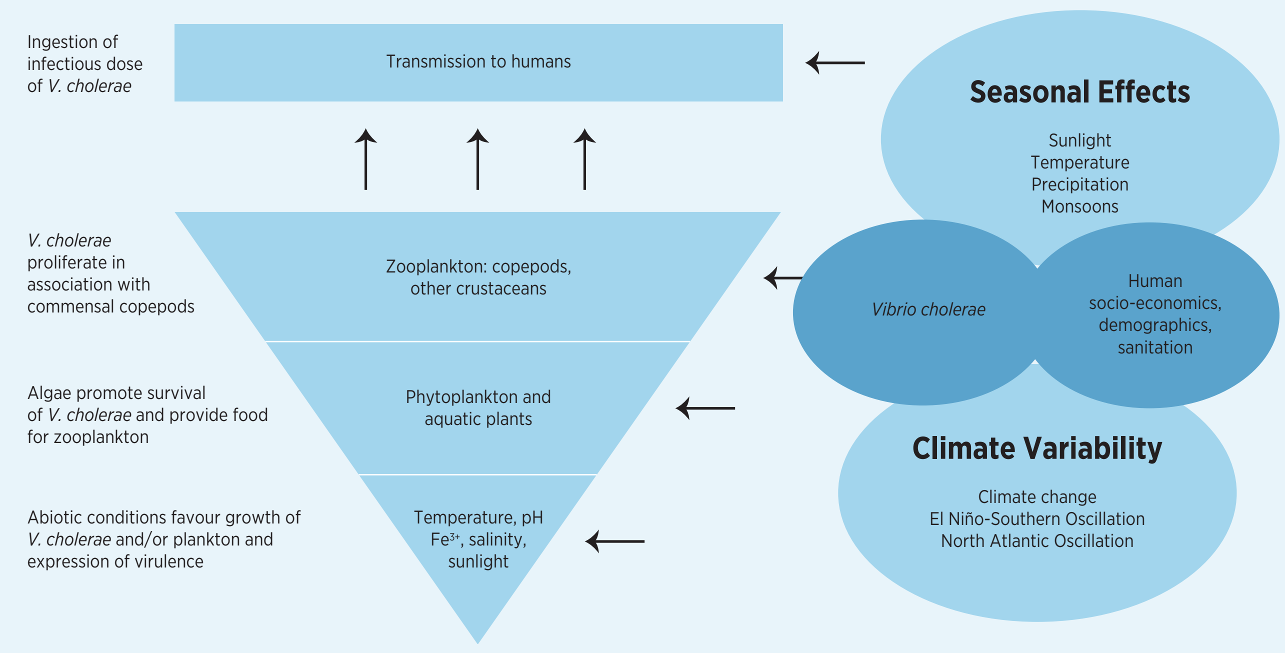
The inability to identify trends and hotspots impairs our ability to make well-informed policy and resource management decisions. Nevertheless, available insights give a basis for action. Some disease risks are rising (e.g. see Figure 34.7), and reasons for these increases can be addressed. Three examples are provided below that illustrate the complex nature of disease risk and highlight how prevention, control and mitigation are being investigated and implemented.

34.3.1 Cholera

Cholera is an acute diarrhoeal disease caused by the ingestion of food or water contaminated with the bacterium *Vibrio cholerae.* There are an estimated 3–5 million cholera cases and 100,000–120,000 deaths due to cholera each year (the WHO estimates that 5–10% of cases are reported). The number of cases reported to the WHO increased by 43% in 2010 compared to 2009, and this number has increased by 130% over the last decade (Figure 34.7) (WHO, 2010*a*). Cholera occurs in regions with poor socio-economic conditions, rudimentary sanitary systems, and where public hygiene and safe drinking water is lacking (Huq et al., 1996). It is endemic in parts of Africa, Asia and the Americas. Risk factors in endemic regions can include proximity to surface waters, high population densities and educational levels (Ali et al., 2001), while temperature, salinity, sunlight, pH levels, iron, as well as phytoplankton and zooplankton growth factors affect *V. cholerae* itself (Lipp et al., 2002). Figure 34.8 describes environmental cholera transmission (Lipp et al., 2002). The risk of cholera outbreaks is intensified during humanitarian crises, such as conflicts and floods, and when large populations are displaced. The 2010 increase is largely due to the outbreak that started in Haiti in October 2010. At-risk areas include peri-urban slums without basic water and sanitation infrastructure, and refugee camps, where minimum requirements for safe water and sanitation are not met. The re-emergence of cholera has coincided with increasing populations living in unsanitary conditions (Barrett et al., 1998).

FIGURE 34.8

Hierarchical model for environmental cholera transmission



Source: Lipp et al. (2002, fig. 1, p. 763, reproduced with permission from The American Society for Microbiology).

Up to 80% of cholera cases can be effectively *treated* using oral rehydration salts. However *prevention* relies on availability and use of safe water and improved sanitation and hygiene. Prevention strategies are critical to averting or mitigating cholera outbreaks. In the case of the Haiti outbreak, the country's health response – led by the Ministry of Public Health and Population and supported by the WHO and other partners – incorporates multiple public health solutions: delivery of soap for hand washing; delivery of chlorine and other products or devices for household water treatment; construction of latrines; improved hygiene in public places (markets, schools, health care facilities and prisons); and health education through various media including community mobilizers (WHO, 2010*b*). In fact, the availability of safe water supplies may prove to be more important for combating cholera than antibiotics or vaccines. A recent study showed that provision of safe water may avert 105,000 cases of cholera (95% confidence interval [CI] 88,000–116,000) and 1,500 deaths (95% CI 1,100–2,300) in Haiti between March 2011 and November 2011, more than the estimated individual effects of antibiotics or vaccines (Andrews and Basu, 2011).

With increasing populations living in peri-urban slums and refugee camps, as well as increasing numbers of people exposed to the impacts of humanitarian crises, the risk from cholera will likely increase worldwide, reinforcing the need for safe drinking water, adequate sanitation and improved hygiene behaviour under these conditions.

34.3.2 Harmful algal blooms

Harmful algal blooms (HABs) comprise algae that are harmful to humans, plants or animals (most algal species are non-toxic natural components of marine and freshwater ecosystems). While HABs do not represent a major global disease burden, bloom detection is increasing and it is likely that disease incidence will similarly increase. The causes of increased bloom detection include natural and anthropogenic species dispersal, nutrient pollution, climate change, as well as increased surveillance (Granéli and Turner, 2006). Approximately 60,000 cases and clusters of human intoxication occur annually (Van Dolah et al., 2001). Although is not fully understood how HABs affect human health, authorities monitor HABs and develop guidelines to mitigate their impacts. For example, the United States Environmental Protection Agency has added specific HAB-related algae to its Drinking Water Contaminant Candidate List, which identifies priority organisms and toxins for investigation. Direct control (biological, chemical, genetic and environmental manipulation) of HABs is more difficult and controversial than mitigation, and HAB prevention is hampered by a lack of understanding of the causes of HAB blooms and an inability to modify or control determinants. For example, nutrients (from agriculture, households and industry) contribute to the growth of HABs, and much of the nutrient input comes from non-point sources (Anderson et al., 2002), which are difficult to control. Effective strategies include land use management, maintaining landscape integrity and reducing non-point source pollution (Piehler, 2008).

34.3.3 Dengue

In 2004, approximately 9 million people contracted the febrile illness dengue (WHO, 2008*a*), the global incidence of which is rising. Approximately 2.5 billion people are now at risk. Because there is no drug or vaccine for the virus, prevention is key. Dengue is transmitted by the *Aedes aegypti* and *Aedes albopictus* mosquitoes, which breed in temporary water storage containers. Thus safe storage of household water supplies is critical for dengue prevention, especially where rainwater harvesting is practised and where large household storage vessels are used (e.g. Mariappan, 2008). Household water containers can be fitted with screens or lids to exclude mosquitoes, but scrupulous maintenance and consistent use is hard to achieve. Covers treated with insecticide can reduce vector density and potentially impact dengue transmission (Kroeger et al., 2006; Seng et al., 2008). Water containers can also be eliminated with piped water supplies; however, extension of piped water supplies to villages has expanded the range of dengue, where unreliable piped water has forced people to store water in their homes for longer periods of time than when they relied on well water (e.g. Nguyen et al., 2011). An integrated approach, incorporating household water treatment and safe storage for reduction of diarrhoeal as well as other water-associated diseases (e.g. dengue and malaria) is needed.

34.4 Solution options

Modelling the environment–health pathway for each of the major threats associated with water and health (Section 34.2) assists in determining the effectiveness of public health solutions for combating water-related disease risks. However, further determination of the populations at greatest risk for each of these threats would allow resources to be targeted more effectively. In this section, regions susceptible to five of the diseases described above are used to illustrate how governments, communities and organizations apply public health solutions to these challenges.

34.4.1 Diarrhoeal diseases in India

Diarrhoeal diseases are a global problem. They are especially prevalent in low income countries, where they are the third leading cause of death, and among children under five years, for who diarrhoeal diseases are responsible for 17% of all deaths (Mathers et al., 2008). Diarrhoeal diseases cause 454,000 deaths annually in India alone (NCMH, 2005), despite the fact that the population using improved water sources has risen from 72% in 1990 to 88% in 2008 (WHO and UNICEF, 2010). Urban dwellers have more access to improved water sources (WHO and UNICEF, 2010) and piped water supplies 69% of households in large cities (McKenzie and Ray, 2009). Nevertheless, water supply in most Indian cities is available for a few hours per day and water quality is questionable (McKenzie and Ray, 2009). Problems with access and quality are mainly attributed to poor management and inadequate regulation (Planning Commission, 2002). Water supply is a state responsibility, but various ministries share responsibility at central and state levels. Institutional arrangements for water supply vary within cities: a state-level agency is responsible for planning and investment, and local government is responsible for operation and maintenance. Local governments are increasingly turning operating and maintenance responsibilities to private companies. This fragmentation results in duplication and ambiguity of functions; poor coordination between the water supply programme and health and education programmes; and a water system that does not aim to reduce disease and poverty, nor to improve hygiene and education (Planning Commission, 2002).

34.4.2 Intestinal nematode infections in Brazil

Intestinal nematode infections are frequent in low income countries, especially in children under 15 years, with high intensity infections common in Africa, South-East Asia and the western Pacific (WHO, 2008*a*). Salvador is the largest city on the north-east coast of Brazil and the capital of the north-eastern state of Bahia. In 1997, 26% of households were connected to an improved sanitation system, and most of these were in upper and middle socio-economic areas (Barreto et al., 2007). Other areas used septic tanks or insanitary methods such as discharging sewage into the street (Barreto et al., 2007). Intestinal nematode prevalence was 43% for *Trichuris trichuria*, 33% for *Ascaris lumbricoides* and 10% for hookworms (Mascarini-Serra et al., 2010). A large sanitation project (Bahia Azul or Blue Bay), mainly financed by a loan from the

Inter-American Development Bank, was initiated to increase the number of households with adequate sewerage systems from 26% to 80% and hence control the pollution of marine waters by domestic wastewater. Approximately half the total budget of US$440 million was allocated for constructing 2,000 km of sewer pipes, 86 pumping stations and over 300,000 household connections between 1996 and 2004 (Barreto et al., 2010). The prevalence of *A. lumbricoides, T. trichuria* and hookworm in schoolchildren was reduced by 25%, 33% and 82%, respectively (Barreto et al., 2010).

34.4.3 Trachoma and trichiasis in Morocco

The highest prevalence of active trachoma and trichiasis is in Africa, predominantly in the savannah regions of East and Central Africa and the Sahel of West Africa (Polack et al., 2005). Morocco was the first country to eliminate trachoma in the 'Alliance for the Global Elimination of Blinding Trachoma by the year 2020' (GET 2020) campaign. Trachoma was largely eradicated from urban areas in the 1970s and 1980s by increased standards of living and antibiotic treatment of schoolchildren, but the disease persisted in poorer rural regions. Incorporation of the SAFE (surgery, antibiotics, facial cleanliness and environmental improvement) strategy into the National Blindness Control Program enabled Morocco to eradicate trachoma (Montgomery and Bartram, 2010). Poor facial cleanliness is consistently associated with trachoma (Taylor et al., 1989; West et al., 1991; West et al., 1996) and is likely the most important modifiable risk factor (Wright et al., 2008). Key to the success of Morocco's programme was its aggressive approach to provide safe drinking water and improved sanitation for at-risk populations (Kumaresan and Mecaskey, 2003).

34.4.4 Malaria in Africa

Malaria is widespread in tropical and subtropical regions, including most of sub-Saharan Africa, Asia and the Americas. Approximately 3.3 billion people are at risk. In Africa, malaria is responsible for 27% of deaths in children under five (Black et al., 2010). The 'Roll Back Malaria' campaign focuses on controlling malaria in sub-Saharan Africa with prevention and case management. The principal interventions are long lasting insecticide treated mosquito nets (LLINs) and indoor residual spraying (IRS) (WHO, 2010*c*). Environmental management is rarely applied. Nevertheless, environmental management can be efficacious and cost-effective. Utzinger and others (2001) reviewed a malaria control programme at copper mines in the former Northern Rhodesia (now Zambia), a hyperendemic area, between 1929 and 1949. The programme implemented multiple control methods, many of which were environmental management methods, including vegetation clearance, modification of river boundaries, draining swamps, oil application to open water bodies, house screening, as well as quinine administration and bednet provision (Watson, 1953). Utzinger and others determined efficacy and cost-effectiveness compared to current malaria control. Within the first three to five years of the programme it was observed that malaria-related mortality, morbidity and incidence rates reduced by 70–95%, and between 1929 and 1949 the programme averted 4,173 deaths and 161,205 malaria attacks (Utzinger et al., 2001). The cost per death averted (US$858) is similar to that for insecticide treated nets in Gambia, Ghana, Kenya and South Africa (US$219–US$2,958) (Goodman and Mills, 1999; Goodman et al., 2001), and the cost per malaria attack averted (US$22.20) is slightly higher than the cost for insecticide treated nets in Gambia (US$15.75) (Graves, 1998). Currently, environmental management is viewed as complementary to other malaria control methods in a minority of settings – where mosquito breeding sites are few, fixed, and easy to identify, map and treat (WHO, 2010*c*) – but it may be beneficial to further integrate environmental management with pharmacological, insecticidal and bednet interventions to decrease adverse ecological effects from chemical spraying and increase sustainability of malaria programmes.

34.4.5 Schistosomiasis in Lao PDR

Schistosomiasis is predominant in tropical and subtropical areas, especially in poor communities without access to safe drinking water and adequate sanitation. It is most prevalent in Africa (88% of all cases) (WHO, 2008*a*). A significant risk factor for schistosomiasis is proximity to irrigation schemes or dams. Of the estimated 779 million people at risk for schistosomiasis, 13.6% live in irrigation schemes or close to large dam reservoirs (Steinmann et al., 2006). The health impacts of development projects such as these were rarely addressed because health was considered the responsibility of the health sector. The spread and intensification of diseases such as schistosomiasis and malaria were unintended consequences of hydropower and irrigation projects (Jobin, 1999; Scudder, 2005; Southgate, 1997; Steinmann et al., 2006). There is an opportunity to improve public health by incorporating HIAs into non-health sector policies (Fewtrell et al., 2008). Use of HIAs for development projects has been increasing, but their influence on decision-making is limited by various challenges. One challenge is the availability of data for quantitative HIAs, especially for projects, programmes and policies within developing countries (Fewtrell et al., 2008). Nevertheless, an HIA was used in drafting the public health management plan for the Nam Theun 2 hydroelectric project in Lao PDR (Krieger et al., 2008). Through site visits, discussions with stakeholders, and gathering and analysis of (mainly qualitative) health and economic data, groups most at risk for specific adverse health effects were identified and mitigation strategies suggested (Krieger et al., 2008). Schistosomiasis was not considered to pose a great risk, and now that the dam is operating, the HIA's ability to predict and avert this disease (and others) can be evaluated. HIAs should be part of the planning, implementation and operation of development projects to efficiently avert adverse health effects.

Protection of public health requires practitioners to act outside the narrowly defined 'health sector' (Rehfuess et al., 2009). Public health professionals must collaborate widely to change the way energy is generated, land is managed, food is produced and transportation is managed in order to improve the health of both the population and the environment (Bartram and Platt, 2010). Policy-makers and project managers in diverse sectors must incorporate health concerns into decision-making. The benefits and disadvantages of development projects could be more thoroughly assessed if decision-making were better coordinated across agencies.

Conclusions

This report examines the water-related diseases that contribute the greatest burden of disease globally and that are realistically amenable to change: diarrhoeal diseases, arsenic and fluoride poisoning, intestinal nematodes, trachoma, schistosomiasis, malaria, onchocerciasis, Japanese encephalitis, lymphatic filariasis and dengue. Using an environment–health pathway and the DPSEEA framework, the drivers predicted to have the greatest effect on disease via the water environment are identified as population growth, agriculture, infrastructure development and climate change. These affect disease rates both directly and indirectly, and increase uncertainty for human health.

There are numerous other environmental and non-environmental determinants of health. The interplay of these with the drivers investigated here may drastically alter predicted morbidity and mortality rates. These determinants will not be proportional between geographic areas or between various populations, making the identification of trends and hotspots in water and health nearly impossible.

While this knowledge gap somewhat impairs our ability to make well-informed policy and resource management decisions, it cannot be used as an excuse for complacency. By outlining the environment–health pathway for each of the major water-related disease groups, five key public health interventions were identified: access to safe drinking water and sanitation, improved hygiene, environmental management and the use of HIAs. Implementation of these actions would contribute to reducing the burdens of diverse diseases and improve the quality of life for billions of people.

This was reaffirmed in May 2011, when resolutions on 'drinking-water, sanitation and health' and on 'Cholera: mechanism for prevention and control' were unanimously adopted at the sixty-fourth World Health Assembly (WHO, 2011*c*). These resolutions fix the policy framework for the WHO, its sister United Nations agencies, in particular UNICEF, and the ministries of health in its 193 Member States to take determined action to promote access to safe and clean drinking water, and to promote basic sanitation and hygiene practices. Member States were urged to re-affirm a strong role for drinking water, sanitation and hygiene in their public health strategies.

Actions for combating the major water-related disease burdens can be pursued at different levels:

- The formulation of policies and the creation of institutional arrangements resulting in an enabling environment (e.g. HIAs).
- Networking to bring together professionals – as promoted by WHO-hosted international networks (drinking water regulators network; small community water supplies management network), the WHO/UNICEF network on household water treatment and safe storage, and the WHO/International Water Association network on operation and maintenance.
- Strengthening normative capacities – such as the fourth edition of the WHO guidelines for drinking water quality (WHO, 2011*b*) and the water safety planning approach as the instrument to implement them (Bartram et al., 2009).

- Monitoring and surveillance – including global monitoring by the WHO/UNICEF Joint Monitoring Programme on Water Supply and Sanitation and by the UN-Water/WHO Global Analysis and Assessment of Sanitation and Drinking-water to guide policies, resource allocation, and actions to achieve the millennium development goals target and provide a platform for the development of indicators and targets for post-2015 monitoring linked to criteria for the human right to water and sanitation (WHO and UNICEF, 2011).

In addition to reinforcing these public health solutions, outlining the environment–health pathway for each disease also enabled the identification of major risks, uncertainties and opportunities. These include the risk of increasing failures of ageing water infrastructure and, conversely, the opportunity to increase the overall impact of water resource, water supply and sanitation infrastructure through improved management. The impact of such actions improves use of limited financial resources thereby enhancing both access to water and sanitation and associated service quality, and leads indirectly to improvements in wider health indicators such as malnutrition. In-depth studies are required to more accurately identify the risks and opportunities related to water and health. The 2030 Vision Study, commissioned by the United Kingdom Department for International Development (DFID) and the WHO, performed such an analysis of the major risks, uncertainties and opportunities related to the resilience of water supply and sanitation in the face of climate change (WHO and DFID, 2009). The study brought together evidence from projections on climate change, trends in technology application, and developing knowledge about drinking water and sanitation adaptability and resilience to identify key policy, planning and operational changes that will be required to adapt to climate change, particularly in low and middle income countries where access to water supply and sanitation services are more limited. Five key conclusions resulted from this study:

1. Climate change is widely perceived as a threat rather than an opportunity. There may be significant overall benefits to health and development in adapting to climate change.
2. Major changes in policy and planning are needed if ongoing and future investments are not to be wasted.
3. Potential adaptive capacity is high but rarely achieved. Resilience needs to be integrated into drinking water and sanitation management to cope with present climate variability. It will be critical in controlling adverse effects of future variability.
4. Although some of the climate trends at regional levels are uncertain, there is sufficient knowledge to inform urgent and prudent changes in policy and planning in most regions.
5. There are important gaps in our knowledge that already or soon will impede effective action. Targeted research is urgently needed to fill gaps in technology and basic information, to develop simple tools, and to provide regional information on climate change.

The relationship between the drivers of water-related diseases and human health is complex. Protection of human health cannot be accomplished without intersectoral collaboration. Policies and projects in non-water or non-health sectors must incorporate health into decision-making to avoid unintended public health consequences and to increase overall benefits. In the case of drinking water quality, addressing the root causes of water contamination is more effective and sustainable then reacting to problems. The guidelines for drinking water quality (WHO, 2011*b*) emphasize collaboration between stakeholders, including land users or householders who may discharge industrial, agricultural or domestic waste; policy-makers from various ministries overseeing the implementation and enforcement of environmental regulations; practitioners delivering water; and consumers. This preventive and collaborative approach towards water safety planning yields cost-savings and sustainable improvements. Experience has also shown, most recently from south and east Asia, that while progress is being made, it remains a challenge to implement such a rigorous 'no short-cut' approach – each risk management solution needs to be tailor-made to the water supply in question, and demands that key stakeholders become engaged and committed to a common goal.

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CHAPTER 35

Water and gender

WWAP, with special thanks to the WWAP Gender Advisory Group

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Acknowledgements Feedback received from the WWAP Advisory Group on Gender Equality was useful in finalizing the chapter. The author would like to acknowledge Gülser Corat, Kusum Athukorala and Marcia Brewster.

Improving women's access to safe water for productive and consumptive uses will not only help increase food production globally, but also improve food, health and livelihood security at community and household levels.

35.1 Introduction

The gender gap in water arises from gender divisions in society, which allocate many water responsibilities to women but vest most water-related powers and rights in men. To improve the balance between responsibilities and powers and rights, changes need to be made in water policy, planning and management. The gender gap will be reduced when both men and women are able to challenge gender-based unequal water roles and allocations, and participate in decision-making at different levels.

Among the many challenges in water faced across the world, scarcity, deteriorating water quality, the linkages between water and food security and the need for improved governance are most significant in the context of gender differences in the access to and control over water resources. These challenges are expected to become more intense due to the growing uncertainty and risk associated with the availability and quality of freshwater resources arising from increasing demand for various uses, climate variability and natural disasters.

Water is used for a wide range of social and economic activities, including public health, agriculture, energy and industry. Water has different values for different uses and purposes, and the same source of water can be used for social as well as economic purposes. Social and environmental valuation is more prevalent at the local level, where water sources may be designated for different uses, such as for drinking, or for common use, such as bathing and washing, depending on the quality of water, or regarded as sacred for religious purposes. In fact, water that has been valued as an economic good, such as irrigation water supplied through an irrigation scheme, also has a social value for local communities, especially for women, who may use the same irrigation water source for both domestic and farming purposes. Opportunities for improving access to water for women and improving their water security can be found by analysing water values through the gender lens.

Water policies based on broad, generalized perspectives are more likely to miss out local knowledge, and social and gender dimensions and their implications. Recognizing the various purposes for which these local water resources are used by different groups of men and women in the community would help successfully integrate gender considerations not only in water resource management, but also in sectors such as urban water supply, agriculture, industry and energy that depend upon water resources, and which are often in conflict over water allocations and their demand for freshwater resources. By working together in partnership with these sectors, synergies and trade-offs in providing access to different groups of men and women in local communities can be understood and addressed by decision-makers in government bodies, private sectors and civil society. This would help in anticipating risks and uncertainties and planning for safe-guards to be put in place for the most vulnerable groups in the community.

35.2 Challenges and opportunities

35.2.1 Gender dimensions of water scarcity

About a third of the world's population is experiencing some kind of physical or economic water scarcity (IFAD, 2007). Among the many causes of scarcity, the growing competition for water from different sectors, including industry, agriculture, power generation, domestic use and the environment, is creating an acute crisis for poor people, making it difficult for them to access water for consumptive, productive and social uses. The scarcity created at the local level from this crisis is increasing inequity within local communities with regard to access and control over local water resources, affecting poor people, and poor women the most. Physical scarcity, especially in arid and semi-arid regions is increasing due to climate variability, droughts and population pressures. The drudgery and health consequences for women in these regions, especially for poor women, and their increased work

BOX 35.1

Women carry the water burden

There are 884 million people in the world who still do not get their water from improved sources, almost all of them in developing regions. For families without a drinking water source on the premises, it is usually women who go to the source to collect drinking water. Surveys from 45 developing countries show that this is the case in almost two thirds of households, while in almost a quarter of households it is men who usually collect the water. In 12% of households, children carry the main responsibility for collecting water, with girls under 15 years of age being twice as likely to carry this responsibility as boys under the age of 15 years.

Source: WHO and UNICEF (2010).

burden in acquiring water for home consumption is very well-documented.

Water scarcity can occur or be experienced due to 'social and gender constructs' or social and economic differences within the society, and customary behaviour that discriminates against women and the socially disadvantaged. When access to local water sources is denied to a section of the population, those people experience scarcity. Access can be denied due to caste (as in India) and class differences or because of conflict between ethnic communities. Women may also be denied access to water where the community water supply is located on the property of the village headman or a local official.

Scarcity can also be caused by the deteriorating quality of freshwater resources. When water sources are polluted, the quantity of clean water or safe drinking water in a particular location is reduced. Although there are accepted minimum standards for water quality, there are also concerns and cultural beliefs that determine and influence the use of different sources of water for different purposes, such as drinking, cooking and bathing. These cultural beliefs, which are often more significant for women, need to be kept in mind when water sources are being exploited for different purposes. If women need to travel long distances to fetch safe and clean water, then the time and energy costs of fetching water are likely to govern their perceptions of hygiene in disease prevention, resulting in lower hygiene levels in the home.

While scarcity affects the lives of all people in the community, these effects manifest themselves differently for men and women of different ages and socio-economic status. Scarcity aggravates the water poverty of women and of young girls who are expected to help their mothers to collect water, often missing school when the water shortage is acute. Research indicates that girls under the age of 15 are twice as likely to carry this responsibility than boys under the age of 15 (WHO/UNICEF, 2010) (Box 35.1). Women from economically well-off or 'upper class' families experience scarcity less intensely than women from poor and socially disadvantaged families.

35.2.2 Gender dimensions of water governance

'Water governance encompasses the political, economic and social processes and institutions by which government, civil society and the private sectors make decisions about how best to use, develop and manage water resources' (UNDP, 2004, p. 10). Water governance is more than national-level legislations, regulations and institutions, and refers to the processes that exist to promote stakeholder participation and mechanisms for decision-making.

Accessibility and availability of safe and sufficient water is therefore often determined by governance, which in turn is affected by social structures and gender relations. There is a close link between water governance, gender and power divides in society. Who takes decisions and at what levels, and the types of decisions taken are greatly influenced by the culture of social relations. Gender relations and social structures will determine at what level women, and which group of women, can participate in decision-making and what that mechanism will be. To make water governance more effective, existing formal and informal mechanisms for decision-making, including power structures within the society which are governed by class, gender and ethnicity need to be challenged. When traditional roles are challenged, power relations are likely to change therefore reducing the gender gap is a process that is accompanied by women's empowerment.[1]

Debates around gender dimensions of water governance tend to delegate gender considerations to the realm of the 'grassroots'. Keeping the focus of discussion on women's physical burden of fetching water for household purposes is politically comfortable and does not challenge the larger and broader access and power issues that increase women's water burden in the first place. It is easier to bring the drinking water pipeline to the community than to challenge the gender divide that places the responsibility of fetching water for the household on the woman. Although it may be true that gender concerns become more pronounced closer to the grassroots, where people interact directly with water and natural resources, it is important to understand that national and international policy affects access and control over local water resources as well.

Decisions about water sharing, allocation and distribution between different uses and across regions are most often made at higher levels where economic and political considerations play a more important role than social concerns. These decisions impact water resources locally available to communities that are likely to lose access to the very resources that sustained their livelihoods and fulfilled their needs. Rural women often rely upon common water resources, such as small water bodies, ponds and streams to meet their water needs, but in many regions these sources have either been eroded or have disappeared due to changes in land use or have been appropriated for development by the state or industry.

Water policies based on broad, generalized perspectives are more likely to miss out local knowledge, and social and gender dimensions and their implications. Social and gender analysis conducted at the lowest possible level to capture the local context, such as the community water source, the sub-basin level, or micro-watershed level can help in understanding the problems and potential impact of the policy on different groups of women. Community water sources, whether natural or man-made lakes, ponds and irrigation schemes, serve many purposes, including fishing, agriculture, kitchen gardens, washing and bathing. Women use water for many different purposes, including domestic, agriculture, health and sanitation, whereas men are generally concerned only with water use for agriculture and livestock. Recognizing the various purposes for which these local water resources are used by different groups of men and women in the community would help successfully integrate gender considerations in water management.

This analysis can inform broad national, regional and international policies, not only related to water management, but also to other sectors, such as agriculture, energy and industry. An evaluation of the Food and Agricultural Organization's (FAO) work and role in water found that irrigation and agriculture policy statements with the clearest description of local farmer typologies and the challenges faced by them succeeded best in developing strategies responsive to circumstances in the country (FAO, 2010*a*). By identifying different farmer groups, the policies were able to develop action plans for addressing the concerns of men and women farmers in Zambia, Malawi and Swaziland and to a lesser degree in Mozambique, Kenya and the United Republic of Tanzania (FAO, 2010*a*) (Box 35.2).

Climate change impacts, increasing population pressures on water resources, and competition from different uses are likely to increase women's water poverty in the future. Women depend upon and use water to sustain the food security, health and economic stability of their families and communities. To reduce women's water poverty, changes would need to be made at many different levels. The decision-making and policy processes would need to be opened up to include consultation with or active participation of the appropriate group of women in the given context and to support their right to water. Recent trends in governance in various aspects of water management which use multi-stakeholder platforms for increasing participation and transparency can provide a space for women to express their views and opinions, and encourage a gender perspective in policy making and implementation.

At the field level, appropriate groups of women need to be consulted during the design and implementation of water projects to maximize the benefit of these projects. Wives of rich farmers, for example, are less likely to be interested in community irrigation or drinking water schemes than poorer women, but may participate for political reasons. Therefore it would be necessary to identify and involve women whose interests are directly affected by the project or intervention; if this is not done the project could have a negative impact on those women who need the intervention the most. Women are generally not recognized as decision-makers or as contributors to the household economy; in

BOX 35.2

Gender mainstreaming through effective policy formulation

An evaluation of the Food and Agricultural Organization's role and work in water in 2010 highlighted that for effective policy development, it was important to clearly identify the relevant target populations for whom the policy was meant. An analysis of irrigation and agriculture policies in seven countries from a gender and social inclusion perspective found that policy statements with the clearest description of local farmer typologies and the challenges faced by them in the context of the country's food security and poverty goals generally succeeded best in developing strategies responsive to circumstances in the country and took into account and addressed the issues and concerns of smallholder farmers and socially disadvantaged groups. Agriculture and irrigation policies in Zambia, Malawi and Swaziland identified gender disparities among farmers and developed strategies to address them, whereas although gender disparities were identified in Mozambique, Kenya and the United Republic of Tanzania, the strategies for addressing these were still being developed.

Source: FAO (2010a).

many aspects they are still viewed as family labourers or unpaid labour, especially in agricultural households. On one hand these cultural constraints usually hinder women's participation in water management organizations and decision-making, and on the other, women's engagement in domestic household chores usually prevents them from active participation in local water management organizations.

However, gender sensitization for men and women in the community, and capacity development for women could make their participation more effective. Women's groups, such as self-help groups, could also provide a collective voice for participation. Other interventions could include creating greater gender awareness among water managers, including gender expertise in water projects, providing technical training to women to enable them to participate in technical discussions, and developing and disseminating tools for gender mainstreaming in water management and governance.

35.2.3 Agriculture, food security and gender dimensions

According to latest estimates by FAO, 925 million people are undernourished, of which 62% live in Asia and the Pacific, the world's most populous region, followed by sub-Saharan Africa, which is home to 26% of the world's undernourished population. The rise in global undernourishment is a combined result of declining investments in agriculture, increased production costs and rising food prices, in particular the continued increase in prices of staple cereals and oil crops (FAO, 2010*b*).

Food production would have to increase by 70% to feed a population of 9 billion people by 2050. Of the 1.5 billion hectares (ha) of cropland worldwide, only 277 million ha (or 18%) is irrigated land; the remaining 82% is rainfed land. Recent research indicates that to meet the demand for food, water productivity needs to be improved, not only in irrigated, but also in rainfed areas (FAO, 2010*b*). This is because, due to the high investment costs and the growing competition for water, the scope for further expansion in irrigation is limited in many countries.

Women play an important role in irrigated as well as non-irrigated agriculture, and a larger number of women than men is engaged in rainfed agriculture, producing 'two-thirds of the food in most developing countries' (World Bank, 2006). It is important to note that 'the vast majority of the world's farms are small; 85% of them are less than 2 hectares, and 97% less than 10. In Africa, 80% of farmed land is cultivated by smallholder farmers, the majority of whom are women' (UN, 2009, p. 8). According to the *World Development Report 2008* (World Bank, 2007, p. 7), 'where women are the majority of smallholder farmers, failure to realize their full potential in agriculture is a contributing factor to low growth and food insecurity'.

Women comprise an average of 43% of the agricultural labour force in developing countries (FAO, 2011). Eighty% of the basic food in sub-Saharan Africa is produced by women (FAO, 2006). In Africa, Europe and Central Asia, and some East Asian countries, men and women work equally in agricultural self-employment (World Bank, 2007). 'In Mozambique, Rwanda, Uganda, and Egypt, women are even more likely to participate in agricultural self-employment, whereas in Latin America and South Asia, women reportedly work less in agricultural self-employment.' (World Bank, 2007, p. 79). In all these regions, as well as in Africa, women have broadened and deepened their involvement in agricultural production in recent decades (World Bank, 2007). In spite of this, agriculture and water policies continue to wrongly assume that farmers are men, reinforcing many of the constraints faced by women in agricultural production.

Gender inequalities exist all along the food production chain, beginning with asymmetries in ownership of, access to, and control of livelihood assets, such as land, water, energy, credit, knowledge and labour. Women in general have less access to productive resources than men.

Across the regions, less than 5% to about 15% women own agricultural land (FAO, 2011). In nearly all regions of the world, water rights and access to water are tied to land ownership. Land ownership is also associated with recognition as farmers. When women lack this recognition they cannot access other services important for food production, such as extension services, credit and subsidies, and are denied participation in decision-making processes. As membership to water users associations (WUAs) in formal and informal irrigation schemes is restricted to landowners, most women do not have access to irrigation.

In the developing world, men tend to focus on market-oriented or cash crop production, whereas women work with subsistence agriculture, minor crops and vegetable gardens, and often grow a wider diversity of crops (World Bank et al., 2009). Consequently, the use and management of irrigation water is likely to be different for men and women farmers (World Bank et al., 2009). For example, in gender-based farming systems in sub-Saharan Africa, where men and women often cultivate separate fields (Van Koppen, 2002), this reality has often been ignored in irrigation projects. As a result, while men could irrigate their cash crops, women did not have access to irrigation systems for vegetable gardens and subsistence crops.

The lack of recognition of the different needs of men and women has often resulted in the partial or total failure of irrigation schemes. As key decisions in site selection, beneficiaries, land (re)allocation and water rights are made during the planning phase of water-related investment projects, the lack of recognition of women's irrigation needs at the planning stage itself forms the basis of gender inclusion or exclusion in the projects (Van Koppen, 2002). As more men out-migrate, leaving women in charge of managing the farms, it becomes even more important to involve women in managing irrigation. It is also important to acknowledge and plan for the fact that women use 'irrigation' water for productive and domestic purposes. Multiple use systems therefore provide better opportunities for women to participate in irrigation management and decision-making, thereby improving the sustainability of the systems (Box 35. 3).

Technical interventions for improving rainfed agriculture, such as rainwater harvesting, which are also good climate change adaptation measures, access to small-scale irrigation technologies, and developing the capacity of women farmers for conserving water and soil moisture, would provide an opportunity for women to play an important role in increasing food production, securing livelihoods and improving food security. By improving the agricultural yields of women farmers, the number of undernourished people could be reduced by as much as 100–150 million (FAO, 2011).

Improving women's agricultural productivity would not only make more food available to their families, but also provide much-needed cash income for securing the health, education and food security of their households. Food and nutrition security varies within the household as family members have differential access to food. In many cultures women and girls eat last and therefore in poorer households women may be deprived of adequate food and nutrition. Improved incomes and economic empowerment may help women improve their own food and nutrition security, as well as that of their children.

35.2.4 Gender dimensions of biofuel production

As water rights are closely linked to land rights, and both land and water are required for crop production, any debate on the production of bio-fuels for energy would need to address the impacts of diverting land and water resources from food production to the production of bio-fuel, and the gender dimensions of food security.

BOX 35.3

Making participatory irrigation development beneficial for women in the United Republic of Tanzania

In an International Fund for Agricultural Development (IFAD)-supported Participatory Irrigation Development Programme (1997–2007) in the United Republic of Tanzania, farmers are encouraged to take responsibility for irrigation development so that schemes reflect their needs and not those of planners.

Water supply schemes are built for multiple uses besides irrigation, to address women's concerns about water availability for domestic uses. Thus, shallow tubewell schemes have been constructed to provide water for horticultural crops, rice seedling nurseries and domestic use. This is particularly aimed at reducing workloads by reducing the time women spend in fetching water for domestic use.

Women are actively involved in the water users associations (WUAs), sometimes even more than the male members. The responsibilities of the WUA committees are shared equally by male and female members. Although most plot owners are men, the proportion of women with plots and membership in WUAs is over 30%. Women manage shallow wells and have access to irrigation for growing vegetables for both food and income. As a result of gender training and sensitization, women have also taken up leadership roles in WUAs and district councils, and participate in savings groups and credit associations.

Source: IFAD (2005).

> 'FAO estimates that, in sub-Saharan Africa and the Caribbean, women produce as much as 80% of basic foods, while in South and Southeast Asia, 60% of cultivation work and other food production is done by women.' (FAO, 2006, p. 2). 'Furthermore, although FAO projections to 2010 indicate a continued reduction in the overall female participation in agriculture globally, the percentage of economically active women working in agriculture in LDCs (least developed countries) is projected to remain above 70%.' (FAO, 2006, p. 5).

The potential depletion (or degradation) of natural resources associated with biofuel production, such as increased soil and water pollution, soil erosion and water runoff, with subsequent loss of biodiversity and reduced production of food crops is therefore more likely to impact women's agricultural and rural livelihoods. In addition to decreasing food security, competition for land and water resources between food and energy crop production could displace farming communities from traditional farmlands and reduce access to common lands which provided fuel and fodder for rural households and their animals. This in turn would mean that women would have to spend longer hours in accessing fodder and firewood as it is traditionally their responsibility to do so. Further, 'the replacement of local crops with energy crop plantations could also threaten the extensive knowledge and the traditional set of skills of smallholder farmers in the management of local crops. It would also threaten the knowledge related to the selection and storage of seeds and crops, all activities traditionally performed mainly by women.' (FAO, 1999).

A growing concern about the possible impacts of biofuel production has initiated efforts to understand how biofuel production can be pro-poor, and pro-women, helping to not only safeguard women's livelihoods but also to alleviate their work burden. Research by the International Food Policy Research Institute (Arndt et al., 2009) shows that positive technological spillover effects from the cultivation of biofuel, particularly when key staple crops are cultivated, could benefit subsistence, smallholder agriculture. To address potential conflict between the goals of poverty reduction and agro-business,[2] industry type of biofuel production, some countries have begun to adopt strategies that integrate subsistence crop systems with energy crop production to 'avoid complete domination by mono-crop plantation systems and allow for a more varied agricultural landscape and the ability to capture pro-poor benefits.' (Arndt et al., 2009).

A review of local biofuel projects in Africa and Asia conducted by the International Network on Gender and Sustainable Energy (ENERGIA)[3] found that 'village level projects have great potential in terms of sustainable fuel production and increased access to energy in rural areas of developing countries – if participatory processes are employed in the development and implementation of the projects. On a small scale, locally produced plant oils and biodiesel can successfully be

BOX 35.4

Extraction and use of Jatropha oil by a village women's group to power shea butter processing equipment in Ghana

A women's group in Gbimsi, Ghana is producing biofuel to run shea butter processing equipment and to use it as a kerosene substitute in lanterns. The women grow Jatropha plants, extract oil from the seeds and mix it with diesel (70% plant oil/30% diesel) to produce fuel. The project serves as a model for village level biofuel production linked to the empowerment of women, and efforts are being made to finance similar projects in other villages.

For the members of the women's group, much of the drudgery involved in the shea butter processing has been eliminated, resulting in increased production and improved access to credit from the local bank. The processing time is reduced by six hours, making more time available for household interaction; more relaxation for improved health, entertainment, community peace and harmony; and increased attention to other income generating activities.

'Regular group interaction and participation in meetings and workshops has broadened the outlook of the women. ... Over all, they have more ability to make their own choices, and have gained in terms of improved self-esteem, better negotiating skills, more time for volunteering, and greater opportunities for contributing to the household budget.'

Note: This project has been undertaken by a women's group in Gbimsi, a town about 2 km from Walewale in the West Mamprusi District of the northern region of Ghana, with support from the United Nations Development Fund for Women (UNIFEM), the GRATIS Foundation in Ghana, and the United Nations Development Programme – Global Environment Facility (UNDP-GEF) Small Grants Programme.
Source: Karlsson and Banda (2009, p. 15).

used to power diesel engines and generators in rural villages – for agricultural processing, enterprises, and income generation' (Box 35.4), and contribute to reducing the work burden of women. Women could then engage in new income-generating activities that could enable them to 'send their children to school, feed their families nutritious food, provide better health care and living conditions, and have more power to make decisions within their households and communities' (Karlsson and Banda, 2009, pp. 4–5).

It was also found that unlike the threats related to biofuel production which come from the operation of big plantations run on an agro-business model, in village-based models, it is possible to protect the interests of small landowners and engage them as producers and processors of biofuel as part of a larger value production and supply chain without compromising food and water security. By utilizing land and water resources effectively, production and use of biofuel locally can improve the livelihoods of women.

35.2.5 Gender dimensions of urban water security

It is expected that by 2020, the developing countries of Africa, Asia and Latin America will have the largest number of people living in urban areas. Seventy-five% (FAO, 2008) of all urban dwellers worldwide will be in these regions, and 85% of the poor in Latin America, and about 40–45% of the poor in Africa and Asia will be concentrated in towns and cities (FAO, 2008). Providing safe and secure water for this fast growing urban population is one of the greatest challenges for the present and the future. An even bigger challenge is to provide safe, secure and affordable water to the poor communities that live within these urban conglomerates.

An estimated 40% of people living in Asian cities with a population of over 1 million, most of whom are poor, do not have access to piped water (Das et al., 2010). Access to piped water within the household averages about 85% for the wealthiest 20% of the population, compared with 25% for the poorest 20% (UNDP, 2006). In most developing countries, the poorest people not only have access to less water, and to less clean water, but they also pay some of the world's highest prices. Poor people living in slums often pay 5–10 times more per litre of water than wealthy people living in the same city (UNDP, 2006). For example, 'people living in the slums of Jakarta, Indonesia; Manila, the Philippines; and Nairobi, Kenya, pay 5–10 times more for water per unit than those in high-income areas of their own cities—and more than consumers pay in London or New York; and the poorest 20% of households in El Salvador, Jamaica and Nicaragua spend on average more than 10% of their household income on water. In the United Kingdom a 3% threshold is seen as an indicator of hardship.' (UNDP, 2006, p. 7).

Being able to access piped water supply depends upon the household's financial ability to connect to the pipeline. Connection fees are generally high and can exceed $100 even in the poorest countries (UNDP, 2006), making it difficult for poor people to have access to piped water supply. For example, in Manila the cost of connecting to the utility 'represents about three months' income for the poorest 20% of households', and 'about six months' income for the poorest in urban Kenya'. (UNDP, 2006, p. 10). In addition, utilities in many cities refuse to connect households that lack formal property titles, which again are often the poorest. (UNDP, 2006). Location is another barrier to connecting to the water utility. Slums or informal settlements are often situated in difficult-to-connect locations in terms of distance and topography (Pangare and Pangare, 2008).

As water passes through intermediaries and each adds transport and marketing costs, prices increase. The rising block tariff system being implemented by most utilities aims to combine equity with efficiency by raising the price with the volume of water used. However, distance from utilities tends to inflate prices, and in practice, the poorest households are often locked into the higher tariff bands as the intermediaries serving poor households are buying water in bulk at the highest rate. In Dakar, poor households using standpipes pay more than three times the price paid by households connected to the utility (UNDP, 2006).

Efforts to improve urban water supply through private sector participation have not been as successful as expected in improving access for poor households and women. The Cochabamba experience (in Bolivia) showed that social differences, inequities and vulnerabilities can increase if the approach is not pro-poor (Ledo, 2004). However the success of the reform process undertaken in Cambodia by the Phnom Penh Water Supply Authority (PPWSA) showed that the poor can gain access to piped water supply if the efficiency and effectiveness of public water utilities is improved (Box 35.5). Not only did the water supply in

Phnom Penh improve as a result of these reforms, but cost recovery measures were also successful because stratified subsidies were made available to the poor (Das et al., 2010).

When poor households or communities living in slums or informal settlements do not have access to piped water networks, they tend to meet their water needs through a combination of different sources and means. They (most likely women and girls) either collect water freely from public or private protected or unprotected sources and/or purchase water from formal or informal vendors, depending upon the quantity and quality of water available (Pangare and Pangare, 2008). As a result, the poorest, especially the women, often pay the most for water, particularly taking into account the smaller quantities of water they are able to purchase (such as paying for each bucket of water) and the additional indirect cost of poor quality water in terms of waterborne diseases and health care.

A recent study on urban water vending in Uganda found that water vendors by re-selling piped water to the poor who are unable to invest in obtaining a private or yard tap connection for their households, are actually extending the National Water and Sewerage Corporation (NWSC) coverage to the urban poor (Pangare and Pangare, 2008). A majority of the water vendors in Uganda had employed young children or women to manage the taps or water-selling points, because they could be employed at very low salaries (Pangare and Pangare, 2008).

BOX 35.5

Improving access for the poor: Phnom Penh Water Supply Authority, Phnom Penh, Cambodia

Soy Najy, whose household consists of seven members, received her Phnom Penh Water Supply Authority (PPWSA) connection in 2005. She used it to purchase three drums (20 L per drum) of water from vendors every day at a price of 2000 Riel per drum, amounting to Riel 150,000 or US$37.5 per month. She has a sewing and tailoring shop, and requires more water than is normally used for domestic consumption. In 2005, residents from the squatter colony in which she lives urged PPWSA to extend their network to their locality. Now that Soy Najy has access to the water supplied by the public utility, she pays 15,000 Riel or US$4 per month for water – that is, one-tenth of what she paid before. It has helped her reduce expenses to a great extent.

Prior to the PPWSA connection, the locality received water only at night because the slum was located at a higher elevation. Now residents have 24-hour water supply and at a much lower cost.

Source: Das et al. (2010).

35.2.6 Gender concerns in health and sanitation

Access to water for life is a basic human need and a fundamental human right. Yet 884 million people are denied the right to clean water and 2.6 billion people lack access to adequate sanitation (WHO and UNICEF, 2010). Every day, almost 5,000 children, (about 1.8 million children per year), die as a result of diarrhoea and other diseases caused by unclean water and lack of sanitation, making it the second largest cause of child mortality. Easier access to clean water and sanitation improves hygiene behaviour and can reduce the risk of a child dying by as much as 50% (UNDP, 2006).

'Every day millions of women and young girls collect water for their families, a ritual that reinforces gender inequalities in employment and education.' (UNDP, 2006). Women often spend up to six hours every day fetching water, the time calculated includes walking to the source of water, waiting in queues and then carrying back the heavy containers filled with water (UNDP, 2006). In addition, carrying water in large containers on their heads is more likely to have severe health implications for women and girls, such as backache and headaches, and other problems, such as anxiety, stress, light-headedness, vomiting and vertigo after walking many hours with a huge gallon of water (UN-HABITAT/GWA, 2006).

With increasing contamination of surface water and groundwater sources, women, as primary collectors of water, are the first to be exposed to waterborne diseases. This not only affects their own health and reproductive health but also often results in birth defects and high infant mortality. Also the stigma attached to waterborne diseases, such as urinary schistosomiasis in women affects their own health-seeking behaviour and access to health care.

Both men and women suffer indignity and ill health from inadequate sanitation. However, men, women and children have different sanitation needs, and these need to be kept in mind when designing sanitation facilities. It is also important to facilitate privacy and security in common facilities for young children and women.

Lack of water and sanitation perpetuates gender inequality and disempowers women in different ways. Particularly in water-scarce regions, millions of girls are unable to attend school because they must fetch water for their households. In addition, lack of sanitation facilities in schools keeps young girls out of school, especially during puberty, limiting their opportunity for continuing their education, consequently limiting their life and livelihood choices. The time spent fetching and collecting water and caring for children and family members made ill by waterborne diseases and their own associated health problems reduces women's opportunities to engage in productive work.

In general, not having access to clean water and adequate sanitation is a major cause of poverty and malnutrition; the associated ill health traps vulnerable households in cycles of poverty, undermining the productivity of the poor people and reinforcing economic inequalities.

35.2.7 Gender dimensions of water-related disasters

Thousands of women and men die worldwide every year as a result of water-related disasters. It is predicted that climate change will further increase the number of human deaths from heat waves, floods, storms and droughts, as these extreme weather events will increase in frequency and intensity. Although there is not enough sex-disaggregated data available on how these disasters affect men and women, there are indications that mortality differences by sex may vary from one country to another and by type of hazard.

Recent information on the impact of the tsunami in December 2004 suggests that women and girls may be more vulnerable to some natural disasters as a result of less access to information and life skills development, and culturally constrained mobility of women outside of their homes. Many more women than men died in several locations hit by the tsunami, and a large number of them were between 19–29 years of age, suggesting a combination of increased vulnerability of women staying home with children at the time of the sea level rise and the more fortunate situation of some of the young men who were far away from the coastline, fishing at sea or out in the agricultural fields (Oxfam International, 2005).

Strategies and responses developed to mitigate the impacts of water-related disasters are usually designed for the entire population of the vulnerable area, and use existing social structures for decision-making and communicating information. Responses would be more effective if the different needs, constraints and strengths of different groups of men and women in the local community were identified and this information was used while preparing mitigation and response strategies and plans.

As the Pan American Health Organization (PAHO) points out on the basis of its experience, natural disasters often offer women the opportunity to challenge their gendered status in society. Not only do women take up traditionally male tasks outside their domestic spheres, but often do so against the wishes of the men in the community, thus challenging their perceived roles in society. Women are 'most effective at mobilizing the community to respond to disasters', and as a result of their response efforts, women are developing new skills, such as natural resource and agricultural management, which in the presence of appropriate enabling frameworks, could represent opportunities for income generation (PAHO, 2001).

35.3 The way forward

Over many decades, the UN has made significant progress in advancing gender equality, including through landmark agreements, such as the Beijing Declaration and Platform for Action, and the Convention on the Elimination of All Forms of Discrimination against Women (CEDAW), and setting up of UN Women to accelerate progress in achieving gender equality and women's empowerment. Water and Gender is listed as one of UN-Water's Thematic Priority Areas in its 2010–2011 Work Programme and promoting gender equality and the empowerment of women worldwide is one of UNESCO's two global priorities for 2008–2013 (UNESCO, 2009).

There is enough evidence to show that integrating a gender-sensitive approach to development can have a positive impact on the effectiveness and sustainability of water interventions and on the conservation of water resources. Involving both men and women in the design and implementation of interventions leads to effective new solutions to water problems; helps governments avoid poor investments and expensive mistakes; makes projects more sustainable; ensures that infrastructure development yields the maximum social and economic returns; and furthers development goals, such as reducing hunger, child mortality, and improving gender equality (Oxfam International, 2005 and 2007).

Although it is true that many socially constructed barriers need to be overcome to facilitate the involvement of both men and women in decision-making and management of water resources, it is also true that traditional gender roles have often been challenged successfully by developing women's capacities to manage water interventions and providing them with opportunities to play leadership roles and improve their economic conditions. However, these successes are more often limited to the local context as the larger issues, such as providing water rights to women, are governed by externalities which are not only outside the purview of these interventions, but involve traditional, cultural and political realities that are difficult to change in the short-term, and require long-term commitment from policy-makers, governments, politicians and advocacy groups.

It is clear that to meet future challenges in water in all its uses it is necessary to decrease the gender gap in water. Opportunities for addressing these challenges call for greater participation by women for which new methods of water governance would be required, actions would need to be taken to improve women's access to productive resources and capacities would need to be built to facilitate these changes and make them effective. Suggested below are action points in three areas.

35.3.1 Mainstreaming gender considerations in water governance

- Recognize women as important decision-makers in water governance.
- Recognize the diversity of women, and social and gender constructs in society. Identify the specific groups of women who form the relevant stakeholder group in a given context and enable them to participate in decision-making. Some of these specific groups include, but are not limited to, poor women, rural women, women in peri-urban areas, women farmers, and women who have been denied access to a water source due to social constructs, such as class, ethnicity and cultural constraints in the community.
- Enable women to become members of water management institutions, such as water user organizations through by detaching water rights from land rights, reducing membership fees and broadening the mandate of irrigation schemes to acknowledge and include multiple water use.
- Enable women to participate in the decision-making process by organizing meetings and forums, keeping in mind the convenience of time and space for women to attend.
- Facilitate the development of the capacity of men and women to participate in joint meetings at different levels and to listen to each other's views.
- Facilitate the development of the capacity of women to express their views in multi-stakeholder meetings
- Establish accountability measures and indicators to ensure that the participation of women is encouraged and facilitated.
- Establish gender indicators and conduct gender audits to strengthen women's participation in governance processes. Collection and analysis of gender disaggregated data would need to be made mandatory for developing effective gender indicators and conducting gender audits.
- Ensure that the budgets provide for gender mainstreaming.

35.3.2 Improving women's access to water and other productive resources

- Recognize women as independent users of water.
- Enable women to access water rights, regardless of land ownership.
- Recognize women as farmers and irrigators.
- Ensure women have access to extension services, credit and other resources for improving livelihoods.
- Identify constraints that prevent different groups of women from accessing water resources, such as social and gender constructs, and power relations in the community, and facilitate the removal of these constraints.
- Provide technical training to women on water management, irrigation, rainwater harvesting, other small holder irrigation technologies and rainfed agriculture.
- Improve water supply services to cover the needs of the poorer sections of the population by initiating reforms that make water affordable to the poor families in urban and peri-urban areas, such as instalment schemes for connection charges and subsidies.
- Introduce new targets for improving gender sensitive sanitation: put gender equity in water and sanitation at the centre of national poverty reduction strategies.

35.3.3 Enhancing capacities of men and women to understand and address gender differences and concerns in water management

- Gender sensitization for different levels of government, project and civil society staff.
- Gender sensitization for men and women in the community.
- Improve, adapt and use existing tools for gender mainstreaming in water management and governance, and provide training in how these can be used effectively.

Notes

1 While women's access to education and employment has improved in recent decades, the transformative potential of those changes has been curtailed by persisting inequalities in the gender distribution of resources. There is an implicit assumption that as economic opportunities for women expand, households will adjust the gender division of unpaid labour in ways that allow women to respond to changing market incentives on an equal basis with men. Experience has not borne this assumption out. Women's increasing participation in paid work has not been accompanied by a commensurate increase in men's share of unpaid work within the home. The gender division of unpaid domestic work has displayed a remarkable resilience and continues to shape the terms on which women are able to take up paid work. It limits the transformative potential of employment for the position of women within the home and in the wider society (UNDESA, 2009).

2 Agro-business refers to modern economic activities devoted to the production, processing and distribution of food and fibre products and by-products (as opposed to family farms). In highly industrialized countries, many activities essential to agriculture are carried out separately from the farm. Many of these farms use extensive mechanization and computer technology to increase production (*Encyclopaedia Britannica,* 2011).

3 The International Network on Gender and Sustainable Energy (ENERGIA) has recommended that environmental and social impact assessments of proposed biofuel projects or programs should include an evaluation of gender-differentiated impacts – through consultative processes designed to ensure substantial participation of women – and that gender equity should be one of the principles considered in those assessments.

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CHAPTER 36
Groundwater

WWAP, in collaboration with UNESCO-IHP

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Acknowledgements Comments on successive drafts: Michela Miletto (WWAP), Alice Aureli (UNESCO-IHP), Olcay Ünver (WWAP), Richard Connor (WWAP), Holger Treidel (UNESCO-IHP), Alexandros Makarigakis (UNESCO-IHP) and Lucilla Minelli (UNESCO-IHP)

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Knowledge on the world's groundwater resources, their functions and their use is quickly increasing and views on groundwater and its interlinkages are changing accordingly.

Groundwater is globally a resource in transition: during the twentieth century, groundwater exploitation started booming (the 'silent revolution'), resulting in much higher benefits from groundwater than ever before, but triggering unprecedented changes in the state of groundwater as well.

The key issues to be addressed to ensure the sustainability of groundwater resources are groundwater storage depletion (declining water levels) and groundwater pollution.

Climate change will affect groundwater, but groundwater is more resilient than surface water, due to its characteristic buffer capacity. Therefore, in areas where climate change will cause water resources to become scarcer, the relative role of groundwater may become more prominent.

Groundwater governance is complex and needs to be tailored to local conditions. In transboundary aquifer systems, the international dimension adds complexity.

36.1 Groundwater in a web of interdependencies

Addressing groundwater in a separate chapter of WWDR4 underlines the importance of groundwater in relation to coping with risks and uncertainties in a changing world, but should not suggest that groundwater systems can be understood and properly managed on the basis of hydrogeological information only, nor in isolation from surface water. On the contrary, groundwater is a component of the hydrological cycle and interacts closely with other components of this cycle, at various temporal and spatial scales. It is also involved in various other cycles, such as chemical cycles (solute transport) and biochemical cycles (biosphere), and is affected by climate change resulting from changes in the carbon cycle. In addition, groundwater interactions and interdependencies are not limited to physical systems, such as surface waters, soils, ecosystems, oceans, lithosphere and atmosphere, but are related as well to socio-economic, legal, institutional and political systems. Hence, groundwater is entrenched in a web of interdependencies. Changes in the state of groundwater systems are taking place due to these interdependencies, and causal chains link these changes to the drivers of change (root causes).

Different categories of drivers are behind the processes of change in groundwater systems. Demographic drivers and socio-economic drivers explain to a large extent water demands, pollution loads and people's behaviour with respect to groundwater. Science and technological innovation have put their footmarks as well on the use and state of many groundwater systems around the world (e.g. by systematic aquifer exploration and improved drilling and pumping technologies). Policy, law and finance form an important category of drivers behind planned change, in the context of groundwater resources development and management. Climate variability and change affect in particular aquifers in arid and semi-arid regions (changes in groundwater recharge, water demands and availability of alternative sources of fresh water) and in coastal zones (sea level rise). Finally, natural and anthropogenic hazards may cause sudden rather than gradual changes in the state of groundwater systems.

36.2 Panorama of change

36.2.1 Increasing knowledge of the world's groundwater

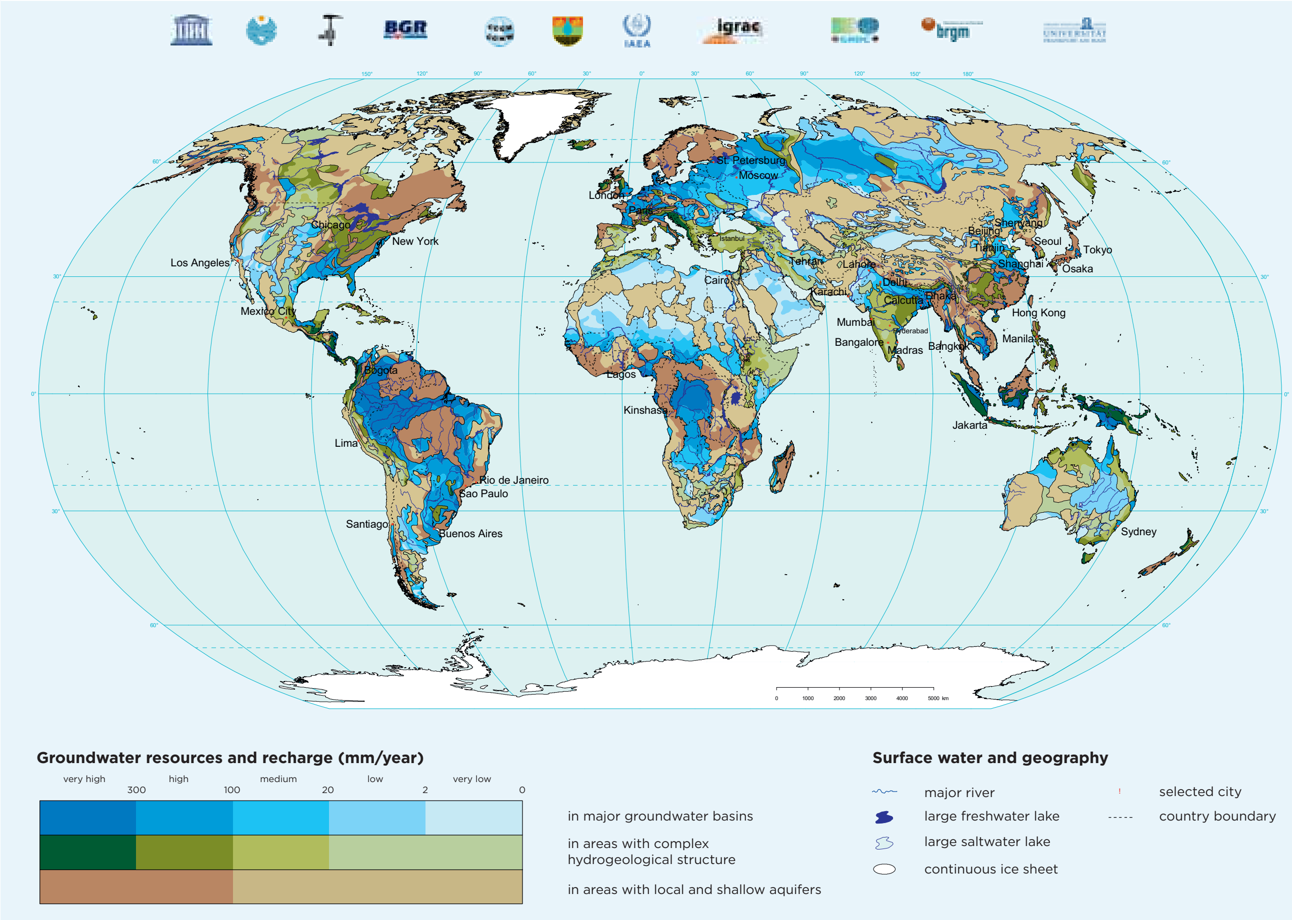
Significant advances in the knowledge of the world's groundwater have been witnessed in recent years. While they are observed at all scale levels, the focus in this *World Water Development Report* is on the global and regional scales. Important achievements are the consolidated version of the Groundwater Resources Map of the World (WHYMAP, 2008; Figure 36.1); the outcomes of global-scale hydrological modelling, such as on worldwide groundwater recharge with the WaterGAP Global Hydrological Model (Döll and Fiedler, 2008) and on groundwater depletion with PCR-GLOBWB (Wada et al., 2010); a global assessment of current groundwater use for irrigation (Siebert et al., 2010) and a comprehensive monograph on the geography of the world's groundwater (Margat, 2008). Special attention for transboundary aquifers has resulted in rapidly increasing documentation and tools on transboundary aquifers (Section 36.4).

The total volume of fresh groundwater stored on Earth is believed to be 8–10 million km^3 (Margat, 2008), which is more than two thousand times the current annual withdrawal of surface water and groundwater combined. This is a huge volume, but where are these freshwater buffers located and what fraction of their stock is available for depletion? Figure 36.1 answers the first question by showing the geographic distribution of the world's major groundwater basins (blue map units – covering 36% of the area of the continents). This is where the main groundwater buffers are located. Additional ones, but less continuous and smaller, are present in the areas with complex hydrogeological structure (green map units – 18%) and to a lesser extent even in the remaining 46% of the area of the continents. The groundwater buffers allow the convenient bridging of periodic, seasonal or multi-annual dry periods, without the risk of sudden unexpected water shortages. In large parts of the globe, sustainable groundwater development is possible by the alternation of storage depletion during dry periods and storage recovery during wet periods. The groundwater reservoirs are rather insensitive for variations in the length of the dry periods and therefore resilient to this aspect of climate variation and climate change. In principle it is possible to ignore the sustainability criterion and exploit a large part of the stored groundwater volumes, but in practice it is unattractive and difficult to do so, because depletion comes at a cost, as explained in Section 36.3.

Recent outcomes of the Gravity Recovery and Climate Experiment (GRACE) mark a major step forward in assessing groundwater storage variations in some of the world's major aquifer systems (Famiglietti et al., 2009;

FIGURE 36.1

Groundwater resources of the world



Source: BGR and UNESCO, from WHYMAP (2008).

Rodell et al., 2009; Tiwari et al., 2009; Muskett and Romanovsky, 2009; Moiwo et al., 2009; Bonsor et al., 2010; Chen et al., 2009). The results of the experiment suggest that satellite mapping of the Earth's gravity field (satellite gravimetry) is a promising innovative technique for hydrogeological investigations in the near future[1], for monitoring long-term trends, seasonal variations and variations during droughts. Global simulation models linking the terrestrial and atmospheric components of the hydrological cycle are likely to become another important tool to enhance the knowledge of groundwater regimes, in particular for exploring how they may respond to climate change (Döll, 2009).

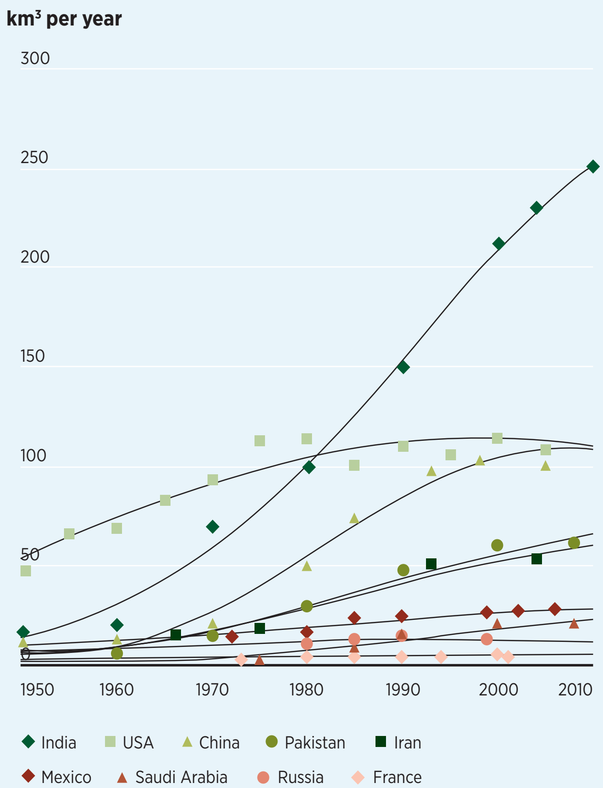
36.2.2 The 'silent revolution'

Driven by population growth, technological and scientific progress, economic development and the need for food and income, groundwater abstraction across the world has explosively increased during the twentieth century. By far the largest share of the additional abstracted volumes has been allocated to irrigated agriculture. The boom in groundwater development for irrigation started in Italy, Mexico, Spain and the United States during the early part of the twentieth century (Shah et al., 2007). A second wave began in South Asia, the North China Plain, and parts of the Middle East and North Africa during the 1970s, and still continues. The authors perceive a likely third wave of increasing abstractions in many regions of Africa and in some South and Southeast Asian countries such as Sri Lanka and Viet Nam. This worldwide boom in groundwater abstraction has resulted largely from numerous individual decisions by farmers, without centralized planning or coordination, and has been named the 'silent revolution' (Llamas and Martínez-Santos, 2005).

Based on recent estimates at country level (IGRAC, 2010; Margat; 2008; Siebert et al., 2010, AQUASTAT, 2011; EUROSTAT, 2011), the world's aggregated

FIGURE 36.2

Groundwater abstraction trends in selected countries (in cubic kilometres per year)



Source: Adapted from Margat (2008, fig. 4.6, p. 107).

TABLE 36.1

Top 10 groundwater abstracting countries (as at 2010)

Country	Abstraction (km³/year)
1 India	251
2 China	112
3 USA	112
4 Pakistan	64
5 Iran	60
6 Bangladesh	35
7 Mexico	29
8 Saudi Arabia	23
9 Indonesia	14
10 Italy	14

Note: Around 72% of the global groundwater abstraction takes place in these ten countries only.

groundwater abstraction as at 2010 is estimated to be approximately 1000 km³ per year, of which about 67% is used for irrigation, 22% for domestic and 11% for industrial purposes (IGRAC, 2010)[2]. The lion's share of the total quantity (two-thirds) is abstracted in Asia, with India, China, Pakistan, Iran and Bangladesh as major consumers (Tables 36.1 and 36.2). The global groundwater abstraction rate has at least tripled over the last 50 years and is increasing at an annual rate between 1 and 2%. Nevertheless, in some countries where intensive groundwater development started early, abstraction rates have peaked and now are stable or even decreasing (Shah et al., 2007), as is illustrated in Figure 36.2. Although the global estimates are not accurate, they suggest that the current global abstraction of groundwater represents approximately 26% of total fresh water withdrawal on Earth (Table 36.2) and that its rate corresponds to some 8% of the mean globally aggregated rate of groundwater recharge. Groundwater is supplying almost half of all drinking water in the world (WWAP, 2009) and 43% of the global consumptive use of water in irrigation[3] (Siebert et al., 2010).

The silent revolution has contributed tremendously to economic development and welfare in many countries of the world, especially in the rural areas. Nevertheless, it has also introduced unprecedented problems that are in some areas difficult to control (Section 36.3).

36.2.3 Changing views on groundwater

Groundwater has become an interdisciplinary subject, no longer the exclusive domain of hydrogeologists and engineers, but also addressed by economists, sociologists, ecologists, climatologists, lawyers, institutional experts and communication specialists. Analysing groundwater from different angles puts it in a wider context, resulting in changing views on this natural resource.

There are changing views regarding the value and functions of groundwater. Measuring the importance of groundwater by comparing its recharge rate, withdrawal or stored volume to those of surface water is gradually being replaced by more economically oriented approaches, focused on the 'added value' produced by groundwater. Groundwater often produces higher economic returns per unit of water used in irrigation than surface water (Llamas and Garrido, 2007; Shah, 2007), because its stored volume reduces risk. Awareness is growing that functions and services of a

TABLE 36.2

Key estimates on global groundwater abstraction (2010)

Continent	Groundwater abstraction[1]					Compared to total water abstraction	
	Irrigation (km^3/year)	Domestic (km^3/year)	Industrial (km^3/year)	Total (km^3/year)	%	Total water abstraction[2] (km^3/year)	Share of groundwater (%)
North America	99	26	18	143	15	524	27
Central America and the Caribbean	5	7	2	14	1	149	9
South America	12	8	6	26	3	182	14
Europe (including Russian Federation)	23	37	16	76	8	497	15
Africa	27	15	2	44	4	196	23
Asia	497	116	63	676	68	2 257	30
Oceania	4	2	1	7	1	26	25
World	666	212	108	986	100	3 831	26

[1] Estimated on the basis of IGRAC (2010), AQUASTAT (2011), EUROSTAT (2011), Margat (2008) and Siebert et al. (2010).
[2] Average of the 1995 and 2025 'business as usual scenario' estimates presented by Alcamo et al. (2003).

groundwater system go beyond water withdrawal and include a number of *in situ* services as well, such as the support of ecosystems, phreatophytic agriculture, spring flow and base flow; the prevention of land subsidence and seawater intrusion; and the potential for exploiting geothermal energy or storing heat.
A second category of changing views refers to the role of people. Not long ago, diagnostic analysis and management of groundwater resources was based almost exclusively on the analysis of the physical components (groundwater systems and related ecosystems). There is wide consensus now that socio-economic aspects deserve ample attention as well and that groundwater resources management is likely to be successful only if stakeholders are involved and if adequate groundwater institutions, legislation and related regulatory frameworks exist.

Further, the debate on climate change has made clear that hydrogeologists and hydrologists have to abandon their traditional implicit assumption of stochastic stationarity of natural hydrological fluxes. The assumption that groundwater recharge rates assessed in the past would provide an unbiased estimate for future conditions is no longer appropriate.

36.2.4 Conjunctive management, Integrated Water Resources Management and beyond

Groundwater is no longer explored and exploited as an isolated resource. After the advantages of *conjunctive use* of groundwater and surface water were recognized, already long ago (Todd, 1959), the notion of *conjunctive management* has been embraced. Under this paradigm the water resources are not only used but also managed, whereby surface water and groundwater are managed jointly as components of a single system. It may include Managed Aquifer Recharge (MAR), the intentional storage of water in aquifers for subsequent recovery or environmental benefit, applied in countless small and large schemes around the world (Dillon, 2009). MAR includes groundwater level control in flat areas by manipulating surface water levels, such as widely practiced in The Netherlands.

A next step is integration across water use sectors, as advocated by Integrated Water Resources Management (IWRM): the coordinated development and management of water, land and related resources, aiming for maximum economic and social welfare without compromising the sustainability of ecosystems and the environment (GWP, 2011). This cross-sectoral approach to water has replaced in many countries the previous traditional, fragmented sectoral approaches that ignored the interconnection between the different water uses and services. There are tendencies towards a higher level of integration of area-specific strategic planning, in search of better coherence between policy domains, such as water resources management, land use planning, nature conservation, environmental management and economic development.

36.2.5 Increasing international focus on groundwater

Groundwater, a local natural resource producing mainly local benefits, is progressively subject to initiatives at the international level. Initiatives such as the World-wide Hydrogeological Mapping and Assessment Programme (WHYMAP), International Groundwater Resources Assessment Centre (IGRAC), Groundwater Management Advisory Team (GWMATE), International Waters Learning Exchange and Resource Network (IW:LEARN), Internationally Shared Aquifers Resources Management Programme (ISARM) and global hydrological modelling are based on the idea that exchanging, sharing, compiling and analysing area-specific information on groundwater contribute to dissemination of knowledge and produce added value by providing views at a higher level of spatial aggregation. Several international initiatives are triggering or guiding action in the field of groundwater assessment, monitoring or management. Examples not specific for groundwater are the Millennium Development Goals and the European Water Framework Directive (WFD). Recent groundwater-specific initiatives in this category are transboundary aquifer projects in the Global Environment Facility (GEF) International Waters (IW) portfolio, the new European Groundwater Directive ('daughter directive' of the WFD), the Draft Articles on the Law of Transboundary Aquifers and the establishment of the African Groundwater Commission. Several recent international declarations, including the Alicante Declaration (IGME, 2006) and the African Groundwater Declaration demonstrate growing awareness on the relevance of groundwater and the willingness to address it.

36.3 Key issues on groundwater

36.3.1 Declining groundwater levels and storage depletion

The silent revolution caused an unprecedented increase in groundwater withdrawal across the globe. It has produced enormous socio-economic benefits around the world, but not without modifying drastically the hydrogeological regimes of many aquifers, in particular poorly recharged aquifers. The stress placed on groundwater systems by groundwater abstraction builds up when the ratio of abstraction to mean recharge increases. Figure 36.3 shows the geographical variation of the corresponding groundwater development stress indicator. The highest stresses occur in the more arid parts of the world. As the groundwater development stress indicator is averaged over entire countries, it cannot reveal stressed aquifer systems much smaller in size. As a result of intensive groundwater development, steady depletion of groundwater storage, accompanied by continuously declining groundwater levels, has spread over significant parts of the arid and semi-arid zones. This produces a wide range of problems (Van der Gun and Lipponen, 2010) and in many areas a lack of control threatens to result in a complete loss of the groundwater resource as an affordable source of irrigation and domestic water supply. In the more seriously affected aquifer zones, multi-annual groundwater level declines are typically in the range of one to several metres per year (Margat, 2008).

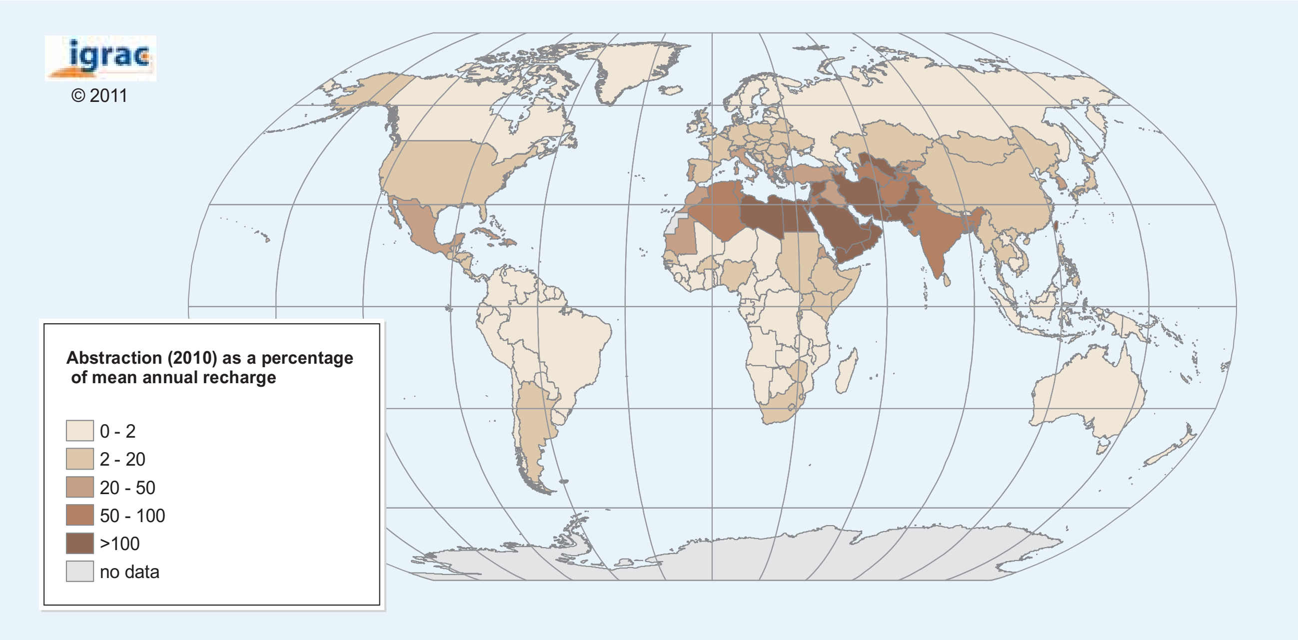
Prominent aquifers characterized by very significant long-term groundwater level declines are almost all located in the world's arid and semi-arid zones. In North America they include the Californian Central Valley (Famiglietti, 2009) and the High Plains aquifer (McGuire, 2009; Sophocleus, 2010) in the USA, as well as aquifers scattered over Mexico, including the Basin of Mexico aquifer (Carrera-Hernández and Gaskin, 2007). In Europe, the aquifers of the Upper Guadiana basin, the Segura basin and the volcanics of Gran Canaria and Tenerife can be mentioned, all belonging to Spain (Custodio, 2002; Llamas and Custodio, 2003; Molinero et al., 2008). Various zones of the huge non-renewable North-Western Sahara Aquifer System (Mamou et al., 2006; OSS, 2008) and the Nubian Sandstone Aquifer System in North Africa (Bakhbakhi, 2006) are affected by significant groundwater level declines. On the Arabian Peninsula, there are unprecedented trends of strongly declining groundwater levels in the Tertiary aquifer system of the Arabian Platform (mainly in Saudi Arabia; Brown, 2011) and in the Yemen Highland basins (Van der Gun et al., 1995). More eastward, the Varamin, Zarand and many other mountain basins of Iran suffer from steadily declining groundwater levels (Vali-Khodjeini, 1995; Motagh et al., 2008) as do parts of the extensive aquifer systems of the Indus basin, especially in the Indian states of Rajasthan, Gujarat, Punjab, Haryana and Delhi (Rodell et al., 2009; Centre for Water Policy, 2005). The North China Plain aquifer has become notorious for severe groundwater level declines (Jia and You, 2010; Kendy et al., 2004; Sakura et al., 2003; Liu et al., 2001; Endersbee, 2006). Finally, continuous groundwater outflow through numerous artesian wells has produced groundwater level declines in excess of 100 m in parts of the Australian Great Artesian Basin (Habermehl, 2006). There are numerous other aquifers around the world where levels have declined or are still declining, with variable impacts on society and the environment.

New, useful information on the magnitude of groundwater storage depletion has become available in recent years. Konikow and Kendy (2005) estimate that about 700–800 km^3 of groundwater has been depleted from aquifers in the USA during the twentieth century. Recent assessments by GRACE of the massive groundwater storage depletion observed in California's Central Valley and in north-western India have produced groundwater storage depletion estimates for some large groundwater systems (Rodell et al., 2009; Famiglietti et al., 2009; Tiwari et al., 2009). These estimates are shown in Table 36.3, together with estimated depletion rates for other large aquifer systems around the world. A model study by Wada et al. (2010) provides a global picture. The model estimates that by the year 2000 the world's groundwater was being depleted at a rate of 283 km^3 per year, corresponding with 39% of the global abstraction rate as estimated by the authors[4]. The global pattern of groundwater depletion produced by this model matches existing knowledge on areas notorious for large and persistent groundwater level declines, such as in western North America, the Middle East, South and Central Asia and North China.

Depleting groundwater storage comes at a cost. This cost is not limited to a permanently higher unit cost of pumped groundwater, but may also include negative impacts on environmental and other *in situ* functions of the groundwater system, water quality degradation and even, in the long run, physical exhaustion of the aquifer. In some cases, however, there may be good reasons for planned groundwater depletion during a finite period and for accepting the associated negative impacts. This may be so in case of sudden disasters or if there is a need to buy time for a smooth transition to sustainable groundwater development after dynamic equilibrium conditions have been disturbed by exploding pumping intensities or by climate change.

FIGURE 36.3

Groundwater development stress indicator at country level (based on groundwater abstraction estimates for 2010)



Source: Prepared by IGRAC for this chapter.

The risks and problems resulting from declining water levels vary from aquifer to aquifer, as do options and current practices for control. The situation on the High Plains is typical for numerous intensively exploited aquifers in the world, large and small. On the one hand there is a growing awareness of the need to stop depleting the resource; on the other hand, reducing groundwater abstraction to a sustainable level seems disastrous for the local economy and is not readily accepted by many individual stakeholders who risk to lose part of their income if groundwater abstractions are curtailed (Peck, 2007; McGuire, 2009; Sophocleous, 2010). A similar dilemma is present in the much smaller Sana'a basin in Yemen: effective partnerships with water users seem the only way to prevent catastrophic water shortages in the near future (Hydrosult et al., 2010). In the Umatilla basin (Oregon) a community-based approach is attempted to manage conflicts resulting from aquifer depletion (Jarvis, 2010). The Great Artesian Basin (Australia) is completely different: massive waste of water freely flowing from artesian wells can be eliminated by technical solutions. Although their implementation is expensive, these measures are less controversial because there is no explicit conflict of interests (Habermehl, 2006; Herczeg and Love, 2007; SKM, 2008; GABCC, 2009).

Shallow alluvial aquifers in arid and semi-arid zones form a special category. Due to their limited storage capacity, they are affected by seasonal rather than long-term depletion problems. Increasing abstraction rates shorten the period between the recharge season and the moment that wells run seasonally dry. Awareness of this phenomenon motivates people to conserve, even more so if springs and qanats[5] are linked to the system. Although groundwater depletion risks tend to be insignificant for groundwater systems in humid climates, control of groundwater levels may still be important, especially to prevent undesired environmental impacts, such as sea water intrusion, land subsidence and wetland degradation.

Fundamental options for controlling declining groundwater levels and storage are augmenting the groundwater resource and restricting its discharge. Resource augmentation measures are of a technical nature and include MAR techniques (artificial recharge) and land use management. Once decided upon, their implementation is relatively straightforward. Different types of measures are available for restricting pumping from aquifers (demand management). Enforcement of regulations (e.g. licensing well drilling and abstractions) based on groundwater legislation forms the first type. Alternatively, groundwater abstraction is discouraged selectively by financial disincentives, restricting energy supply or enhancing people's awareness on sustainability problems. A third type of measures for restricting groundwater outflow is the reduction of water losses at the well head and in transport (as in the Great Artesian Basin), or where it is used (e.g. by

TABLE 36.3

Groundwater depletion rates in large aquifer systems

Aquifer or region	Lateral extent km^2	Rate of depletion (in recent years)		Period or year	Reference
		km^3 per year	mm water per year[1]		
Renewable groundwater					
High Plains, USA	483 844	12.4	26	2000–2007	McGuire (2003, 2009)
Central Valley, California, USA	58 000	3.7	64	2003–2009	Famiglietti et al. (2009)
NW India	438 000	17.7	40	2003–2009	Rodell et al. (2009)
Northern India and surroundings	2 700 000	54	20	2003–2009	Tiwari et al. (2009)
North China Plain	131 000	6.12	47	2004	Jia and You (2010)
Non-renewable groundwater					
NW Sahara Aquifer System	1 019 000	1.5	1.5	2000	Margat (2008)
Great Artesian basin	1 700 000	0.311	0.2	1965–2000	Welsh (2006)

[1] Expressed as depth of an equivalent layer of water over the total horizontal extent of the aquifer system (scale-independent depletion indicator).

enhancing irrigation efficiency or recycling used water). Worldwide experiences show that successfully implementing measures is difficult, especially if existing withdrawals need to be reduced and alternative sources of water are not available. A common understanding of the problem among stakeholders and their firm commitment to support a chosen solution are crucial.

36.3.2 Groundwater quality and pollution

Although most groundwater around the globe at conventional well drilling depths is of good quality, it remains a major concern to protect this water against quality degradation and prevent poor quality groundwater from entering active freshwater cycles.

Trivial but important is the occurrence of brackish and saline groundwater, unfit for most intended groundwater uses. Most groundwater at great depths is saline. According to a recent global inventory (Van Weert et al., 2009), at shallow and intermediate depths (upper 500 m below surface, approximately) bodies of brackish or saline groundwater are found under 13% of the area of the continents. Only 8% of the identified brackish or saline bodies has an anthropogenic origin, with mineralization by irrigation return flows as the predominant mechanism. Risks of adding 'new' saline or brackish water to fresh groundwater domains are present near the coast (sea water intrusion), in zones of irrigated lands and at locations where liquid waste is dumped. As most of the saline or brackish groundwater bodies are immobile, it is a good strategy to keep them in that state. The same is true for bodies of groundwater with excessive concentrations of other natural constituents, such as fluoride or arsenic (Appelo, 2008).

Anthropogenic groundwater pollution and its control has been a major issue already for many decennia. It is a complex field due to the many sources of pollution, the myriad of substances that may be involved, large variations in vulnerability of aquifers, lack of monitoring data and uncertainties on impacts of excessive concentrations of pollutants, in addition to the usual dilemmas and problems in designing and effectively implementing programmes for protection and control (Morris et al., 2003; Schmoll et al., 2006). As groundwater usually is moving very slowly, groundwater pollution is almost irreversible or at least very persistent and, therefore, preventing and monitoring pollution influxes are basic components of any control strategy. In Europe, an important step forward is the new Groundwater Directive (GWD), introduced in 2006 as an integral part of the Water Framework Directive (WFD). GWD obliges European Union member states to take steps leading towards compliance with good chemical status criteria by the end of 2015. Reporting until 2010 reveals that 30% of all groundwater bodies is unlikely to achieve the envisaged 'good quality status' by 2015. However, GWD is flexible and offers the member states two options: adjusting the targets to more feasible values and delaying the compliance until 2021 or 2027 (European Commission, 2006 and 2008; European Environmental Agency, 2010).

Groundwater quality is also an important aspect in managed aquifer recharge. This management tool is in some cases even purposely used to improve or control water quality, making use of the aquifer's capacity for attenuation and decomposition of substances, or using the injected water to prevent excessive shrinking of exploited freshwater lenses overlaying saline groundwater. In all cases, however, there should be an awareness that managed aquifer recharge may also introduce risks, including groundwater pollution risks. Page et al. (2010) present an approach for assessing such risks.

In recent years there is growing attention for micro-pollutants, in particular for *pharmaceuticals and personal care products (PPCPs)* and for *endocrine disruptive compounds (EDCs)* (Schmoll et al., 2006; Musolff, 2009; SIWI, 2010). Disseminated by sewage, landfills and manure, these substances occur in natural waters in very low concentrations only (pg per L to ng per L range) and are not removed by conventional wastewater treatment plants. There is still much uncertainty on their possible impacts. Pharmaceuticals are designed to be bioactive and although in groundwater they are too diluted to provide therapeutic doses to humans and animals on the short-term, it is unknown what their effects may be after long-term exposure. EDCs – present in steroid-based food supplements, drugs, fungicides, herbicides and a range of household and industrial products – have the capacity to interfere with the functions of hormones that control growth and reproduction in humans and animals. PPCPs and EDCs are ubiquitous in surface water and shallow groundwater, and progress in analytical methods is likely to reveal them more widely in future years.

36.3.3 Climate change, climate variability and sea level rise

Climate change modifies groundwater recharge. Global hydrological models recently have produced estimates of mean annual global groundwater recharge, ranging from 12,700 km^3 per year (Döll and Fiedler, 2008) to 15,200 km^3 per year (Wada et al., 2010), which is at least three orders of magnitude smaller than the estimated total groundwater storage. These estimates and the corresponding spatial patterns, however, are based on mean climatic conditions prevailing during the second half of the twentieth century. For periods ahead, new estimates have to be produced, taking into account the possible influence of climate change. The latter has been subject of model investigations by Döll (2009), using four Intergovernmental Panel on Climate Change (IPCC) climate change scenarios and comparing the model outcomes with those of the reference period 1961–1990. She concludes that by the 2050s groundwater recharge is likely to have increased in the northern latitudes, but strongly decreased (by 30–70% or even more) in some currently semi-arid zones, including the Mediterranean, north-eastern Brazil and south-western Africa (Figure 36.4). Simulations for ten other climate scenarios produced different trends for some regions, except for the Mediterranean region and the high northern latitudes. The four simulated scenarios in Figure 36.4 suggest a decrease of the long-term mean global groundwater recharge by more than 10%. Climate change is difficult to predict and at the scale of tens of years it is hard to distinguish it from the climate variability as produced by El Niño Southern Oscillation (ENSO), Pacific Decadal Oscillation (PDO), Atlantic Multidecadal Oscillation (AMO) and other inter-annual to multi-decadal climate oscillations (Gurdak et al., 2009).

Climate change will not only change mean annual groundwater recharge and surface water flow, it is expected to also affect their distribution in time. Wet episodes may become more concentrated in time in many regions, while dry periods tend to become longer. However, this will not significantly affect the water supply capacity of most groundwater systems, due to their buffer capacity. The buffers cannot prevent long-term groundwater availability to decrease if climate change reduces the mean recharge rates, but they facilitate a gradual adaptation to new conditions.

Climate change will also modify water demands and water use. As the patterns of change in mean groundwater recharge shown in Figure 36.4 show positive correlation with patterns of change in mean precipitation and mean runoff as predicted by IPCC (Bates et al., 2008), it may be concluded that higher water demands will particularly affect areas where mean groundwater recharge is expected to decrease. This will produce severe problems, in the numerous small and shallow wadi aquifer systems scattered over arid and semi-arid regions probably more than anywhere else (Van der Gun, 2009). Nevertheless, it is expected that in many increasingly water-scarce areas around the world, dependency on groundwater will increase as the storage buffer renders groundwater more resilient than surface water sources. This is one more reason to manage groundwater carefully in such regions.

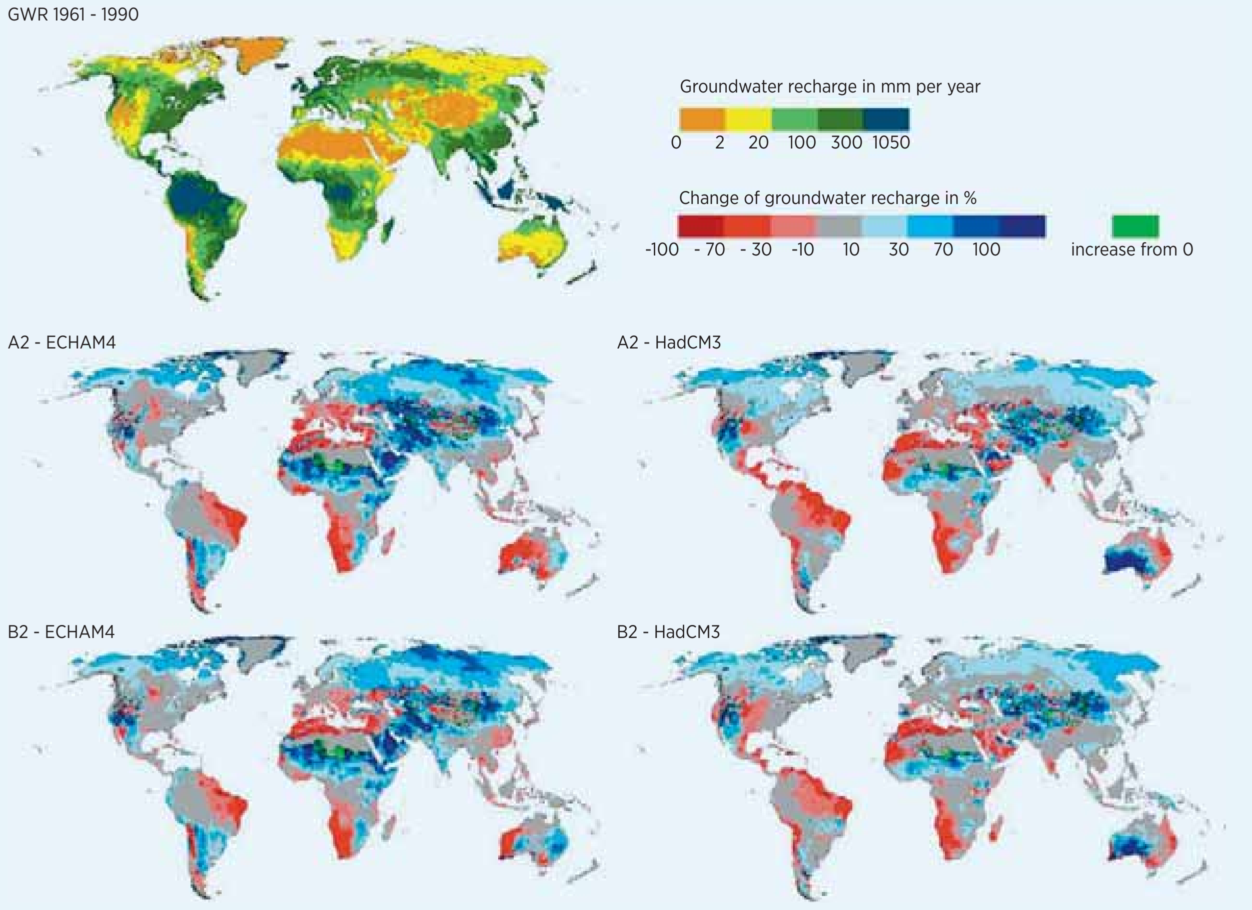
Ongoing and predicted sea level rise is largely caused by climate change, but progressive groundwater depletion contributes to it as well. Konikow and Kendy (2005) argue that the ultimate sink for groundwater removed from the aquifers by depletion is the oceans. They calculate that the total volume depleted from the High Plains aquifer in the USA during the twentieth century contributed 0.75 mm to sea level rise, which is 0.5% of the total sea level rise observed during the twentieth century. For all USA aquifers combined, the corresponding estimates are 2.03 mm and 1.3%, respectively (Konikow, 2009). Wada et al. (2010) estimated that global groundwater storage depletion by the year 2000 would have contributed 0.8 mm a year to sea level rise, which is 25% of the current rate of sea level rise according to the latest IPCC data. Assuming this estimated depletion to be reasonably reliable, thus a significant part of observed sea level rise is likely to be produced by causes other than climate change. In relation to groundwater, the main impact of sea level rise is intrusion of saline water into coastal aquifers. Worldwide, sea water intrusion is a real threat to coastal aquifers and may have huge repercussions as a large percentage of the world's population lives in coastal zones. A series of papers in a recent issue of the *Hydrogeology Journal* provides a geographic overview of saltwater–freshwater interactions in coastal aquifers (Barlow, 2010; Bocanegra et al., 2010; Custodio, 2010; Steyl and Dennis, 2010; White and Falkland, 2010). A recent study on the impact of sea level rise on coastal groundwater in the Netherlands (Oude Essink et al., 2010) concluded that expected sea level rise will affect the Dutch coastal groundwater systems and trigger saline water intrusion, but only in a narrow zone within 10 km from the coastline and the main lowland rivers.

36.3.4 Transboundary groundwater resources

Behaviour and functions of transboundary aquifers do not differ from those of other aquifers, but

FIGURE 36.4

Global pattern of estimated mean groundwater recharge in 1961–1990 and percentage change from 1961–1990 to 2041–2070 for four Intergovernmental Panel on Climate Change (IPCC) scenarios



Note: Climate scenarios were computed using climate models ECHAM4 (Röckner et al., 1996) and HadCM3 (Gordon et al., 2000) on the basis of IPCC greenhouse gas emission scenarios A2 (emissions increase during 1990–2050 from 11 to 25 Gt C per year) and B2 (from 11 to 16 Gt C per year), respectively.
Source: Döll (2009, fig. 1, p. 6).

administrative borders that cross them render coordinated development and management of their groundwater resources more complex. Borders complicate the acquisition of consistent information on the entire aquifer, while allocating aquifer segments to different jurisdictions is at odds with the transboundary effects of pressures within each of these segments. Information gaps, conflicting interests and lack of coordination across the boundaries easily lead to problems that are avoidable if transboundary aquifer management approaches are adopted.

Enormous progress has been made since transboundary aquifers were put on the international agenda at the end of the twentieth century. Regional inventories and characterization of transboundary aquifer systems have been conducted under the umbrella of the United Nations Economic Commission for Europe (UNECE) in Europe (UNECE, 1999) as well as in the Caucasus, Central Asia and South-East Europe (UNECE, 2007); and under the ISARM programme in the Americas (UNESCO, 2007 and 2008), Africa (UNESCO, 2010*a*) and Asia (UNESCO, 2010*b*). The map Transboundary Aquifers of the World (IGRAC, 2009), showing the locations and selected properties of 318 identified transboundary aquifers in the world, and ISARM's Atlas of Transboundary Aquifers (Puri and Aureli, 2009) are both largely based on the outcomes of these regional activities.

At the level of individual aquifers, important projects have been carried out or are ongoing in the framework of GEF's IW focal area. As an example, the

Guaraní Aquifer project (Argentina, Brazil, Paraguay and Uruguay) developed agreed transboundary aquifer management instruments and the four countries involved signed in August 2010 an agreement on this aquifer system.

Institutional arrangements and legal instruments are integral parts of transboundary aquifer resources management. A study on groundwater in international law by Burchi and Mechlem (2005) shows that international law until recently has rarely taken account of groundwater and that only few legal instruments exist exclusively designed for groundwater: for the Geneva aquifer, the Nubian Sandstone aquifer and the NW Sahara aquifer system. The development of such instruments is expected to be catalysed by the Draft Articles on the Law of Transboundary Aquifers, jointly elaborated by the United Nations International Law Commission (UNILC) and the UNESCO International Hydrological Programme (IHP) during 2002–2008 and adopted by resolution A/RES/63/124 of the UN General Assembly in December 2008 (Stephan, 2009). Important principles included in these Draft Articles are the obligation to cooperate and exchange information, the no-harm principle and the intention to protect, preserve and manage the aquifer resources.

The UN General Assembly reaffirmed in its sixty-sixth session on 9 December 2011 the importance of transboundary aquifers and the related Draft Articles. It adopted a resolution in which States are encouraged to make proper arrangements for transboundary aquifer management and UNESCO-IHP to continue its related scientific and technical support to the States. In addition, the General Assembly decided to put 'The Law of Transboundary Aquifers' on the provisional agenda of its sixty-eight session, in order to examine - among others - the final form to be given to the Draft Articles. The momentum produced by all ongoing transboundary aquifer activities are transforming transboundary aquifers from potential problems into opportunities for international cooperation.

Conclusions

Groundwater – by far the largest volume of unfrozen fresh water on Earth – is a natural resource of enormous importance, but it is hidden to the eye and poorly known and understood among the general public. Hydrogeologists and other scientists have made significant progress over the last few decades in collecting information on the world's groundwater systems, understanding their role and functions, observing changes over time, and identifying options for enhancing benefits from groundwater as well as threats that need to be addressed to safeguard the resource's sustainability. Gradually it has become clear how strongly the development and state of groundwater systems are interrelated with other systems and external drivers. It has also become clear that the value of groundwater is not limited to its abstraction for multiple uses, but includes a range of valuable in situ services, such as support of wetlands, springs, baseflows and stability of the land surface. As a result, groundwater resources management has evolved into a multi-disciplinary activity, addressing multiple objectives and not only focusing on physical systems and technical measures, but also paying significant attention to demography, socio-economics and governance. Modern groundwater resources management approaches incorporate the principles of conjunctive management and integrated water resources management.

Globally aggregated values and shares in total water supply are indicators of the relevance of groundwater, but it is worth looking beyond the volumes of water used. Without groundwater with its storage buffer, many parts of the dryer regions on Earth would be inhabitable due to seasonal or permanent lack of fresh water, and water supply in rural areas distant from permanent streams would be extremely expensive. The economic returns per unit of water used for irrigation and in other economic water use sectors tend to be higher for groundwater than for other sources of water because of groundwater's higher reliability.

Groundwater is in transition throughout the world. Current stresses on groundwater systems are in many parts of the world without precedent in history, as a result of the silent revolution and of progressive pollution inherent to modern lifestyles. These stresses are increasing and produce considerable risk and uncertainty. Will there be enough groundwater in the future, and will its quality meet the requirements of intended uses? After defining how to strike a balance between using and conserving groundwater, how should a corresponding behaviour of people be established in relation to this open-access resource that often is considered as common property? How should the inflow of anthropogenic pollutants into aquifers be reduced? Such questions pose enormous challenges to the groundwater community, water managers and local stakeholders. Solutions have to be tailored to the specific conditions of each area. Basic to the success of these solutions are a good understanding of the trade-offs between groundwater abstraction and other services of the aquifer, and the selection of measures compatible with the socio-political setting. The risks are in principle manageable, but their control is not easy and requires significant management efforts.

The buffer capacity of groundwater systems, on the other hand, offers unique opportunities for the overall reduction of risk and uncertainty regarding water availability, now and in the future. Changes over time of the availability and quality of groundwater proceed very slowly compared to those of the components of the water cycle with smaller mean residence times, and the predictability of these changes is much better for groundwater. This enables groundwater to bridge prolonged dry periods and allows time to smoothly adjust overall water use in areas where reduced levels of sustainable water availability are expected to result from intensification of water use upflow or from climate change.

Notes

1 In June 2010 NASA and DLR signed an agreement to continue the current GRACE mission through 2015 (NASA, 2010).

2 Most values mentioned in this paragraph are globally aggregated or averaged and therefore cannot be used to draw conclusions on conditions at a local or regional scale.

3 Siebert et al. (2010) estimate global consumptive irrigation water use to be 1277 km^3 per year, being 48% of the global agricultural water withdrawals. Their estimate for the share of groundwater in this figure (545 km^3 per year), is fairly consistent with the estimated global groundwater abstraction for irrigation, taking into account irrigation water losses.

4 The accuracy of this global depletion figure obtained by modelling is significantly lower than most of the estimates shown in Table 36.3. While the latter are based on observation, the global figure is affected by groundwater abstraction data of variable quality, highly simplifying model assumptions and averaging over large spatial units.

5 A qanat is a slightly sloping tunnel, designed for tapping groundwater and conveying it under gravity, often over a large distance, into an open section, from where it can be diverted for use.

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BOXES, TABLES AND FIGURES

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WWDR4

The United Nations World Water Assessment Programme (WWAP) is hosted by UNESCO and brings together the work of 28 UN-Water members and partners in the triennial *World Water Development Report* (WWDR).

This flagship report is a comprehensive review that gives an overall picture of the world's freshwater resources. It analyses pressures from decisions that drive demand for water and affect its availability. It offers tools and response options to help leaders in government, the private sector and civil society address current and future challenges. It suggests ways in which institutions can be reformed and their behaviour modified, and explores possible sources of financing for the urgently needed investment in water.

The WWDR4 is a milestone within the WWDR series, reporting directly on regions and highlighting hotspots, and it has been mainstreamed for gender equality. It introduces a thematic approach – 'Managing Water under Uncertainty and Risk' – in the context of a world which is changing faster than ever in often unforeseeable ways, with increasing uncertainties and risks. It highlights that historical experience will no longer be sufficient to approximate the relationship between the quantities of available water and shifting future demands. Like the earlier editions, the WWDR4 also contains country-level case studies describing the progress made in meeting water-related objectives.

The WWDR4 also seeks to show that water has a central role in all aspects of economic development and social welfare, and that concerted action via a collective approach of the water-using sectors is needed to ensure water's many benefits are maximized and shared equitably and that water-related development goals are achieved.

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UN-Water is the United Nations (UN) inter-agency coordination mechanism for all freshwater related issues. It was formally established in 2003 building on a long history of collaboration in the UN family. It currently counts 29 UN Members and 25 other international Partners. UN-Water complements and adds value to existing UN initiatives by facilitating synergies and joint efforts among the implementing agencies. See www.unwater.org

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THE UNITED NATIONS WORLD WATER DEVELOPMENT REPORT 4

VOLUME 3

Published in 2012 by the United Nations Educational,
Scientific and Cultural Organization
7, place de Fontenoy, 75352 Paris 07 SP, France

ISBN 978-92-3-104235-5
e-book ISBN 978-92-3-001045-4

Original title: The United Nations World Water Development Report 4: *Managing Water under Uncertainty and Risk* (Vol. 1), *Knowledge Base* (Vol. 2) and *Facing the Challenges* (Vol. 3).

Published in 2012 by the United Nations Educational,
Scientific and Cultural Organization

UNESCO Publishing: http://publishing.unesco.org/

Suggested citation:
WWAP (World Water Assessment Programme). 2012. *The United Nations World Water Development Report 4: Managing Water under Uncertainty and Risk*. Paris, UNESCO.

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The contents of Volume 2 were contributed by the UN-Water members and partners listed on the title pages of the chapters therein. UNESCO and the United Nations World Water Assessment Programme (WWAP) are not responsible for errors in the content provided or for discrepancies in data and content between contributed chapters.

WWAP provided the opportunity for individuals to be listed as authors and contributors or to be acknowledged in Volume 2. WWAP is not responsible for any omissions in this regard.

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Cover and interior design and typesetting by Phoenix Design Aid A/S, an ISO 14001 (environmental management) and a DS 49001 (corporate social responsibility) certified and approved carbon neutral company.

Printed by Imprimerie Centrale S. A. (Imprim'Vert certified) for UNESCO CLD, Paris.

This publication is printed with vegetable inks on FSC Mixed Sources paper, supporting responsible use of forest reserves. This is a carbon neutral print product. Imprimerie Centrale will contribute funds to a project replanting trees in Panama for this publication.

Printed in Luxembourg

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WWDR4 has been published on behalf of the United Nations World Water Assessment Programme (WWAP) with the support of the following organizations:

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“We can’t solve problems by using the same kind of thinking we used when we created them.”
Albert Einstein

FOREWORD

by Olcay Ünver, Coordinator, United Nations World Water Assessment Programme

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From its first edition in 2003, the *United Nations World Water Development Report* (WWDR) has shown how decisions made in every realm of life and work can have an impact on our water resources. Rapidly changing conditions across the globe are creating new pressures on water, and introducing new uncertainties and risks for its use and management. The resilience of societies to cope with these challenges varies greatly, largely determined by their institutional and legal frameworks and the availability of financial and human resources.

Case studies are a significant part of each WWDR. Collectively, they illustrate the challenges that confront policy-makers and water managers around the globe, and how they are responding to them. The present volume, Facing the Challenges, features concise summaries of fifteen case studies compiled over a period of three years, providing 'snapshots' of water management and use today in diverse regions of the world. These case studies, by design, closely complement the other volumes of the 2012 *World Water Development Report 4,* as most of the factors influencing water resources management discussed in those volumes can be observed, in one form or another, in the pages presented here.

Since the launch of the United Nations World Water Assessment Programme (WWAP) in 2000, the number of case studies has continuously risen. Overall, 58 regional studies at the basin or national level have been completed so far, through partnerships with national bodies worldwide. The mobilization of key stakeholders is also important to the development of case study projects. As we move forward, WWAP will continue working with national partners and other stakeholders to develop further case studies of water management and use in diverse countries and river basins, to achieve as wide a regional coverage as possible.

This volume constitutes a valuable contribution to the international community. The experiences and policies it describes provide different perspectives for all those working towards sustainable development – not only water professionals, but managers and decision makers at all levels, and researchers from within or outside the 'water box'[1] – helping all to make informed decisions with better knowledge.

Olcay Ünver
Coordinator, United Nations World Water Assessment Programme

Note

1 The concept of the 'water box' is used in the third edition of the *World Water Development Report* to describe the specific sphere (the 'water sector') to which questions of water management are too-often confined.

SUMMARY

Case study development process and highlights of the findings

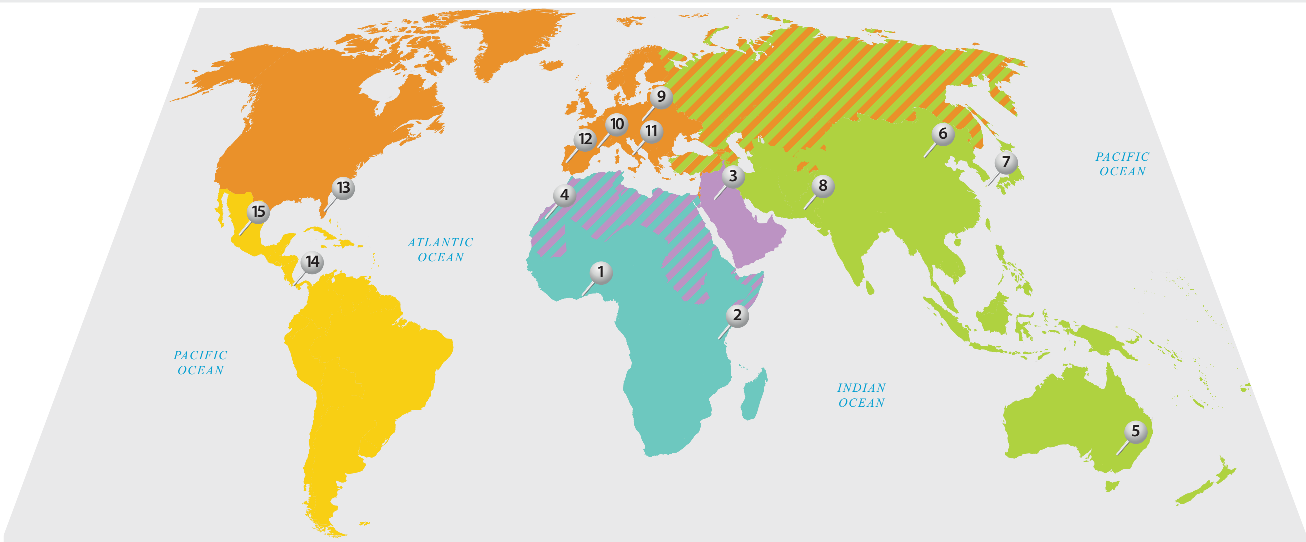
This fourth edition of the *United Nations World Water Development Report* (WWDR) features 15 case studies from different geographies of the world. For the first time, there are pilot studies from North America (St Johns River Basin, Florida, USA) and the Middle East (Jordan). As with previous volumes of the WWDR, the focus continues to be on the common challenges that the countries and regions included are facing: the management and allocation of freshwater resources, shortcomings in institutional and legal frameworks, environmental degradation, declining water quality, and the risks posed by climatic variations and climate change.

The regional distribution of case studies that are featured in this volume is shown in the map below.

Eight of these pilot projects (See map below, case studies 2, 5, 6, 10, 11, 12, 13 and 15) have been conducted at the river basin level, while the others showcase national efforts. Although the majority of the countries that participated in the development of these case studies are new WWAP partners, five of them – China, France, Italy, Mexico and the Republic of Korea – have also contributed to earlier volumes of the WWDR. We would like to express our deep appreciation to all our country partners for their significant input.

This volume presents concise summaries of these 15 case study reports, the original versions of which represent approximately one thousand pages. The amount of work that went into preparing the full

Regional distribution of the case studies



AFRICA
1. Ghana
2. Kenya-Tanzania (Mara River basin)

ARAB STATES
3. Jordan
4. Morocco

ASIA and the PACIFIC
5. Australia (Murray-Darling basin)
6. China (Yellow River basin)
7. Korea (Jeju Island)
8. Pakistan (with special reference to the Indus River basin)

EUROPE and NORTH AMERICA
9. Czech Republic
10. France (Marseille Provence Métropole Urban Community)
11. Italy (Tiber River basin)
12. Portugal (Tagus River basin)
13. United States of America (St Johns River basin, Florida)

LATIN AMERICA and the CARIBBEAN
14. Costa Rica
15. Mexico (Lerma-Chapala basin)

Countries included in both Africa and Arab States Regions of UNESCO

Countries included in both Europe/North America and Asia/Pacific Regions of UNESCO case study reports and their concise summaries is noteworthy: on average each report went through two iterations to ensure the quality of the final studies.

The areas covered by the case studies vary greatly. In this edition, Jeju Island, Korea is the smallest in size (approximately 1,850 km^2) whereas the Yellow River basin, China (approximately 795,000 km^2) and the Murray–Darling River basin, Australia (more than a million km^2) are the two largest.

The concise summaries provide a snapshot of reality. They present the current situation of water resources and their use in each area covered through a common framework that includes the state of the resource, how water resources are utilized, competition among sectors, legal and administrative frameworks, the status of ecosystems, impacts of climate change and climatic variations, water related disasters, and more. Boxes highlight important recent events (the catastrophic flood in Pakistan, the recent drought in the Murray–Darling basin), key water-related projects (ecosystem conservation efforts in Jordan, sediment load reduction in the Yellow River basin, attempts to introduce payment for ecosystem services in the Mara River basin) and the structure and functioning of river basin organizations (the Lerma–Chapala Basin Council in Mexico, river basin district administrations in Portugal).

Regardless of a country's level of development, water resources management and protection are areas where constant improvement is sought. Australia has produced a blueprint for water reform in its 2004 National Water Initiative, while on Jeju Island (Republic of Korea) there is a clear understanding of the importance of integrated water resource management for effective planning. Strict control of water allocation at the district level in the Yellow River basin ensures the flow of the river throughout its course, and especially to its lower reaches. The government of Pakistan is working to reform irrigation water management in the Indus River basin, and in the St Johns River basin (Florida, USA) the Watershed Restoration Act has helped control problems of pollution. The 2000 EU Water Framework Directive is being implemented by all European nations, with different countries currently at different stages of completing its requirements.

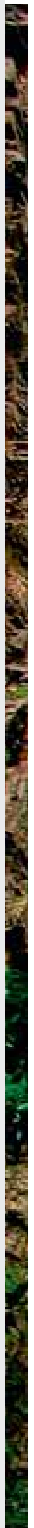
Climate change and climatic variations are likely to pose challenges of varying degree and intensity. While several models suggest likely scenarios, some countries have already started experiencing the effects of climate change in the shape of more frequent and intense water-related natural disasters (e.g. floods, droughts, mudslides, tornados). Almost all of our case study partners reported increasing variability in the occurrence of such events. All of these countries, without exception, have mechanisms and legislations in place for disaster mitigation, however, their institutional and financial capacity to respond when such disasters strike are closely linked to their level of economic development.

Cooperation among riparian countries in the context of international water resources is critical for the sharing and protection of scarce water resources in an era of increasing climatic variability and climate change. Jordan and Israel reached an agreement on water rights in the Jordan River basin in their 1994 peace treaty. In the case of Spain and Portugal, the Albufeira Convention applies to several transboundary rivers and covers issues such as the exchange of information, pollution control and prevention, the evaluation of the transboundary impacts of water uses, and conflict resolution and the assignment of rights. The Convention allows for future revisions to ensure the achievement of environmental objectives set at basin level and to integrate climate change adaptation measures. Cooperation is vital for shared water resources in the national context, too. The Yellow River basin crosses nine provinces of China, however the 1987 Water Allocation Scheme and 2006 ordinance have created the basis for regulating water use to satisfy demand in all provinces and improve environmental conditions, especially in the lower reaches of the basin.

Water and food security are among the most important issues of concern not only in arid regions, such as Jordan and Morocco, but also in regions that are well endowed in terms of water resources. In Ghana, for example, the absence of adequate storage and agro-processing facilities leads to losses of perishable crops. Overall, increasing demographic pressures and climatic variations, such as floods and droughts, that affect crop yields are other drivers that diminish food security.

The case studies reveal that approaches towards sustainable utilization of water resources are evolving in the direction of integrated water resources management (IWRM). The need to integrate surface water and groundwater resources within basins and to balance competing sectoral interests with the needs of ecosystems are increasingly accepted at all levels of governance. However, considerable progress is necessary to make the IWRM approach a mainstream objective at the global level. The same observation applies to the attainment of the Millennium Development Goals (MDGs), for which there are blatant regional disparities.

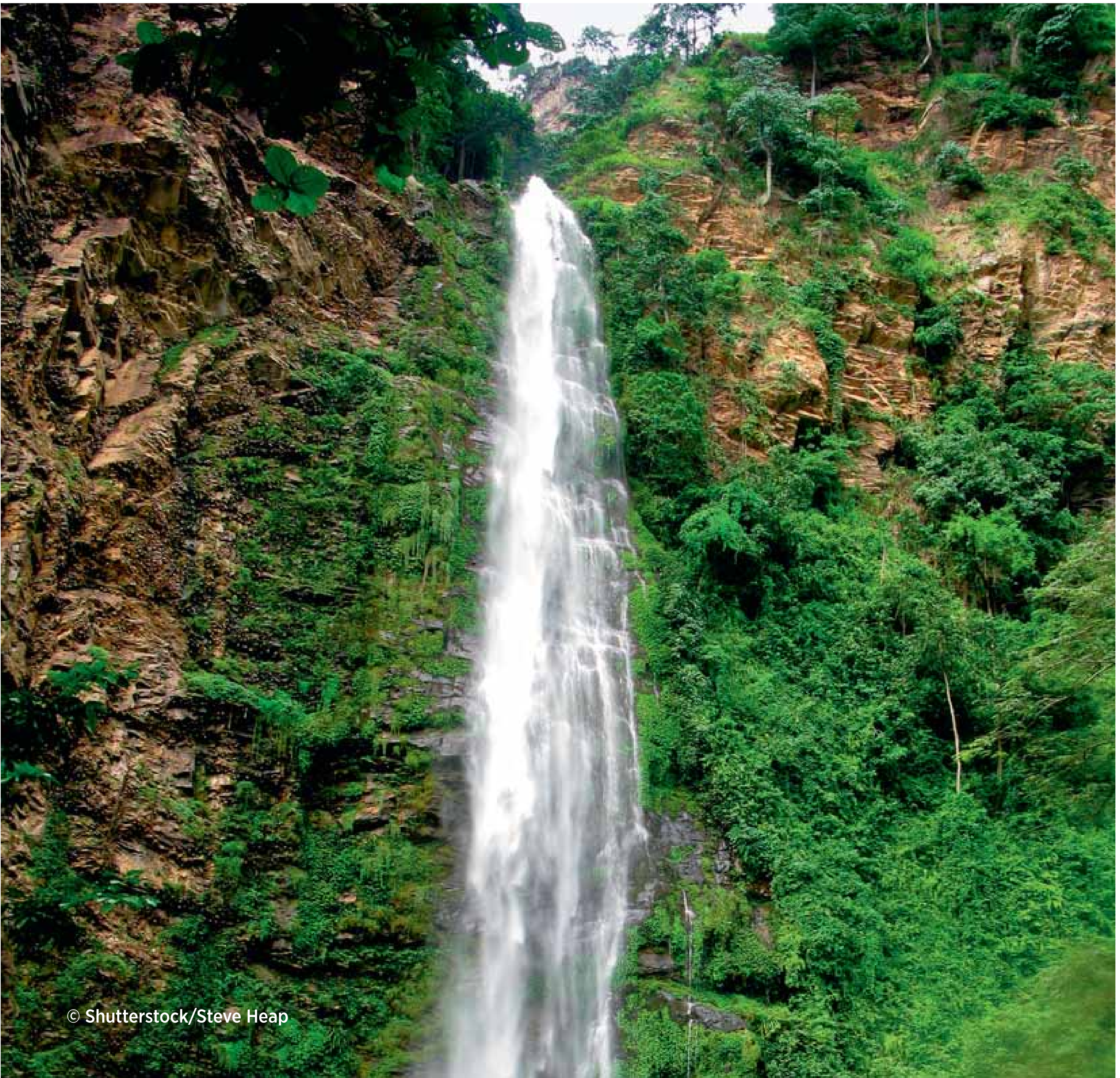
The case studies clearly highlight the diversity of circumstances, challenges and priorities facing different regions. Consequently, efforts towards attaining wider coverage will continue in subsequent editions of the WWDR, as additional case study partners are sought.



CHAPTER 37

Ghana

Acknowledgements Kodwo Andah, Ben Ampomah, Christine Young Adjei, Winston Ekow Andah



Location and general characteristics

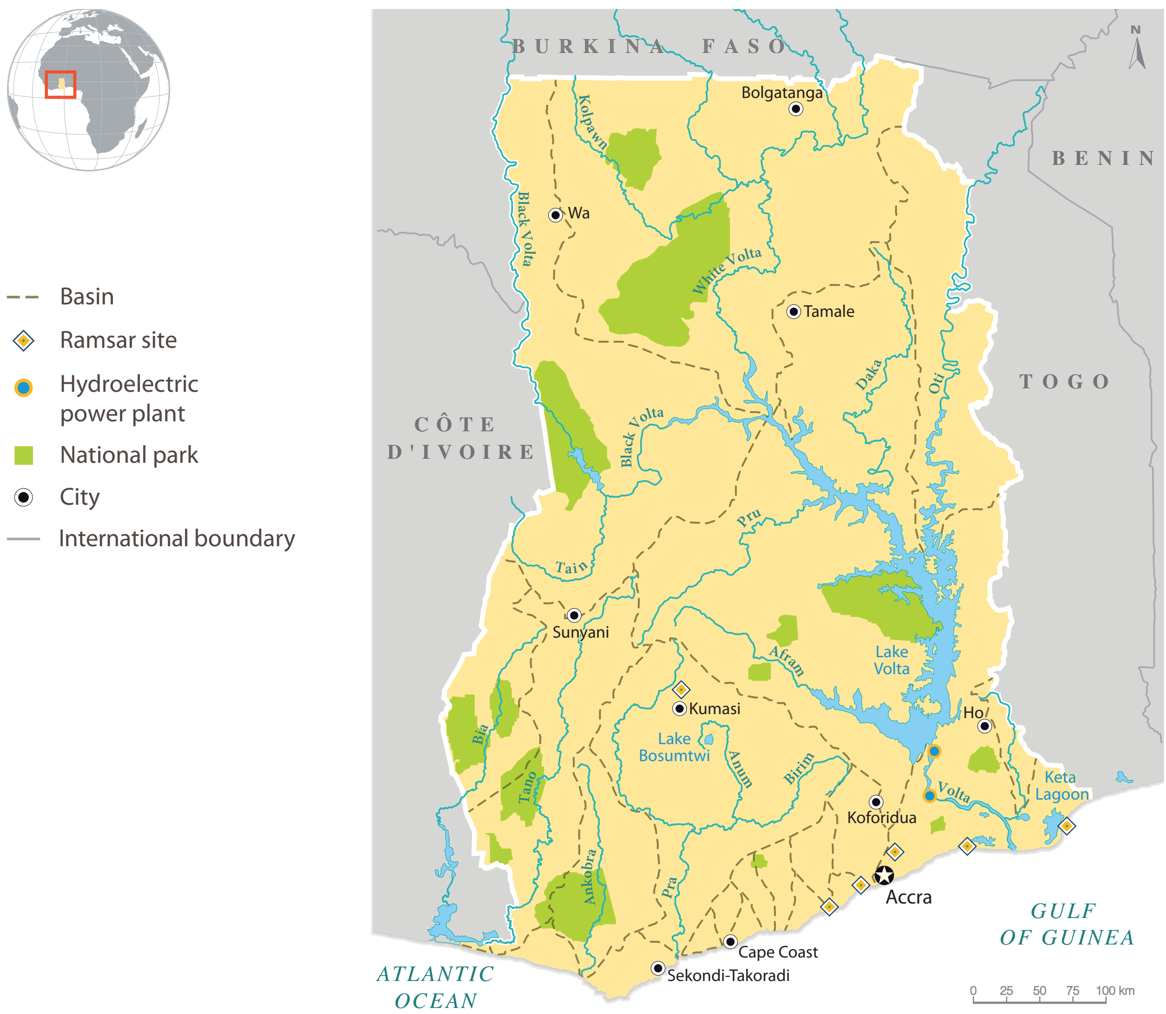
The Republic of Ghana (Ghana from here on) is located in West Africa. It is bounded to the north by Burkina Faso, to the east by Togo, to the west by Côte d'Ivoire and to the south by the Gulf of Guinea and the Atlantic Ocean (Map 37.1). The country extends over an area of 238,540 km^2, and it has 24.3 million inhabitants (2010). The national capital, Accra, is home to about 2 million people (2009).

The topography consists mainly of rolling plains, escarpments and low hill ranges. The highest elevation in Ghana, Mount Afadjato in the Akwapim–Togo Ranges, rises 880 m above sea level. Ghana has a warm, humid tropical climate. Mean annual temperatures range from 26°C near the coast to 29°C in the extreme north. The highest annual rainfall is 2,150 mm in the extreme south-west of the country, and this reduces progressively to a low of 800 mm in the south-east and about 1,000 mm in the north-east. Disparity in the geographical and seasonal distribution of precipitation causes water stress at the local and regional levels. For example, even in the high rainfall belt in the south and west, water scarcity in the dry season can last three to five months. In the northern and the south-eastern regions, where rainfall is the lowest, the dry season continues over eight to nine months.

Ghana has a relatively diverse and rich natural resource base – principally gold, diamonds, manganese ore, and bauxite. Gold and cocoa are Ghana's top two exports, and the country has been an oil exporter since 2010.

MAP 37.1

Ghana



Water resources availability, their use and management

Ghana is drained by three main river systems. These are the Volta, South-Western and Coastal river systems, which respectively cover 70%, 22% and 8% of the country. The Volta river system consists of the Oti and Daka rivers, the White and Black Volta, and the Pru, Sene and Afram rivers. The south-western river system comprises the Bia, Tano, Ankobra and Pra rivers. The coastal river system includes the Ochi-Nakwa, Ochi Amissah, Ayensu, Densu and Tordzie rivers. The total annual runoff from all the rivers combined is 56.5 billion m^3 of water, of which 40 billion m^3 is accounted for by the Volta River. Approximately 40% of total water resources availability originates outside Ghana's territory.

The only significant natural freshwater lake is Lake Bosumtwi, which has a surface area of 50 km^2, and a depth of 78 m. Lake Volta, which is the reservoir of the Akosombo Dam, is one of the world's largest artificial lakes, and it covers an area of 8,500 km^2.

In 2000, total water withdrawal was approximately 980 million m^3. Of this, about 652 million m^3 (66%) was used for irrigation and raising livestock, 235 million m^3 (24%) was used for water supply and sanitation, and 95 million m^3 (10%) was used by industry. Non-consumptive water use for generating hydroelectricity (only at the Akosombo Dam), is around 38 billion m^3 per year (FAO-Aquastat, n.d.). The consumptive water demand for 2020 is projected to reach 5 billion m^3.

Agriculture forms the most important segment of the economy (Box 37.1), accounting for about 30% of gross domestic product (GDP) and about 55% of formal employment. Industry, including mining, manufacturing, construction and electricity generation, accounts for about 20% of GDP. The services sector has been growing fast, and now generates half of national GDP (2010). Poverty rates in the country are not evenly dispersed.

While Ghana has over 50,000 boreholes and hand-dug wells, the country's groundwater resources are not well studied. However, annual renewable capacity is estimated to be around 26 billion m^3 (2005). In the Volta basin, annual groundwater use is approximately 90 million m^3. Measurements in other basins similarly showed that actual use is well below groundwater recharge. Groundwater abstraction is projected to increase by approximately 70% in order to meet the water demand in 2020.

Since the beginning of the 1980s, the Government of Ghana has introduced a number of policy reforms that were specially intended to improve efficiency in rural, urban and irrigation water use as well as to attain measures of environmental protection and conservation. The key problem was the absence of a holistic water policy that included all aspects of water resources management. The Water Resources Commission, which was established in 1996 to regulate and manage the use of freshwater resources and to coordinate policies in relation to them, responded to this challenge by introducing the draft Water Policy in 2002. A wider consultative process was initiated later in 2004 to incorporate policies that were specific to water supply and sanitation services. The draft Policy was further enhanced through integration of the principles of environmental assessment to promote the sustainability of natural resources. In 2007, the National Water Policy – which took an integrated water resources management approach as one of its core principles – was approved. The policy recognizes the various cross-sectoral issues related to water use, and the links to other relevant sectoral policies such as those on sanitation, agriculture, transport and energy (MWRWH, 2007). This holistic approach makes the water policy complementary to the national Poverty Reduction Strategy and the 'Africa Water Vision' put forward by the New Partnership for Africa's Development (NEPAD).

In terms of institutional framework, water sector reforms that started in the 1990s led to the establishment of Ghana's Environmental Protection Agency in 1994, and the Water Resources Commission in 1996. The Public Utilities Regulatory Commission was launched in 1997 to regulate and oversee the provision of utilities. Ghana Water Company Limited was set up in 1998 to provide water supply to urban areas. The same year, the Community Water and Sanitation Agency was established to administer rural water supplies.

Climate change, water-related disasters and risk management

Ghana often experiences floods and droughts, particularly in the northern Savannah belt. The country faced widespread floods in 1962 and 1963. Then

BOX 37.1

Agriculture and food security

In Ghana, overall sustained economic and agricultural growth has been accompanied by rapid poverty reduction. Growth has created a vibrant market for local farmers, and higher incomes have reduced poverty and led to increases in food demand. Thanks to economic reforms that began in 1983, Ghana was able to turn its agriculture sector around. A stable economy, market liberalization, and improved infrastructure have restored incentives to farm, which has both benefited small farmers and encouraged some large-scale investment in cash crops such as pineapples and palm oil. After 1983, agriculture grew at an average annual rate of 5.1%. Food supply has been growing faster than the population growth rate, making Ghana largely self-sufficient in terms of staples. At the same time, food prices have fallen. More accessible food helped to lower the rate of undernourishment from 34% in 1991 down to 8% by 2003. Child malnutrition also declined, with the proportion of underweight infants falling from 30% in 1988 to 17% in 2008. The proportion of the population living in poverty fell from 52% in 1991 to 28.5% in 2006, with rural poverty falling from 64% to 40% over the same period. The most recent estimates suggest that only 10% of the urban population lives below the poverty line (IFAD, n.d.). Overall, Ghana is on track to achieve the Millennium Development Goal of halving poverty and hunger (MDG 1).

However, in spite of these developments, food security is not in place in Ghana. Of 19,000 km^2 of potentially irrigable land, only 338 km^2 is irrigated (2007). In addition, the rehabilitation of many of the irrigation schemes is long overdue. Another challenge facing Ghana is losses in perishable crops as a result of the absence of adequate storage and agro-processing facilities. Climatic variations, such as floods and droughts that affect the crop yield, and a rapidly growing population also have a negative impact on food security.

Source: FAO-Aquastat (n.d.).

between 1991 and 2008, there were six major floods. The 1991 flood affected approximately 2 million people and the catastrophic floods in the north in 2007 affected more than 325,000 Ghanaians, with close to 100,000 requiring assistance to restore their livelihoods (UN-ISDR/WB, 2009). In 2011, there were many floods across the country, especially in the eastern and northern regions. Scientific studies suggest that the periodicity of 5.6 years is highly significant for flood occurrence. At the opposite end of the spectrum, Ghana also experienced significant droughts in 1977, 1983 and 1992. In fact, the 2007 flood was followed immediately by a period of drought that damaged the initial maize harvest. The economic impact of water-related disasters at the national and regional levels is not well documented.

With international support, Ghana developed national climate change scenarios and climate change vulnerability assessment studies for water resources and the coastal zone. Major findings were that over a 30-year period from 1961 to 1990, temperatures rose by about 1°C, rainfall was reduced by 20%, and stream flows dropped by 30%. Flow reductions of between 15% and 20% were observed for simulations using climate change scenarios for 2020; and reductions of between 30% and 40% were observed for simulations using climate change scenarios for 2050. The simulations predicted that the reduction in groundwater recharge would be between 5% and 22% by 2020, and between 30% and 40% by 2050. The maize yield was predicted to decrease by about 7% in 2020. It was found that millet yield would probably not be affected because it is more tolerant of higher temperatures.

It was found too that irrigation water demand could be affected considerably by climate change. The simulations revealed that in the humid part of the country, the increase in irrigation water demand could range from about 40% (2020) and 150% (2050) of the base period water demand. For the dry interior Savannah, the corresponding increase in irrigation water demand in 2020 and 2050 could be about 150% and 1200% respectively. Hydropower generation could also be seriously affected by climate change. The projected reduction of the amount of electricity generated by 2020 can be about 60%. In the coastal zone, over 1,000 km^2 of land may be lost due to sea level rise, which could be as high as one metre. Consequently, over 130,000 residents living along the east coast are considered to be at risk. Important wetlands, especially in the Volta Delta, may be lost as a result of land erosion and inundation. Increased water depths and the salinization of lagoons as a result of sea level rise could have a negative impact on the feeding of migratory and local birds.

Confronted with water-related and other natural hazards, the Government of Ghana, with the help of donor support, is in the process of developing strategies and strengthening its institutional capacity in disaster risk management. Disaster risk reduction is the responsibility of the National Disaster Management Organization (NADMO), established in the Ministry of the Interior. NADMO functions under a national secretariat and comprises a network of ten regional secretariats, 168 district/municipal secretariats and 900 local offices. Since its inception under parliamentary Act 517 in 1996, NADMO has contributed considerably to disaster management across the country. However, its activities and response capacity on the ground are constrained by a lack of adequate funding (NADMO, 2011). The 1997 National Disaster Management Plan was revised in 2009 along with a parliamentary amendment to Act 517. In order to accomplish its objectives, NADMO has set up technical sub-committees to cover all types of disasters including geological and hydro-meteorological events, pest and insect infestations, bushfires and lightning, disease outbreaks and epidemics.

Water and health

Even though 90% of people in urban areas have access to safe drinking water, only about 32% had home connections in 2008 – compared to about 40% in 2000. This drop in coverage is because infrastructural development is falling behind the rate of population growth and urbanization. The coverage in rural areas in 2008 was 60%.

The portion of population that has access to improved sanitation facilities is very low. In 2008, it was only 18% in urban areas and 7% in rural areas (UNICEF, n.d.*a*). Close to 40% of all public schools have no access to safe drinking water; and about 50% of public schools have no toilet facilities (2011). As a result, water-related diseases, such as malaria, schistosomiasis, guinea worm and lymphatic filariasis are common. According to the World Malaria Report (WHO, 2009) there were 3.2 million reported malaria cases in 2008. Of those cases, approximately 1 million affected children under the age of five. Malaria is a nationwide problem that claims the lives of approximately 20,000 children every year. The annual economic burden of malaria is estimated 1% to 2% of GDP (UNICEF, n.d.*b*). Other communicable diseases such as cholera and yellow fever are also widespread in Ghana and cause epidemics from time to time. As a combined result of these problems, life expectancy is about 58 years.

It is estimated that 51.5% of the population lives in urban settlements, and in 2007, approximately 5 million people were living in slums with limited or no water supply (UN-HABITAT, 2008). This led to the emergence of water vendors to service such deprived areas, who are now grouped under the Private Water Tanker Owners Association. Unfortunately, those who rely on water tankers usually pay more than ten times the official rate for piped water and end up spending over 10% of their income on potable water. To improve the situation, a Water Sector Rehabilitation Project was initiated in 1992. Furthermore, the Water Sector Restructuring Programme (2003–2009) was implemented to improve the provision of water by building new production and transmission facilities and rehabilitating the existing ones in urban areas. Consequently, water production by Ghana Water Company Limited increased steadily from 205.2 million m^3 to 231.77 million m^3 between 2003 and 2009. Since 2006, it has carried out major expansion and rehabilitation works on a number of urban water supply systems throughout the country. It must be noted that the unaccounted for water (i.e. non-revenue water) in the water supply network is still around 50% (MWRWH, 2009).

Environment and ecosystems

There is a lack of information on the wealth of Ghana's biodiversity. So far, about 2,974 indigenous plant species, 504 fish species, 728 bird species, 225 different types of mammals, and 221 species of amphibians and reptiles have been recorded. Some 16% of Ghana's land has been designated as forest reserve, national park or other wildlife reserve. Five wetland areas – the Densu Delta, the Songor, the Keta Lagoon Complex, the Muni-Pomadze coastal wetlands and the Sakumo Lagoon – are Ramsar sites of international importance. Other wetlands located in the forest and wildlife reserves of the Mole National Park, the Black Volta, the Sene, the Bia and the Owabi Wildlife Sanctuaries are also protected (FAO-Aquastat, n.d.). Despite these efforts, increasing pressure from agricultural expansion, mining, timber extraction and other socio-economic factors have had a negative impact on the environment and the ecosystems. It is estimated that the country is experiencing a rapid deforestation at about 220 km^2 per year. In economic terms, the loss of biodiversity through deforestation and land degradation is estimated to cost about US$1.2 billion annually (Agyemang, 2011). This is partially the result of uncoordinated implementation of sectoral socio-economic development policies. The situation warrants urgent action if further environmental degradation is to be averted (Ministry of Environment and Science, 2002).

Even though industrial water demand accounts for around 10% of annual water use, industrial activities are the main source of pollution. This adds to water stress and impairs the health of society. Mining is the industrial activity that contributes most to pollution. The 2008 report of Ghana's Commission for Human Rights and Administrative Justice stressed that 82 rivers and streams in five mining communities in Ghana had either been polluted, destroyed, diverted or dried-up as a result of mining companies. In its 2010 evaluation report, Ghana's Environmental Protection Agency concluded that mining companies' observation of environmental standards is poor. This is caused by environmental laws that are not sufficiently strict on pollution prevention. The major concern lies not with the big mining firms, whose activities are easy to monitor, but with illegal small-scale miners whose activities are neither registered nor monitored.

Water and energy

Ghana has one of the highest rates of electrification in Africa. Access to electricity in urban areas is close to 70%, and almost 30% of rural households are connected. On average, access to electricity in Ghana is about 60% (IEA, 2009). There are two main large dams in operation in Ghana with a combined hydropower generation capacity of 1,072 MW: the Akosombo Dam (134 m high) and the Kpong Dam (29 m high). These plants harness approximately 58% of the country's 10,600 GWh/year hydropower potential. The construction of the 400 MW Bui hydropower plant on the Black Volta began in 2005 and is expected to commence energy production towards the end of 2012. Sites for a further 17 potential hydroelectric power plants have been identified, and feasibility studies have been carried out. Once these projects are phased in, fluctuations in the supply of electricity caused by droughts will stabilize.

Conclusions

Ghana is well endowed with freshwater resources. However, disparity in distribution causes water stress, which is further worsened by the uncertainties posed by climate change, climatic variation, rapid population growth, environmental degradation and pollution. Thanks to continuous economic growth, the country is on track to meet the Millennium Development Goal (MDG) on eradicating extreme poverty and hunger. However, roughly 40% of rural dwellers remain poor. One of the most critical challenges facing the country is very poor access to improved sanitation facilities. Combined with a less than ideal water supply network, diseases such as malaria, cholera and yellow fever are widespread, causing significant numbers of casualties. Food security is another concern that leaves the country at the mercy of climatic variations and makes it dependent on imported food to feed its growing population. Increasing the amount of cultivated land (both rainfed and irrigated), improving the irrigation infrastructure and developing the agro-industry are crucial issues that require both national investment and international donor support. Mining activities, while creating considerable amount of income, are among the main causes of water quality degradation. Strengthening environmental protection laws and enforcing them requires urgent action. Inadequate and unreliable data on water resources and their use is the major roadblock to sustainable development.

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Except where otherwise noted, information in this concise summary is adapted from the *Case Study Report of Ghana* prepared in 2011 by Kodwoh Andah (unpublished).

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CHAPTER 38

Mara River Basin, Kenya and Tanzania

Acknowledgements Nathan Karres, Iman Yazdani, Maria C. Donoso, Michael McClain

Location and general characteristics

The Amala and Nyangores rivers originate in Kenya's Mau Forest and converge to form the Mara River (Map 38.1). Other tributaries, the Engare, Talek and Sand also flow into the Mara to form the transboundary Mara River basin.

The Mara River is about 400 km long and drains into Lake Victoria in Tanzania, which makes the river part of the larger Nile basin. The Mara River basin covers an area of approximately 13,750 km^2, of which 65% is located in Kenya and 35% in Tanzania. The amount of annual rainfall in the basin varies from 1,400 mm in the hills of the Mau Forest to 500–700 mm in the dry plains of north-west Tanzania.

Approximately 840,000 people live in the basin (2010) – the majority of whom are have settled in rural areas. The Kenyan part of the basin is home to 558,000 and the remaining 282,000 inhabitants live in the Tanzanian portion of the basin. According to projections, by 2030, the overall population in the basin could almost double to as much as 1.35 million.

Poverty is a major concern in the basin. In Kenya, nearly half of the basin's population lives below the poverty line[1]. On the Tanzanian side, the rate of poverty is around 40%. In general, those living in the basin earn their living from growing food crops (36.1%), cash crops (9.6%), livestock production (5.9%), fishing (9.5%) and business enterprises (11.4%).

Water resources and their use

As a result of insufficient data, there are only rough estimates of the water potential of the Mara River. The lower estimate is approximately 475 million m^3 per year, which only takes into account the flow rates of its two main perennial tributaries, the Amala and the Nyangores. A higher, and probably more accurate estimate based on data from more of the tributaries and a gauging station, is around 950 million m^3 per year. The total annual water demand in the Mara River basin is approximately 23.8 million m^3 per year (2006). Irrigated agriculture is the major user of water throughout the basin followed by domestic consumption and livestock production (Table 38.1).

TABLE 38.1

Water use in the Mara River basin (2006)

Use	Water demand (m^3/year)
Large-scale irrigation	12,323,400
Domestic	4,820,336
Livestock production	4,054,566
Wildlife	1,836,711
Mining	624,807
Tourism	152,634
Total	**23,812,454**

MAP 38.1

Mara River basin

While water use is significantly less than the basin's potential, the intra-annual variability in supply and poor and outdated agronomic practices, lead to problems meeting the demand. Furthermore, the frequency of water shortages and their severity is likely to increase in parallel with the expansion of irrigated land in the basin. Presently, 51% of the water demand is linked to a few big farms in Kenya. These farms produce mainly maize, beans, gum trees and wheat.

Biodiversity, tourism and the potential impact of climate change

Within the basin, there are important habitats that support the region's vibrant biodiversity. Among the most important of these are the Mau Forest, the Mara Swamp and the Mara–Serengeti eco-region, which is a UNESCO World Heritage Site. The Mara–Serengeti alone contains over 90 mammals and more than 450 bird species. There have been conservation programmes in the basin implemented by the Kenyan and Tanzanian governments as well as regional and international institutions. However, despite these efforts, the condition of the habitats continues to decline. For example, over the past few decades, the Mau Forest has been reduced by 23% as a result of forest clearing for tea plantations, farming and timber harvesting. Even though there are laws protecting the buffer zones, the corridor of riverine forest along the Mara River has been greatly degraded by grazing and cultivation in both Kenya and Tanzania.

Socio-economic demands such as a growing tourism sector are adding to the problem. The number of tourists visiting the Masai Mara National Reserve in Kenya and the Serengeti National Park in Tanzania rose from approximately 190,000 in the 1990s to over 600,000 in the early 2000s. The growing concerns are clearly highlighted in the management plan of the Masai Mara National Reserve, which states:

> The Reserve is faced by unprecedented challenges. Inside the Reserve, escalating pressures from tourism development and growing visitor numbers … are leading to a … deterioration of the natural habitats on which the Reserve's tourism product is based … Outside the Reserve, there is growing pressure from local communities to use the Reserve's pastures and water sources for livestock, because of the diminishing supplies of these resources in the wider ecosystem and deteriorating community livelihoods …

All these issues point to a need for an integrated transboundary strategic planning approach to biodiversity conservation and water resources management in the basin.

Protecting the environment and ecosystems is essential for ensuring the sustainable development of both nations. Consequently, Florida International University within the framework of the Global Water for Sustainability (GLOWS) programme conducted an environmental flow assessment in three pilot sites in the basin. The study concluded that in the years when precipitation is normal (compared to the long-term average of mean annual rainfall), sufficient water exists to satisfy the needs of the human population and nature. However, during periods of drought, especially in the upper and middle reaches of the river, natural flow is well below the threshold required to meet the established reserve for environmental needs. This means that no water can be allocated for other uses (domestic, industrial, tourism, agriculture, etc.) and it is necessary to construct reservoirs to meet these demands. While the study is limited in scale, it clearly demonstrates the vulnerability of both the human and the wildlife populations in the basin.

Climate change can complicate matters further. Scenarios predict that the flow in the Upper Mara River may decrease significantly as a result of increased ambient temperature and less rainfall. This can have a serious impact on both human livelihoods and ecosystems. In fact, the importance of the Mara River is that it is the main source of water for the migrating animals of the Mara–Serengeti eco-region, especially during the dry season. Statistical analysis of rainfall data reveals that droughts are likely to occur every seven years in the basin. Depending on the severity of the conditions, 20% to 80% of the migrating wildebeest may die. With a 50% die-off rate, it will take approximately 20 years for the animal population to recover, while with an 80% die-off rate, there may be no population recovery at all. Such ecologically disastrous conditions would have severe repercussions for tourism in the Mara River basin as well, which in turn would affect the Kenyan and Tanzanian economies. The climate change scenarios also predict an increase in periods of intense rainfall which would result in an increased erosion and a drop in water quality caused by higher sediment content in the river. The best management practices that are proposed as a part of the 'Payment for Ecosystem Services (PES)' schemes (Box 38.1) include preserving riparian buffers, reinforcing river banks by planting trees and decreasing grazing as potential remedies to alleviate erosion problem.

Water and health

A large percentage of the population in the Mara River basin does not have access to a safe drinking water supply or adequate sanitation facilities (Table 38.2 and Table 38.3). Surveys conducted in the Trans Mara and Bomet districts of Kenya's Rift Valley Province revealed the lack of sewer infrastructure, with pit latrines being the only faecal disposal method available to the population. In general, the majority did not have any knowledge of basic sanitation or hygiene.

In Bomet, approximately 56% of households draw their drinking water from the Mara River during the dry season and 46% of households are forced to fetch water from water points that are between 1 km and 5 km away. Only 36% of households in Bomet reported any form of water treatment prior to consumption. As a consequence of over-reliance on unprotected water sources and poor hygiene practices, rates of diarrheal disease and intestinal worms are very high in both districts. Unfortunately, the unfavourable conditions described above are similar on the Tanzanian side of the basin.

Water resources management and regulations

Kenya's most recent constitution, adopted in August 2010, sets the foundation for the sustainable use and efficient management of natural resources. It articulates the obligations that the individual and the state have to the environment. Moreover, it also enables the formation of a National Land Commission which, among its other duties, has supervisory responsibility for land use planning throughout Kenya. The new constitution mandates the decentralization of government, allowing for effective governance at the district or basin level.

TABLE 38.2

Rate of access to water resources in the Mara River basin

	Piped water (%)	Spring/well (%)	Rain harvesting (%)	River/stream (%)	Pond/dam/ lake (%)	Other (%)
Kenya: Rift Valley Province*	22.8	36.3	1.2	29.3	4.7	5.5
Tanzania: Mara Region	14.2	63.2	-	6.6	15.6	-

**The Mara River basin lies within the southern section of the Rift Valley Province*

TABLE 38.3

Rate of access to sanitation facilities in the Mara River basin

	Conventional sewerage (%)	Pit latrine (%)	Septic tank (%)	No latrine (i.e. open defecation) (%)	Other (%)
Kenya: Rift Valley Province*	3.3	73.3	2.2	20.7	0.4
Tanzania: Mara Region	1.9	77.6	-	20.3	-

**The Mara River basin lies within the southern section of the Rift Valley Province*

Kenya Vision 2030 (formulated in 2007) and the Water Act (2002) constitute the main elements of the country's national water policy. Kenya Vision defines the goals and strategies of the country between 2007 and 2030 with particular attention to compensation for environmental services and the provision of incentives for environmental compliance. The Water Act allows for the establishment of the Water Resources Management Authority, which has a mandate to manage and protect river basins. It also encourages communities to participate in water management at the basin level and aims to ensure that sufficient and good-quality water is available to satisfy basic human needs and to protect ecosystems. The 1999 Environment Management and Coordination Act and the 2009 National Land Policy also play a part in water and biodiversity conservation in Kenya.

But Tanzania's constitution, unlike Kenya's, does not explicitly contain provisions for land and the environment. However, there are other major national legal instruments such as the Tanzania Development Vision 2025 (launched in 2000), the National Water Policy (2002), the Water Resources Management Act (2009) and the National Environmental Policy (1997). All these underpin the conservation of biodiversity and the regulation of water resources in the country.

Vision 2025 is Tanzania's national development blueprint. It projects fast growth while effectively reversing current adverse trends in environmental resources such as forests, fisheries, biodiversity as well as fresh water and land resources. Universal access to safe water is also a part of Vision 2025. The National Water Policy promotes decentralizing water resource management through integrated water resources management, involving water user associations and the private sector in decision making, ensuring the sustainable use of water resources through economic incentives such as appropriate pricing mechanisms, and establishing institutions such as the National Water Board, the Basin Water Boards and Basin and Sub-basin Water Committees.

The National Environmental Policy emphasizes sustainability and the conservation of natural resources and allows for economic instruments (such as PES, potentially) as approaches to environmental resource protection. The Water Resources Management Act gives effect to the 2002 National Water Policy and includes

BOX 38.1

Payment for ecosystem services

The ecosystems in the Mara River basin contribute significantly to the region's economy by providing valuable services without the need for any direct human labour or input. Payment for Ecosystem – or Environmental – Services (PES) is a mechanism to integrate this intrinsic wealth or productivity within an economic system.

In principle, the PES mechanism would allow for sustainable land use within the basin without the need for outside funding. The Mara River basin presents an ideal scenario for implementing a PES scheme because of the conflict of interest between the farmers upstream and wildlife tourism downstream. This 'vying for benefits' creates an opportunity for the transfer of ecosystem-based benefits to the upstream farmers in the form of economic support for the improvement of agricultural practices.

The first step towards a PES mechanism was taken in 2006 as a part of the project, Transboundary Water for Biodiversity and Human Health in the Mara River Basin. A feasibility study identified market-financed PES as the most appropriate methodology for economically incentivizing conservation efforts.

Thanks to surveys, analyses, and stakeholder meetings, the project has made considerable progress towards the development and eventual implementation of a PES mechanism. A final document is expected in 2012, which would present the culmination of the consensus-building process. However, while current policies in Kenya and Tanzania are generally supportive of PES schemes, they lack any concrete instruments in terms of laws and regulations for PES agreements. This observation presents an important challenge for translating a theoretical PES mechanism into a functional market-based system. Although existing legal and contractual mechanisms in both countries may enable the formation of a basic framework for a PES scheme, the introduction of supplemental regulations seems necessary.

legislation related to transboundary water resources management. This Act also allows for the creation of the Lake Victoria Basin Water Office, which is responsible for management of the Mara River.

Conclusions

The Mara River Basin is facing the mounting challenges of water scarcity, pollution and environmental degradation as a result of agricultural expansion, intensification of irrigation, population growth and the increasing impact of tourism. The main competition for water resources in the basin is between irrigated agriculture and the Masai Mara and Serengeti Wildlife areas.

Limited access to safe drinking water supply and practically the absence of a sanitation infrastructure add to widespread poverty through a heavy burden of disease. Legislation to address issues related to water and other natural resources is gradually being developed and put in place in both Kenya and Tanzania. Their implementation can help to operationalize mechanisms such as Payment for Ecosystem Services (PES), which can create sustainable financial support for efforts to conserve and protect natural resources.

Unless appropriate action is taken, growing problems will have a direct impact on the livelihoods of local people as well as on the national economies of both countries.

Notes

1 The Kenyan poverty line is set at approximately US$1.50 per day for rural populations and US$3.50 per day for urban populations.

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Except where otherwise noted, information in this concise summary is adapted from the *Case Study Report of the Mara River Basin in Kenya and Tanzania,* prepared in 2011 by the Global Water for Sustainability (GLOWS) Programme, Florida International University, supported by USAID (forthcoming).

CHAPTER 39

Jordan

Acknowledgements Maysoon Al-Zubi

Jordan: Gardens created in the middle of the Wadi Rum desert (29°33′ N, 35°39′ E)

Location and general characteristics

The Hashemite Kingdom of Jordan (Jordan from here on) is located in the eastern Mediterranean and bordered by Syria to the north, Iraq to the north-east, the Kingdom of Saudi Arabia to the east and south, and the West Bank and Israel to the west (Map 39.1). Jordan's population is around 6.3 million and it has a surface area of approximately 90,000 km^2. The Jordan Rift Valley, a narrow strip of highlands (with a maximum elevation of 1,600 m above sea level), the steppe, the desert zone and the Dead Sea (426 m below sea level in 2010) are the most distinctive topographical features.

Climate varies significantly from one region to another. The west of Jordan has a Mediterranean climate, characterized by dry hot summers, mild wet winters and extreme variability in rainfall during the year as well as from year to year. The climate in the highlands is characterized by mild summers and cold winters. Aqaba Governorate and the Jordan Rift Valley have a subtropical climate – hot in summer and warm in winter. The steppe and the steppe desert regions have a continental climate with large variations in temperature.

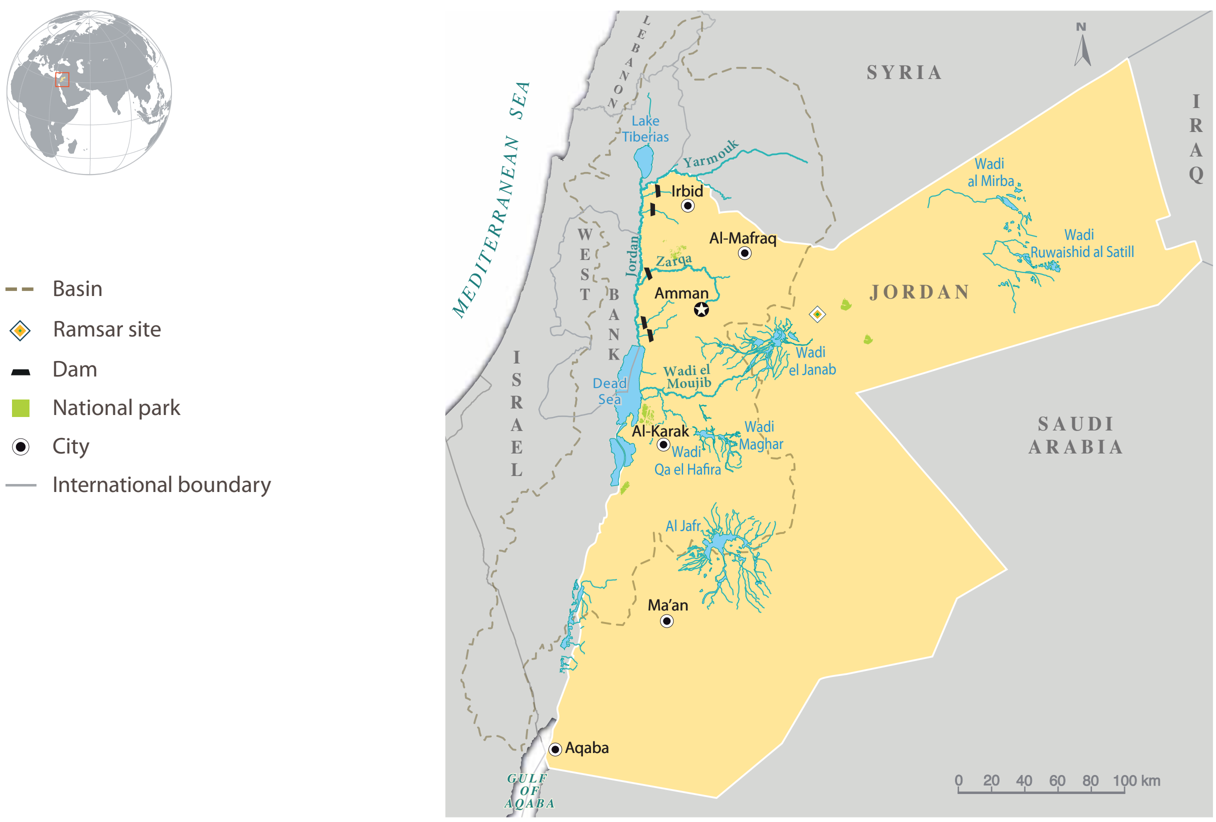
Precipitation in the country is very limited and ranges from 30 mm to 600 mm annually. Some 93.5% of the country has less than 200 mm of rainfall, and only 0.7% of the country has annual precipitation of more than 500 mm. Most of the rainfall occurs between November and April, and, in general, decreases considerably from west to east and from north to south. Overall, 83% of the country is composed of desert and desert steppe.

Water resources availability and their use

Jordan is one of the most arid countries in the world. While the average annual rainfall is approximately 8.2 billion m^3, 92% of this is lost through evaporation. Total internal renewable water resources are seriously limited. At an estimated 682 million m^3/year, the country is far below the water poverty line. Developed surface water potential was approximately 295 million m^3 in 2007, and is projected to reach 365 million m^3 by 2022.

MAP 39.1

Jordan River basin



On average, rivers constitute 37% of the national water supply. Jordan's most important surface water resources, the Jordan River and its main tributary, the Yarmouk, are shared with neighbouring countries. The Zarqa River, the second main tributary of the Jordan River, flows entirely within the territory of Jordan. The Yarmouk River is particularly critical as it accounts for almost 50% of the country's surface water resources. Allocation of these trans-boundary water resources has been one of the most difficult regional issues. Jordan and Israel reached an agreement on water rights in the Jordan River basin in their 1994 peace treaty. A joint water committee was also formed as a permanent institution charged with implementing the agreement.

Total internal renewable groundwater resources are approximately 450 million m^3/year, with a safe yield of 275.5 million m^3 (FAO, n.d.). At present, aquifers are being exploited at about twice their recharge rate. In particular, groundwater abstraction for agriculture is beyond sustainable limits, resulting in an annual groundwater deficit of 151 million m^3 (2007). The problem is worsened by the fact that there are hundreds of illegal wells. The protection of aquifers is critical as groundwater constitutes approximately 54% of the national water supply.

Agriculture is practised over 3% of the national territory (2005), whereas potentially cultivatable land is estimated at around 10% or 8,800 km^2 (FAO, n.d.). Water availability and soil quality are the main obstacles to the further expansion of agriculture. As a result of scarcity, only about 800 km^2 of land, mainly confined to the Jordan Rift Valley, is irrigated (2006). In an effort to maximize water-use efficiency, improved irrigation systems are being introduced. In fact, 60% of the irrigation in the Jordan Rift Valley, and about 85% in the highlands is through micro-irrigation. Even so, the agricultural sector still uses about 574 million m^3 of water, which corresponds to 60% of annual water use in Jordan (2009). In spite of consuming large quantities of water, agriculture contributes just 3% of Jordan's gross domestic product (GDP). Municipal water demand accounts for about 33% of overall consumption (approximately 315 million m^3). This demand is met largely from aquifers. Water use by industry and for livestock production is relatively insignificant at 39 million m^3 and 7.5 million m^3 respectively. While tourism accounts for approximately 1% of water use, the contribution of the sector to GDP was 10.6% in 2009 (Kreishan, 2010).

In addition to surface water and groundwater, other sources, such as fossil water, treated wastewater (110 million m^3 in 2009) and brackish water, are also used in Jordan. Overall, revenue collection systems are weak and more than 42% of the water delivered to the municipal water supply system cannot be accounted for. In addition, tariffs are low and do not cover total operation and maintenance costs.

A significant increase in population has led to a sharp decrease in per-capita water availability, which dropped from 3,600 m^3 in 1946 to 145 m^3 in 2008. It is projected that by 2022, the population may exceed 7.8 million, and total water demand may reach 1,673 million m^3. If current and planned projects are fully implemented, including the Disi water conveyance plan, the Red Sea-Dead Sea canal project, and plans to increase the use of treated wastewater, Jordan's current water deficit of 659 million m^3 (2009) could be reduced to 457 million m^3 by 2022.

In order to cope with water scarcity, 28 dams with a total storage capacity of 368 million m^3 were constructed between 1950 and 2008. At the same time, locations were identified for a number of reservoirs that would give the potential to add 444 million m^3 to Jordan's water storage capacity.

Climate change and its likely impact

Water is a scarce resource in Jordan, and a high population growth rate of approximately 2.3% per year is leading to growing demands from both agriculture and the municipalities.

Analyses of climate change scenarios indicate that Jordan will experience more frequent droughts during the twenty-first century as a consequence of year-round increases in temperature that may reach as high as 3°C (±0.5°C) in winter and 4.5°C (±1°C) in summer by the end of the century. The same climate change simulations show little or no change in precipitation to offset these big increases in temperature. In addition to this, runoff is expected to decrease over most of the country, except for the region south of the Dead Sea (RSCN, 2010). This could have a serious impact on water and food security. In fact, the results of a vulnerability assessment showed that climate change could have a significant impact on agriculture, particularly on wheat and barley production, which depend heavily on rainfall. The expansion of arid rangelands with decreased vegetation will have implications for grazing, as well. This will affect livestock production, and will have a consequent negative impact on the diet and income of poor farming households.

Water and settlements, water reuse

Over the past 60 years Jordan has become highly urbanized. The percentage of the population living in cities increased from 39.6% in 1952 to 78% in 2009 (UNICEF, n.d.). This increase is largely the result of internal migration, combined with an influx of refugees and migrants, mainly from Palestine and Iraq. Out of Jordan's twelve governorates, 65% of the population lives in Amman, Zarqa and Irbid. In terms of its regions, 91% of the population lives either in the north (Irbid, Jerash, Ajlum and Mafraq) or in central Jordan (Amman, Zarqa, Balqa and Madaba).

During the International Drinking Water Supply and Sanitation Decade (1981–1990), Jordan's government carried out a number of significant wastewater management projects. These were primarily related to the improvement of sanitation. This has raised the level of sanitation services, improved public health, and strengthened pollution control of surface water and groundwater in the areas served by wastewater facilities. According to the WHO/UNICEF Joint Monitoring Report (WHO/UNICEF, 2010), 96% of the population had access to a safe water supply, and 98% had access to improved sanitation in 2008. Approximately 64% of the population is connected to a sewerage network that collects wastewater for treatment and re-use. In 2008, approximately 100 million m^3 of effluent was processed in treatment plants. As a result of low water availability, treated wastewater represents a significant portion of the river flow in various parts of the country.

Sewerage systems for collecting a greater quantity of wastewater are expanding in parallel with population growth and increased water consumption. It is estimated that by 2022, approximately 250 million m^3 of wastewater will be generated. With proper treatment, this represents an important source of water that can be used for purposes other than for drinking.

Water quality, environment and ecosystems

The quality of surface water and groundwater has deteriorated significantly because of pollution. This is most notably the result of overuse of agrochemicals, over-pumping of aquifers, seepage from landfill sites and septic tanks, improper disposal of dangerous chemicals, and demographic pressure. Because of the diminishing per-capita water supply and quality issues, wastewater reuse has been an effective method of reclaiming a percentage of scarce water sources. Since the early 1980s, the general approach has been to treat the wastewater and then either discharge it into the environment – where it mixes with freshwater flows and is indirectly reused downstream – or to use the resulting effluent to irrigate restricted, relatively low-value crops (USAID, n.d.). However, the increasing dominance of effluent in the water balance, and the overloading of wastewater treatment plants, has raised concerns about the health risks and environmental hazards associated with wastewater reuse. To minimize such risks and their implications, effluent quality standards were set in 1995 and revised in 2003 (MEDAWARE, 2005), and most wastewater treatment plants have been upgraded to meet these standards. However, there is still a constant need to monitor the treatment plants and improve their capacity.

Because of its arid climate there are only a few large natural wetlands in Jordan, the best known being Azraq Oasis in the eastern desert. This large desert oasis, which formerly covered some 120 km^2, has diminished significantly as a result of over-exploitation of groundwater and the construction of dams on the major wadis. Similarly, the seasonal marshes in the Al Jafr area are also diminishing because of agricultural activities. Consequently, many aquatic species are endangered in Jordan (Budieri, 1995). Deforestation and desertification are other important environmental issues that require attention. To raise awareness about water use and environmental degradation, new literature is being introduced into the school curriculum (HKJ, n.d.). In terms of legislation, the Environment Protection Law No. 52 (2006) and the National Environmental Strategy (1992) form the main pillars of environmental protection in the country. As a novel approach, eco-tourism has also been introduced in Jordan to demonstrate that local development and efforts for conservation of nature can go hand-in-hand (Box 39.1).

Water resources management and the national strategy

Jordan's National Water Strategy is a set of guidelines that define the country's vision up to 2022. The Strategy aims to ensure the sustainability of water resources by balancing supply and demand through improved water resources management. The over-arching priority

BOX 39.1

A new era in conservational thinking

The development of the eco-tourism sector is being spearheaded by a long-established non-governmental organization, the Royal Society for the Conservation of Nature (RSCN). The RSCN is entrusted by the government with the protection and management of Jordan's special ecosystems. For several decades, the RSCN managed its protected areas as isolated, fenced sanctuaries that were guarded from the general public and had little involvement from local communities.

This all changed in 1992 with the Rio Summit and the Biodiversity Convention. As a signatory to the Convention, Jordan was the first country in the Middle East to be awarded a multi-million dollar pilot project under the Global Environment Facility (GEF). The project was to develop a regional model of integrated conservation and development. It was focused on the Dana Nature Reserve in southern Jordan, where the creation of the protected area in 1994 was linked to the socio-economic development of the local community. This pioneering initiative ushered in a new era in conservation thinking, which the RSCN continues to lead today.

The number of tourists to RSCN sites exceeded 137,000 in 2010, generating approximately US$1.7 million in revenue. In the same year, over 16,000 people from poor rural communities were supported by this tourism for nature conservation scheme. This revenue stream also covered over 50% of 2010's conservation costs.

Source: From Aziz and Szivas (2011)

of the National Water Strategy is 'to achieve national water security and to serve the overall development objectives' set out in the Strategy (HKJ, n.d.). Priority is given to the further development of land and water resources in the Jordan Rift Valley, which is the food basket of the country. The strategy recognizes the critical problem of the excessive use of aquifers, and highlights the need for limiting water abstraction to levels that are sustainable over the long term. Controlling, and even reducing, water consumption in all sectors is also one of the main pillars of the strategy.

In this context, farmers' water user associations play a key role in protecting water resources from pollution, increasing the efficiency of the irrigation infrastructure, and minimizing operation and maintenance costs – all of which are part of the National Water Strategy. As a specific response to the over-consumption of groundwater resources, the Highland Water Forum was created in 2010 with the aim of achieving the sustainable management of aquifers in the highlands. Moreover, as an overarching target the Forum promotes stakeholder dialogue focusing on sustainable groundwater management in Jordan.

Because Jordan shares all of its surface water resources with riparian countries, pursuing bilateral and multilateral cooperation with neighbouring states, and advocating regional cooperation are among the issues that are highlighted in the water strategy.

A number of policy papers have been drawn up within the framework of the National Water Strategy. These identify the main threads of water resources management. The four policy papers are the Water Utility Policy, Irrigation Water Policy, Groundwater Management Policy, and Wastewater Management Policy. The National Water Strategy and the four policy papers, coupled with a comprehensive investment programme, chart a road map for sustainable development (HKJ, n.d.).

Until 1987, water resources were managed by two independent authorities, the Water Authority of Jordan for water supply and sewerage, and the Jordan Valley Authority for irrigation and development in the Jordan Rift Valley. In 1987, the two authorities were brought together under the umbrella of the Ministry of Water and Irrigation. The National Water Strategy sets out the mission and key priorities of the Ministry.

Conclusions

Jordan is among the poorest countries in the world in terms of water resources. Consequently, priority is given to structural investments which help to develop more of its water potential. However, increasing demand and a growing population have pushed water consumption beyond sustainable limits and have led to over-use of groundwater resources. Climate change projections point to the possibility of a further reduction in water availability. As things stand, adequately addressing the challenge of an increasing water deficit requires both supply-side and demand-side measures, such as better water management, enhancing water use efficiency, awareness raising to change water consumption patterns, redefinition of water allocation priorities (such as limiting or reducing agricultural water use), and the development of technologies for use of non-conventional water resources (i.e. waste-water recycling). Reversing the trend of water-quality degradation is important to protect public health, while ensuring the sustainability of ecosystems and protecting scarce water resources. The National Water Strategy is a major policy document and its priorities are undoubtedly the correct ones. However, achievement of its goals will require the continuation of institutional changes to allow an integrated approach to water management issues.

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CHAPTER 40

Morocco

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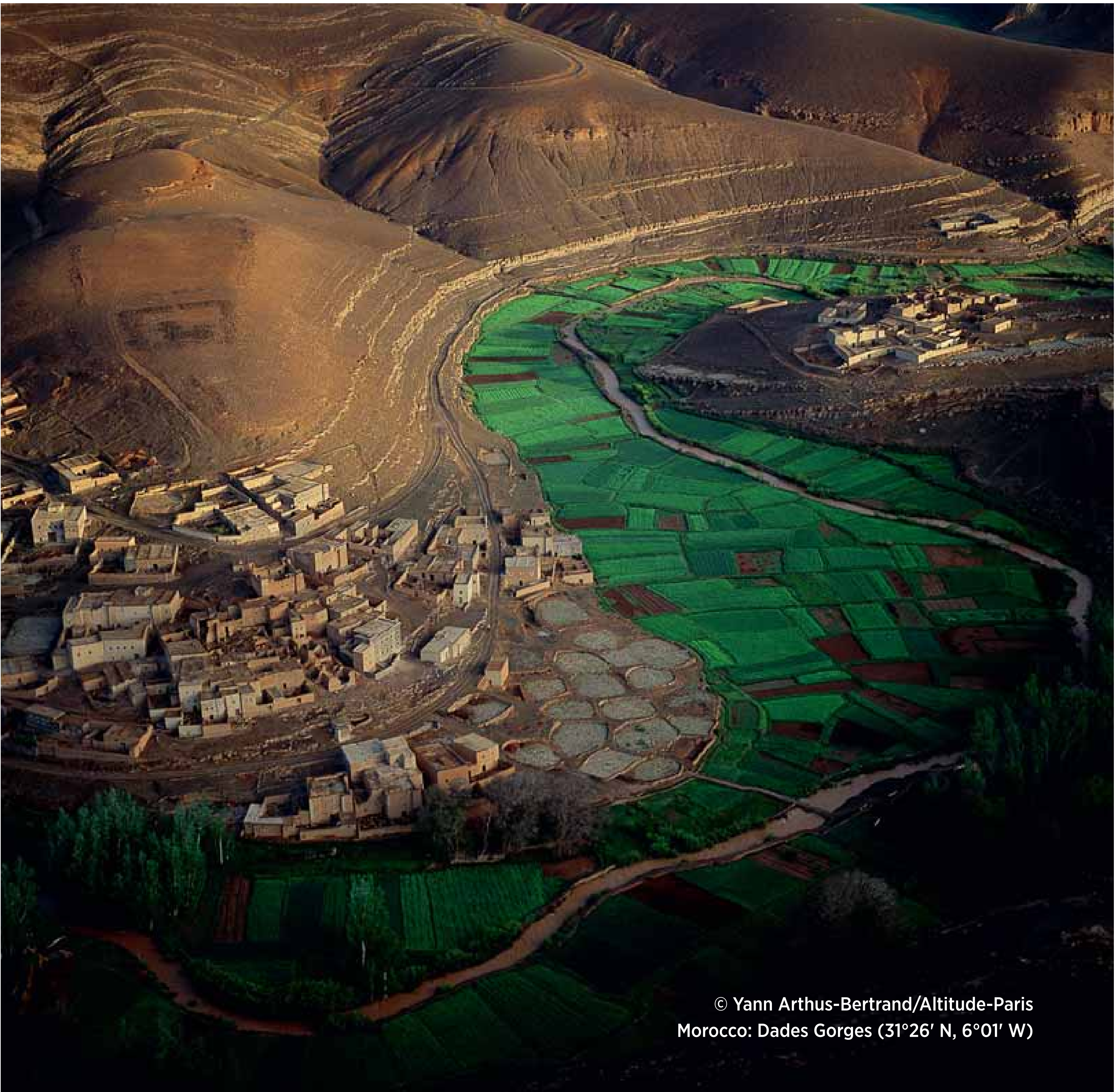


Morocco: Dades Gorges (31°26′ N, 6°01′ W)

Location and general characteristics

The Kingdom of Morocco (Morocco hereafter) is located at the north-west end of the African continent. It covers an area of 710,850 km^2 and has 31.5 million inhabitants (2009). It is bordered by the Mediterranean Sea to the north, the Atlantic Ocean to the west, Algeria to the east and Mauritania to the south.

Morocco's mountainous territory has an average elevation of 800 m. The highest point in North Africa (4,167 m above sea level) is found in the High Atlas Mountains in the centre of the country. The long coastline, alluvial lowlands, mountain chains, high plateaus and the Sahara desert make for a wide variety of landscape.

Most of northern and central Morocco has a Mediterranean climate with cold winters and hot, dry summers. The southern part of the country has semi-arid to desert climate. Therefore, the rainfall regime is highly variable both spatially and temporally. Annual precipitation ranges from 2,000 mm in the north to 100 mm or less in the south-east along the Sahara. The River Draa, which rises in the Atlas Mountains, is the longest river in the country and runs for approximately 1,100 km before draining into the Atlantic Ocean at Tan-Tan. Other important rivers are the Sebou and the Moulouya.

Water resources and their use

Morocco's rivers are fed by rainfall and they are torrential in nature. Other than the Moulouya in the north which discharges into Mediterranean Sea, almost all the major rivers flow to the Atlantic or disappear in the Sahara. The annual water resources potential of the country is approximately 22 billion m^3, of which 82% corresponds to surface water and 18% to groundwater. Water availability per capita is around 700 m^3 – which puts the country into the 'water scarce' category. Surface water resources throughout the country are characterized by a very large annual and inter-annual variability which is marked by alternating wet and dry periods, interspersed with exceptionally wet and dry years. This means that reservoirs need to be built to regulate river flow and to store water for dry seasons. Currently, there are 130 large dams with a total capacity of 17 billion m^3.

There is also a clear disparity in terms of distribution of surface water resources. A few basins in the north (the Sebou, the Loukkos, and the Tangérois, for example) which cover merely 7.3% of the country have approximately half of its surface water resources. There are many aquifers in Morocco with good water quality. However, 66 out of 103 aquifers tested are considered partially or fully brackish. Overall, brackish water potential is estimated at about 570 million m^3 per year.

Agriculture is one of the main pillars of Morocco's economy. The agricultural sector generates approximately 20% of national gross domestic product (GDP) and creates employment for up to 40% of the population (80% in rural areas). Cereals (wheat, barley and maize), sugar beet, sugar cane, citrus fruit, grapes and livestock are the main agricultural products. Approximately 95,000 km^2 of land is cultivated including 15,000 km^2 of irrigated land. Groundwater is of paramount importance to agriculture as 75% of irrigation water is abstracted from wells. While the renewable groundwater capacity is estimated at 3.6 billion m^3/year, actual consumption has surpassed the sustainable limits and reached approximately 5 billion m^3.

Other sources of income are tourism and fisheries. In 2009, 8 million tourists visited Morocco generating approximately US$6 billion of income. While tourism constitutes an increasingly important sector for the national economy, the consumption of water by touristic activities is also growing.

Overall, water consumption in Morocco has risen beyond the level of the currently developed renewable water resources potential. In 2008, annual water demand was 13.5 billion m^3. Of this, 2 billion m^3 came from non-renewable groundwater resources. As a result of over-exploitation coupled with changes in climate, the water level in many aquifers dropped by 20 m to 60 m. The agricultural sector is by far the largest user of water, accounting for 90% of demand. This is followed by municipal needs, which constitute just 8%. By 2030, the water deficit (that is the use of non-renewable sources) is expected to reach 5 billion m^3.

Climate change and disasters

Statistical analysis of hydrometeorological data shows that rainfall increases in October and November and decreases in spring. While winter rainfall seems to be declining, this was not statistically significant. An analysis of variations in temperature between 1960 and 2000 revealed an increase of up to 1.4°C in the south-east and in the Midelt region of central Morocco, but the warming trend in the north was less significant. A temperature increase of 1°C or higher was recorded over two-thirds of the country in summer; and a similar warming trend was observed in winter temperatures. Climate observations also show that the semi-arid zone has been progressing northwards over the past few decades. A worrying trend is that water resources availability has decreased by 16% since 1981 (Figure 40.1). Estimates of possible climate change impacts on water resources indicate an average decrease in water resources in the order of 10% to 15% by 2050.

Flood and drought have also become more pronounced. In the past 35 years, Morocco has faced more than 20 periods of drought – the worst in recent history – with some lasting five years or more. Floods have also had a socio-economic impact on society that is stronger than before. This is not only because of the individual floods tend to be worse, but also because of population growth, urban development, and expanding agricultural, industrial and tourism activities in vulnerable areas. The record rainfall of 2,685 mm at Jbel Outka and the exceptional floods in the Ouergha River basin (maximum discharge of 7000 m^3/s), are only a few examples of extreme events that took place between 2008 and 2011. Frequent floods and droughts have also led to increased land erosion.

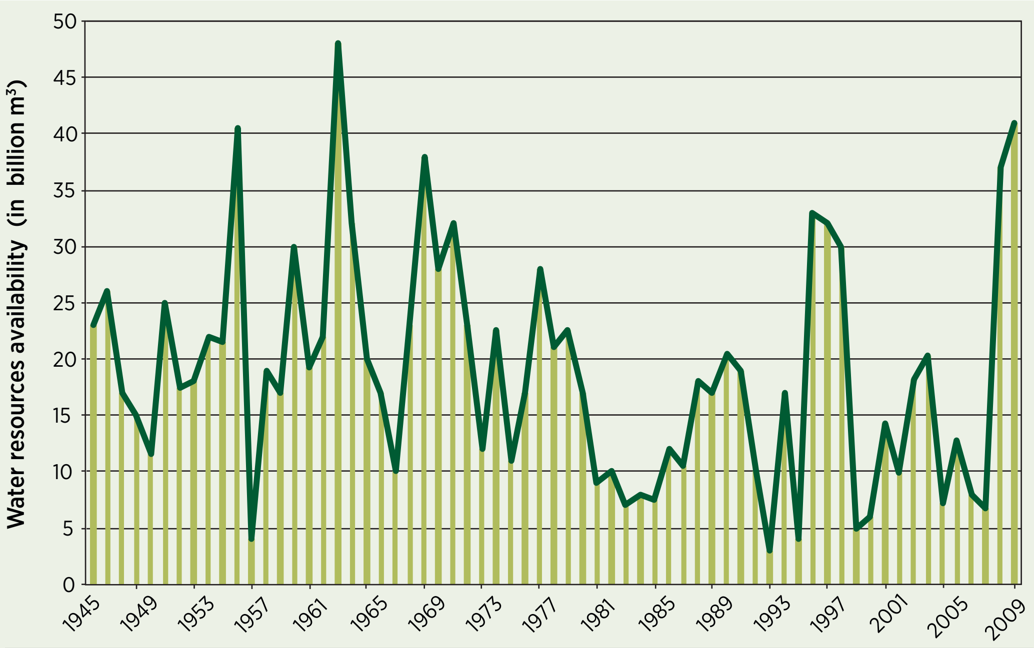
As a part of the United Nations Framework Convention on Climate Change (UNFCCC), Morocco formulated its first national communication in 2001, and its second in 2009. These communications provided details on the national inventory of greenhouse gas emissions and mitigation options including the action plan. It is estimated that by 2030, the annual total mitigation potential of these measures will be equivalent to 52.9 million tonnes of CO2.

In 2009, the National Plan to Fight Against Global Warming (Le Plan National de Lutte Contre le Réchauffement Climatique) was introduced. The Plan comprises mitigation and adaptation measures and identifies a number of priority areas for action, including water resources, agriculture, forestry, desertification, fisheries, coastal land use, health and tourism.

The national water strategy includes an action plan to 'reduce vulnerability to water-related natural hazards and adaptation to climate change'. The measures covered in the plan include improving weather forecasting, the development of warning systems in major basins and sites vulnerable to flooding, the integration of flood risk plans for land use, urban planning and watershed management, and the development of financial mechanisms such as insurance and natural disaster funds.

FIGURE 40.1

Fluctuation in water resources availability between 1945 and 2010



Water resources management and institutional aspects

Since the 1960's, the National Water Policy in Morocco has been oriented towards the development of water resources. This has been done through constructing the major water infrastructure projects – such as large reservoirs and water transfer schemes – that ensure the continuity of the water supply that the country relies on. Increasing demand necessitated an improvement in the way scarce water resources were being managed. Water Law 10-95 (enacted in 1995) represents the legal basis for a forward-looking water policy, which takes into account both supply-related and demand-related issues. Notably, it defines water as a public property and calls for an integrated, participatory and decentralized water resources management mechanism through the establishment of nine river basin agencies. The Water Law requires the preparation of national water management plans and river basin water management plans. It also addresses the issue of cost recovery through water abstraction charges (user-pays), and introduces a water pollution tax (polluter-pays).

Because groundwater resources are so important, the protection of aquifers is an important element of the Water Law. To this end, several measures are being planned, including pricing as an instrument; setting protected zones where groundwater abstraction is banned or limited; imposing strict procedures for granting drilling permits; increasing human, financial and institutional capacity to be able to better enforce the rules and control mechanisms; and improved monitoring of groundwater availability and utilization. Promoting scientific research and the artificial recharge of aquifers are also among the issues that are under consideration.

For better medium-term and long-term planning, the National Water Plan was established to integrate the various regional plans in order to develop a vision of integrated water resources management. The Plan has two overarching targets: developing a national strategy based on the 1995 Water Law, and formulating and adopting specific action plans and investment programmes.

The Water Resources Division of the Ministry of Energy, Mines, Water and Environment (de l'Energie, des Mines, de l'Eau et de l'Environnement – SEEE) is the lead government department responsible for planning and implementing the national policy on the development, management and preservation of water resources. The Division is also charged with the protection of the environment, and oversees the work of the nine river basin agencies. The national bureau for electricity (Office National de l'Electricité) and the national office for drinking water (Office National de l'Eau Potable) both come under the auspices of the same ministry. The Supreme Council for Water and Climate (Conseil Supérieur de l'Eau et du Climat) formulates the general guidelines of national policy on water and climate.

Significant progress has been made on the implementation of the Water Law. However, further improvement of the regulatory and institutional framework, including the revision of certain provisions of the Water Law (such as wastewater discharge at sea, desalination, recycling of wastewater and the protection of wetlands) is anticipated. Establishing a legal framework that aims for a more rational system of abstraction charges and enforcement of water policy is equally critical – especially with respect to controlling the allocation of water and restricting its use.

To address current and imminent challenges, a new national water strategy was launched in 2009 to strengthen existing policies. Its main tenets are water demand management and better valuation; further development of water resources and an improvement in the way they are managed; the preservation and protection of water resources and the environment; the mitigation of risks and a reduction in the vulnerability to water-related hazards; regulatory and institutional reforms; and the modernization of information systems and capacity improvement.

The protection of the environment and ecosystems

Morocco has many wetlands that are located mainly in the mountains and along the coast. Studies conducted locally and nationally on ecosystems and biodiversity identified 160 sites of ecological and biological significance – including 24 internationally recognized Ramsar sites. Morocco's wetlands are home to many species of amphibians, reptiles and mammals, and they have a global importance as passageways for migratory birds. Unfortunately, the ecosystems are under an increasing threat caused by the degradation of water quality, as a result of domestic, agricultural, and industrial pollution as well as prolonged and recurrent droughts. To limit and reduce such threats, a number of strategic plans have been developed – the National Strategy for Sustainable Development, the National Strategy for the Conservation and Sustainable Use of Biodiversity, the National Action Plan for the Environment, the National Strategy on Water, the Master Plan for Integrated Management of Water Resources and the Development Strategy for Mountain Areas.

Pollution – notably domestic and agricultural pollution and, to a lesser extent, industrial and solid waste – is a major concern in Morocco. In 2011, nearly 700 million m^3 of wastewater from settlements was discharged into nature without treatment. Agricultural pollution has caused elevated nitrate concentration in water bodies, notably aquifers. Because of this, protecting the quality of water resources is a strategic priority, which is strengthened through introduction of various programmes such as the National Sanitation and Wastewater Treatment Programme, the National Programme for Rural Sanitation, the National Programme for Prevention Against Industrial Pollution, and a number of other programmes.

Water and health

Some 57% of Morocco's population live in urban areas where 98% have access to safe water (WHO/UNICEF, 2010). In rural areas too, the coverage has been increasing substantially from 14% in 1994 to over 83% in 2010. However, merely 25% of rural dwellers enjoy piped water at home. Coverage of the sewerage system exceeds 70% nationwide, but only 52% of rural dwellers have access to improved sanitation. As a result, diarrhoea and other gastrointestinal diseases continue to be a cause of morbidity and mortality especially among rural children in the lowest income groups, and particularly during the summer season (Ministère de la Sante, 2005).

Conclusions

Morocco's complex climate and hydrology mean that efficient water resources management is vital. Many important water resources development projects, including the construction of large dams and water transfer projects, have been implemented to meet the demand that is necessary for the country's socio-economic development. This is further backed by long-term national planning activities that were initiated in 1980s, and regulatory and institutional advances (for example, Law 10-95) that focus on integrated, participative and decentralized water resources management. However, the scarcity of water resources is being exacerbated by climate change and the over-exploitation of aquifers. The low value attributed to water, particularly in agriculture, and the deterioration of water quality are important problems that remain to be tackled. The new water strategy launched in 2009 to reinforce critical aspects of water policy is intended to address current and imminent challenges.

References

Except where otherwise noted, information in this concise summary is adapted from the *Morocco Case Study Report* prepared in 2011 by Abdelhamid Benabdelfadel, Chief of the Division of Water Resources, Secretariat of State within the Ministry of Energy, Mines, Water and the Environment, in charge of Water and the Environment (unpublished).

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CHAPTER 41

Murray–Darling basin, Australia

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Acknowledgements Marc Leblanc, Albert van Dijk, Sarah Tweed, Bertrand Timbal.

Location and general characteristics

The Murray–Darling basin lies in south-eastern Australia and is formed by the Murray River (2,530 km) and its three main tributaries: the Darling (2,750 km), the Lachlan (1,450 km) and the Murrumbidgee (1,700 km) (Map 41.1). Covering more than a million km^2, or approximately 14% of the continent, the Murray–Darling basin spans most of New South Wales, Victoria, parts of the states of Queensland and South Australia, and the Australian Capital Territory – which includes the country's capital, Canberra. The basin is home to approximately 2 million people.

The topography of the basin is dominated by vast plains, bounded to the east and south by the Great Dividing Range, Australia's most substantial mountain range, which reaches a maximum elevation of 2,228 m above sea level.

The basin has a variety of climatic conditions and diverse landscapes ranging from the sub-tropical far north to the cool, humid uplands to the east, the temperate south-east and the hot, semi-arid and arid western plains, which account for more than two-thirds of the basin. Rainfall is summer-dominated in the north and winter–dominated in the south.

Water resources availability

Approximately 86% of the water currently used in the basin is surface water, with groundwater providing the rest. Water availability varies greatly across the basin and almost 80% of the vast catchment area contributes little or no water to the rivers. The main run-off comes from the southern and eastern boundaries of the basin. Average annual water consumption in the basin is approximately 11 billion m^3, which equates to 48% of the annual surface water potential of the basin. Currently, 84% of the water is used for agriculture and 3% is used by the MDB's towns and cities. The remainder is lost during the storage and transfer of irrigation water (Table 41.1).

To satisfy increases in water demand during the second half of the twentieth century, many structural works were built across the basin. The total water storage capacity in reservoirs rose from 2 km^3 in the 1930s to approximately 35 km^3 in 2007. This latest figure corresponds to about 150% of the average annual water availability in the basin. Surface water use in the basin grew with the increase in public and private storage capacity up to the mid-1990s, when the Murray–Darling Basin Ministerial Council imposed an upper limit on surface water diversions (Figure 41.1).

MAP 41.1

Murray–Darling basin

TABLE 41.1

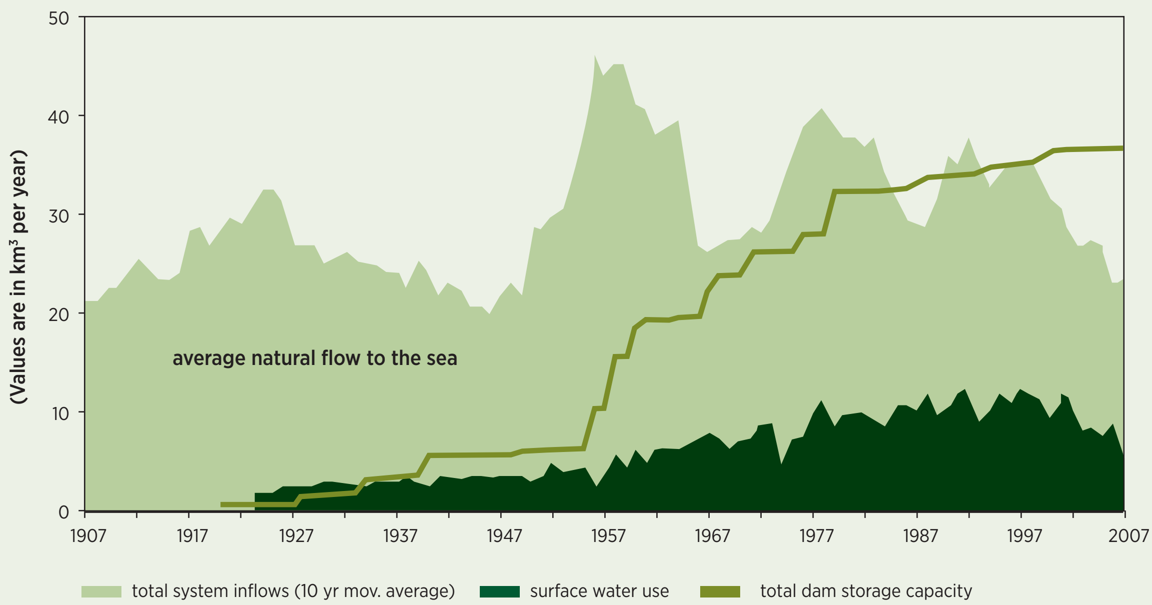
Surface water use in the Murray-Darling basin*

Surface water use	km³/year	% of overall
Net irrigation diversions	9.51	84
Rural stock and domestic	0.08	<1
Urban	0.32	3
Channel and pipe loss	1.24	11
Stream flow loss due to groundwater pumping	0.18	<2

** According to 2006-07 water sharing, water entitlements and irrigation portfolios*

FIGURE 41.1

Total system inflows, surface water use and dam storage capacity in the Murray-Darling basin



Water and agriculture

The Murray–Darling basin is Australia's food bowl. Agriculture is practised approximately in 80% of its area, accounting for about 40% of the country's total agricultural production. The main crops are cotton, rice, wheat, corn, grapes, citrus fruit and other fruit trees. Cattle and sheep production and irrigated dairy farming are also common sources of income. The amount of water used to maintain livestock-related agricultural activities corresponds to around half of Australia's total water consumption and around 60% of total agricultural water use.

Water management at the national level and in the basin

An increase in water diversions led to concerns about the health of the basin and its environmental flows. But because water allocations are governed by separate legislation and policies in the five states that share the basin, achieving the necessary environmental targets is posing a real challenge.

Since the 1990s there has been a progressive shift towards integrated water resources management in the basin. In 1993, the Murray–Darling Basin Commission was established to promote and coordinate the equitable and sustainable use of water across the basin. It was replaced in 2008 by the Murray–Darling Basin Authority, which acts as a government statutory agency. The basin's water resources are managed by the Murray–Darling Basin Authority in conjunction with the states and territories that make up its catchment area. The its main responsibilities are to measure and monitor water resources in the basin; to prepare, implement and enforce the management plan; to set surface and groundwater abstraction limits; and to develop a water rights information service to facilitate water trading.

Because Australia has a federal government system, it was necessary to have national agreement to ensure that there would be compatibility in the way each of Australia's state and territory governments was measuring, planning for, pricing and trading water. To this end, the National Water Initiative was signed by the Council of Australian Governments in 2004. It is an intergovernmental agreement signed by all of Australia's state and territory governments and is the country's blueprint for water reform. Established under the National Water Initiative, the National Water Commission is an independent statutory body that is responsible for helping to drive national water reform and advise governments on water issues. The commission's specific functions in the context of the Murray–Darling basin include monitoring the effects of interstate trade in water access entitlements in the southern part of the basin, advising the various National Water Initiative signatories about these effects, and auditing the effectiveness of the Murray–Darling basin water management plan.

Climate change and climatic variability

The severe drought that affected most of south-eastern Australia (including the southern part of the Murray–Darling basin) began in 1997 and continued for twelve years. This caused significant economic losses across the region (Box 41.1). The average annual rainfall deficit of this drought is similar to that of the 1935–1945 drought. However, the recent drought has led to a much stronger decrease in runoff and groundwater recharge. This can be explained by a change in rainfall patterns during the recent drought: lower inter-annual variability and less rainfall in autumn and winter. The drought ended with rains that caused some of the highest floodwaters on record in 2010–2011.

The semi-arid to arid nature of the region means that it already has very high natural hydroclimatic variability – adding the effects of climate change to this poses an even greater challenge. A comprehensive project commissioned by the federal and state governments suggested that, under a median scenario, surface water availability across the entire Murray–Darling basin would decline by 11% by about 2030 as a result of climate change. The projected reduction in water availability would reduce surface water use by 4%. However, water use in the driest years would be affected far more – by up to 50% in the basin in Victoria.

The greatest impact of climate change is likely to occur close to the mouth of the Murray River, including in the Chowilla floodplains, the Coorong national park and lagoon ecosystem, and the Lower Lakes. The outflows from the Murray River are already affected by current water diversions that reduce annual natural outflows by 40%. And these are projected to drop by an estimated further 30% by 2030. From an ecological point of view, the impact of water diversions on a river basin is often greater than the effects of climate change. However, the combined effects of both the water diversions and climate change could more than double the average duration between beneficial floods. This would have a significant impact on wetlands and their associated ecosystems. Towards the end of the twenty-first century, the impact of climate change could significantly increase, depending on emissions scenarios. What is even more concerning is that the current trend in greenhouse gases emission is alarmingly in excess of most scenarios that are currently considered in climate change projections.

Water and the environment

There are nearly 30,000 wetlands in the Murray–Darling basin that are important for native fish and the feeding and breeding of local and migratory water birds. The major wetlands located along the Darling basin include the Macquarie marshes, the Great Cumbung Swamp, the overflow lakes of the Paroo River, the Narran lakes, and the Gwydir wetlands. The largest wetlands on the Murray are the Barmah–Millewa, Gunbower and Koondrook–Pericoota wetlands, the Chowilla floodplains and the Lower

Lakes and Coorong Lakes systems at the interface with the Southern Ocean (Map 41.1).

Sixteen of the Murray–Darling basin's wetlands are identified as internationally important and listed under the Ramsar Convention. Similarly, the *Directory of Important Wetlands in Australia* includes approximately 200 sites in the basin. There are a large number of nationally and internationally significant plant and animal species in the basin. However, as a result of pollution and modified river flows associated with large-scale water resources development, 95 species are listed as threatened, more than half of its native fish species are considered to be in need of attention and fish populations are estimated to be only about 10% of predevelopment levels.

The 1997–2009 drought exacerbated the severity of these problems. For example, the record-low flows at the outlet of the Murray–Darling led to a sharp decline in inundated areas. It also led to a degradation of water quality as a result of increased salinity, which caused severe ecological and significant socio-economic impacts. During the drought, the water level at Lake Alexandrina, which is the largest water body in the Lower Lakes system (Map 41.1), dropped

BOX 41.1

Drought's heavy toll on Australia

During the 1997–2009 drought, surface water storage dropped to less than 10% of storage capacity and groundwater declined by as much as 100 km^3. This imposed severe water restrictions on both urban communities and farmers who depend on irrigation. Overall estimates of the economic cost of this drought are not readily available, though some studies have estimated aspects of it.

Agricultural exports account for one-fifth of total Australian exports. In 2002, drought was estimated to have lowered gross domestic product (GDP) by 1.6% (more than US$10 billion), of which around 1% was the result of reduced agricultural export. The drought was also implicated in a 1% national decline in employment and wages.

Regional impacts were much stronger, with gross regional production down by more than 15% and employment dropping by more than 3% in the worst-affected regions of the Murray–Darling Basin. The Australian Reserve Bank estimated that the 2006–2007 dry year in Australia reduced GDP by almost 1%, whereas farm GDP fell by around 20%. More recently it was estimated that between 2000 and 2007, the gross value of irrigated agriculture fell by approximately US$ 140 million per year. During the periods 2005–2006 and 2007–2008, the total area of irrigated land fell by 42%.

Production of cotton and rice in the Murray-Darling basin (100 = average annual production for 1990-2000)

by about 1.2 m and the salinity level increased six-fold. The exposure of lake beds that are naturally rich in iron sulphides caused the production of sulphuric acid – threatening the rich flora and fauna of the lake's ecosystems.

The salinization of land and water resources is also environmental problem in the basin. Salt concentrations in soil water and groundwater are predominantly high in the basin because of the concentration of cyclic salts caused by millennia of evapotranspiration. This natural condition has been further aggravated by the extensive land clearance that started in the nineteenth century to increase the amount of land available for farming. Crops and pasture allowed more groundwater recharge than did the area's native vegetation, which caused rising levels of saline groundwater to contaminate the land and the surface water. The area affected by dryland salinity in the Murray–Darling basin states (including sites outside the basin) was estimated at 6,400 km^2 in 1997.

Conclusions

The Murray–Darling basin covers a vast area that is roughly equal to the size of France and Germany combined. Extensive agricultural practices have made the basin the food basket of Australia and a major source of income. However, usage patterns have put great stress on water resources and have passed beyond the critical limit of sustainable use. Land and water resources development have altered the hydrological conditions, caused environmental degradation and significantly affected ecosystems.

In recent decades, water management objectives have shifted from large-scale development of the water resources for irrigation to environmental concerns. In parallel, water governance is gradually moving to a coordinated and integrated management that is shared between the state and the territory governments in the basin catchment area. The severe drought that lasted more than a decade from 1997 to 2009 caused significant economic and environmental damage, and brought the tension between agricultural and environmental objectives to a head. However, the National Water Initiative and the recently established Murray–Darling Basin Authority give hope that water consumption patterns will be reevaluated with a view to improving hydrological conditions to a point where they can sustain the social, ecological and economic systems that depend on them.

References

Except where otherwise noted, information in this concise summary is adapted from the Case Study Report, *The Murray–Darling Basin: A Major Food Bowl In Crisis – Lessons from the Past and Challenges Ahead*, prepared in 2011 by Leblanc et al. (forthcoming).

CHAPTER 42

Yellow River basin, China

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Acknowledgements Hongqi Shang, Feng Sun, Yangbo Sun, Hui Pang, Wu Dong, Ruipeng Son, Zhen Gong, Hai Jin, Zhao Hao, Jing Xu, Ramasamy Jayakumar, Ke Liu, Hao Liu, Bing Wang

The Yellow River basin was covered in detail in the case study volume of the third edition of the *World Water Development Report* (WWAP, 2009). In agreement with the Yellow River Basin Commission, a follow-up study was developed to provide up-to-date information where possible and to further focus on critical challenges such as climate change, erosion, sediment transport and water quality.

Location and general characteristics

The Yellow River, the second-longest in the People's Republic of China (called 'China' from here on), rises in the western part of the country at 4,700 m above sea level. It runs through northern and central China, where the temperate continental monsoon climate is dominant. The southeastern section of the basin has a humid climate, whereas the north-western areas are considerably drier. The river passes through nine provinces – Qinghai, Sichuan, Gansu, Ningxia, Inner-Mongolia, Shaanxi, Shanxi, Henan and Shandong – before draining into the Bo Hai Sea (Map 42.1). Geographically, the Yellow River traverses the Tibetan Plateau (upper basin), the Loess Plateau (middle basin) and the North China Plain (lower basin).

The Yellow River basin covers an area of 795,000 km^2, which is home to approximately 110 million inhabitants – or about 8.7% of China's population in 2000. However, the population is unevenly distributed, with about 70% living in the lower third of the basin. Regarded as the cradle of northern Chinese civilization and the heart of modern China's political, economic and social development, the Yellow River is known as 'the mother river of China'.

Water and land resources in the basin

The average surface water potential of the Yellow River basin is 57 billion m^3 and average groundwater potential is about 38.5 billion m^3. In 2009, water consumption in the basin was 39.3 billion m^3, of which over 78% came from surface water and almost 22% from groundwater resources. Since 1980, the rate of groundwater exploitation has increased rapidly, reaching unsustainable levels. In fact, 65 locations spread over an area of nearly 6,000km^2 have relatively large groundwater depressions.

There are 163,000 km^2 of potentially cultivable land in the basin. Of this, 120,000 km^2 (or 15% of the basin territory) is cultivated, including 75,000 km^2 of irrigated land. Since the 1950s, the importance of agriculture to the economy has declined and other sectors are making a bigger contribution to the gross domestic product (GDP) of the basin (Table 42.1). Many new industrial cities have been founded: Xining, Lanzhou, Yinchuan, Baotou, Huhehot, Taiyuan, Xi'an, Luoyang, Zhengzhou and Jinan. However, agriculture still accounts for 75% of water demand.

MAP 42.1

Yellow River basin

TABLE 42.1

GDP of provinces in the Yellow River basin (2006)

Provinces	Agriculture (million US$)	Industry (million US$)	Service Industry (million US$)	Total GDP (million US$)	Increase since 2000 (million US$)
Qinghai	68	241	237	546	435
Sichuan	4	3	3	10	8
Gansu	224	957	846	2,027	1,736
Ningxia	101	441	354	896	705
Inner Mongolia	271	1,889	1,146	3,306	2,625
Shaanxi	455	2,822	1,792	5,069	3,969
Shanxi	218	2,406	1,277	3,901	3,164
Henan	369	1,908	1,033	3,310	2,645
Shandong	205	1,296	994	2,495	2,011
Yellow River basin	1,915	11,963	7,682	21,560	17,298

Climate change

Between 1961 and 2005, annual average precipitation in the basin decreased slightly – by, on average, 12 mm every ten years. However, this trend was significant at only nine of the 51 stations. Over the long term, the amount of precipitation in January may increase by less than 7 millimeter by 2100. Based on scenarios, the rainfall in the middle and lower reaches of the basin might be higher than in the upper reaches. During the same period, the annual mean air temperature across the basin increased at a rate of 0.3°C every ten years. Over 90% of the monitoring stations (53 of 58 stations) showed a significant increase in the annual mean air temperature. To give an example, at the Menyuan and Hezuo stations, both of which are located in the upper Yellow River basin, the average air temperature in 2004 was 1.14°C higher than in 1960. According to models, January mean temperatures could increase by as much as 5.0°C by 2100. Significant warming could reduce the availability of the water resources (Zhang et al., 2008). Consequently, better water management and the adaptation of technology to improve the efficiency of water use will need to be considered to prevent a critical water shortage in the basin in this century and beyond.

Concerns about environmental degradation and water-related disasters

Water pollution is a severe problem in the basin. In 1997, only 17% of the course of the Yellow River was fit for drinking water. This had a direct negative impact on human health and the basin's ecosystems. In 1982, more than 80% of the 96 algae types found in the Yellow River were either severely or moderately polluted. Furthermore, analysis of historic data since the 1980s shows a reduction in the number of fish species and total fish quantity in the river (Ru et al., 2010).

The Yellow River Conservancy Commission (YRCC), one of seven commissions of the Ministry of Water Resources in China, was set up to address the problem of water quality and manage water resources in the basin (Box 42.1). The YRCC has introduced the following measures:

- Setting a maximum pollutant discharge quantity for the provinces according to the inflow of the Yellow River;
- Strengthening the water quality monitoring on the provincial boundary; and,
- Enforcing the legislation on water pollution prevention and protection.

Thanks to these efforts, the water quality in the main stream of the Yellow River has improved considerably. In 2006, approximately 60% of the course of the river was in the 'good quality' category. And between 2002 and 2006, the areas of the river that were ranked as 'bad quality' fell from 21.1% to 3.1%.

Erosion in the basin occurs mainly along the Loess Plateau, and is a major problem. The plateau covers an area of 640,000 km^2 with average thickness of loess soil ranging from 50 m to 300 m. The volume of sediment in the Yellow River that originates from this region is about 1.2 billion tonnes per year. That accounts for 60% of China's total soil erosion and 10% of the world total. In fact, it is the yellow colour of the suspended sediments that gives the river its name. While the erosion in the loess soil band is a natural phenomenon, it has increased greatly as a result of the environmental degradation caused by human activities, especially deforestation, overgrazing, and over-cropping (Box 42.1).

While a portion of the heavy sediment load is transported to the sea, most of it is deposited on the riverbed and onto the banks. Consequently, the river flows in a channel that is higher than ground level. To give an example, the riverbed is 20 m above ground level in Xingxiang city, 13 m above in Kaifeng city, and 5 m above in Jinan city. The total region where the land is lower than the riverbed covers some 120,000 km^2 and is home to approximately 90 million inhabitants. Because dike breaches could result in devastating floods, the levees on the Yellow River floodplain are regularly maintained and rebuilt. However, all these efforts would not be enough to cope with a major catastrophe such as a 100-year-flood which could cause significant socio-economic damage. A major flood in 1938 affected 12.5 million people and claimed 890,000 lives. Today, approximately 1.9 million people living in the inner flood plain of the lower part of Yellow River basin are facing imminent threat.

Water resources management

As a result of a substantial increase in water demand in the upper and middle reaches of the basin, parts of the river course were dry twenty-one times between 1972 and 1999. In 1987, in an attempt to strike a better balance between supply and demand, China's State Council set up the Yellow River Water Allocation Scheme. This was followed in 2006 by an ordinance to regulate and control water volume in the Yellow River. This ordinance puts water extraction from the Yellow River under state control in order to satisfy demand and improve environmental conditions by ensuring flow, especially in the lower reaches of the basin, (Zhao, 2006). It also aims to promote socio-economic development in the basin.

The ordinance foresees an integrated water allocation scheme. It vests in the YRCC the responsibility of drafting the annual water-use plan in consultation with

BOX 42.1

Sediment management strategies in the Yellow River basin

The Yellow River Conservancy Commission is an agency of the Ministry of Water Resources. It is in charge of managing land and water resources in the basin, including protecting its ecosystems. The YRCC operates within an established legal and regulatory framework to plan, implement and maintain soil and water conservation programmes.

Since the mid-1950s the Commission has put a number of large-scale land management projects into operation in the basin, particularly in the Loess Plateau region. This has included constructing dams, afforestation and terracing efforts, and converting cropland on slopes into grazing land. In general, the key strategies aimed at managing sediment load in the Yellow River basin include:

- Soil conservation works – afforestation, terracing and constructing barriers;
- Improving land use practices – regulating cropping on slopes, enhancing tillage practices, etc.; and
- Commissioning engineering works to control flows and reduce sediment deposition in the river system.

These activities coupled with flood control support have been successful in reducing the sediment load of the Yellow River. However, the soil conservation projects in the Loess Plateau are expected to reduce river runoff by as much as 2 billion m^3 by 2030. Given the increasing demand for water, the reduction in water availability will add to existing competition between sectors for this precious resource.

Source: Adapted from UNESCO and IRTCES (2011).

eleven provinces and autonomous regions. The plan sets the quota for each province according to river flow forecasts. These quotas are then updated on a monthly basis taking into consideration actual water availability in the river. The provincial governments are responsible for the allocation of water resources in their jurisdiction, within the limits of their quota. To ensure that the water allocation system functions properly, administrative and legislative measures are backed by technical methods. For example, during the flood season, all reservoirs are operated in an integrated manner to regulate the river flow and subsequent water distribution. In addition, online river information systems allow accurate observation of water availability along the course of the Yellow River. They also allow the allocation scheme to be adapted to guarantee the water rights of the provinces in the lower reaches of the basin.

Since 1999, there has been no cut-off of the flow in the lower Yellow River basin, and environmental flows have increased by 1 billion m^3 in the low-flow season. Overall, the total flow[1] reserved for sediment flushing and environmental needs has reached approximately to 20 billion m^3. Consequently, estuary wetlands have increased in size by 253 km^2, and biodiversity has improved.

Conclusions

The challenges described in the previous *World Water Development Report* have not changed in the past three years. Consequently, water quality, environmental degradation, the unsustainable use of water resources (notably groundwater) and sediment transport are still high on the agenda of the Yellow River Conservancy Commission (YRCC). On the positive side, measures taken by the YRCC to limit pollutant discharge and to enforce legislation have helped to improve water quality in the river. As a result of the allocation scheme, river flow in the lower basin has met the minimum level required to flush the sediment and sustain basic ecosystem needs. The physical characteristics of the Loess Plateau mean that sediment transport will continue to be a problem in the basin. However, management practices, particularly afforestation and tillage, have reduced sediment loads in the Yellow River and its tributaries. In spite of progress made in various fields, the growing imbalance between supply and demand will require hard choices to be made in order to address diverging needs and reduce water consumption in agriculture, while making other sectors more water efficient.

Notes

1 The *United Nations World Water Development Report 3* (WWAP, 2009) reported that the minimum flow required to flush out sediment is calculated at 14 billion m^3, and an additional 5 billion m^3 is necessary for other environmental requirements.

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CHAPTER 43

Jeju Island, Korea

Acknowledgements Yongje Kim, Gi-Won Koh, Sung Kim, Jae Heyon Park

Location and general characteristics

Jeju Province is the largest island in the Republic of Korea (Korea from here on). Located off the south-west coast of the Korean peninsula in the South Korea Strait, this self-governing province is home to approximately 567,000 inhabitants, and has a surface area of 1,848 km^2. Right in the centre of the island, volcanic Mount Halla is Jeju's dominating geographical feature (Map 43.1), and tops 1,950 metres at its highest point. Jeju Province has two main cities, Jeju in the north and Seogwipo in the south. In total, there are seven towns and five districts on the island. Jeju's gross domestic product (GDP) is slightly lower than that of the Korean mainland. It also has a low population growth rate (0.45% in 2005), and is not subject to significant migratory movements.

Although relatively small, Jeju Province has both sub-tropical oceanic and temperate climates, with a mean annual rainfall of 1,975 mm. About 60% of annual precipitation occurs during the summer monsoon between June and September. A low evapotranspiration rate and high permeability of geologic formations allow year-round recharge of groundwater, as approximately half of the annual rainfall (1.58 billion m^3) permeates into the ground.

Water resources and their use

While surface water potential is 260 million m^3, it is ephemeral in character. Therefore, groundwater is the primary source of water on the island, and it is heavily drawn on. In 2010, annual abstraction corresponded to 20% of estimated safe yield (Table 43.1).

TABLE 43.1

Groundwater development and use in Jeju Island

Consumption	Amount (m^3/d)	%
Domestic	202,000	57.1
Agriculture	144,000	40.7
Industry and others*	8,000	2.2
Total+	**354,000**	**100.0**

** Food processing, etc.*
+ Estimated safe yield: 1,768,000 m^3/d

MAP 43.1

Jeju Island

Agriculture is practised over 31% of the island. The most important agricultural products are oranges and mandarins, followed by other crops such as beans, radishes, garlic and potatoes. Rice is cultivated on an almost negligible scale. Between 1970 and 2002, the size of the agricultural area increased at a rate of 0.5% per year. However, since then there has been a declining trend, which is expected to continue.

The area of irrigated land is approximately 380 km^2, which corresponds to 71% of the total cultivated area as of 2003. Although more agricultural land can be irrigated, the availability of water is the limiting factor. While drip irrigation and sprinklers are used, there is still the possibility of improving efficiency. Overall, 98.8% of irrigation water is drawn from aquifers. Unfortunately, groundwater contamination as a result of agricultural activity is evident in coastal areas. Measurements indicate that 18% of groundwater resources have increased levels of nitrates, sodium, magnesium, calcium and sulfate, which are the chemical components of the fertilizers used. Livestock production also contributes to pollution levels.

Climate change, climatic variations and water-related natural disasters

Analysis of rainfall over the past eighty years shows a slightly increasing trend in annual precipitation and rainfall intensity. Annual precipitation increased from 1,360 mm in the 1930s to more than 1,500 mm in the 1990s. The extreme value of daily precipitation has also increased by 95 mm between 1951 and 2008. The daily precipitation of 542 mm recorded during typhoon Nari in September 2007, corresponded to the rainfall intensity of a once-in-a-thousand-year event.

There has been a 1.6°C increase in average winter temperatures since the 1930s. As a result, both the depth of snow at high elevations (such as Mount Halla) and the total number of days of snowfall have been trending downwards. Since 1960, the average annual rate of sea-level rise around Jeju Island has been approximately 6 mm, which is about three times the global average. Because of this rise and the accompanying sea water intrusion, the quality of groundwater is deteriorating – particularly around the coast where the population density is the highest.

In terms of water related natural disasters, from 1991 to 2000, Jeju Island was hit 23 times by typhoons. The seasonal variation in precipitation results in floods in summer and drought during other seasons. In fact, heavy rainfall, often accompanied by typhoons, brings about 70% of annual precipitation between April and October. Over the last 30 years, the frequency and the intensity of floods and droughts has been increasing (Figure 43.1). The socio-economic impact of such natural disasters is further aggravated by land-use changes, especially due to development in mountainous areas. For example, in September 2007, heavy rainfall from Typhoon Nari caused a major flood necessitating the evacuation of more than 14,000 inhabitants. Thirteen people lost their lives in the floods and the cost of property damage was around US$120 million. This prompted local government to revise the existing master plan to provide better protection against extreme events (Box 43.1).

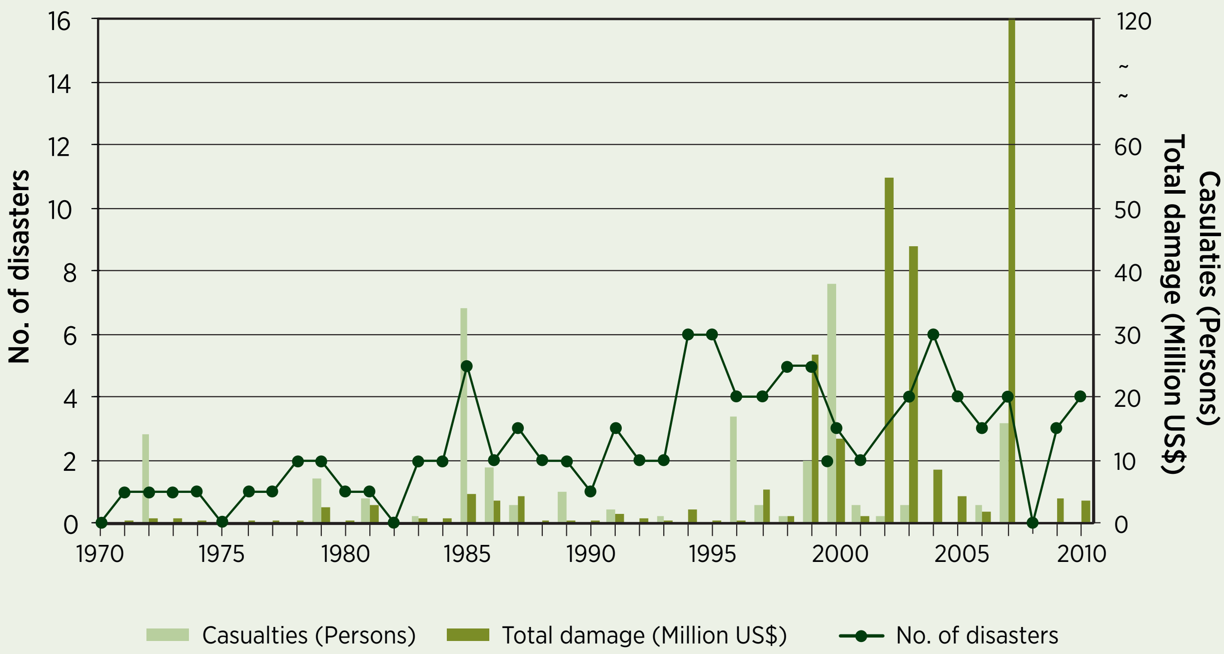
Even though the annual mean precipitation is high in Jeju, the Island often experiences drought caused by the large variations in rainfall. Consequently, to be able to better manage groundwater resources and carry out drought impact assessments, a comprehensive real-time monitoring network has been put in place to collect information on critical variables, notably the groundwater level. The information collected allows the authorities to take appropriate action, such as limiting the use of groundwater to minimize the risk of degradation of aquifers through sea water intrusion and contamination.

Water resources management

All aspects of water management, from resource development to policy making and implementation, are the direct responsibility of the water and sewage administration of the local government. Growing concerns about how to protect groundwater resources from over-pumping and potential seawater intrusion prompted the development of a special Act in 1991, which laid the framework for groundwater management and regulated the drilling of wells. Other administrative measures included regular water-quality inspections across the island, and a tax increase for groundwater use. In 1996, the Jeju Water Resources Development Plan led to the establishment of a multi-region water supply system. The first phase of the system was completed in 2000, ensuring a supply of 145,000 m^3 of water a day from fourteen groundwater abstraction sites on the east of the island. The second phase was launched in 2002. Given the importance of groundwater resources, in 2004 the local government put a specific management plan in place to promote

FIGURE 43.1

Jeju Island: water-related disasters 1970 to 2010 *



** Including typhoon, flood, and heavy snow; Casualties include victims, death and disappearances.*

the improved maintenance of wells, more efficient use of water in agriculture, and the diversification of water resources development. Following structural reforms in 2006, a heavily fragmented city and county approach to water-resources management was abandoned and replaced by the consolidation of all functions in the Jeju Water Supply and Drainage Management Headquarters. This, in addition to better management of water supply, helped in the standardization of environmental practices through the adoption of ISO 14001. Within this context, sewage-related operations, previously administered by cities, were integrated into regional systems in 2008, to ensure a more environmentally conscious overall approach.

Water pricing is also geared towards discouraging the misuse of scarce water resources. In line with guidelines set by central government, those water rates have been increasing gradually, with the eventual aim of reaching full cost recovery. As of 2006, the unit price of water corresponded to 62.5% of its estimated cost.

The local government has plans to invest over US$780 million over a time span of twenty years (2004–2025) on water supply and infrastructure improvement. A limited portion of these funds will come from the private sector. In fact, public private partnerships and privatization of certain services, such as the operation of sewage treatment plants, are becoming more and more common. As a result, a range of strategies is currently under development to promote greater involvement by the private sector.

Water and ecosystems

Jeju Province is rich in flora and fauna. For example, the Gotjawal Forest (located on the middle slopes of Halla Mountain) covers approximately 12% of the island and is listed as an internationally important wetland under the Ramsar Convention. The near-shore of the island provides a thriving environment for its 627 reported invertebrate animal species, a much higher number than in other parts of Korea. The warm currents and coral reef formations along the southern shore provide an ideal habitat for some 300 different

BOX 43.1

Management tools against extreme events

With growing population density, extended land use, and more frequent weather extremes, Jeju Island is becoming much more vulnerable to water-related disasters. Consequently, the local government established a comprehensive master plan for flood control in 2006 which shifted the emphasis in extreme-event management to an approach which emphasized sharing the watershed with nature. This involved the preparation of site-specific flood control plans that combined both structural (such as stream-bed dredging, building of embankments, dams, etc.) and non-structural measures (including a flood forecast and warning system), the improvement of residential land-use planning, and the introduction of a flood insurance system that took into account the effects of climate change.

However, the heavy socio-economic loss associated with Typhoon Nari prompted the expansion of that coverage to include individual streams in 2008. For the first stage of the plan, a general disaster prevention scheme was developed for four streams (the Han, the Byeongmun, the Sanji, and the Doksa) in the old section of the capital, Jeju-si, where the typhoon damage was most severe. As a result, 11 flood mitigation reservoirs, with a total volume of 1,577,000 m^3, were planned and partially constructed. Near the Han stream, two of these reservoirs were connected to artificial groundwater recharge systems to augment the replenishment of this vital resource. Debris barriers and screens were also put in place to prevent the clogging of channels in the stream.

species of fish. The island is also home to many bird species, mammals, reptiles, and amphibians. Unfortunately, uncontrolled hunting in the past, along with over-use of agricultural chemicals and rapid urbanization, has done considerable and irreversible damage to ecosystems. In terms of eco-parks, Mulyeongari-oreum in Seogwipo-si became the first protected area in Korea with the enactment of new wetland protection laws in 1999.

Water and settlements

Since the 1990s, the number of inhabitants living in the island's rural areas has remained the same while its urban population has steadily increased. In 2005, approximately 70% of the island's population lived in urban settlements. In terms of access to safe drinking water, almost all the population, irrespective of whether it is urban or rural, is served (Table 43.2). Average water consumption per capita per day is 340 litres (2005). Minimizing losses from infrastructure is among the main priorities of the local government.

In 2005, 72.3% of the island's population was connected to centralized waste-water treatment facilities. At 96.1%, coverage in urban areas is significantly higher than in rural settlements, where only 18.5% of the population is connected. A substantial effort will be required by the local administration to improve this service in rural settlements while keeping up with the urban growth. The daily capacity of all sewage treatment facilities is 178,479 m^3 (2005), operating at approximately 70% of their design capacity.

TABLE 43.2

Access to improved water supply in Jeju Province

	Population (person)	Water supply capacity (m^3/day)	Water supply rate (%)	Daily water consumption per capita (litre)
Jeju Province	559,747	316,548	100.0	340
Urban areas	387,885	207,600	100.0	357
Rural areas	171,862	108,948	99.9	302

Allocating water between uses and users

With the exception of the period during the summer monsoons, most of Jeju's rivers and streams are ephemeral in character. However, near the coast and across the mid-slopes of Mount Halla, groundwater discharge from fractures in the bedrock forms numerous springs. Historically, villages were established in areas where such springs were abundant. As a result, communities learned to share surface water and groundwater in peace through the centuries. However, with increasing demand, conflicts have begun to arise. While the constitution of Korea and local laws in Jeju provide basic judicial and administrative guidance in terms of developing groundwater, springs and streams, the lack of specificity as to fair use and allocation remains a problem that needs to be addressed with urgency.

Conclusions

Thanks to investment, the of Jeju Province has made significant progress in terms of socio-economic standards, with its inhabitants boasting the highest longevity in the country. Aquifers have long provided a dependable supply of fresh water for development needs. However, current levels of use, coupled with challenges such as pollution, seawater intrusion, and increasing demand, mean that more effective planning through integrated water resource management is essential. There will also be need for additional legislation, supported by practical mechanisms for the allocation of limited water resources among competing sectors. Jeju Island is one of the areas in Korea with the highest rainfall, and hydro-meteorological data shows a trend towards increasing intensity. The master plan for flood control and continuing improvements in infrastructure provide a strong basis for disaster mitigation in the future. Overall, the necessary financial and human resources are in place to address the water-related challenges facing Jeju Island.

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Except where otherwise noted, information in this concise summary is adapted from the Republic of Korea Case Study Report, *Time for Solutions: An Assessment of Water Development in Jeju, Korea,* a WWAP study prepared for the fourth edition of the *United Nations World Water Development Report* by the Ministry of Land, Transport and Maritime Affairs, Republic of Korea, 2011 (forthcoming).

CHAPTER 44

Pakistan, with special reference to the Indus River basin

Acknowledgements Kozue Kay Nagata, Arslan Syed

Location and general characteristics

Pakistan is bordered by Afghanistan to the north, the Arabian Sea to the south, China to the north-east, India to the east and the Islamic Republic of Iran to the south-west (Map 44.1). There are three major geographical areas: the northern highlands, the Indus River plain and the Balochistan Plateau. The northern highlands include parts of the Himalayas. The Indus Plain, made up of alluvium deposited by the Indus River and its tributaries, stretches from the Salt Range to the Arabian Sea. The Balochistan Plateau is composed of dry hills and deserts that run from north-east to south-west.

Pakistan has a surface area of 800,000 km² and a population of approximately 185 million people (2010). The country is divided into four administrative provinces: the Punjab, Sindh, Khyber Pakhtunkhaw and Balochistan, as well as several areas with special administrative status.

In general, the climate is arid, and mean annual precipitation ranges from less than 100 mm in parts of the Lower Indus Plain to over 750 mm in the Upper Indus Plain. The Monsoons and the western disturbances – extratropical storms that originate in the Mediterranean – are the major sources of rainfall, two-thirds of which usually falls between July and September. On the Indus Plains, most of the rain falls during the Monsoons in early July.

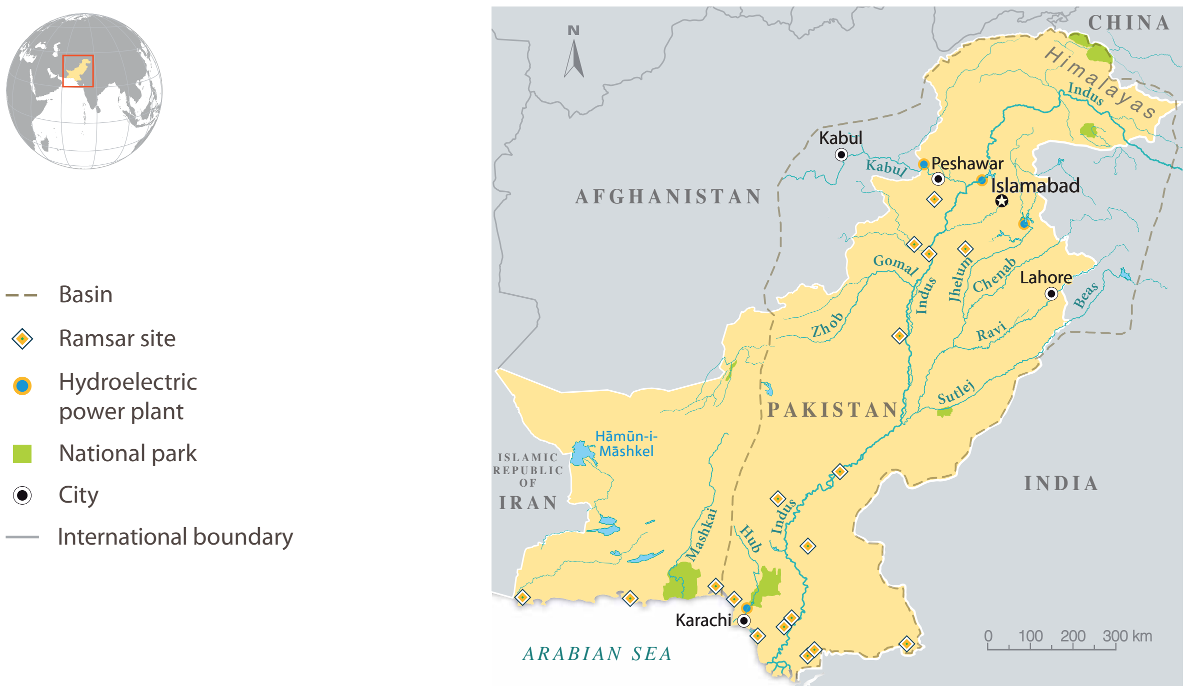
Originating in the mountains of the Tibetan Plateau, at an altitude of 5,000 m above sea level, the Indus River is Pakistan's most important source of fresh water. With a drainage area of approximately 1.1 million km², the Indus River basin covers approximately 65% of the territory of Pakistan (FAO–Aquastat, 2011*a*), and extends into the neighbouring countries of India, China and Afghanistan.

Water resources and potential impact of climate change

The Indus River and its tributaries (the Jhelum, the Chenab, the Ravi, the Sutlej, the Beas and the Kabul) have an average combined potential of 190 billion m³ of water. The 1960 Indus Basin Treaty gives Pakistan exclusive use of three western rivers (the Indus, the Jhelum and the Chenab), whereas three eastern rivers (the Ravi, the Sutlej and the Beas) are allocated to India (Map 44.1). The Permanent Indus Commission, with a representative from each country, serves as the regular channel of communication on matters relating to the implementation of the Treaty, particularly the exchange of data and information. Most of the rivers

MAP 44.1

Indus River basin



outside the Indus River basin are insubstantial streams, which flow only during the rainy season and do not contribute significantly to the availability of surface water.

Beneath the Indus River basin is an aquifer extending over an area of 160,000 km^2. While the safe yield is estimated to be about 68 billion m^3, the volume of groundwater abstraction by different sectors, including domestic consumption, is already approaching 62 billion m^3 (FAO–Aquastat, 2011*b*). Over the last two decades, groundwater has played an important role in sustaining irrigated agriculture in Pakistan, with more than 50% of the irrigation water coming from more than one million privately owned wells. However, the current rate of use is not sustainable, and groundwater levels are declining in many areas.

Himalayan glaciers are the major source of the freshwater that feeds the Indus River and its tributaries. According to climate change scenarios, following an initial period of high flows caused by accelerated glacial melt, it is predicted that the amount of water flowing into the Indus River system may decrease by as much as 30% to 40% within the next two decades. Furthermore, the effects of climate change and siltation may reduce already-low reservoir capacity in the basin by 30%. The overall reduction in water availability may potentially have a serious impact on irrigation. This, in turn, may affect food security nationwide. There is already concern about forecasts that increasing temperatures may reduce grain yields in Asia by 15% to 20% by 2050 (IFPRI, 2011).

Climate change is also expected to affect the South Asian monsoon. According to the Intergovernmental Panel on Climate Change (IPCC), an increase in rainfall of up to 24% may amplify the frequency and magnitude of floods. The 2010 flood (Box 44.1) is an example that illustrates how devastating the socio-economic impact of such calamities can be at the nation-wide level. A more recent example, the 2011 flooding of Sindh province, has affected 5.4 million people to date. The number of deaths has reached 223 and over 600,000 homes have been damaged or destroyed. Nearly 300,000 people, the majority of whom are women and children, are currently living in camps (OCHA, 2011). These extreme events clearly demonstrate that planning and mitigation measures are required if the country is to be prepared to cope with climate change and climatic variations.

Water and agriculture

In Pakistan, 220,000 km^2 of land (approximately 27% of the country) is cultivated. Irrigation is used on 80% of arable land nationwide, and is practised mainly in the Indus River basin. The irrigation system in the Indus River basin is one of the largest in the world, with a total of 59,000 km of canals. Overall, almost 90% of all agricultural production is supported by irrigation. Livestock production is also widespread, particularly in Balochistan province, where it is responsible for almost 40% of agricultural income.

While agricultural yield grew at an average annual rate of 4.5% over the last decade, its contribution to gross domestic product (GDP) has been steadily decreasing over the years. In 2010, its share was down to 19.6%, while the service sector has grown to 53.7% and industry to 26.8%. However, the importance of agriculture lies in the fact that it employs about 44% of the nation's workforce, supports about 75% of the population and accounts for more than 60% of export earnings.

Irrigation has had a negative impact on soil fertility in the basin as a result of waterlogging (oversaturation of soil by groundwater) and soil salinization, which between them have already affected over 20,000 km^2 of land. These problems result from a combination of several factors, including seepage from unlined earthen canal systems, inadequate provision of surface and sub-surface drainage, poor water management practices, and the use of poor quality groundwater for irrigation.

A social problem linked to irrigation is the inequity of water distribution. The operation of the basin's irrigation system is based on a continuous water supply and is not related to actual crop water requirements. The distribution of water from the canal outlets is done on a seven-day rotational system (locally known as *warabandi*). Farmers are allowed to take an entire flow of the outlet once in seven days, and for a period proportional to the size of their land holding. However, the *warabandi* system discriminates against 'tail-enders', who end up getting 40% or less water than 'head-enders'. This has serious implications not only in terms of equity but in terms of crop productivity.

As a result of age and neglect, much of the infrastructure in the basin's irrigation system is in poor shape, resulting in considerable losses across the system and low performance in carrying water to the lower reaches of canals. Many elements of the vast hydraulic system are now reaching the end of their design lives and have to be rehabilitated or replaced at an estimated cost of around US$ 60 billion. Unfortunately, there is a huge backlog of deferred repair and maintenance, a problem which was aggravated by the floods of 2010 (Box 44.1).

Agriculture is the primary user of water resources. In fact, agriculture took 96% of the 183.5 billion m^3 of water used in 2008, followed by municipal and industrial uses (FAO–Aquastat, 2011*b*). Projections clearly show that water supply in the Indus River basin will gradually begin to fall short of demand, with the requirement for irrigation water expected to rise to 250 billion m^3 in 2025, as against availability of 190 billion m^3. This imminent challenge calls for more efficient use of water in agriculture, the adoption of water-conservation measures, and the augmentation of water storage capacity in order to prevent problems feeding the growing population.

Water and health

Access to safe drinking water and sanitation in Pakistan is an issue that requires considerable attention and investment. In 2008, about 95% of the urban population had access to water supplies (WHO/UNICEF, 2010*a*), but only some 55% of that number had household connections. In rural areas, almost half of the population uses water from sources that are not properly suitable for human consumption – sources such as streams, canals, village ponds, and springs. In fact, an estimated 62% of the urban population and 84% of the rural population do not treat their water prior to use. In national terms, the rate of access to sanitation is 45% (WHO/UNICEF, 2010*b*). Given this low value, it will be difficult to achieve the national target of 90% coverage by 2015. The financial cost of the disease burden that is linked to lack of safe drinking water and proper sanitation is equal to approximately 2% of Pakistan's GDP.

Among the reasons for such low rates of access to water supply and sanitation are low tariffs and inadequate revenue collection. These problems result in meagre investment and the degradation of water and sanitation infrastructure caused by a lack of periodical maintenance. In fact, water-related public investment corresponds to only 0.25% of GDP (ADB–APWF, 2007). Consequently, tariff adjustment that better reflects the true value of water and covers the cost of service provision is considered vital if current challenges are to be addressed.

Poverty is a serious problem in Pakistan. Some 60% of the population lives on less than two dollars a day, while another 22% lives on less than one dollar a day. More than 38% of children under five are malnourished, with 13% of those severely underweight. Poor health in children is linked directly to lack of education for women. As a result of substantial gender inequality, the literacy rate for women is just 35%, compared to 59% for men. And broadly speaking, while there has been some success in the fight against poverty, the devastation caused by the massive flood in 2010 (Box 44.1) is likely to have had a detrimental effect on this trend.

Water and energy

The potential of hydropower generated by the Indus River is estimated at 35,700 MW and over 55,000 MW for the entire Indus River system. While only 15% of that overall potential of the Indus River is currently being tapped, the completion of projects that are already underway or at the planning stage will mean that the overall hydropower generation capacity of Pakistan can be increased to 25,000 MW.

With demand growing at an annual rate of 10%, and the absence of any hydropower development since 1975, the energy mix in Pakistan has shifted towards carbon-based sources. This has led to more expensive electricity, and shortages that affect every sector of the economy, particularly industry. Coal reserves remain as a potential source for thermal energy generation.

Environment and ecosystems

Despite its generally arid climate, there are more than 225 significant wetlands in Pakistan. Of these, 19 are internationally recognized under the Ramsar Convention. The Indus River and its floodplains form the main axis of these wetlands, both man-made and natural, which cover a total area of approximately 7,800 km^2. In addition, the Thar, Thal, Cholistan[1], Kharan and Indus Valley deserts also support a wide range of animal and plant species. In all, there are 18 threatened

BOX 44.1

The 2010 Flood in Pakistan

Pakistan experienced torrential rainfall between mid-July and September 2010. This caused the worst floods since 1929, which affected the entire country. The socio-economic impact of the disaster was overwhelming. According to the National Disaster Management Authority (NDMA), 1,700 people died and over 20 million were displaced. Many of those displaced suffered from various maladies, including at least 700,000 cases of acute diarrhoea, 800,000 cases of acute respiratory infection, nearly a million cases of skin disease, and almost 183,000 cases of suspected malaria. Flash floods and landslides triggered by the rain caused severe damage to infrastructure, urban settlements and agricultural production.

According to the World Bank–Asian Development Bank joint damage and needs assessment the overall recovery and reconstruction cost associated with the floods is expected to be between US$8.74 billion and US$10.85 billion, which includes estimated costs for relief, early recovery and medium to long-term reconstruction.

Source: Adapted from ADB ReliefWeb (2010) and CNN (2010).

species of wetlands dependent mammals, including the Indus River dolphin. There is now a very real threat to the twenty bird species, twelve species of reptile, two endemic species of amphibian, and more than 190 indigenous freshwater fish species that are supported by Pakistan's wetlands.

The Indus River basin wetlands, in addition to their intrinsic value as a rich source of biodiversity, also contribute to the fight against poverty through the raw materials they produce that help to sustain subsistence living.

While forest cover is only around 6%, businesses associated with forestry employ almost half a million people. Fuel-wood production, which provides one third of the country's national energy needs, is unfortunately one of the major causes of shrinking forests. The continuing loss of forest habitat, and the associated fauna and flora, have serious implications for the region's ecosystems, as well as for the fight against poverty.

The water quality of the Indus and its main tributaries deteriorates towards their downstream end as a result of municipal and industrial contaminants and return water from irrigation, which is polluted with fertilizers. However, the dissolved oxygen level in all rivers remains higher than the threshold value of 5 mg/l.

Water resources management

At the federal level, the Ministry of Water and Power is responsible for water and energy-related issues. The Water and Power Development Authority was established in 1959 as a government-owned public institute for the planning, design and implementation of irrigation, drainage and power projects.

Up to 1997, the distribution of irrigation water to farmers, the collection of water fees, and the repair and maintenance of the irrigation infrastructure was the responsibility of the Provincial Irrigation Departments. However, following a governmental reform, backed financially by the World Bank, to address problems in irrigated agriculture and water management, the Provincial Irrigation Departments were transformed into newly established autonomous Provincial Irrigation and Drainage Authorities. As a part of this reform, at the main and branch canals level, commercially oriented Area Water Boards were established. At the same time, the operation and management of the system at distributor and minor levels was handed over to independently elected farmer organizations. Overall, a total of 340 farmer organizations have been formed, of which 257 have taken over the management of irrigation systems. These organizations are responsible for collecting water charges, settling water-related disputes, and supplying irrigation water equitably and efficiently to users. While collection of revenues increased initially, it gradually fell back (in some cases by as much as 50%), because of the lack of technical assistance provided to farmer organizations by government agencies, and insufficient funds being allocated for their efficient functioning. Unfortunately, this situation raises questions about the long-term sustainability of farmer organizations in Pakistan.

Conclusions

The Indus River system is the lifeblood of Pakistan. It is the major source of freshwater that allows the country to thrive in an otherwise arid environment. Irrigated agriculture is the only way to secure the food production that is necessary to feed a growing population. However, the country is now facing critical problems, such as deteriorating infrastructure that causes significant losses during irrigation water transfer, low agricultural productivity, and a water management system that is unable to adequately address the challenges on the ground. Water-use projections show clearly that under a business-as-usual scenario, water demand will exceed supply by 2025. Climatic variations and climate change, coupled with low water storage capacity, may further aggravate this situation. Consequently, it is crucial to develop new strategies and policies that take into account the potential effects of projected climate change, with a view to promoting sustainable water use in all sectors. This will help to ensure food security, help in the fight against widespread poverty, and help to protect the environment.

Notes

1 Cholistan Desert was covered as a case study in *United Nations World Water Development Report 3* (WWAP, 2009), http://webworld.unesco.org/water/wwap/wwdr/wwdr3/case_studies/pdf/Case_Studies_AsiaPacific.pdf#page=13

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CHAPTER 45

Czech Republic

Acknowledgements Jaroslav Plainer, Michal Vrabec, Josef Hladný

Location and general characteristics

The Czech Republic is an inland country located in central Europe. Its neighbours are Poland to the north-east, Germany to the west, Austria to the south, and Slovakia to the south-east (Map 45.1). The total area of the Czech Republic is around 79,000 km^2. In 2008, its total population was approximately 10.5 million. Its highest point is Sněžka, at an altitude of 1,604 m above sea level, is situated in the mountains in the north of the country. The lowest point is in the Labe Valley, where the Labe River leaves the Czech Republic, at an altitude of 115 m above sea level. The average air temperature of the country is 7.5°C.

TABLE 45.1

Basic characteristics of major river basins in the Czech Republic

	Elbe basin	Morava* basin	Oder basin
Extent of the basin (km^2)	51,410	24,109	4,715
Average annual discharge (m^3/s)	309	59.6	48.1

**Morava basin at Strážnice, upstream of the Dyje river*

Water resources, their use and management

Because of its relatively high altitude and climatic conditions, the Czech Republic receives an average of 674 mm of precipitation annually. There are more than 3,600 rivers that have basins of 5 km^2 or larger. These include the sources of a number of major European rivers, such as the Elbe (Labe in Czech), the Oder (Odra in Czech) and the Morava, which is a tributary of the Danube. The Elbe has the largest basin in the Czech Republic, followed by the Morava and the Oder (Table 45.1). These rivers discharge into the North Sea, the Black Sea, and the Baltic Sea, respectively.

Groundwater resources tend to be unconfined, or slightly artesian in character, and usually not very deep below the surface. The largest usable aquifers are located in the lowlands. Groundwater accounts for approximately 6% of total available water, therefore its importance in terms of overall water supply is relatively low. Because of its high quality, however, groundwater is frequently used as drinking water.

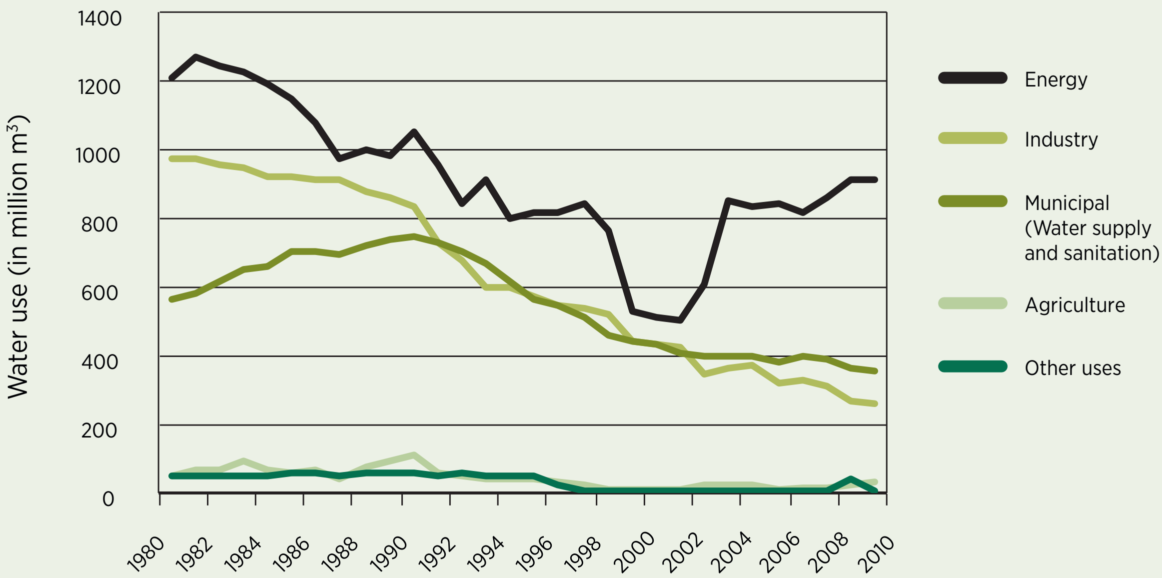
The highest demand for surface water comes from the energy sector, mainly for use in thermal and nuclear power plants. The levels of demand for water for industrial use, drinking water and sanitation (including settlements and animal farms) are broadly comparable. Agricultural demand is low because crop production mainly depends on rainfall. With the exception of energy production, there has been a declining trend in water use in all sectors since 1990 (Figure 45.1). Rising water prices and the

MAP 45.1

Czech Republic

FIGURE 45.1

Surface water abstraction in the Czech Republic between 1980 and 2009



increased use of advanced technology have both contributed to this decline. For example, in 2004, water abstraction was almost 35% less than in 1991. In parallel, the unit price of drinking water and water for sanitation rose from approximately US$0.25 in 1991 to US$3.0 in 2009. As a net outcome, wastewater generation dropped by 26% between 1991 and 2004.

Water resources management in the Czech Republic involves local, regional and national authorities. At national level, responsibility is spread between the ministries of agriculture, the environment, the interior, health and transport. The management of important watercourses such as the Vltava, the Elbe, the Ohře, the Morava and the Oder is entrusted to the River Basin Boards established by the government. Their main task is to operate and maintain the major water structures, such as dams, reservoirs, weirs and locks. In that context, key legislation includes the Water Act (No. 254/2001 Coll.) and the Water Supply and Sewerage Systems for Public Needs Act (No. 274/2001 Coll.). In 2010, Act No. 150 came into force, amending the Water Law. These acts, together with the European Union Water Framework Directive, established the framework for community action in the field of water policy.

Climate change and hydrologic extremes

While there are climate change scenarios for central Europe, none of these has been able to produce reliable models that can be used to predict changes in precipitation and hydrological conditions. In fact, there have been no statistically significant trends available for monthly or annual precipitation in the Czech Republic since 1961 (EEA, 2011).

Floods are frequent, but are not a regular phenomenon. In the period from 1990 to 2010, their frequency increased somewhat, and the floods in 1997 and 2002 were among the most serious in the country's history. There is a comprehensive mechanism in place for flood prevention, emergency response, and protection, which involves local, regional, and national authorities. The Central Flood Protection Committee, which operates at the highest level, is appointed by the government. In line with the EU Flood Directive (2007/60/EU), the Czech Republic is in compliance with the requirements of flood risk assessment. This is a process in which the country has drawn on its experience and previous knowledge in the field of natural disaster related risk management.

Drought also occurs infrequently in the Czech Republic. Short periods of drought occur mostly in the second half of the vegetation season. The worst drought in the twentieth century was in 1947, when the recorded rainfall deficit in Bohemia during the vegetation period reached almost 45% of the long-term average. Within the last 135 years, there have been five vegetation seasons with similar rainfall deficits.

Water and the environment

Water used in industry and for the production of electricity is returned almost entirely to the rivers. However, discharged water is 'thermally polluted' (that is, it is warmer than the ambient temperature of normal water bodies). Such elevated water temperature may cause variations in dissolved oxygen levels, which adversely affects ecosystems. The influence of other types of industry – particularly chemical, pulp-paper, and steel factories – on water quality was significant in the past because of the absence of wastewater treatment systems. However, in the 1970s, water quality began to improve gradually, as a result of restrictions on industrial wastewater discharge and the introduction of advanced treatment technologies. In 1971, the proportion of pollution caused by industry was approximately 57% or 79,400 tonnes[1]. By 1990, this proportion had dropped to almost 30% or approximately 49,000 tonnes.

From the 1950s, growth in agriculture and the increased use of fertilizers, insecticides and herbicides caused soil and water pollution. Following the political changes that took place in 1989, agricultural policies that had been part of the former socialist regime's 'planned economy' were abandoned. Agricultural modernization, as well as the privatization and restitution of property, led to reduced water demand from the agriculture sector. Overall, agricultural production has dropped by about 30%. Further development of agriculture has been affected by the Czech Republic's membership of the European Union (EU). As a combined result of these changes, the use of artificial fertilizers has been dropping.

Alongside the social and political changes of 1989, the principles of environmental protection have been introduced and implemented rigorously. The Nature and Landscape Act (No. 114) came into force in 1992, and the Programme for Revitalization of the River Systems was introduced the same year. The Czech Republic joined the EU in 2004, and since then has been bound by the EU Water Framework Directive. This has also contributed to an overall improvement in environmental conditions.

Conclusions

Apart from local shortages, the availability of water resources is sufficient in the Czech Republic. In the 1960s and 1970s, water quality deteriorated rapidly as a result of booming water demand and discharges of wastewater from industry, agriculture and human settlements. However, political reforms initiated in the 1990s began to reduce that demand, and the associated pollution. This positive trend gained further momentum following EU accession. The national water management policy reflects the top priorities of the country: sustainable management of freshwater resources and the protection of ecosystems. Czech Republic is now working towards meeting the targets of the EU Water Framework Directive.

Notes

1 This measurement indicates the corresponding BOD_5 value. BOD_5 is an index used to assess aquatic organic pollution and commonly used to monitor organic load for environmental and process control in industry.

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Except where otherwise noted, information in this concise summary is adapted from the Czech Republic Case Study Report, *Water and Water Resources in the Czech Republic*, prepared in 2010 by the Czech National Committee for the International Hydrological Programme of UNESCO (forthcoming).

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CHAPTER 46

Marseille Provence Métropole Urban Community, France

Acknowledgements Marseille Provence Métropole – Water and Sanitation Agency

Location and general characteristics

The Marseille Provence Métropole (MPM) Urban Community was created in 2000 and is home to approximately one million inhabitants. The MPM is located in the Provence-Alpes-Côte d'Azur region of France on the shores of the Mediterranean Sea. It covers a surface area of 607 km^2, comprising the city of Marseille and eighteen municipalities, concentrating 23% of the region's population on just over 2% of its territory (Map 46.1). Marseille alone, France's second-largest city after Paris, extends over an area of 240 km^2.

The MPM lies in the temperate zone and has a Mediterranean climate. Average annual rainfall is around 550 mm, which is concentrated into a period of approximately 80 days, mostly in the spring and autumn months as violent, localized precipitation. The area is subject to summer droughts.

Water resources, their management and sanitation

The regional proverb *Eici, l'aigo es d'or* (here, water is gold) clearly illustrates the shortage of the resource. In fact, the lack of water, and the health consequences that underlie this, have been the principal cause of severe epidemics in the past, such as the outbreaks of bubonic plague in 1347 and 1720, and the cholera epidemics in 1834 and 1884 – all of which resulted in significant numbers of deaths.

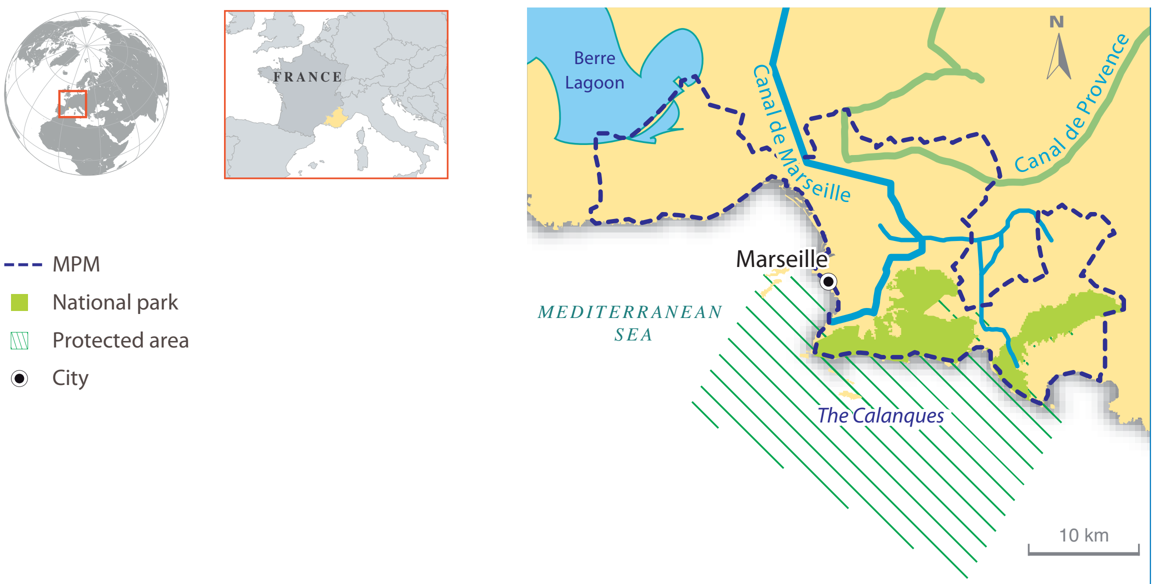
To alleviate water scarcity, a diversion canal, locally known as Canal de Marseille, was begun in 1838 to transfer the flow of the Durance River to the city of Marseille. Today, the main artery of the canal is 97 km long and its minor arteries extend over 195 km. The canal system comprises two dams, a number of underground canals and twenty aqueducts. The capacity of the canal has almost tripled since the middle of the nineteenth century, from 5.75 m^3/s to 15 m^3/s – although the flow varies depending on seasonal conditions and on an allocation agreement between the City of Marseille and the national utility company, Electricité de France.

On average, the canal provides 193 million m^3 of water per year to 1.2 million inhabitants in 36 municipalities. Today, the canal accounts for two-thirds of the water brought to Marseille, with the rest coming from the Verdon River through the Canal de Provence. Underground water resources are also used in the MPM to increase water availability in Marseille and to provide drinking water to the towns of Aubagne and Gemenos. As a result, protection zones are being established to minimize the risk of pollution of surface water and groundwater resources, including the network of the Canal de Marseille.

Annual water consumption in the MPM is about 100 million m^3, 95% of which is processed in wastewater treatment plants before being released back into the

MAP 46.1

Marseille Provence Métropole Urban Community



environment. Since 1942, Marseille's water supply has been managed by the Société des Eaux de Marseille. This has included the operation of the Canal de Marseille, as well as the production and distribution of drinking water. The Societe des Eaux de Marseille, a private company, also manages water supply in 15 of the MPM's municipalities. Marseille's first large-scale sewer system, the combined length of which is 346 km, was completed in 1896. The sewer network has been extended, improved and modernized over the past hundred years.

The first physico-chemical treatment plant was put into service in 1987. In 2008, the MPM Urban Community completed the construction of one of the world's largest underground biological treatment facilities – an investment of some US$270 million. Since 1981, the management of the City of Marseille's sanitation system (sewage and storm-water) has been delegated to a private company. In seventeen of the other MPM municipalities, sanitation services are also almost exclusively provided by private companies on an operation and maintenance basis.

To ensure that the water supply is secure, potential risks are constantly being evaluated – to prevent, for example, accidental pollution and failure in the purification plants or distribution network. Such studies have provided the basis of preparation of a five-year water plan. The plan is submitted to the MPM Urban Community's elected representatives, who select the projects that are to be carried out. The first MPM plan was approved in 2006, and represented an investment of US$165 million. The goal of this plan was to identify the weaknesses of the region's drinking water supply system and help to rectify them. Some 85% of the analysis section of this plan was achieved, and 65% of the project implementation was completed by the end of 2010. The MPM Urban Community is now preparing a second five-year plan, this time with the objective of ensuring water security for all the member municipalities. The budget for the new plan has not yet been established.

Climate change and risk management

Although water resources are limited, occasional heavy rainfall in the autumn and winter may cause severe floods. The Durance River in particular has caused frequent and violent floods. Similarly, intense precipitation causes floods in Marseille. To address these challenges, the MPM, on behalf of the City of Marseille, has introduced a strategy that combines regulatory arrangements and crisis management. Other developments too have helped to mitigate climate change effects – an extensive hydrographic network with sensors transmitting data in real time, river channel improvements and the construction of flood control reservoirs. Currently, the retention capacity of the reservoirs in Marseille is 130,000 m^3 and the MPM Urban Community is studying the feasibility of constructing 27 more to provide an additional storage of 200,000 m^3.

In the field of risk management, raising public awareness and involving local residents are high priorities. For example, in the district of Saint Loup, an SMS-based information system was set up following the mudslides in 2009. This is to inform residents of hazardous situations as quickly as possible and to make them an integral part of civil security operations.

While analysis of hydrometeorological data gathered by the MPM Urban Community does not show any specific trend that points to climate change, the likely consequences of climate change – such as rises in sea levels and the accelerated melting of the snow and ice that feed the rivers bringing water to the MPM – could be serious. Swollen rivers could flood because the storage capacity of reservoirs might not be sufficient to regulate higher flow rates, and rising sea levels could cause seawater intrusion into coastal aquifers and sewer system weirs. Recent studies point out the need to identify flood prone areas and adapt water works to be able to mitigate the effects of a potential change in rainfall regime. On the other hand, the flooding of coastal settlements is less likely because of Marseille's topography.

Environmental protection and use of modern technology

Environmental protection and the optimization of water use is a permanent priority for the MPM Urban Community. Consequently, the following measures has been taken:

- Unused water in the Canal de Marseille is now returned to the environment;
- Inspections to detect infrastructure leaks are carried out periodically;
- Out-dated lead connections have been changed;
- The sewer network is maintained regularly; and
- Street-cleaning vehicles are specially designed to minimize water use.

FIGURE 46.1

Evolution of water consumption in the MPM from 1995 to 2009

As a result, average annual water use in the MPM has remained relatively stable over the years (Figure 46.1). The MPM Urban Community also deals with wastewater management through operating 2,525 km of sewerage networks and 10 wastewater treatment plants. Moreover, it monitors the impact that discharges have on the marine environment.

Drinking water production and wastewater treatment plants in the MPM are upgraded regularly in line with regulatory requirements and technological advances (Box 46.1). For example, the drinking water production plant at Sainte Marthe, which was built in 1934, still complies with current standards. In addition, the sewage treatment plant at Ensuès-la-Redonne has been using advanced bio-reactor technology since 2009. However, in spite of the sophisticated technology utilized, treated wastewater is not re-used in the MPM because of potential environmental and sanitary risks.

All major modernization projects as well as maintenance operations are subject to public consultation. These are submitted for approval to the Regional Committee for the Environment and to the regional and national commissions that oversee sites with a recognized natural, ecological or cultural value. This can lead to changes in the proposed projects. For example, a project to modernize the sludge facility of the Marseille wastewater treatment plant, which is located in in the

BOX 46.1

The use of renewable energy in the MPM

As a part of its environmentally conscious approach, various sources of renewable energy are used to reduce emissions in the MPM. For example, the Sainte Marthe drinking water plant is equipped with a turbine that generates enough electricity for the facility to be self-sufficient[i]. Another turbine was installed on the Batarelle main, downstream of the Vallon Dol reservoir[ii]. The Marseille wastewater treatment plant uses thermophile anaerobic digestion to produce methane that is used in the plant for thermal processes, or, when economically feasible, to produce electricity[iii].

The MPM Urban Community is also studying the possibility of capturing the energy that is contained in wastewater through the installation of heat exchangers. Implementation of these innovative methods is being prioritized in the construction of new infrastructure or in modernizing the current sewer network. The sites are selected according to their potential in terms of connected population equivalent (PE)[iv].

[i] *Mean annual electricity production at Sainte Marthe: 3 million kWh or 266 TOE*

[ii] *Mean annual electricity production at Batarelle: 820,000 kWh or 70 TOE*

[iii] *Production of biogas in the sludge treatment plant: 10 million Nm^3 in 2010, or 6300 TOE.*

[iv] *PE is an estimation of the organic biodegradable load that will be entering a treatment plant. Thus, it is an estimate of the usage of sewage facilities and not a measure of population.*

classified site of the Calanques, had to be modified to adapt to the biological characteristics of the local flora and fauna.

To ensure environmental flow, the MPM Urban Community agreed to allocate water from the Canal de Marseille to compensate for low water levels in rivers such as the Arc and the Touloubre, following discussions with local stakeholders and representatives of relevant governmental organizations.

Conclusions

The Marseille Provence Métropole (MPM) is home to a large urban community in a region where water is rather limited. Local efforts to secure freshwater resources and proper sanitation infrastructure began more than a century ago. The ambitious projects that have been carried out since have allowed the people in the region to enjoy high living standards, free of the diseases that prevailed in the past. The canals (Canal de Marseille and Canal de Provence), in conjunction with groundwater resources, provide a sufficient quantity of water to meet the growing demand. The challenge is to minimize the environmental footprint of this urban conglomerate, which has approximately one million inhabitants. Use of modern technology, the introduction of innovative approaches, and the handling of operation and maintenance by the private sector makes the MPM Urban Community confident of its ability to overcome the difficulties it faces.

References

Except where otherwise noted, information in this concise summary is adapted from the Marseille Provence Métropole Urban Community (MPM) Case Study Report, *Managing Water and its Risks, from Mountain to Sea*, prepared in 2011 by the Water and Sanitation Agency of the Marseille Provence Métropole Urban Community (forthcoming).

CHAPTER 47

Tiber River basin, Italy

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Acknowledgements Giorgio Cesari, Remo Pelillo, Giorgio Pineschi, Giuseppe Bortone, Katia Raffaelli, Maurizio Baudone, Francesca Caparrini, Enzo Di Carlo, Sergio Paderi, Raniero De Filippis, Luca Fegatelli, Mauro Lasagna, Angelo Viterbo, Nicola Berni, Mario Smargiasso, Emidio Primavera, Sabrina Di Giuseppe, Tiziana Di Lorenzo

Location and general characteristics

The Tiber River begins the in the northern part of the Apennine Mountains in Italy and travels about 400 km before draining into the Tyrrhenian Sea (Map 47.1). The river runs through the Italian capital, Rome. The Tiber River basin covers an area of about 17,500 km^2, which crosses six administrative regions. Almost 90% of the basin lies in the regions of Umbria and Lazio, and the remainder falls within the regions of Emilia–Romagna, Tuscany, Marche and Abruzzo. The basin lies fully in the Central Apennines District , which includes all the regions of the basin and Italy's newest region, Molise (Table 47.1).

The Tiber River basin has approximately 4.7 million inhabitants (2009), some 60% of whom live in Rome. Overall, 83% of the population is composed of urban dwellers. The topography of the basin varies from lowlands to highlands and is mainly characterized by a temperate climate with hot, dry summers and cool, wet winters. The highest precipitation in both the Tiber River basin and the Central Apennines District is usually recorded in the autumn and spring, with a peak in early winter and a dry season during the summer.

Water resources availability and their use

The annual average discharge of the Tiber River into the Tyrrhenian Sea is 225 m^3/s or approximately 7 billion m^3 (calculated on a long-term average) (Cesari, 2010). Depending on the hydrologic conditions, the maximum discharge can exceed 1500 m^3/s or can be as low as 60 m^3/s. Groundwater availability in the basin is about 3.5 billion m^3.

With the exception of the Emilia–Romagna region, the basin and its immediate surroundings are mainly characterized by small farms (Table 47.2). Irrigation is practised through sprinklers, drip systems and canals over a combined area of 2,100 km^2, which corresponds to approximately 8% of agricultural land in the five regions. The most commonly cultivated products are fruit and vegetables (such as cereals and potato) and tobacco.

The territory is not very industrialized. However, there are important steelworks in Terni and beverage, tobacco, agro-processing and paper factories in the basin. Since the 1990s, industrial activity has been reducing gradually, and the services sector has become the main contributor to the region's gross domestic product (GDP) (Table 47.3).

In the largely rural Emilia–Romagna region, agriculture is the sector with the highest water demand, followed by municipal use and industry. In fact, irrigation accounts for 66% of overall water consumption. In other regions, agricultural water demand is relatively low. However, generally speaking, all regions are implementing various projects to improve water

MAP 47.1

Tiber River basin and Central Apennines District

TABLE 47.1

Extent of regions and distribution of the Tiber River basin

Region	Proportion of national territory (%)	Proportion of Central Apennines District (%)	Proportion of Tiber River basin (%)
Emilia–Romagna	7.45	0.08	0.1
Tuscany	7.63	3.46	6.7
Umbria	2.81	22.37	46.8
Marche	3.11	12.17	1.2
Abruzzo	3.57	25.31	3.7
Lazio	5.72	36.26	41.5
Molise	1.47	0.36	-

TABLE 47.2

Basic regional statistics about agricultural land use (2007)

Region	Average land holding size (km^2)	Irrigated area (km^2)	Cultivated area (km^2)	Irrigated/cultivated area (%)
Emilia–Romagna	1.28	2,966	10,525	28.20
Tuscany	0.10	472	8,064	5.90
Umbria	0.09	244	3,394	7.20
Marche	0.10	245	4,964	4.90
Lazio	0.07	861	6,740	12.80
Abruzzo	0.07	345	4,340	8.00

TABLE 47.3

Contribution of various sectors to GDP at the national, Central Apennines District and Tiber River basin levels

Sector/Region	Italy	Central Apennines District	Tiber River basin
Agriculture, Forestry, Fishing	2.5%	2.0%	1.7%
Industry	27.2%	22.0%	19.8%
Services	70.3%	76.0%	78.5%

demand management and to reduce seasonal water deficits. Umbria and Tuscany have facilitated access to information by developing databases on water use that are linked to online portals. Similarly, Emilia–Romagna introduced an 'Irrinet' service to reduce water consumption in agriculture, and has achieved successful results (Box 47.1). This region has also had its successes in the municipal sector, with a 7% drop in water use between 2002 and 2006. Umbria is aiming to increase public awareness of the need to reduce water consumption and has made improvements to its infrastructure to minimize water loss from the network.

In 2005, Rome's municipal water requirement was approximately 450 million m^3, and in the rest of the Tiber River basin it was about 80 million m^3. The same

BOX 47.1

Developing knowledge and capacity: Irrinet and Irrinet plus

The 'Irrinet' project, which aims to reduce irrigational water use, is an initiative of Emilia–Romagna region and part of the 2007–2013 Rural Development Programme. The Irrinet service is freely available on the internet and provides irrigational advice using data from the Regional Agency for Environmental Protection (Agenzia Regionale per la Protezione Dell'Ambiente – ARPA), the region's geologic, seismic and soil service, and the experimental activities of the consortium of the Canale Emiliano–Romagnolo.

Based on their geographical location, it is possible to indicate to farmers when to irrigate and how much in order to achieve the highest productivity. It has been estimated that the Irrinet service has helped to save about 50 million m^3 of water between 2006 and 2007. Since 2009, Irrinet has evolved into Irrinet Plus, which provides farmers with further information specifying the economic benefits associated with a particular irrigation routine that uses an intuitive advisory system. This project provides institutions with a practical instrument for managing the water demand for irrigation and helping farmers to use the right amount of water to minimize the risk of overuse. Also, institutions can monitor the irrigational water consumption, thus facilitating water rationing especially in drought periods.

year, water use for drinking and sanitation in the wider Central Apennines District was around 1.2 billion m^3, 90% of which was withdrawn from springs and aquifers. In general, a significant increase in water use is not expected and there are plans to reduce water consumption by as much as 8% by 2015.

In the Central Apennines District, there are approximately 40 dams, over 30 of which are hydroelectric power plants (HEPP) with an installed capacity of 1,400 MW. HEPPs in the TRB are mainly concentrated on the Tiber and Nera Rivers. About 8% of national electricity production comes from hydropower in the region, and almost all the power that is produced is consumed locally. While hydropower generation is a non-consumptive water use, it requires about 40 billion m^3 per year, and therefore adds to the competition from other sectors. Although a reduction in the production of hydroelectricity could increase water availability for other water users, it would have a negative impact on the national target of producing 20% of energy from renewable resources (Cesari et al., 2010).

Climatic variability, climate change and risk management

The Intergovernmental Panel on Climate Change (IPCC) predicts that the Mediterranean region in general will suffer from a reduction in water resources availability. In addition, the most severe climate change scenarios for central Italy – where a 6°C to 8°C increase in temperature is forecast by 2080 – foresee a decreasing trend in rainfall throughout the year, most notably between October and April where precipitation could drop by as much as 50%.

These predictions are partially confirmed by measurements. Data collected between 1952 and 2007 show a consistent trend of gradually decreasing annual precipitation (mainly in winter, with falls of up to 30%) with rising surface temperatures. Throughout the TRB, the amount of precipitation has decreased by 2 billion m^3 in the same period. While there have been exceptionally dry years (2007) and exceptionally wet years (2008), the Tiber River basin, in general, has experienced prolonged dry periods. In fact, major drought events that affected the entire basin occurred in 1955, 1971, 1987, 1990, 1993, 2003 and 2007. The droughts at the turn of the twenty-first century did not get much attention from the point of view of water scarcity. Instead, what were highlighted were the weaknesses in supply systems – including poor flexibility in the operation of reservoirs – and the lack of integrated management.

Floods are usual along the Tiber River. There were frequent floods in the first decade of the millennium, fortunately none of them was a major event and losses were economic in nature.

Because climate change is expected to exacerbate droughts and floods, there are policies and structural measures in place in Italy and throughout the Tiber River basin to deal with disaster mitigation and disaster preparedness. For example, at national level, the Local Action Programme uses meteorological and agro-meteorological indicators to highlight risks related to drought and desertification that could have an impact on agriculture, the environment and society in general. In the Emilia–Romagna region, 460 additional small reservoirs were built after the Programme identified that there was insufficient capacity to meet agricultural water demand in dry periods during the summer. The national civil protection service runs simulations to forecast water requirements under different climate scenarios and issues drought alerts. Regions are also cooperating to alleviate seasonal water shortages. For instance, in Tuscany and Umbria, extensive studies on water sharing led to an agreement between the regions for the joint use of the Montedoglio reservoir, which is located in the upper Tiber River basin.

Flood management is ensured through national directives that include early warning systems, and there are regional offices to implement the necessary measures. Legislative Decree 49, which came into force in 2010, transposed the EU Floods Directive (2007/60) into national law. In fact, the Tiber River Basin Authority had anticipated the contents of the EU directive and had already developed a planning tool (in line with Law 183/89 on soil protection) for the identification of flood-prone areas and the level of risk exposure. However, two main requirements of the Floods Directive remain to be implemented in the Central Apennines District: public participation in the planning process and the economic analysis and development of civil protection plans. Regarding public involvement, the Tiber River Basin Authority participated in the EU project 'integrative flood risk governance approach for improvement of risk awareness and increased public participation (IMRA)' to develop a method of risk communication and participation in local communities that are located in flood-risk areas.

Policy framework and decision-making

At national level, the 1933 Italian Royal Decree recognized water resources as a public good. In 1989, Law 183 established major basin authorities and identified the river basin as the basic unit for water resources management, water pollution control and soil protection activities. In 1994, Law 36 introduced a reform under which municipal utilities were aggregated into Optimal Territorial Areas which are responsible for the management and supply of water services such as wastewater treatment, sanitation and the provision of drinking water.

Legislative Decree 152 was introduced in 1999 to protect water resources by preventing and reducing pollution, and improving water quality. This Decree delegated certain responsibilities to the regions. Accordingly, each region had the right to make its own laws, and shared the responsibility for local implementation with the provinces (sub-units of the regions). In 2006, Legislative Decree 152 incorporated the contents of the EU Water Framework Directive and replaced the 1999 Legislative Decree 152. The new decree set out for the creation of a Central Apennines District Authority, with several ministries (Environment, Infrastructure and Transport, Economic Development, Cultural Heritage, Agriculture, Civil Function and Civil Protection) and regions (Emilia–Romagna, Tuscany, Umbria, Marche, Lazio, Abruzzo and Molise) as members. Although the Central Apennines District Authority remains to be established, some of its functions (such as the coordination and implementation of the district River Basin Management Plans) have been temporarily assigned to the river basin authorities including the Tiber River Basin Authority. As an ongoing process, with the full implementation of the EU Water Framework Directive and Floods Directive, CADA will take over as the TRBA will merge into this Authority.

The regional governments have adopted strategies to reverse the current trend of environmental degradation and to integrate sustainable development principles into their work programmes. These strategies, which form a part of the Central Apennines District Management Plan (Piano di Gestione del Distretto dell'Appennino Centrale) are defined by the Regional Plan for Water Protection (Piano Regionale di Tutela delle Acque) and identify both quality-related and quantity-related measures that make up a holistic approach. The regions have also developed other strategies to address matters not included in the water protection plan, including natural disaster risk management, agricultural development, environmental protection, and energy production from renewable resources.

A comprehensive approach involving the close interaction of district and regional authorities is followed to prevent pollution and to protect water resources. It is the responsibility of the district authority to balance water availability with water demand. To do this, it defines appropriate goals and priorities. The regions then define the actions that are necessary to achieve those targets, including recovering the cost of water supply and sanitation services. The district authority audits these actions to ensure compliance with the goals and priorities. Once the actions are approved, the regions adopt and implement the Regional Plan for Water Protection.

In terms of water resources management, regional governments plan for and manage the services that are provided. For irrigation purposes, each district's rural development plan is taken as basis for helping to improve irrigation networks, wastewater treatment plants and aqueducts. For electricity generation, regional governments prepare plans to develop renewable energy sources, and identify the areas that are most suitable for the construction of hydroelectric power plants.

Water and the environment

The heavy and uncontrolled exploitation of surface water and groundwater resources has had a negative impact on water quality in the basin. Fertilizers used in agriculture along with municipal and industrial pollution have all added to environmental degradation. In 2010, 61% of rivers and 69% of lakes in the TIber basin were assessed to be of sufficient quality or higher. But during the summer, when there is little rain and demand for water peaks, the flow of the some streams is sustained mainly by wastewater returns. The Regional Plan for Water Protection aims to address environmental and water-quality related problems by holding open discussions with the participation of all stakeholders in an effort to identify appropriate actions. Furthermore, the Central Apennines District management plan emphasises EU Directive 42/2001 on strategic environmental assessment regarding the main drivers of water consumption and pollution, such as agriculture, industry, hydropower and drinking water.

The central and regional governments are proactive when it comes to finding solutions to environmental challenges. This is because their overarching objective is to maintain the quality of water resources (which is an integral part of the Central Apennines District Management Plan and the Regional Plan for Water Protection). For example, the Abruzzo and Umbria Regions are implementing their action plans to combat the high level of nitrate pollution, which is a common problem in Italy. These plans focus on the correct use of fertilizers and promote best practices – such as suggesting the appropriate amount of fertilizer to use for various crops, recommending the best periods during which to use it, and advising on the best ways of storing and transporting it. The action plans do this through direct communication with farmers and landowners. In addressing the issue of nitrate pollution, the Central Apennines regions put significant emphasis on public participation. Communication tools such as websites, information sheets and meetings are used to facilitate better interaction between local authorities and stakeholders. This approach also aims to inform stakeholders and help them to tackle the problems associated with nitrate pollution.

An ongoing project in the Marche Region in cooperation with the major Italian energy distribution company, Enel, aims to determine the degree to which increasing the amount of water discharge from dams affects the quality of surface water resources and the recharge rate of aquifers, especially in dry periods. The findings of this project will contribute to a better understanding of how to adjust minimum environmental flow requirements – an area where experimental research is lacking.

Conclusions

The water resources of the Central Apennines District and the Tiber River basin are important for the socio-economic development of central Italy and the country's capital, Rome. Agriculture, which is practised throughout the basin, is the sector with highest water requirement, accounting for over 60% of annual water demand. The sector contributes little to regional GDP, however, and is one of the sources of the ongoing problem of nitrate pollution. Consequently, regional authorities have been implementing projects to curb agriculture's impact on the environment and to reduce the amount of water it uses. Declining water availability, caused by climatic variability and climate change, has also necessitated a revisit of current water policies on allocation and supply. Implementing the EU Water Framework Directive, which was on hold until recently, can help to address the aforementioned challenges of seasonal water scarcity and environmental pollution, while improving public participation in decision making.

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CHAPTER 48

Tagus River basin, Portugal

Acknowledgements Manuel Lacerda, Simone Pio, Santa Clara Gomes, the Office for International Relations of the Ministry of Agriculture, Sea, Environment and Spatial Planning, Portugal, DHV, S.A., Hidroprojecto – Engenharia e Gestão, S.A., Laboratório Nacional de Engenharia Civil (LNEC), International Centre for Coastal Ecohydrology (ICCE), Instituto Nacional de Recursos Biológicos, I.P./IPIMAR; Biodesign, Lda., ARH do Tejo team

Location and general characteristics

The River Tagus has its source in Spain and flows into the Atlantic Ocean near Lisbon in Portugal. The Tagus River basin is home to 9.5 million people and covers an area of 80,550 km^2 – almost one-third of which is in Portugal. At 1,100 km long, the Tagus is the longest river in the Iberian Peninsula and it is an important source of water for both Spain and Portugal. The capitals, Madrid and Lisbon, rely on the Tagus River basin for their water supply, which further increases its critical value.

This case study focuses on the lower section of the basin, which is situated in Portugal (Map 48.1). In 2008, approximately 3.5 million people were living in this area. The basin is subdivided into 23 sub-basins, three of which (Tejo Superior, Erges and Sever) are transboundary.

Water resources, their use and potential effects of climate change

Portugal has a mild Mediterranean climate with distinct wet seasons in autumn and winter. Annual precipitation in the basin varies from 2,700 mm in the mountainous north-east to 520 mm in its westernmost regions. Generally, in summer most of the smaller rivers dry up, whereas intense precipitation in the autumn and winter months often causes floods. However, the flow regime of the Tagus and its tributaries is quite irregular as a result of rainfall variation from year to year as well as on a seasonal basis.

In the study area, the surface water availability (6.3 billion m^3) in average is higher than the groundwater potential (3 billion m^3) (ECOSOC, 2011). However, groundwater use predominates in the majority of the sub-basins.

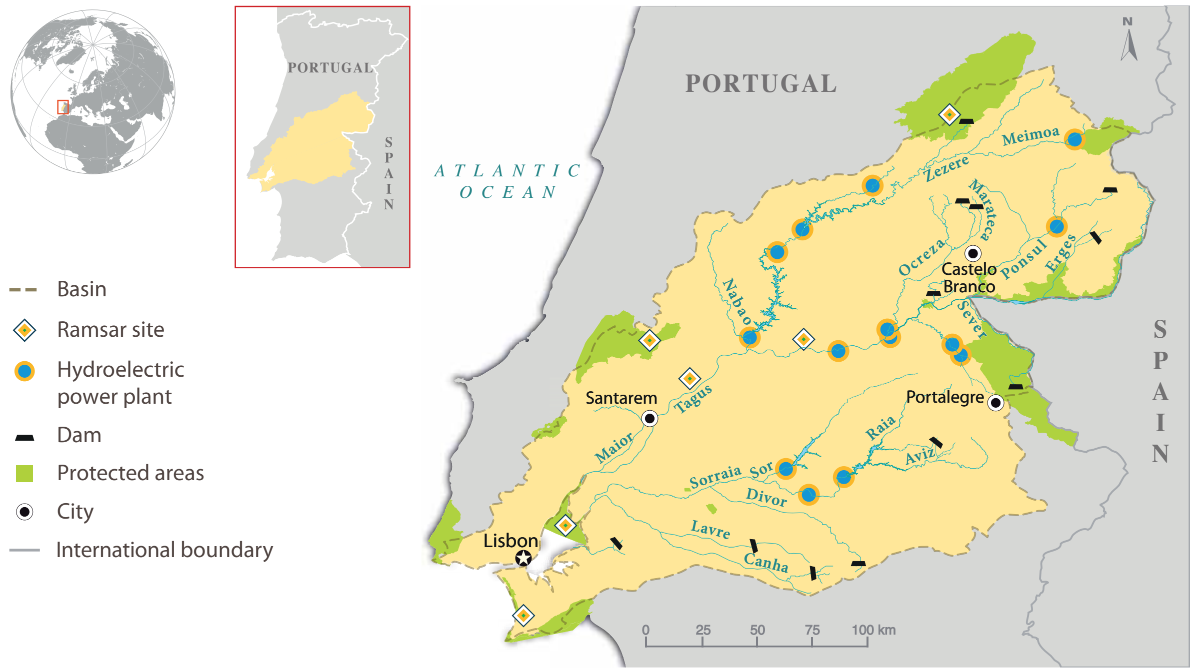
While agriculture and agro-forestry employ only 2.7% of the labour force, approximately 45% of the river basin is given over to farming and forestry. The water requirement of this sector (944 million m^3) accounts for 65% of the total water demand in the basin. The remainder is largely used by municipalities (27%) and to a much lesser extent, by industry (6%).

Overall, the local water stress caused by the seasonal and other temporal variations is more of a concern than water availability. In order to cope with this problem, over 30 dams have been built with a total storage capacity of 2.3 billion m^3.

Climate change scenarios indicated a potential decrease in the amount of precipitation in the order of

MAP 48.1

Tagus River basin



100 mm per year, particularly in the centre of Portugal and to the south. The regional model, however, predicts a 20% to 50% increase in precipitation in winter. This pattern of change may substantially increase the risk of floods. The prediction is that by 2100, the annual mean runoff from the Tagus River basin will be 10% to 30% lower. Such a reduction implies longer periods with low flow, and that is likely to have a negative impact on agriculture and tourism. It is also expected that a reduction in water availability will affect ecosystems, energy production and water quality which is extremely important in terms of human health, ecosystem services and other water uses.

To analyse the long-term trends, Portugal's national water authority (Instituto da Água – INAG) carried out a climate assessment on the period from 1931 to 2000. This study revealed that Portugal's mean annual air temperature had been increasing since the 1970s. Precipitation data for the same period showed a weak decreasing trend that became more pronounced after 1976. Analysis of data also showed an increase in the frequency of both heavy precipitation events and severe and extreme droughts – particularly in the southern regions between 1990 and 2000.

The national water authority assessment also pointed out the imminent threat of rising sea levels. About 75% of Portugal's population lives along the coastal zone, and 85% of gross domestic product (GDP) is generated there (Santos et al., 2002). In accordance with Portugal's 2004 National Climate Change Programme, and its adaptation strategies, a number of complementary actions have been taken including enacting the new Water Law (2005), a revision of the Strategic Plan for Water Supply and Sanitation for 2007–2013 (PEAASAR II, MAOTDR 2006), a revision in 2007 of the original National Climate Change Programme, and the Scenarios, Impacts and Adaptation Measures (SIAM 1 and SIAM 2), research project (Santos et al. 2002; Santos and Miranda, 2006; da Cunha, 2007).

Transboundary cooperation

Spain and Portugal share several rivers. The Albufeira Convention applies to the Minho, Lima, Douro, Tagus and Guadiana rivers and covers issues such as the exchange of information, pollution control and prevention, the evaluation of the transboundary impacts of water uses, the assignment of rights and conflict resolution. The Albufeira Convention is administered by the Commission for the Application and Development of the Convention. This is an intergovernmental technical commission coordinated by the foreign ministries of both riparian countries, with technical support from their environment ministries. Under the Convention, which came into force in 2000 and was revised in 2008, Spain guarantees to release 2.7 billion m^3 of water to Portugal measured at the downstream section of the Cedillo dam. This corresponds to approximately 37% of the annual average river flow (modified hydrologic regime). The current text of the Convention allows for future revisions of the established hydrologic regimes in order to ensure the achievement of the environmental objectives set at basin level and to integrate the climate change issue and adaptation measures.

Environmental status and legal framework

The River Tagus flows into the Tagus estuary, one of the largest estuaries in Western Europe. Because of its rich biodiversity and variety of habitats, the estuary is protected under the EC Directive on the Conservation of Wild Birds, which also makes it part of the Natura 2000 network. It is also classified as nature reserve under Portuguese national legislation.

Water quality in the basin continues to be an issue that demands attention. A series of consultations with stakeholders was conducted as a part of the preparation of a river basin management plan. These consultations identified nutrient enrichment, pollution (organic, microbial, heavy metals, dangerous substances) and eutrophication as the most significant issues influencing water quality degradation in the basin. The preliminary water status assessment shows that 54% of the surface water bodies and 66.7% of the groundwater bodies are classified as good or excellent (ARH do Tejo, 2011).

Nutrient enrichment, particularly in the form of nitrogen and phosphorus, is mainly the result of fertilizer use in agriculture and wastewater discharge from other sectors (including municipal use). To reduce nitrate concentrations in water bodies, the Code of Good Agricultural Practice was drawn up and steps have been taken to raise farmers' awareness by means of nationwide training initiatives. The code sets out general guidelines, mainly with a view to helping farmers to rationalize the use of fertilizers. It also proposes a range of growing techniques and methods that protect surface water and groundwater from pollution (EEA, 2010). A national strategy for agricultural and agro-industrial wastewater treatment (Estratégia Nacional para os Efluentes Agro-Pecuários e Agro-Industriais) was approved in 2007 to define environmentally sustainable solutions and to ensure the reduction, or the elimination of the pollution being caused by discharges from agro-industrial activities.

In relation to reducing urban pollution, the second phase (2007-2013) of the Strategic Plan for Water Supply and Wastewater Treatment (Plano Estratégico de Abastecimento de Água e de Saneamento de Águas Residuais – PEAASAR II) was adopted to make further progress towards attaining the objectives of the EU directives (MAOTDR, 2006). PEAASAR II aims to optimize the management and environmental performance of water supply and sanitation utilities to reduce costs and to maximize efficiency. In 2009, the sewage treatment plant connection rate was 79% in the basin, against a national target of 90% (ARH do Tejo, 2011).

Water resources management and institutions

The first water resources planning exercise took place during the EU Water Framework Directive co-decision procedure (1997–2000). It resulted in the preparation of Portugal's national water plan as well as fifteen separate river basin plans and two regional water plans. Work is still ongoing on the formulation of the revised national water plan and the river basin management plans.

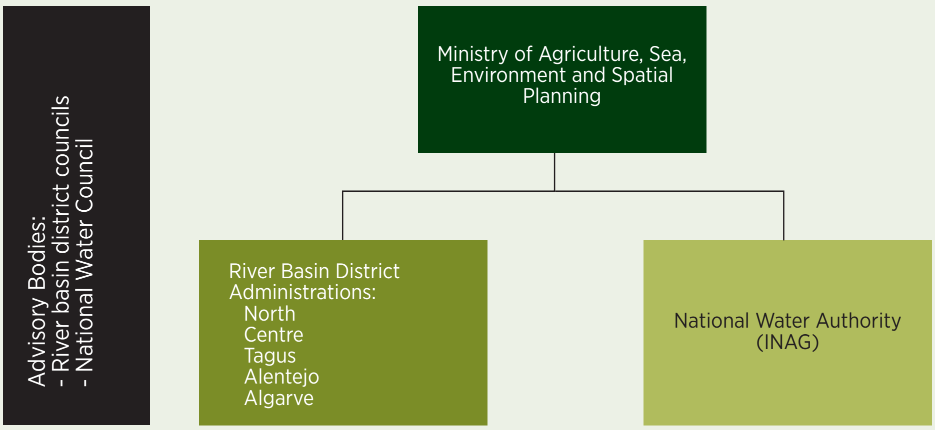
The Water Law was adopted in 2005 as part of the EU Water Framework Directive implementation process (Box 48.1). The law has a broader scope than the EU Directive as it includes all the elements of the integrated water resources management approach, including both quantitative and qualitative aspects, as well as mitigating the effects of extreme events. To complete the legal framework on water resources management, a number of additional regulations were also introduced, notably Decree 226–A (2007) on the

BOX 48.1

The Water Law and the river basin district administrations

The Water Law, adopted in 2005, established a new institutional model in Portugal. It is based on five river basin district administrations and Portugal's national water authority, the Instituto da Água (INAG), which is responsible for water resources planning and coordination in all parts of the country. The district administrations are in charge of water resources management at the basin level – in particular, they look after planning, licensing, infrastructure management, monitoring, and information and communication activities.

In this configuration, the river basin district councils and the National Water Council are the advisory bodies. The district councils provide advice to the district administrations and are composed of representatives from central government, municipalities, the private sector and civil society. The National Water Council makes its recommendations at the governmental level, particularly to the Ministry of Agriculture, Sea, Environment and Spatial Planning. All five river basin district administrations function according to the principles of stakeholder participation (user associations, for example), transparency, coherence, responsiveness and accountability.



establishment of a licensing system for water resources uses, Decree 348 (2007) on the establishment of water users associations and Decree 97 (2008) on the establishment of an economic and financial regime for water resources. Decree 97 aims to implement the 'polluter-pays' and 'user-pays' principles, and integrates the social and economic values of water as well as the environmental aspects of water resources management.

Conclusions

Annual, seasonal and geographic variability in the levels of rainfall the Tagus River basin receives causes water stress at a local level. However, the current challenge facing the basin is to improve the quality of water resources. The interests of the agricultural (such as large-scale irrigation) and agro-industry sectors often conflict with the environmental standards set by the EU Water Framework Directive, leaving water managers and decision-makers with a number of complex problems. While resource availability has been improved by constructing many large dams, this has also caused significant changes in the flow regime, which have had consequences for the ecosystems.

Climate change and climatic variability are concerns in a transboundary setting. Consequently, it is important to assess the water allocation agreement between Portugal and Spain based on climate change studies and to meet environmental objectives set by EU Water Framework Directive. Portugal has been making significant efforts to address current and imminent challenges by developing national strategies and implementing programmes that are holistic and broader in scope than the Directive. It is critical to keep up this momentum as the Tagus River basin lies at the heart of both Portugal and Spain.

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Except where otherwise noted, information in this concise summary is adapted from the *Tagus River Basin Case Study Report,* prepared in 2011 by the Administração da Região Hidrográfica do Tejo, Ministério do Ambiente e do Ordenamento do Território (forthcoming).

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CHAPTER 49

St Johns River basin, Florida, United States of America

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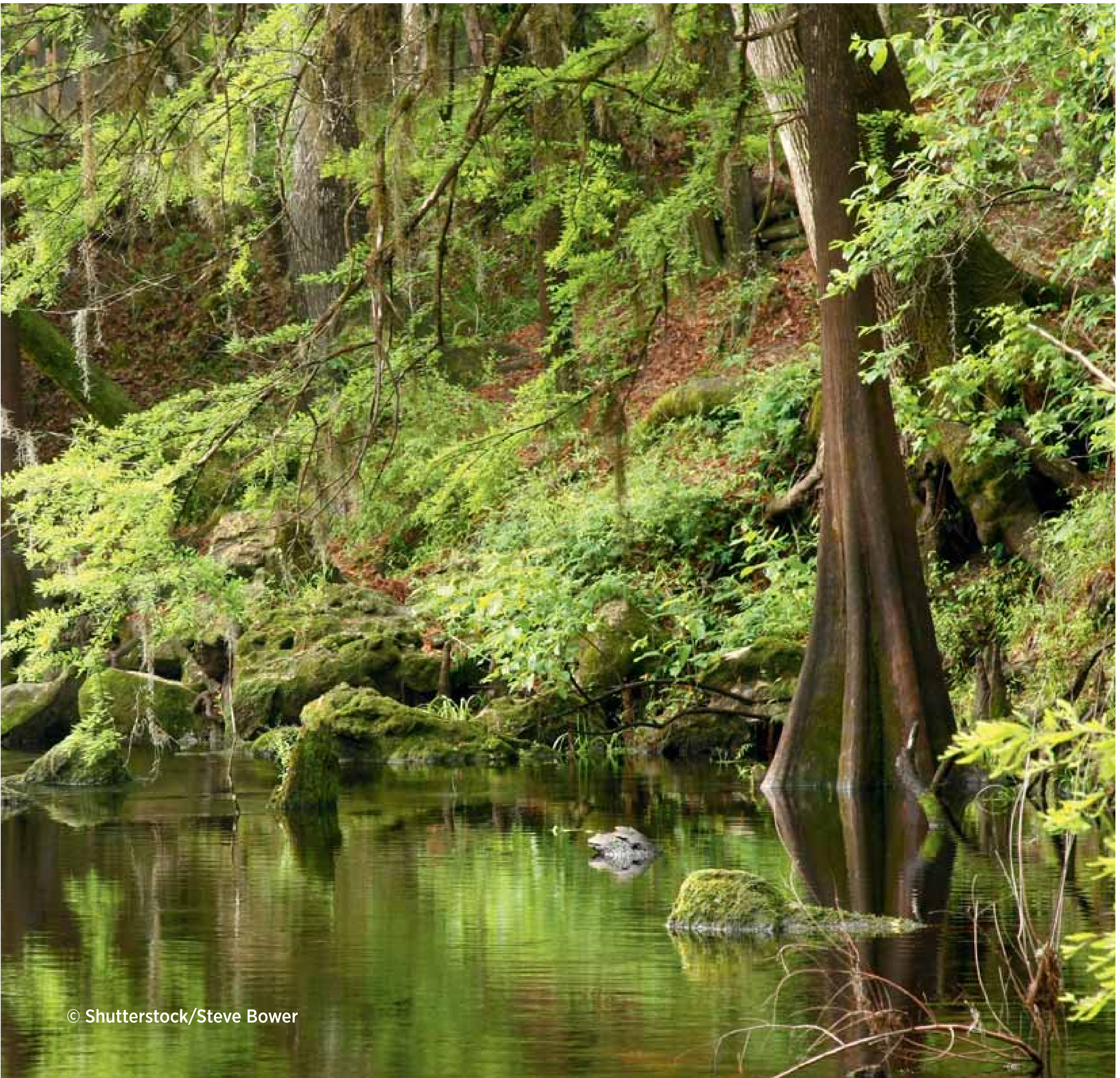
Acknowledgements Radha Pyati, Heather McCarthy, Gretchen Bielmyer, Stuart Chalk, Daniel McCarthy, Gerry Pinto, Lucinda Sonnenberg, Patrick Welsh



Location and general characteristics

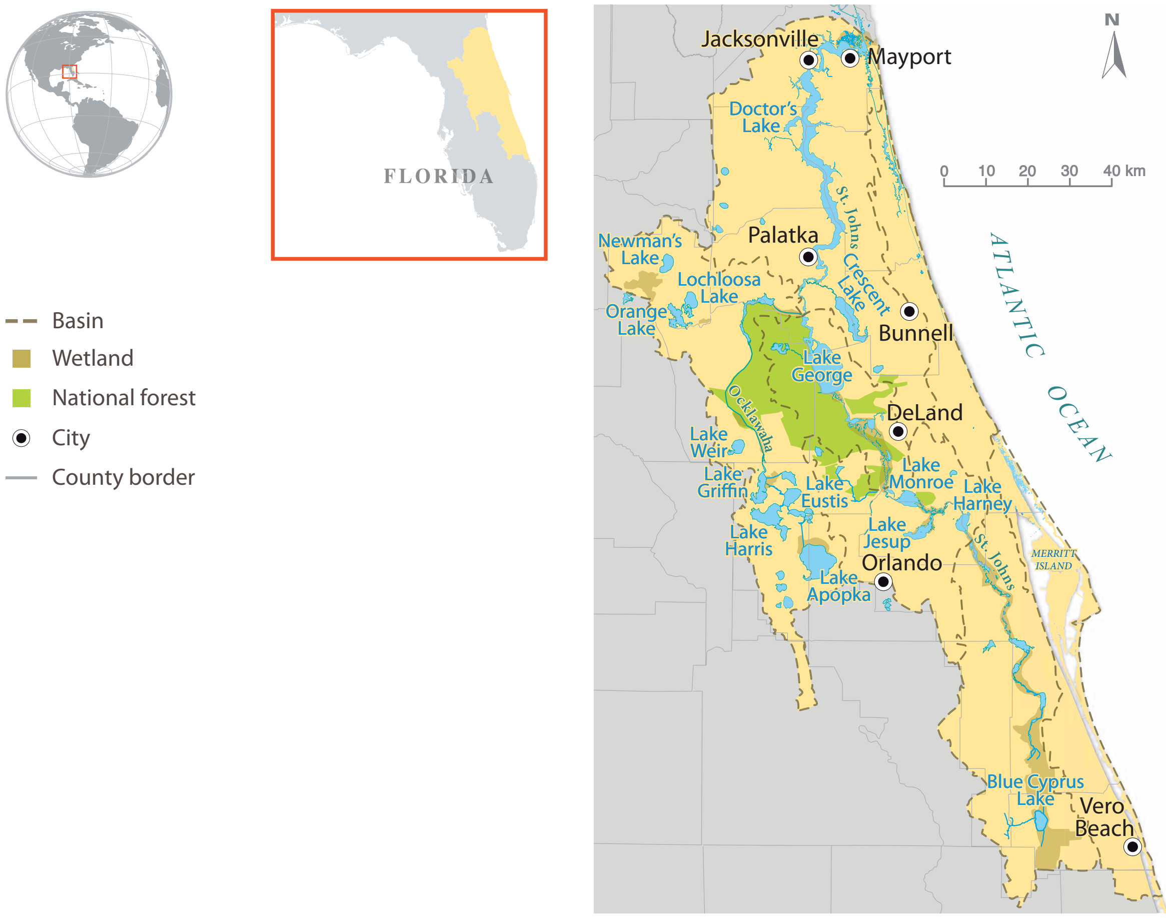
The St Johns River basin lies in central and northern Florida – the most south-easterly state in the United States of America. The river, which is composed of upper, middle and lower sub-basins, rises in Indian River County in Central Florida and flows into the Atlantic Ocean at Mayport, Jacksonville (Map 49.1). The St Johns is one of very few rivers in the USA that runs from south to north. The major tributaries that feed into it are the Ocklawaha River, Dunns Creek, Black Creek, the Wekiva River and the Econlockhatchee River. Over its 500 km long journey, the river flows very slowly as the total drop (the difference in altitude between the source and point of flow into the ocean) is merely 10 metres. Jacksonville, the largest city in the basin, has a population of about 800,000 (2009). Moreover, some sections of the Orlando metropolitan area also lie in the basin. With a drainage area covering 32,000 km^2 or about 25% of Florida, the St Johns River basin is home to approximately 4.7 million inhabitants (St Johns River Water Management District, 2011*a*).

Water resources and their use

St Johns River lies within a humid subtropical zone and rainfall typically occurs in late summer and early autumn. The average annual precipitation in the basin is approximately 132 cm per year and the average annual discharge at the mouth of the river is around 7.5 billion m^3. The Floridan aquifer is an important groundwater source that extends over an area of 259,000 km^2, which includes all of Florida and parts of Georgia, Alabama, Mississippi and South Carolina. Nearly all the drinking water for central and northern Florida, including the St Johns River basin, comes from this aquifer (Marella and Berndt, 2005). The population of the basin is growing rapidly – between 1950 and 2000, the number of inhabitants in Florida increased six fold. The amount of water withdrawal from this aquifer has also steadily increased, and

MAP 49.1

St Johns River basin



reached approximately 5.5 billion m^3 per year in 2000. Nearly 78% of this water was withdrawn in Florida. While a study by the US Geological Survey is currently underway to determine how sustainable current rates of water withdrawal are, the St Johns River Water Management District estimates that the level of abstraction of groundwater is about to reach the limit of sustainable use (District, 2005). The matter of quantity is further complicated by the fact that water quality is threatened by saltwater intrusion and the introduction of contaminants to the aquifer.

The various categories of water uses are listed in Table 49.1. According to projections, by 2030, agricultural consumption will decrease by 12%, whereas municipal consumption (that is, the demand for the public water supply) may increase by as much as 10% (St Johns River Water Management District, 2005.)

In terms of importance, agriculture is second only to tourism in Florida's economy. Important agricultural activities include growing oranges and other citrus fruit as well as cattle ranching for both beef and dairy products. Florida possesses 68.1% of the market share of orange production in the USA. These activities are all typical of the St Johns River basin.

Climate change and climatic variability

Precipitation patterns in Florida are dependent on larger-scale climatic anomalies such as El Niño and the Atlantic Multidecadal Oscillation. Climate change could amplify the effects of these anomalies and make rainfall patterns even more unpredictable. However, in the southern parts of the state, the effects are expected to be a decrease in rainfall during both the dry and the wet seasons, a loss in dry season refugia[1] and saltwater intrusion. Sea level rise, a phenomenon associated with the melting of polar ice caps as a result of global warming, poses a significant threat to the St Johns River basin because of its low-lying nature. According to estimates, sea levels in Florida may rise by as much as 35 centimetres by 2080. The general consequences of this include the inundation of low-lying areas and salt-water intrusion into aquifers and estuaries. Preliminary results of modelling studies being conducted near the mouth of the St Johns River indicated that areas of open water and estuary channels may already be elevated and the marshes near the river mouth are likely to be inundated more frequently. However, only a small area of the marsh would actually change from being 'regularly submerged' to 'fully submerged'.

TABLE 49.1

Annual water use by category in the St Johns River basin, 2010

Category	Freshwater (million m^3)	Saline water (million m^3)	Water reuse (million m^3)	Total water use (million m^3)	%
Public supply	742.29	0.00	0.00	742.29	40.26
Domestic self-supply and small public supply systems	93.62	0.00	0.00	93.62	5.08
Commercial/industrial/ institutional self-supply	134.52	3.84	31.32	169.68	9.20
Agricultural irrigation self-supply	570.95	0.00	10.57	581.52	31.54
Recreational self-supply	88.03	0.00	157.48	245.51	13.32
Thermoelectric power generation self-supply	11.18	0.00	0.00	11.18	0.61
Total	**1,640.59**	**3.84**	**199.37**	**1,843.80**	**100.00**

Note: Source of domestic self-supply is assumed to be groundwater and domestic self supply is an estimate. Estimated amounts are based on best available data at the time of publication.
Source: St Johns River Water Management District (2011a).

Droughts, floods and hurricanes are the natural disasters that cause socio-economic losses in the State of Florida. The 2004 and 2005 hurricane seasons were especially notable for the frequency of major storms and the extent of hurricane damage. The 2004 season included four major storms that caused the highest cumulative single-year damage costs in Florida's history (Malmstad et al., 2009)[2].

Droughts and floods also have a significant impact on the St Johns River basin. Tropical storm Fay deposited over 40 cm of rain in a five-day period in Brevard County in 2008. The water level rose by approximately two metres in Seminole County in four days, setting a record. Overall, the storm led to severe flooding in the middle section of the basin and caused damage of an estimated half a billion dollars over three neighbouring states, Florida, Georgia and Alabama (Stewart and Beven, 2009). In spite of uncertainty in predicting the impact of climate change on meteorological extremes, there is a possibility that these events will become both more frequent and more severe.

Environment and ecosystems

The St Johns is a blackwater river. Dissolved organic matter from decaying plants in swamps dissipates across the basin reducing the depth of light penetration and giving the river its dark colour. Other issues that affect water quality and environmental conditions in the basin are slow flow, salinity fluctuation, marshland destruction and human-induced pollution (St Johns River Water Management District, 2011*b*).

The river's extremely low gradient slows the flow, holds back drainage, decelerates the flushing of pollutants and intensifies flooding and pooling of water along its length. This creates numerous lakes and extensive wetlands throughout the St Johns River basin. The retention time of the water (and its dissolved and suspended components) in the river is around three to four months. The high retention times of pollutants have severe impacts on water quality.

A number of salty springs feed into the basin and cause localized areas of elevated salinity (>5 ppt) in otherwise freshwater sections of the river. Reverse flows triggered by weather conditions and massive ocean tides cause the river to flow in an upstream direction. And this too results in abrupt changes in salinity. Reverse flows have been detected as far as 257 km upstream. Such variations in salinity have profound hydrological and ecological effects.

Wetlands are vital to the Northeast Florida ecosystem. However, in the Upper St Johns River basin, the marshes have been drained to grow citrus fruit and for animal husbandry. Trends in wetland coverage cannot be accurately established because of insufficient and inconsistent information. On the other hand, since 1988, the St Johns River Water Management District and the U.S. Army Corps of Engineers have restored and enhanced more than 600 km^2 of marshes in Indian River and Brevard counties (St Johns River Water Management District, 2011*b*). However, because of habitat loss, increased boating traffic and drought, some species such as the Florida manatee, the wood stork, the shortnose sturgeon, the piping plover, the Florida scrub jay and the eastern indigo snake continue to be vulnerable and face extinction.

Every year, more than 14,000 tonnes of nitrogen and phosphorus enter the St Johns River – mainly as a result of the disposal of partially treated sewage (St Johns River Water Management District, 2011*c*). Other significant pollution sources include farms in the agricultural areas of Flagler, Putnam and St Johns counties. Agricultural runoff from farming areas carries animal waste, fertilizers and pesticides into the river. Storm water from urban areas also takes pollutants such as lawn fertilizers, sediments, pesticides and trash into the river. Consequently, nutrient levels in the river's main stem and faecal coliform levels in the tributaries exceed limits set by water quality standards. In addition, because of the river's slow flow, the lower St. Johns River in particular is facing pollution problems. These include the growth of algal blooms which block sunlight from reaching underwater vegetation, produce toxins, deplete dissolved oxygen and endanger fish and other wildlife. Efforts are ongoing to reduce nutrient loading by setting a total maximum daily load (TMDL), by drawing up a Basin Management Action Plan, through collaboration between government and industry and public education.

Water resources management

Federal laws on water resources include the Clean Water Act (CWA) and the Safe Drinking Water Act (SDWA). The CWA, which was passed in 1972 and amended in 1977 and 1978, shifted the focus of pollution control from being solely oriented towards water-quality standards to looking at ways of limiting effluent from point sources. Following the CWA, the SDWA was passed in 1974 and amended in 1986. With it came the establishment of monitoring and water-quality standards for all public water supply systems. In the State of Florida, the Florida Department of Environmental Protection (FDEP) and other entities implement these efforts.

In 1972, the Florida Legislature passed the Florida Water Resources Act, which established five water management districts in the state, supervised by the FDEP. Each district was tasked with managing water resources in its basin, granting permits for water use, developing and implementing flood control and drought planning projects, performing technical and scientific evaluations of water resources in the basin and acquiring land to protect water resources and habitats. The St Johns River Water Management District is one of these five districts.

Unfortunately, in the years since it was passed, the FWRA has not been able to assure water availability or quality. This is because many exceptions have been made to the laws – mostly in order to enable population growth and land development in Florida – which have significantly weakened the impact of the Act. The 1972 CWA had more direct impact on water quality issues but some of its provisions, particularly on TMDLs were not actively enforced by the U.S. Environmental Protection Agency (EPA) until citizen lawsuits in the late 1990s forced the agency to start collecting information from states on water resources that did not meet quality standards.

Florida's enforcement of TMDLs effectively began in 1999 with the passage of the Watershed Restoration Act. Following that law, all the water bodies in the state were organized into basins, which were further collected into groups. The basins were assessed in a five-year cycle to address their TMDLs. Basically, the TMDL programme establishes total amounts for a number of pollutants (both point sources and non-point sources). These total amounts are the maximum levels that can be absorbed by a specific water body without breaching the water quality standards set to protect human health and aquatic life. Once a TMDL is drafted and approved (which includes a time period for public comments and discussion), it is implemented through a Basin Management Action Plan, which prescribes strategies such as wastewater treatment improvements, redirecting wastewater discharge toward reuse, prescribing best-management practices in agricultural, urban, and rural settings, and facilitating environmental education. Nutrient TMDLs have been successfully established for the lower, middle and upper basins. In addition, Basin Management Action Plan have been developed for a large number of water bodies and pollutants, including several within all stretches of the river and its tributaries. However, the lower St Johns River basin is the only section of the river with a nutrient Basin Management Action Plan which it adopted in 2008.

Conclusions

Despite high levels of rainfall, water supply has become a contentious issue in Florida. The growing population and ever greater demands for water are putting increasing pressure on water resources, notably on the Floridan aquifer system that provides drinking water for five states. The river's slow flow and continuous disposal of partially treated wastewater mean that both phosphorus and nitrogen levels generally exceed EPA recommended standards in both the main stem of the St Johns River and its tributaries. Dissolved oxygen concentrations also fall below the site-specific minimum standard in several tributaries. Consequently, water quality in both surface and groundwater is becoming a major concern. Although institutions are in place both federally and at state level, a lack of enforcement of the legislation up to the 1990s has caused basin-wide degradation. While restoration and prevention activities by state and local governments in the St Johns River basin are ongoing, there is a clear need to compound these efforts by involving other governmental agencies, organizations and the public.

Notes

1 Refugia are the water-holding areas that offer refuge to a variety of species during a dry season.

2 Hurricanes Charley, Frances, Ivan and Jeanne caused a combined damage of US$49 billion in Florida.

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Except where otherwise noted, information in this concise summary is adapted from the *Case Study Report of St Johns River basin, Florida, USA* prepared in 2011 by Pyati et al. (forthcoming).

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CHAPTER 50

Costa Rica

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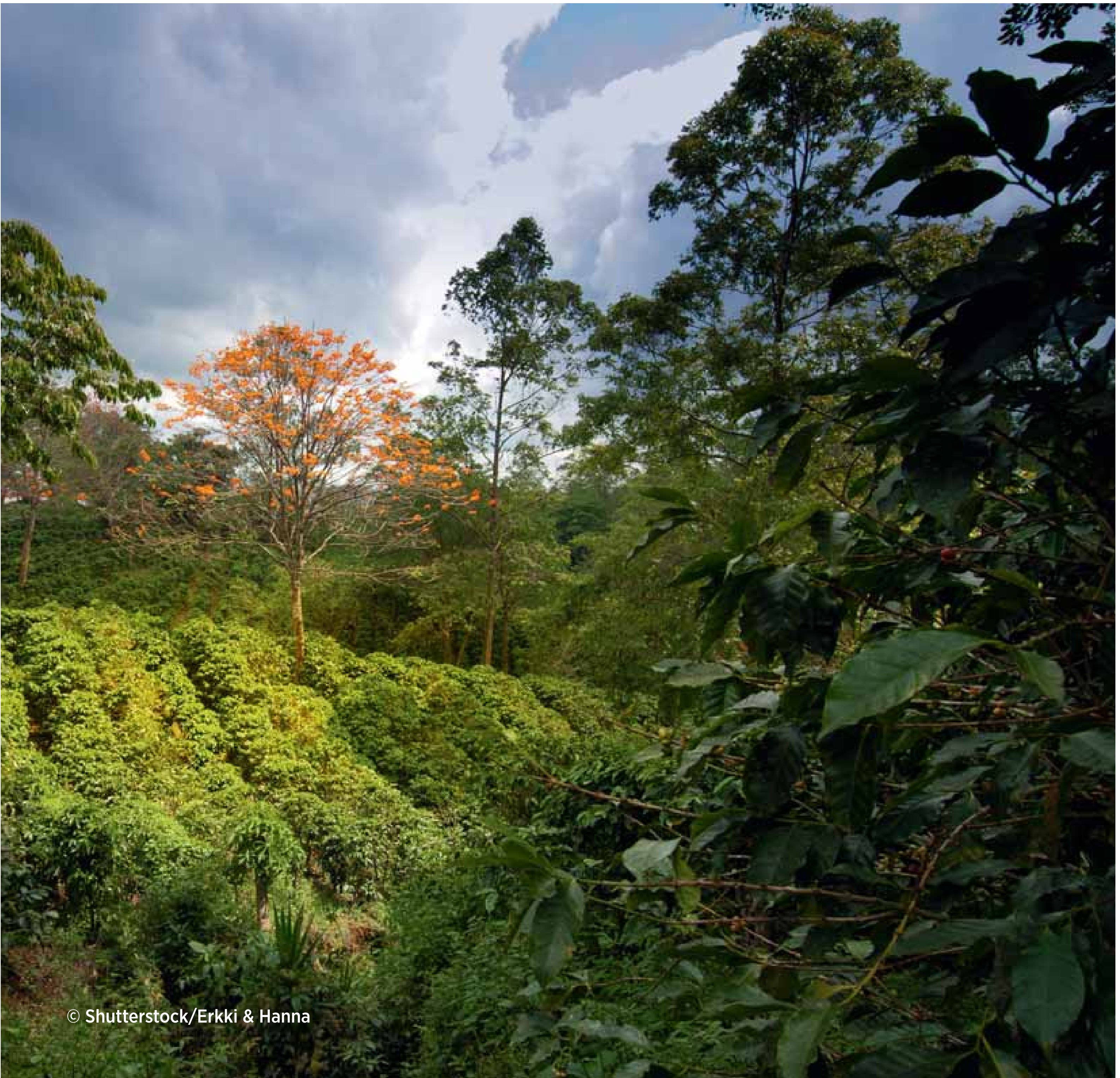

Location and general characteristics

Costa Rica is located in the narrowest part of Central America, bordered by Nicaragua to the north and Panama to the south. To the east, it forms a coastline with the Caribbean Sea and to the west, with the Pacific Ocean (Map 50.1). The surface area of the country is around 50,000 km^2.

Costa Rica's population in 2010 was slightly over 4.6 million – about 59% of whom live in urban areas. The capital, San José, is the largest city in the country, with a population of 1.6 million. There are seven provinces – Alajuela, Cartago, Guanacaste, Heredia, Limón, Puntarenas and San José (FAO–Aquastat, n.d.). The provinces are divided into six regions for planning purposes – Chorotega, Huetar Atlantic, Huetar North, Central Pacific, Central and Brunca.

There are many volcanoes in the country, some of which are still active. The Poás (2,708 m above sea level), located in the Central Highlands, is one of Costa Rica's largest and most active volcanoes (Arenal.net, n.d.).

The country lies in a humid tropical zone. While the amount of rainfall varies from one basin to another, Costa Rica has annual average rainfall of 3,300 mm (UNESCO IHP, 2007). In general, the north of the country on the Pacific side is drier than the Caribbean region, which is humid almost all year round. The rainy season extends from May to November on the Pacific side, and from May to February on the Caribbean side. Forests cover approximately 25,000 km^2, or approximately half the country's land surface.

Water resources availability and their use

There are 34 river basins in Costa Rica, ranging in size from 200 km^2 to 5,000 km^2 (FAO–Aquastat, n.d.). Unfortunately, reliable information is available for only 15 of those basins. The country has total renewable water resources of slightly more than 110 billion m^3 (MINAET, 2008*a*). Of this, surface water accounts for 73 billion m^3.

Research initiatives begun in the 1960s helped to identify 58 aquifers across the country, 34 of which are coastal. As a result of seasonal shortages in the availability of surface water and growing pollution, the exploitation of groundwater has become more common. According to estimates, annual water demand is approximately 23.5 billion m^3 (2010), almost 88% of which is met by aquifers. Consequently, the

MAP 50.1
Costa Rica

sustainable exploitation of groundwater resources is of great importance.

The Central region has the biggest demand for water in the country because more than half the population lives here and there is a high concentration of industrial and economic activity (Mora Valverde, n.d.). Nationwide, generating hydroelectricity accounts for 80% of total water demand, followed by agriculture at 16%. The remaining 4% is used for drinking water, and by industry and tourism. Given that the water used for hydropower generation returns to the flow without loss, agriculture remains the largest user (3.2 billion m^3) in terms of actual consumption. In 2008, agricultural activities were practised over approximately 4,190 km^2 of land (8% of national territory), 920 km^2 of which were irrigated. Some 70% of the irrigated land is developed by the private sector, and the most important agricultural products grown are coffee, rice, African palm, sugar cane, banana and pineapple (SEPSA, 2009).

The sectors that contribute most to economic growth are industry at 32.5% and agriculture at 14% (MINAET/IMN, 2009). Unfortunately, 80% of water contamination originates in these two sectors. Urban settlements are also a big source of pollution because only around 3% of wastewater is treated prior to being disposed of into nature (FAO–Aquastat, n.d.).

According to various scenarios, water demand may substantially increase by 2030 to reach approximately 109 billion m^3, the upper limit of freshwater availability in the country. However, the energy sector will continue, by a large margin, to be the major (non-consumer) water user, processing 100 billion m^3 in hydroelectricity generation. Consequently, the main challenge will not be water scarcity but to plan for water use in an integrated fashion to be able to satisfy the demand of all sectors.

Natural disasters, national strategies and climate change

Central America and the Caribbean region are highly vulnerable to extremes of climate. Of 248 hydrometeorological disasters between 1930 and 2008, some 85% were floods, tropical storms, landslides or mudslides, while 9% were droughts.

Because of the steep slopes of the mountainous terrain, rivers run fast in the central part of Costa Rica, and are known to cause violent floods. Urban development, deforestation, and channel modification, especially in the Caribbean slope and the South Pacific, have worsened these conditions, causing floods to affect ever larger human settlements, agricultural areas, infrastructure, and nature reserves. Consequently, between 1994 and 2003, approximately 120,000 people and 17,000 housing units were reported to have been affected by floods, landslides, and windstorms. As recently as 2010, heavy rain and mudslides affected over 2,000 km of national roads, and caused US$242 million worth of damage. The same year, over 3,000 houses were damaged, at an estimated cost of US$50 million. The loss to agriculture was in the vicinity of US$40 million. To a lesser extent, the country is also prone to drought. In fact, recurring droughts in 1997 and 1998 and again in 2001 caused a combined economic loss of US$18 million.

Risk management in Costa Rica has gone through a process of institutionalization. The 1969 Emergencies Act led to the establishment of the National Commission for Risk Prevention and Emergency Response (ComisiónNacional de Prevención de Riesgos y Atención de Emergencias) and the National Emergency Funds. Later amendments to the law required the integration of risk management into the planning activities of all national institutions as well as into all national development policies.

Costa Rica is understandably concerned with the likely effects of climate change. Current climatic models indicate the possibility that, by 2100, temperatures may have increased as much as 3.8°C, precipitation may have decreased by up to 60%, and the sea level may have risen by as much as one metre (World Bank, 2009). Under a business-as-usual scenario (that is, no reduction in carbon emissions), by 2100, the cumulative cost of climate change in Central American countries is estimated to reach approximately US$52 billion (2002 US$ reference). In Costa Rica alone, additional investment of as much as US$3.4 billion may be required for the adaptation of sectors relying on water and biodiversity for the provision of their services. Given that heavy financial burden, and the potentially severe implications of climatic extremes, a National Strategy on Climate Change has been established and is being overseen by the Ministry of Environment, Energy and Telecommunication (MINAET). This strategy aims to improve overall efficiency in all sectors, with the goal of reducing greenhouse gases. The strategy document also estimates that the largest amount of investment (71%) needs to be made in the energy sector, followed by agriculture (21%), to compensate for the effects of climate change (Box 50.1). These two sectors have traditionally been financed through external funds. The most important source of internal funding for climate change adaptation is the National Fund for Forest Financing (Fondo Nacional de Financiamiento Forestal), established by the Forestry Law and linked to payment for ecosystem services. In line with the 'Peace with Nature' initiative, promoted by President Oscar Arias Sánchez, Costa Rica has pledged to become a carbon neutral country by 2021.

Water resources management: National strategy and water policy

Costa Rica's national strategy has the overarching aims of boosting economic development and increasing human welfare, in harmony with the environment (MINAET, 2008*b*). Integrated water resources management (IWRM) is central to this strategy. As a result, the State has established a number of guiding principles for water policy that identify water as a public good, and access to drinking water as a human right under the constitution. Other important issues identified by the strategy document include the equitable use of water resources, the improvement of water infrastructure and the application of technology to improve the efficiency of water use and curb water pollution. It also highlights the importance of the economic valuation of water, the promotion of integrated, decentralized, and participatory basin management programmes, and the protection of water resources for human well-being and the protection of ecosystems.

The National Water Policy seeks to harmonize the priorities of economic growth, poverty reduction and nature conservation through IWRM, the aim being to ensure that both water quantity and quality meet the demands of sustainable national growth (MINAET, 2009). In terms of national water security, the policy has six strategic priorities: increasing the competitiveness of domestic industry, promoting holistic water management, ensuring the sustainable use of water resources, creating a water culture, mitigating the effects of climate change, and involving public participation in decision-making processes.

There are a number of institutions involved in implementing and overseeing the National Water Policy. MINAET is the lead agency responsible for implementing the 1942 Water Law. The Water Board (Dirección de Agua) and the National Register of Concessions are other national bodies that support MINAET's efforts through promoting the rational use of water resources and centralizing inquiries for water abstraction. The National Service of Groundwater, Irrigation and Drainage (Servicio Nacional de Aguas Subterráneas, Riego y Avenamiento) is a public agency that promotes sustainable agricultural development through efficient management and the use of surface water and groundwater. The Costa Rican Water and Sewer Institute (Instituto Costarricense de Acueductos y Alcantarillados) provides drinking water and sanitation services in both urban and rural settlements. The Institute also aims to conserve river basins and to reduce water pollution. The Costa Rican Institute of Electricity (Instituto Costarricense de Electricidad) is the main operator providing electricity and telecommunications services.

In terms of a legal framework, the Water Law, which has been relied on to regulate all aspects of water use is outdated. The reality is that in a time of increasing demand for water and growing competition among different sectors for the resource, it no longer provides sufficient means to manage and protect the country's water resources. In recognition of this, MINAET is drafting a water bill to modernize the current water management policy.

Poverty, access to water supply and sanitation services

According to the 2010 National Household Survey (INEC, 2010) approximately 21% of Costa Rica's population lives in poverty, while 6% face extreme poverty every day. The incidence of poverty in rural areas is significantly higher at 26.3% than in urban areas at 18.3%. There is a marked difference also in terms of gender equality, with the number of men in work significantly higher than the number of women (71.4% and 39.4%, respectively). This illustrates the greater difficulty that women face in the labour market and in gaining access to employment.

In general, 99% of the population has access to safe drinking water (2009), almost all of which is piped to their premises. In rural areas, the rate of access is 92%. Access to improved sanitation is equally high at 95%. However, only 40% of the urban population and 4% of rural dwellers are served by the sanitation infrastructure (WHO/UNICEF, 2010).

Protection of Environment and Biodiversity

Costa Rica, in spite of its small size, accounts for approximately 6% of the world's biodiversity. That is because of its geographical location and its varying landscape, which ranges from islands and beaches to rainforests (Embassy of Costa Rica, n.d.). Since the middle of the last century, Costa Rica has developed an extensive network of protected areas, totalling approximately 26% of its land surface. Cocos Island and La Amistad, for example, are two renowned national parks which have received international recognition as UNESCO World Heritage Sites.

Costa Rica, as a signatory to 45 international environmental treaties, has also enacted a number of regulatory instruments such as the Organic Law, drawn up by the Ministry of Environment and Energy (1993), the Environment Law (1995), and the Forestry Law (1996). The Biodiversity Act (1998) deals specifically with the protection of biodiversity and endangered species. The National System of Conservation Areas, which operates within the MINAET, is responsible for promoting the conservation of biodiversity and the sustainable use of forests, mangroves, wetlands, and forest plantations (Embassy of Costa Rica, n.d.). In addition, the National Biodiversity Institute was established in 1989 as a private, not-for-profit, organization to carry out monitoring and research. Its key aims are the establishment of a biodiversity inventory, the promotion of conservation activities, and the provision of data which inform decision-making in relation to the protection and sustainable use of biodiversity.

Costa Rica has pioneered the use of 'payment for environmental services', by establishing a countrywide mechanism –locally known as Pago de Servicios Ambientales – to charge users for the environmental services they receive. In spite of initial difficulties caused by the reluctance of service users to pay for conservation, the programme is now well established within Costa Rica and widely perceived as successful (Pagiola, 2006).

In line with the Peace with Nature initiative, which aims to make Costa Rica carbon neutral by 2021, 93.6% of electricity is generated using renewable sources of energy, notably hydropower. Similarly, the 2007–2021 strategic plan developed by the Costa Rican Institute of Electricity (Instituto Costarricense de Electricidad) foresees further development of hydropower through the construction of dams with the minimum possible environmental impact, and the use of alternative sources of power such as wave, wind and geothermal energy. This plan will require an investment of US$1.4 billion (2005 US$ reference).

However, the other side of the coin is that population growth, the expansion of urban settlements, industrial development and the intensification of agricultural

BOX 50.1

Potential implications of climate change on agriculture

In 2008, approximately 20% of cultivated land in Costa Rica was irrigated. A vulnerability study has been conducted in the three most important river basins, the Reventazón, the Grande de Terraba and the Grande de Tárcoles, using climate scenarios in which temperatures increase by 1°C to 2°C, with changes in precipitation of ±15% on the Pacific side and ±10% on the Atlantic side. Results predict that marked variations in water flow will occur in these areas, which will affect agriculture especially during the transition between the dry season and the rainy season.

There is also expected to be an increase in floods, which will have a direct impact on irrigation systems and lead to more soil erosion. At the same time, there will be an increase in the frequency of droughts in some parts of the country, leading to less water for irrigation.

According to an analysis of the vulnerability of water resources to climate change, the country's most vulnerable regions are those where most land is used for agriculture, or areas where there is conflicting land use. In 2009, Costa Rica's Second National Communication to the United Nations Framework Convention on Climate Change examined several adaptation measures concerning water resources. These included the following: water storage facilities, the protection of aquifers, the monitoring of water resources, water rationing and projects aimed at increasing water efficiency in irrigation.

Source: Modified from the World Bank (2009).

activities, including livestock production, have all led to an increase in the amount of contaminants. These range from industrial, agricultural, and solid waste, to agro-chemicals and sewage, and they are being discharged into Costa Rica's water bodies. Nationwide, only 3.6% of sewage is treated. Consequently, many streams, rivers, and aquifers are polluted to varying degrees.

An example of this complex and growing problem is the Tárcoles River basin, which is home to 51% of the population and 85% of the country's industries. Severe pollution in the major rivers of this basin and in some tributaries of the Virilla River (such as the María Aguilar, the Torres and the Tiribí rivers) has considerably limited water availability in the most economically developed region of the country. While this is an impediment to sustainable development, it also raises serious health and environmental concerns (GWP, 2011).

Conclusions

Costa Rica, with average annual water availability of 24,000 m^3 per capita, is well endowed in terms of water resources. While rainfall is abundant, seasonal shortages in surface water have prompted the widespread exploitation of aquifers. However, greater use of water in all sectors, combined with increasing population density, has led to the contamination of rivers and some aquifers, such as those in the Central Valley, where more than half the population lives.

On the positive side, Costa Rica is the first country in the world which has pledged to become carbon neutral by 2021. This aspiration goes hand in hand with the efforts to protect the country's rich biodiversity and environment. Almost 94% of electricity production already comes from renewable resources, and the government aims to promote further diversification into renewable forms of energy such as wave, wind and solar power, in addition to hydroelectricity.

Costa Rica is also a pioneer in Latin America in terms of the implementation of Payment for Ecosystem Services, which, in turn, generates national funds for climate change adaptation. The major challenges are to update the obsolete Water Law, improve legislation and mechanisms that deal with extreme events, and reduce poverty. Enhancing hydrometeorological information by extending research and monitoring activities to all the river basins, ensuring the sustainable use of groundwater resources, extending sanitation coverage, and curbing pollution, are some of the issues that now require further attention at national level.

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Except where otherwise noted, information in this concise summary is adapted from the Costa Rica Case Study Report, *Informe de Recursos Hídricos de Costa Rica (Recopilación)*, prepared in 2011 by the Costa Rica IHP National Committee, the National Institute of Statistics, and the Costa Rican Institute of Electricity (forthcoming).

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CHAPTER 51

Lerma–Chapala basin, Mexico

Acknowledgements Gerencia de Ingeniería y Normas Técnicas (Subdirección General Técnica), Comisión Nacional del Agua - Mario López Pérez, Colin Herron, Mestre Rodríguez

Location and general characteristics

The Lerma River is the longest inland watercourse in the United Mexican States (Mexico from here on). It rises at about 3,800 m above sea level in western central Mexico. After covering a distance of 750 km, the Lerma flows into Lake Chapala (1,510 m above sea level), which is the largest natural lake in Mexico. The entire Lerma–Chapala basin is located in a high altitude area with mountain chains and extensive valleys. It covers a total area of 54,451 km^2 and includes portions of five States: Mexico, Queretaro, Michoacán, Guanajuato and Jalisco.

Overall, the climate in the basin is warm. However, it ranges from semi-hot and humid in the central and southern areas, to dry and temperate in the northern areas. The winters are relatively cold, and the summers are semi-humid. Depending on the location, rainfall varies from around 270 mm to more than 1,000 mm per year, with 825 mm being the average. Most rainfall occurs in the high plateaus and peaks between April and early October, with the second half of the season (from mid-June until mid-October) usually bringing the heaviest rainfall.

The Lerma–Chapala basin is home to approximately 10 million people. In 2005, population density in the basin was roughly four times the national average. In terms of productivity, the basin generated 11.5% of Mexico's gross domestic product (GDP) in 2009. Industry represents almost 25% of the basin's contribution to the national economy. The automobile industry is particularly advanced, with 50% of the country's automobile production located here. Economic activity is concentrated in specific cities such as Leon, Silao, Toluca, Queretaro, Morelia, Irapuato, Salamanca and Celaya. As a result, more than 50% of the basin's total value-added production takes place in just seven of its 127 municipalities.

Water resources availability and their use

Compared to other river basins in Mexico, the Lerma–Chapala basin is not rich in terms of water resources. The Lerma River has average annual water potential of 4.9 billion m^3. During the dry season, which extends from early November until mid-May, it becomes a shallow river with a modest flow. Lake Chapala itself is a shallow tropical lake, with mean depths of 7.2 m, and never deeper than 18 m along its 1150 km^2 influence area. The lake is the most important water source for the Guadalajara Metropolitan Area, providing almost 75% of its water supply. Its water level drops rapidly in response to over-use of water, and recharges rapidly in the rainy season.

There are 40 aquifers in the basin, with a combined annual renewable capacity of 4.1 billion m^3. Groundwater is a crucial resource in the basin and is used heavily. In 2004, for example, 79.3% of all water rights in the Lerma–Chapala basin were granted in

MAP 51.1

Lerma–Chapala basin

relation to groundwater resources. Because of this substantial use of aquifers, overdrafting has been a concern since the early 1970s. Today, about 70% of aquifers in the basin, most notably in Guanajuato, are being pushed beyond their sustainable limits. In fact, since the 1980s, water demand has commonly exceeded availability almost every year. Overall, total annual abstraction exceeds recharge by approximately 1.3 billion m^3 (2011). When this is combined with water-quality degradation and immigration, it is clear that the current water availability per person, which stood at 932 m^3 in 2010, is likely to worsen.

The basin boasts the highest rate of agricultural land use in Mexico, thanks to a combination of fertile soil and favourable climatic conditions. In 2000, approximately 30,000 km^2 of land (56% of the basin) was allocated to agriculture. Rainfed agriculture is most common, practised over 41% of the basin, while the rest of the cultivated land (15%) is irrigated. Maize and sorghum are the main crops and are planted on 65% of the agricultural land. Water demand from this sector accounts for roughly 80% of all water abstraction, whereas the sector's contribution to GDP is around 5%. By comparison, water demand from industry accounts for less than 4% of overall water use, while the sector generates around 23% of the basin's GDP (2009).

To improve water efficiency in all sectors, water tariffs have been increased to reflect more accurately the real cost of service provision and maintenance. Between 1989 and 1994, the price of irrigation water increased ten-fold. In addition subsidies were offered favouring farm investments that led to more efficient water use. Unfortunately, public interest is waning because the pay-out is seen as insufficient, and in some areas, tariffs are still well below real costs. Furthermore, because the water revenue goes straight to the Mexican Federal Treasury, and regions do not benefit directly, people's willingness to pay remains limited. Consequently, there is an immediate need to define appropriate mechanisms for the redistribution of water revenue.

Climate change and water-related disasters

Since the early 1920s, there has been a gradual increase in the difference between mean summer temperatures and mean winter temperatures – or, in other words, warmer summers and colder winters. Such trends can be seen clearly between 1985 and 2010, when average temperatures rose by almost 2°C in spring and summer, and dropped by a similar average in winter.

Rainfall patterns also indicate a movement towards extremes: less precipitation during the dry season, with more violent storms; and greater surface run-off in the wet season. Overall, in the 40-year period up to 2010, annual rainfall and surface run-off has decreased by some 3.6%. Since the 1900s, analysis of long-term rainfall data indicates a series of alternating wet and dry periods, each lasting several years. Droughts occur in the basin almost every decade and may last up to five years or more. The most recent drought, which lasted for 10 years from 1993 until 2003, is a notable example. In 2002, the water level in Lake Chapala dropped to 14% of its capacity, the second-lowest level recorded since data collection began in 1934. The worst droughts usually occur in the northern sub-basins where the climate is drier.

Greater climatic variations have affected the opposite end of the spectrum too, leading to more frequent floods. Heavy rainfall (defined as 20% or more above the monthly or yearly average), of an intensity that leads to flooding disasters, typically returns every three to six years. The probability of floods is higher in the southern part of the basin; however, such events also affect the central and western portions of the basin, with considerable damage to urban settlements, industry and farmland.

Over 500 dams and reservoirs in the basin provide structural safeguards against water-related natural disasters. However, increasing vulnerability, specifically to floods, calls for the adoption of a basin-wide integrated strategic plan that combines both legislative and engineering measures.

Water and settlements: Health issues and poverty

The Lerma–Chapala basin is highly urbanized and an estimated 77% of the population is concentrated in its cities. In addition, the water resources of the basin are used not only by the 10 million inhabitants of the basin area itself, but also by an additional 5.5 million people living outside the basin in the metropolitan areas of Mexico City and Guadalajara. Total annual water demand is around 1.1 billion m^3. Of this, 73% is supplied from groundwater resources. The water tariff in the basin ranges from US$0.04 to US$0.12, the average being US$0.09. Tariff systems are designed to benefit the poor and marginalized groups, and, as a result, charges for low water consumption are relatively insignificant. Overall, collected fees cover only around 50% of operating costs.

Water-related diseases have been on the decline since the early 1930s. At the same time, the 1991 Clean Water Act required local water utilities to meet national water quality standards. Consequently, morbidity and mortality caused by water-related diseases are nowadays practically negligible. However, problems do persist in remote rural areas, which often also suffer from low incomes, low level of education, poor infrastructure, and water scarcity. Approximately 1.5 million basin inhabitants live below the national poverty line (2008), and the global financial crisis is expected to add to this problem. However, extreme poverty and famine are non-existent in the basin.

Environment, ecosystems and water quality

Mexico is very rich in terms of plant species, animals, and micro-organisms. The region in which the Lerma–Chapala basin is located fosters a wide diversity of flora and fauna thanks to the varying landscape, with its mountains, lakes, the extensive marshes of the Toluca Valley, and the Lerma River itself. Overall, there are over 7,000 species of flora and fauna in the Lerma–Chapala basin, including more than 800 species of mammals, birds, reptiles, amphibians and fish. The basin is particularly distinctive in its freshwater fish endemism, as 30 of the 42 species of fish found here are unique. In addition, according to the National Ecology Institute of Mexico, 988 plant species found here have value either from an economic or from an ecological point of view.

There are 12 protected areas, including the Monarch Butterfly Sanctuary in Michoacán, the Nevado de Toluca area in the State of Mexico, and the Sierra Gorda in Queretaro, listed as Common Heritage of Mankind. Unfortunately, changes in land use patterns stemming from urbanization, as well as agricultural and industrial development, have put increasing pressure on this environment and its ecosystems. For example, untreated effluent has caused serious local and regional pollution in the basin. By 1989, most of the rivers in the basin were polluted, and 90% of the reservoir of Chapala Lake was unsuitable for drinking or for breeding fish. Groundwater quality also changed dramatically, with several aquifers affected by contamination from urban settlements and industrial zones. Given this critical situation, the federal government and the five state governments in the river basin signed an agreement in 1989 with four main objectives: formulation of a new water allocation policy, treatment of raw municipal and industrial effluents to improve water quality, increased efficiency in the way water is used, and the protection and conservation of the water resources of the basin. In line with this agreement, the first phase of the Regional Water Treatment Plan was put into effect, with the aim of constructing 48 new treatment plants for municipal wastewater. In 1993, the second phase of the Plan was agreed by the Lerma–Chapala River Basin Council, with the aim of enlarging those treatment plants and allowing them to treat 10,835 l/s of effluent. Taking those two stages together, the aim was that about 80% of all municipal wastewater would be treated.

The first phase was started during the 1990s and continued during the first decade of the millennium. However, most of the programme has not been implemented yet. The second phase is facing financial difficulties. In general, the basin has the largest water treatment capacity in the region and since the 1990s, new treatment facilities and technical improvements have been introduced. While there is progress, and water quality has improved in the basin overall, the four objectives of the 1989 agreement have yet to be accomplished. This slow progress has been attributed to poor enforcement of laws, lack of political support, inadequate financing, the lack of a water culture based on the ‘polluter pays’ principle, and a lack of awareness in society about the importance of water.

Another environmental problem that affects 36% of the basin is soil degradation, including loss of fertility and erosion. The former is the more critical as it has an impact on 26% of the basin area – with serious consequences for agricultural production. Unfortunately, there are no large-scale soil conservation projects or capacity building programmes for farmers to address these problems.

Water resources management and legislation

In Mexico, water is the property of the nation and its management is the responsibility of the federal government. Article 27 of the Constitution sets out the main guidelines for water resources management and land resources management. A federal water law, derived from this article, was enacted during the 1960s. This was followed by the National Water Plan in 1975. In 1989, the National Water Commission (Comisión Nacional del Agua - CONAGUA) was established as the federal water authority responsible for overall planning, management and the development of national water resources. Its broad responsibilities included the allocation of water among its users, the collection of water tariffs, and the planning, construction, and operation of hydraulic works.

In 1992, the National Water Law was enacted to improve water management. One notable aspect was the establishment of a water rights system and the creation of a public registry enabling users to buy and sell water rights (Arreguín-Cortés et al., 2007). The National Water Law also provided the legal foundation for the creation of river basin councils (RBCs) as coordinating agencies. As of 2010, 26 RBCs were established. Being at the forefront of the national water resources development agenda, the first basin council in Lerma–Chapala was created as early as 1993, bringing water users from different sectors together. Today, its composition is much larger, with representatives of federal, state and municipal government, water user associations and social organizations (Box 51.1).

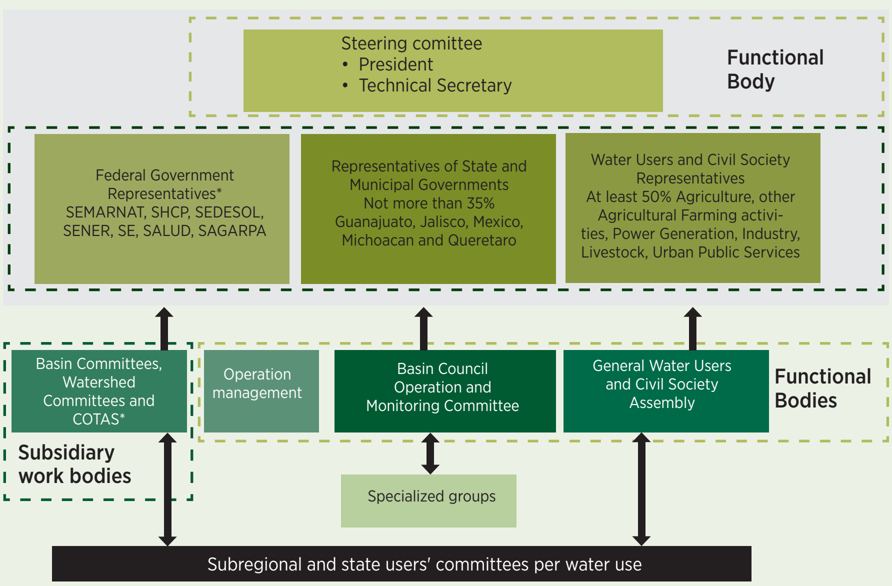
BOX 51.1

The Lerma–Chapala River Basin Council

River basin councils in Mexico derive their legitimacy from the National Water Law. They have the sustainable and integrated management and protection of water resources as their ultimate target. The Lerma–Chapala River Basin Council, one of 26 river basin councils in Mexico, coordinates action among government institutions and stakeholders. To accomplish this goal, it brings together government officials, water users and representatives of NGOs. By definition, the council is a consultative body that can propose programmes for implementation and specific actions to address challenges, and survey their performance. It is also entitled to intervene to conciliate problems between users and to recommend specific actions to CONAGUA, though it is not entitled to make decisions.

The Lerma–Chapala River Basin Council is neither a regulatory body nor a service provider. It is a forum within which stakeholders can meet one another, and meet government officials, to examine complaints, search for solutions, raise issues, and promote projects of varying scope. In summary, the council is a mechanism for identifying problems and dealing with competition and conflicts.

Lerma-Chapala River Basin Council Composition. 2008



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Ministry of Environment and Natural Resources (Secretaría de Medio Ambiente y Recursos Naturales – SEMARNAT)

Ministry of Finance and Public Credit (Secretaria de Hacienda y Crédito Público - SHCP)

Ministry of Social Development (Secretaria de Desarrollo Social - SEDESOL)

Ministry of Energy (Secretaría de Energía - SENER)

Ministry of Economy (Secretaria de Economía - SE)

Ministry of Health (Secretaria de Salud - SALUD)

Ministry of Agriculture, Livestock, Rural Development, Fisheries and Food (Secretaria de Agricultura, Ganadería, Desarrollo Rural, Pesca y Alimentación - SAGARPA)

Technical Groundwater Committee (Comité Técnico de Aguas Subterráneas – COTAS)

In 1994, CONAGUA became a part of the Environment, Natural Resources, and Fishing Secretariat, which had the aim of intensifying national efforts towards sustainable development. In 2000, this became the Ministry of Environment and Natural Resources (Tortajada, 2005). In 2004, the National Water Law was revised so that water rights, and their transmission from one user to another, could be identified and tracked more easily. The same revision introduced integrated water resources management (IWRM) with a conflict resolution dimension. The reform also allowed for the creation of river basin organizations (which are regional administrative branches of CONAGUA) and bolstered the role of river basin councils as autonomous consultative bodies. However, in spite of continuing efforts, a centralized (top-down) management approach still prevails. This calls for further emphasis on the promotion of IWRM.

Conclusions

The Lerma–Chapala basin has experienced strong demographic and economic growth, with a high increase in water demand. Unfortunately, that demand has now reached the point at which it has surpassed the current limit of renewable water resources availability. While increasing water efficiency in all sectors is desirable, reducing agricultural water consumption from its current level of 80% of all water abstracted is a necessity for sustainable development in the basin. Worsening pollution load has led to degradation of the environment and of water resources. Efforts to augment the capacity of wastewater treatment plants have helped to improve water quality and environmental conditions. However, the Regional Water Treatment Plan, which was initially introduced in the early 1990s, has yet to be implemented fully. Poor enforcement of laws, mainly stemming from lack of political support and inadequate financing, is an important dimension of continuing pollution. The revised National Water Law is an important milestone because it clearly introduces the integrated water resources management (IWRM) approach. On the other hand, central management of water resources continues to operate in parallel. For that reason, the ongoing process of strengthening the roles of river basin organizations and river basin councils constitutes a strategic priority both nationally and locally. At the basin level, successful implementation of IWRM is crucial because it is the first step to minimizing the negative effects of climatic variability, and stopping unsustainable levels of water use – allowing holistic and effective management of the basin's limited resources. Consequently, tough measures that regulate water resources demand and improve the efficiency of water use and reuse are essential, and are gradually and successfully being implemented.

References

Except where otherwise noted, information in this concise summary is adapted from the 2011, *Lerma–Chapala Basin Case Study: A Fruitful Sustainable Water Management Experience*. Mexico City, CONAGUA (National Water Commission, Mexico) (forthcoming).

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BOXES, TABLES, FIGURES AND MAPS

BOXES

TABLES

FIGURES

MAPS

WWDR4

The United Nations World Water Assessment Programme (WWAP) is hosted by UNESCO and brings together the work of 28 UN-Water members and partners in the triennial *World Water Development Report* (WWDR).

This flagship report is a comprehensive review that gives an overall picture of the world's freshwater resources. It analyses pressures from decisions that drive demand for water and affect its availability. It offers tools and response options to help leaders in government, the private sector and civil society address current and future challenges. It suggests ways in which institutions can be reformed and their behaviour modified, and explores possible sources of financing for the urgently needed investment in water.

The WWDR4 is a milestone within the WWDR series, reporting directly on regions and highlighting hotspots, and it has been mainstreamed for gender equality. It introduces a thematic approach – 'Managing Water under Uncertainty and Risk' – in the context of a world which is changing faster than ever in often unforeseeable ways, with increasing uncertainties and risks. It highlights that historical experience will no longer be sufficient to approximate the relationship between the quantities of available water and shifting future demands. Like the earlier editions, the WWDR4 also contains country-level case studies describing the progress made in meeting water-related objectives.

The WWDR4 also seeks to show that water has a central role in all aspects of economic development and social welfare, and that concerted action via a collective approach of the water-using sectors is needed to ensure water's many benefits are maximized and shared equitably and that water-related development goals are achieved.

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UN-Water is the United Nations (UN) inter-agency coordination mechanism for all freshwater related issues. It was formally established in 2003 building on a long history of collaboration in the UN family. It currently counts 29 UN Members and 25 other international Partners. UN-Water complements and adds value to existing UN initiatives by facilitating synergies and joint efforts among the implementing agencies. See www.unwater.org

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United Nations Educational, Scientific and Cultural Organization

World Water Assessment Programme

UN WATER