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Securing water for people, crops, and ecosystems: New mindset and new priorities

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Abstract

A fundamentally new approach to water and human development will be needed during this new century if we are to secure sufficient freshwater to meet the needs of some 9 billion people while at the same time protecting the critical ecosystem services upon which the human economy depends. Signs of unsustainable water use — including falling water tables, shrinking lakes, and the drying up of rivers and streams — are widespread and spreading. In many regions, greater modification and appropriation of freshwater systems for human purposes will yield greater costs than benefits and create the risk of irreversible losses of species and ecosystem services. A new mindset is needed to guide water use and management in this new century, one that views the human water economy as a subset of nature's water economy. Living within nature's limits will require that societies satisfy the basic needs of people and ecosystems before non-essential water demands are met. It will require on the order of a doubling of water productivity. And it will require stronger institutions to encourage equitable sharing of water to alleviate tensions within and between countries.

Keywords: Water; Freshwater ecosystems; Rivers; Sustainability; Water policy; Water management; Ecosystem services; Conservation, Water productivity; International river basins.

1. Introduction

Centuries ago, the Greek philosopher Aristotle observed that, "What is common to the greatest number gets the least amount of care." Unfortunately, his words apply aptly to that most precious and vital of earthly substances — freshwater.

All non-marine life depends on freshwater for survival. Even many coastal marine organisms rely on freshwater emptying into the sea for nutrients and the maintenance of particular levels of salinity. Water is therefore not just a commodity, like oil or copper, but rather a fundamental life support. Rivers, lakes, wetlands and other freshwater ecosystems are not just sources of water supply; they are habitats for a wide variety of plant and animal species. These ecosystems also perform valuable services to human societies — such as moderating floods and droughts, purifying water, and sustaining fisheries. As a resource for human activities, freshwater is also unique in that it has no substitutes in most of its uses. It is essential for growing crops, for manufacturing material goods, and for drinking, cooking, and other household functions.

During the last decade, the world's water problems have worsened markedly even as concern about them has risen steadily. A stream of global commissions and conferences has drawn attention to water's fundamental importance to food production, human health, poverty alleviation, ecosystem protection, and regional peace and stability. Actual improvements on the ground, however, have lagged badly behind this growing awareness. More urgently than ever, building a secure water future for this and future generations requires new priorities and approaches for achieving efficient, equitable, and ecologically sustainable water use. The United Nations' designation of 2003 as the International Year of Freshwater may spark the rise in consciousness and collective action needed to achieve these goals.

2. The global freshwater challenge

Throughout the 20th century, the principal challenge of water managers was to satisfy humanity's rising demand for irrigation, urban and industrial water supplies, flood protection, and hydropower generation. The primary approach to meeting this challenge was to construct dams, dikes, river diversions, and groundwater wells in order to bring more water under human control and to make more water accessible where and when needed. Just since 1950,

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the number of large dams (those at least 15 metres high) has climbed from 5,000 to 45,000 — an average of two new large dams constructed each day for the last half century. Through hydropower production, large dams now account for 19% of the world's electricity supply, and they contribute directly to 12–16% of global food production (WCD, 2000). Likewise, with the spread of powerful pumps and new well-drilling technologies, farmers and cities began to tap groundwater on a large scale to meet the surging demand for irrigation, industrial production, and household appliances.

In recent years, however, evidence has come pouring in that the benefits of large-scale water development have come at great cost to freshwater ecosystems, other species, and, all too often, to the poor. The shrinking of the Aral Sea, once the world's fourth largest lake and now a poster child of aquatic ruin, represents the tragic endpoint of a path of water development that ignores the needs of ecosystems. Irrigation expansion for the production of cotton and other crops in the Central Asian deserts resulted in such extensive withdrawals from the two rivers flowing into the Aral Sea that by 1990 those inflows had fallen to about 13% of natural flow levels, depriving the river deltas and the lake of sufficient water to sustain their ecological functions (Micklin, 1992). The Aral Sea has lost two-thirds of its volume, some 60,000 fishing jobs have been wiped out, and people living in these salty and toxic surroundings suffer from a variety of ailments. No place on earth better illustrates the close connection between the health of an ecosystem and the health of the economy, community, and the people who depend on that ecosystem. Yet much of the world is still heading down a very similar path of water development.

Meanwhile, signs that current levels of water use are not sustainable have become more widespread, threatening not only ecosystem health but the food supplies, economic activities, and jobs that depend on that water use. Water tables are falling from the overpumping of groundwater in large portions of China, India, Iran, Mexico, the Middle East, North Africa, Saudi Arabia, and the United States. As much as 8–10% of the global food supply may now depend on this unsustainable practice (Postel, 1999). Many major rivers — including the Colorado, the Ganges, the Indus, the Rio Grande, and the Yellow — now run dry for portions of the year. And increasingly, competition for scarce water threatens social and political stability. Violent protests have erupted in recent years in the lower reaches of both China's Yellow River and Pakistan's Indus River as farmers faced the prospect of a cropping season without sufficient irrigation water (Postel and Wolf, 2001).

In the midst of these signs of unsustainability and a persistent backlog of unmet water needs, societies face rising new demands. The worldwide rate of population growth has slowed substantially, but human numbers are still increasing by approximately 80 million per year (Population Reference Bureau, 2001). Most troubling, populations are expanding fastest in some of the world's most water-short regions, including North Africa, sub-Saharan Africa, the Middle East, other parts of western Asia, and portions of South Asia, including Pakistan. In addition, per capita water demands continue to climb in most areas, especially within developing countries in which rising incomes allow for higher consumption of material goods, meat and other livestock products, and household water.

As supplies tighten, farmers in particular will feel the squeeze as water shifts out of agriculture in order to satisfy rising urban and industrial demands. Recent projections indicate that by 2025, numerous river basins and countries will be in a situation in which 30% or more of their irrigation demands cannot reliably be satisfied because of water shortages (Rosegrant et al., 2002). These include: most river basins in India; the Hai and Yellow basins in China; the Indus in Pakistan; and many river basins in Central Asia, sub-Saharan Africa, North Africa, Bangladesh and Mexico. Besides jeopardizing food production, these projected water shortages will increase the threat of social instability, as the food and income security of rural dwellers deteriorates. In Pakistan, declining agricultural output from land degradation and water scarcity has already unleashed large-scale migration from rural areas to cities. The resulting overcrowding of urban centres and the inability of governments to provide services and jobs for the rush of new urbanites has deepened ethnic cleavages and spawned numerous incidences of unrest (Schwartz and Singh, 1999).

One of the biggest challenges society faces in this new century is that of meeting the water needs of 9 billion people while at the same time protecting the ecosystems that sustain human livelihoods as well as all terrestrial life. The world is entering an unprecedented period of risks to food security, ecosystem health, and social and political stability as water scarcity deepens and spreads — risks that will be compounded by the wild card of global climate change.

3. A shift in mindset

A fundamentally new approach to water and human development will be needed during this new century if we are to establish a secure and sustainable world. As the great physicist Albert Einstein once said, you cannot solve a problem within the mindset that created it.

The mindset that has dominated water development and management for the last two centuries is one that views rivers, lakes, and aquifers as resources to be modified and exploited for human purposes rather than as living systems that perform valuable life-support services. The classic water 'pie' showing the distribution of water among agricultural, industrial, and household uses is a manifestation of this dominant mindset, as are classical estimates of supply and demand, which typically compare estimates of water use by human activities to the quantity of water available. The

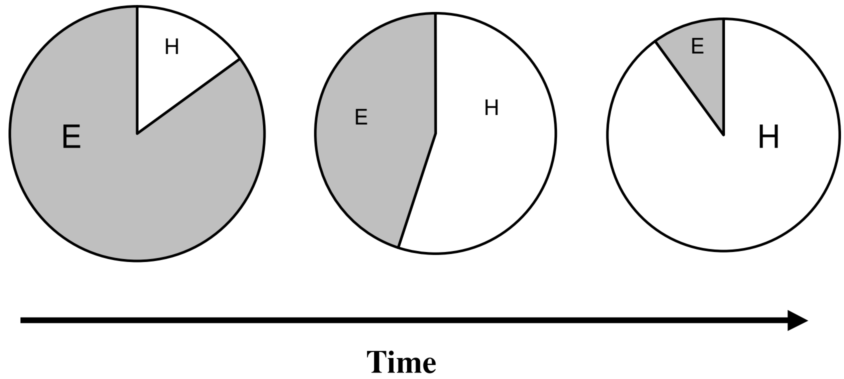

Figure 1. Simple conceptual depiction of the 20th century approach toward water development and allocation. Human extractions from and modification of water systems (H) steadily increase with time, while the portion remaining to sustain ecological functions (E) steadily diminishes. With no limits set on how large H can grow, eventually ecosystems decline, leading to the loss of valuable ecosystem services and irreversible extinction of species. The devastated Aral Sea is an extreme example of the endpoint of this development path. See text for discussion.

water needs of ecosystems themselves rarely appear in these balance sheets. Under this conventional water-development approach, nature's slice of the water pie consists of whatever happens to be left over after agricultural, industrial, and urban demands are met. Nature's portion constantly shrinks in size as the slices going to the human economy get larger (see Figure 1).

This mindset may have served humanity reasonably well as long as water was relatively abundant compared with human demands. But, in much of the world, the residual slice left for nature is now too small to keep aquatic ecosystems functioning. As a result, the valuable goods and services that healthy freshwater ecosystems provide (see Table 1) are diminishing — in some cases rapidly. Because most of these services are not valued monetarily, these losses typically go untallied and are not taken into account in decisions about whether to build another dam or drain another wetland. But the diminishment of ecosystem services nonetheless causes serious harm that takes many forms — including poorer water quality, increased flood damage, the disruption of food webs, the decline of fisheries, and the loss of jobs and livelihoods, to name a few. From the Colorado River delta in northern Mexico to the rich Ganges River delta in Bangladesh, for example, fisheries and the livelihoods that depend on them are declining from the depletion of flows by upstream dams and diversions. Worldwide, at least 20% of the 10,000 freshwater fish species are now endangered, threatened with extinction, or are already extinct (Moyle and Leidy, 1992). In North America, where at least 123 species of freshwater fish, molluscs, crayfish, and amphibians have been extinguished since 1900, projected rates of near-term extinctions of freshwater

Table 1. Life-support services provided by rivers, wetlands and other freshwater ecosystems

Ecosystem service	Benefits and examples
Provision of water supplies	More than 99% of irrigation, industrial and household water supplies worldwide come from natural freshwater systems.
Provision of food	Fish, waterfowl, mussels, clams, etc. are important food sources for people and wildlife.
Water purification/waste treatment	Wetlands filter and break down pollutants, protecting water quality.
Flood mitigation	Healthy watersheds and floodplains absorb rainwater and river flows, reducing flood damage.
Drought mitigation	Healthy watersheds, floodplains and wetlands absorb rainwater, slow runoff, and help recharge groundwater.
Provision of habitat	Rivers, streams, floodplains, and wetlands provide homes and breeding sites for fish, birds, wildlife, and numerous other species.
Soil fertility maintenance	Healthy river-floodplain systems constantly renew the fertility of surrounding soils.
Nutrient delivery	Rivers carry nutrient-rich sediment to deltas and estuaries, helping maintain their productivity.
Maintenance of coastal salinity zones	Freshwater flows maintain the salinity gradients of deltas and coastal marine environments, a key to their biological richness and productivity.
Provision of beauty and life-fulfilling values	Natural rivers and waterscapes are sources of inspiration and deep cultural and spiritual values; their beauty enhances the quality of human life.
Recreational opportunities	Swimming, fishing, hunting, boating, wildlife viewing, water-side hiking and picnicking.
Biodiversity conservation	Diverse assemblages of species perform the work of nature (including all the services in this table), upon which societies depend; conserving genetic diversity preserves options for the future.

Source: Postel and Richter (in press).

animal species rival those for species in tropical rainforests (Ricciardi and Rasmussen, 1999).

Much of this damage and loss is due to the extensive fragmentation of rivers by dams, dikes, and diversions, which has destroyed a great deal of the important work that healthy river systems do — from sustaining fisheries and species diversity to delivering nutrients to highly productive coastal estuaries. The draining and filling of wetlands for agricultural and urban expansion has also taken a heavy toll. Worldwide, wetlands — which provide a host of goods and services that are estimated to be worth as much as $20,000 per hectare in some locations (Costanza et al., 1997) — now cover only half the area they did a century ago (IUCN-The World Conservation Union, 2000). As the area of intact ecosystems declines, the marginal cost of additional losses increases. The fact that our economic calculus does not count these losses does not mean they are not real; it simply means society is unaware of how much human and social welfare is declining as a result.

The antidote to this undesirable trajectory is to replace the prevailing water-development mindset with a more holistic perspective that recognizes that the human water economy is a subset of nature's water economy and is highly dependent on it (see Figure 2). Such an ecologically oriented conceptual view offers a way to optimize the full array of benefits from rivers, lakes, and aquifers by taking into account not only standard economic benefits — such as agricultural or industrial output — that accrue from modifying natural systems, but also the value of the ecological functions those systems provide in their natural state. From this viewpoint, safeguarding ecosystem health is not only an act of stewardship but of wise and rational public policy. It also turns conventional water allocation priorities upside down: rather than natural ecosystems getting whatever water happens to be left over, they get the quantity, quality, and timing of water that they need to continue to provide the goods and services society values. Only after adequate water is provided to meet basic human needs and to safeguard ecosystem health is water allocated for irrigation, hydropower, navigation, industrial use and other water-related benefits.

At the national level, South Africa is pioneering the implementation of this principle following the 1998 passage of a new water act that calls for the establishment of a two-part water 'reserve'. The first part calls for meeting basic human needs by ensuring that all South Africans have at least the minimum quantity of safe drinking water required for good health. The second part of the reserve calls for ecosystems to receive the water they need to sustain their health and ecological integrity. Specifically, the Act says, *"the quantity, quality and reliability of water required to maintain the ecological functions on which humans depend shall be reserved so that the human use of water does not individually or cumulatively compromise the long term sustainability of aquatic and associated ecosystems."* The water determined to constitute this two-pronged reserve has priority over all other uses — including for instance, irrigation and industrial uses (South African National Water Act, 1998). It is too early to judge whether the Act will be successfully implemented — and the hurdles are significant — but many scientists and stakeholder groups are now actively working to bring these goals into effect.

The adoption of such an ecologically based approach is a prerequisite to achieving environmentally sustainable water use. It explicitly recognizes that water is finite, that ecosystem services are valuable and must be protected, and that it therefore makes sense to place a limit or cap on the use and modification of natural freshwater systems. As described below, this shift in mindset opens the door to a wholly new approach to water, one grounded in principles

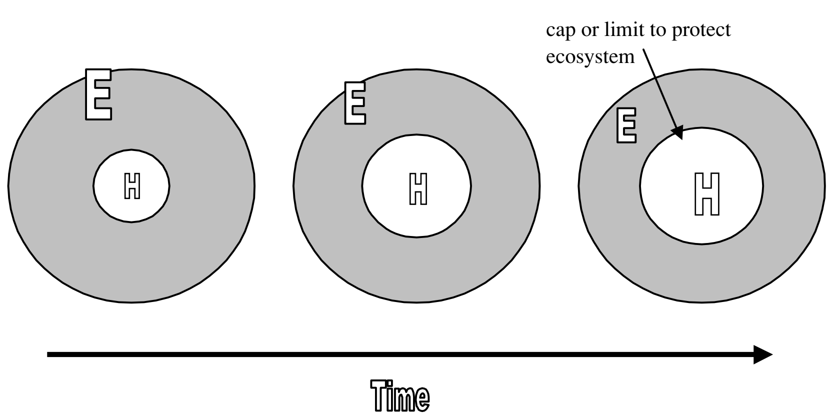

Figure 2. Simple conceptual depiction of the approach needed for the 21st century of water development and allocation. The human water economy (H) is viewed as a subset of nature's water economy (E). In order to sustain the ecosystem services upon which the human economy depends, a boundary or limit is established on the degree to which human activities can alter natural freshwater ecosystems. Since H cannot expand past that limit (represented by the inner boundary line of circle three), a premium is placed on using water more efficiently and sharing it more equitably. See text for discussion.

of equity, efficiency, and ecological integrity — the three pillars of sustainability.

4. From concept to action

A new mindset is a necessary, but not sufficient condition for moving the world onto a sustainable water track. It must be accompanied by changes in policies, priorities, and management practices that translate this conceptual view into concrete action. Here and there around the world, governments, communities, and citizens are taking up this task. But progress is fragmented and piecemeal, and its pace far slower than that at which problems are spreading. Although the World Summit on Sustainable Development held in 2002 in Johannesburg, South Africa produced some notable results, an opportunity was missed to generate a broader international commitment to achieving ecologically sustainable water use and management — backed up by commitments and funding needed to bring these goals about. This missed opportunity, however, need not relegate societies to inaction. A meaningful international response to global problems has emerged outside the context of high-profile global summits, sometimes involving formal international agreements — such as the Montreal Protocol on protecting the ozone layer and the Stockholm Treaty on Persistent Organic Pollutants — and sometimes involving a snowball effect of voluntary action by governments, businesses, private groups, and communities. In whatever form, stronger actions are needed to harmonize human water use and management with the protection of nature's services, and to achieve basic levels of water security for all.

Five top priorities for action are outlined below, along with key policies that can help achieve them.[1]

4.1. Protect ecosystem services — the valuable work nature does for free

The important work that rivers, floodplains, wetlands, and other ecosystems do is easy to neglect because it is not valued in the marketplace. Nonetheless, freshwater ecosystem services are worth hundreds of billions of dollars a year (Costanza et al., 1997; Postel and Carpenter, 1997), and are particularly valuable to the poor, who often depend on nature's services directly for their livelihoods. Some jurisdictions are now taking steps to preserve these services. Australia, South Africa, and parts of the United States, for instance, are establishing environmental flow requirements for rivers. These policies build on a growing scientific consensus that restoring a river's natural pattern of flow variability — its natural highs and lows during the year and across years — is a key to restoring river health overall as well as the riverine habitat that myriad species depend upon for survival (Poff et al., 1997). The establishment of environmental flow requirements is a major feature of South Africa's ecological water reserve, for example. In Australia, the Murray–Darling river basin is pioneering the implementation of a cap on water extractions in order to improve the ecological health of the Murray–Darling river system, Australia's largest. And in the United States, a number of efforts are underway to operate dams differently or to otherwise re-create more natural patterns of river flows in order to protect and restore river habitat and ecosystem services (Postel and Richter, in press).

Investing in natural capital rather than in conventional engineering solutions can also provide an economically sound way of meeting human and ecological needs at the same time. Just like a factory or school, natural capital requires protection and good maintenance in order to keep providing services to the economy. In some cases, investments in natural capital can achieve a particular goal at a lower cost than a more conventional engineering solution — often with significant ancillary environmental benefits as well, as the examples in Box 1 from China, South Africa, and the United States illustrate.

Key policy priorities for achieving greater ecosystem service benefits include:

- protect watersheds, floodplains, wetlands, and other natural capital assets;
- establish environmental flow requirements for rivers, as many Australian states and South Africa are now doing;
- adopt or amend water management laws to require the operation of dams in ways that preserve natural river flows and flood regimes; and
- make ecosystem service protection a core mandate of river basin commissions.

Box 1. Investing in natural capital: examples from watersheds in China, South Africa, and the United States

In 1998, the residents of China's Yangtze River basin experienced one of the worst flooding disasters in modern Chinese history. At least 15 million people were rendered homeless, and direct economic losses were estimated to have totalled at least $26 billion (Neto, 2001). Although scientists identified heavy rainfall and rapid snowmelt as the direct causes of the flooding, they also pointed to the role of deforestation in the upper and middle sections of the Yangtze watershed as likely contributing to the disaster's severity. Total forest cover in the watershed has dropped from at least 30% to less than 10% over the last half century. The severe 1998 flood not only underscored the incomplete flood-protection provided by embankments and other engineering works — the

[1] These priorities and policy recommendations draw and build upon those developed by the author for the Worldwatch Institute's "From Rio To Johannesburg: World Summit Policy Briefs."

conventional structural approach to flood control — but also the benefits lost by destruction of the Yangtze watershed. No longer was the upper and middle watershed absorbing floodwaters and moderating the release of water to downstream regions. As a result, Chinese officials have put in place policies to control the removal of trees and to accelerate the planting of trees. In effect, they have decided that many of the trees in the Yangtze watershed are worth more left standing because of their flood-control benefits than if cleared for timber or other conventional economic purposes. By investing in the protection and restoration of the natural capital of the Yangtze watershed, the Chinese hope to achieve more effective flood control in a cost-effective manner.

Similarly, South Africa is investing in the restoration of watersheds in its western Cape region — in this case, to cost-effectively increase available water supplies. The natural *fynbos* (shrubland) watersheds of the western Cape constitute one of the world's richest regions of endemic plant diversity. Low lying and drought tolerant, *fynbos* vegetation is also very water-thrifty. Over time, the invasion of these watersheds by thirstier alien shrubs and trees (such as Australian acacias) has not only imperiled the native plant diversity but decreased the volume of catchment runoff. When researchers assessed the value of ecosystem services provided by the natural watershed — especially the delivery of water supplies — they found that it made sense on economic grounds alone to invest in the removal of alien species and watershed restoration. They found that a restored catchment yielded nearly 30% more water than one of equivalent size populated by alien invaders. Moreover, the unit cost of the water supplied by the restored catchment was 14% less than that of the unmanaged watershed (Van Wilgen et al., 1996). Through its Working for Water Programme, the South African Government is now removing alien vegetation from its landscape — creating jobs, conserving biodiversity, and protecting water supplies at the same time.

New York City is also investing in natural capital in order to supply high-quality water cost-effectively to its millions of residents. Faced with the prospect of having to construct a $6 billion filtration plant in order to purify its drinking water supply, the City decided instead to invest in restoring and protecting the Catskills watershed from which that supply originates. At a cost of some $1.5 billion, the City is buying land in and around the watershed, improving local sewerage treatment, and paying farmers to forego planting crops or grazing animals right next to streams. As a result, the City is not only avoiding the huge capital cost of a treatment plant as well as the $300 million a year required to operate it, but it is helping to add income to rural parts of the state and improving quality of life in many watershed communities (Heal, 2000).

4.2. Achieve universal access to safe drinking water and sanitation

A safe supply of drinking water, adequate sanitation, and good hygiene practices are essential to human health. Yet the technologies, training, and education needed to secure basic water-related services are still lacking for a large portion of the world's population. Their absence continues to be a leading cause of disease and death in the developing world. Lack of access to safe drinking water alone results in the death of some 3 million people each year — most of them children — from diarrhea and other illnesses caused by contaminated water. According to some estimates, more people have died from diarrhea in the last ten years than have been lost to armed conflict since the Second World War. Individuals, families, communities, and entire countries are paying a high price for society's failure to provide these basic services. Not only are millions of people dying prematurely each year from preventable diseases, but also many more experience greatly reduced productivity and income due to poor health.

According to the World Health Organization (2000), an additional 816 million people acquired access to safe drinking water between 1990 and 2000. But the number of people unserved remains roughly the same — 1.1 billion — because the population grew by nearly as many people as gained access. The number of people lacking adequate sanitation rose slightly between 1990 and 2000, to 2.4 billion, or about 40% of the global population.

The United Nations Millennium Development Goals (MDG) include targets of reducing by half the proportion of people lacking access to safe drinking water and sanitation by 2015. The 2002 World Summit on Sustainable Development spurred new and renewed commitments in these areas, including an agreement to halve the number of people lacking sanitation by 2015. Achieving such goals, however, will take a dedication of political will, leadership, and funding that has been rare to date. A notable exception is South Africa, which is on track to surpass the water MDGs. Within just the first seven years of the post-apartheid Government — between 1994 and 2001 — South Africa reduced the number of people without access to safe drinking water by half, from 14 million people to 7 million people, and is aiming to achieve universal access by 2008. Progress on the sanitation front has been considerably slower, but here, too, the Government is aiming to provide access to adequate sanitation for all by 2015. The privatization and rising costs of water services have spawned civil protest in some areas of South Africa, however, underscoring the importance of equitable access in achieving safe drinking water goals.

Key policy priorities for achieving universal access to safe drinking water and sanitation include:

- Public sector support for the provision of services must be increased, especially in rural areas, which are home to more than 80% of people who lack safe drinking water. Funding, training, and technical assistance should be provided to community-based initiatives;

- in general, governments and communities should assert their primary responsibility for providing water services, rather than transferring this responsibility to the private sector. Privatization can only serve the public good within a strong regulatory framework that ensures that the basic needs of the poor are met and that the water resource itself is conserved — conditions that to date have only rarely been satisfied; and
- efficiency and conservation must be built into new supply and sanitation infrastructure. Leakage from urban water systems, which often exceeds 30%, needs to be reduced.

4.3. Enable access to irrigation water to reduce rural poverty

Although it has received far less attention than the provision of safe drinking water, access to a minimum quantity of water for irrigation is a key to alleviating poverty and improving livelihoods in poor countries. Some 2.8 billion people live on less than $2 a day; and 800 million of these people are chronically hungry. The vast majority of the world's poorest and hungriest people live in rural areas of South Asia and sub-Saharan Africa, where they eke out a living on small farms of less than 2 hectares in size. In the so-called "poverty square" of South Asia, for example, more than half the farmland consists of marginal and small farms of less than one hectare. These poor rural dwellers have neither the means to produce adequate food nor sufficient income to purchase it.

Enabling poor farm families to access irrigation water can be one of the most effective ways of freeing them from the poverty trap. In monsoon climates with a long dry season, as well as in semi-arid and arid regions — which includes most of Africa and Asia — access to irrigation water is critical to raising and stabilizing crop production. Yet most of the modern irrigation technologies, such as diesel pumps, for instance, are too expensive for poor farmers (Polak et al., 1999). A more concerted and coordinated global effort to spread the availability and use of affordable, small-plot irrigation could greatly increase land productivity, incomes, and household food security of the world's poorest farm families (Postel et al., 2001). These affordable technologies include, for example, human-powered pumps to access shallow groundwater, drip irrigation packages designed specifically for small farmers on small plots (starting with $8 bucket drip kits for home gardens in Africa), and inexpensive micro sprinklers.

In many poor rural regions, access to irrigation water can be achieved sustainably and at an appropriate scale through creative water harvesting and watershed restoration projects. India, for example, is now experiencing a revival of these techniques. In *Dying Wisdom*, Agarwal and Narain (1997) provide a comprehensive compendium of traditional Indian water harvesting methods. These can often be built in months rather than years, can be locally controlled, and can be used jointly with modern tubewells and low-cost irrigation systems.

Key policy priorities for improving access to irrigation water by smallholders include:

- increase the use of affordable, small-plot irrigation devices in poor rural areas. One model of success is in Bangladesh, where poor farmers have purchased more than 1.2 million human-powered devices called treadle pumps, boosting incomes an average of $100 per $35 pump in the first year. This model includes development of a private-sector supply chain from manufacturing to installation, as well as effective and culturally appropriate marketing techniques;
- invest in community-based watershed restoration and rainwater harvesting projects. Such projects can help recharge local groundwater, store runoff for dry-season irrigation, and make irrigation more widely available;
- support initiatives to spread low-cost drip irrigation and microsprinkler packages for smallholders; and
- ensure access to credit for smallholders, including women.

4.4. Work toward a doubling of water productivity

In the light of projected rates of population and economic growth over the coming decades, combined with the already serious state of decline of many freshwater ecosystems, achieving sustainable water use will require doing more with less water. Human activities now co-opt more than half of the accessible renewable freshwater runoff globally (Postel et al., 1996). Even with no change in average per capita water demand, this figure could rise to 70% by 2025. Such a level of human appropriation of earth's freshwater would cause substantially greater losses of ecosystem services, aquatic species, fisheries, and other natural and economic values.

It will likely require close to a doubling of water productivity globally — more in some regions, less in others — to satisfy the food and water needs of the global population while at the same time protecting ecological integrity. Water productivity is a broader and deeper concept than water efficiency. It refers to the output, service, satisfaction, or benefit derived from each unit of water removed from natural water sources. For example, it is concerned not only with crop yield per unit water, but with nutritional value per unit water.

A doubling of water productivity would mean getting twice as much benefit or service out of each cubic metre (m^3) of water extracted from rivers, lakes, and aquifers. This is a difficult task, but not an impossible one. Because crop production is highly water-intensive — producing one ton of wheat, for example requires about 1,000 m^3 of water — raising agricultural water productivity is particularly important. A host of measures and practices exist that can

Table 2. Selected menu of options for improving agricultural water productivity

Category	Option or measure
Technical	• Land leveling to apply water more uniformly • Surge irrigation to improve water distribution • Efficient sprinklers to apply water more uniformly • Drip irrigation to cut evaporation and other water losses and to increase crop yields • Furrow diking to promote soil infiltration and reduce runoff • Low-cost irrigation methods for poor farmers
Managerial	• Better irrigation scheduling • Improving canal operations for timely deliveries • Applying water when most crucial to a crop's yield • Water-conserving tillage and field preparation methods • Better maintenance of canals and equipment • Recycling drainage and tail water
Institutional	• Establishing water user organizations for better involvement of farmers and collection of fees • Reducing irrigation subsidies and/or introducing conservation-oriented pricing • Establishing legal framework for efficient and equitable water markets • Securing water rights for communal and traditional water users • Fostering rural infrastructure for dissemination of efficient technologies • Better training and extension efforts
Agronomic	• Selecting crop varieties that maximize yield per litre of transpired water • Intercropping to maximize use of soil moisture • Better matching crops to climate conditions and the quality of water available • Sequencing crops to maximize output under conditions of soil and water salinity • Selecting drought-tolerant crops where water is scarce or unreliable • Breeding water-efficient and drought-tolerant crop varieties

Sources: Adapted from Postel (1999) and Wallace and Batchelor (1997).

dramatically boost agricultural water productivity, and most are vastly underused (see Table 2). Among technologies, for example, drip irrigation has been shown to double or triple output per unit water. Yet drip irrigation accounts for only about 1% of global irrigated area (Postel, 1999).

More than 80% of cropland worldwide is watered only by rainfall. The International Water Management Institute in Sri Lanka estimates that, in an average year, crops consume approximately 20% of all the rain falling on land (Rijsberman and Molden, 2001). Improved rainfed cropping systems, combined in some cases with supplemental irrigation, can therefore also boost crop water productivity. Changes in diets can also have a large impact. A typical US diet requires about 1,970 m^3 of water per year (in the form of evapotranspiration) to produce, while an equally nutritious vegetarian diet takes only 950 m^3, less than half as much (Rijsberman and Molden, 2001). Moving away from animal-based proteins thus creates another opportunity to double agricultural water productivity. Thus, with the same volume of water, two people are fed instead of one person.

Greater recycling of wastewater, industrial process redesign, more widespread use of water-efficient household fixtures and appliances, and the adoption of native landscaping are other measures than can raise water productivity. Only if water utilities and agencies incorporate conservation into long-term water supply planning and management, however, will these measures begin to achieve their full potential to save water and reduce pressure on natural water systems (Vickers, 2001).

Key policy priorities for improving water productivity include:

- establish conservation incentives and goals for urban, industrial, and agricultural users;
- implement water-efficiency measures and reduce system-wide leaks and losses;
- introduce water pricing structures that discourage wasteful and inefficient use;
- regulate or tax groundwater overpumping to slow aquifer depletion and encourage water-efficiency improvements;
- develop more productive rainfed cropping systems;
- redesign tax codes — tax labour and investment less, resource consumption and pollution more; and
- educate citizens on how changes in lifestyles — from diets to landscaping choices — can reduce their personal water-intensity.

4.5. Achieve good governance over water

As the basis of life, water is a public trust. Governing authorities therefore have an obligation to protect and sustain freshwater for current and future generations. Good water governance is grounded in principles of stewardship, sharing, sustainability, and accountability. When the post-apartheid government of South Africa overhauled the nation's water laws and policies, it adopted the public trust doctrine — a legal principle that dates back at least to Roman times — as its guiding ethic: "To make sure that the values of our democracy and our Constitution are given force in South Africa's new water law, the idea of water as a public good will be redeveloped into a doctrine of public trust which is uniquely South African and is designed to fit South Africa's specific circumstances" (Republic of South Africa, 1997). From this foundation, it then went on to develop the concept of the water reserve — the idea that the basic water needs of all people and all ecosystems should be met first — before non-essential water demands are met.

Adoption of the public trust as the guiding ethic or principle for water management puts a premium on equity and sharing — among people, between people and nature, and among countries that share international rivers. By contrast, the notion of treating water more as a commodity has tended to elevate water's economic functions over its life-support functions. The two conceptual views need not be in conflict, however, if it is recognized that the public trust value of water has a higher priority than its commodity functions. Once basic human needs are met and ecosystem health is secured, then the treatment of water more as a commodity in its varied economic functions can make sense in many social and cultural settings and provide a rational mechanism for efficiently allocating water among competing economic uses.

Just as public trust principles of equity and sharing must guide the allocation of water among people and between people and nature, so must they guide water relations between countries. There are currently 261 rivers that are shared by two or more countries. These international watersheds are home to about 40% of the world's people and a significant share of the world's cropland (Postel and Wolf, 2001). The 1997 United Nations Convention on Non-Navigational Uses of International Watercourses establishes two key principles to guide the conduct of nations over shared rivers — 'equitable and reasonable use' and the obligation not to cause 'significant harm' to neighbours (United Nations General Assembly, 1997). It is up to countries themselves, however, to hammer out precisely what these terms mean in their watersheds, and in most international river basins, governance structures remain wholly inadequate. During the past century, nations have signed 145 treaties dealing with non-navigational uses of water, but only one-fifth of these treaties has any enforcement mechanism and fewer than half have any monitoring provisions (Wolf, 1998) Moreover, the vast majority of these treaties are between two countries, even in river basins shared by three or more nations. Treaty provisions to ensure the protection of ecosystem health are practically non-existent.

Currently, there are more than 20 international river basins in which stronger institutions are needed to avert water disputes over the next five to ten years (see Table 3). While these disputes are unlikely to lead to any outright wars, they can lead to serious harm to countries and people that are in less favourable positions hydrologically, economically, politically, or militarily within the basin. In the Mekong River basin, for example, China — one of just three countries that voted against the adoption of the 1997 UN Convention — is the most upstream nation. Since China is not a member of the Mekong River Commission, it has no formal obligation to clear construction of dams on the Mekong with countries downstream. China has at least seven dams and reservoirs planned for the upper Mekong, which may collectively have harmful effects on fish production and biodiversity downstream in Cambodia, Laos, Thailand, and Vietnam (Dudgeon, 2000). Even though these four countries are signatories to a treaty and members of the Mekong Commission, there is little they can do to prevent harm from upstream dam operations without China's cooperation.

Key policy priorities for achieving good governance over water include:

Table 3. Selected international river basins in which stronger institutions are needed to avert water disputes over the next decade

Region	River basin
Southern Africa	Incomati
Southern Africa	Kunene
Southern Africa	Limpopo
Southern Africa	Okavango
Southern Africa	Orange
Southern Africa	Zambezi
Western Africa	Senegal
North-Central Africa	Lake Chad
Northeastern Africa	Nile
South America	La Plata
Central America	Lempa
Western Asia	Jordan
Western Asia	Tigris-Euphrates
Western Asia	Kura Araks
Central Asia	Aral Sea
Northeastern Europe-Asia	Ob
Southern Asia	Ganges-Brahmaputra-Meghna
Southeast Asia	Mekong
Southeast Asia	Salween
East Asia	Tumen
East Asia	Han

Sources: Wolf et al. (forthcoming); Postel and Wolf (2001).

- elevate the public trust as the dominant ethical precept guiding the allocation and management of freshwater;
- initiate preventative diplomacy in river basins at risk of tensions over water;
- establish watershed commissions in those international basins where they do not yet exist, and strengthen them where they do exist;
- abide by the recommendations issued by the World Commission on Dams (WCD, 2000) — this applies to governments, the World Bank, and other financiers of large water projects. The Commission espoused five core values — equity, efficiency, participation, sustainability, and accountability — to guide future decision-making about dams;
- grant legal recognition of water rights to communal and traditional water users; and
- form and support citizen watershed groups for effective stakeholder involvement in decision-making on water issues.

5. Moving forward

Clearly a tall order, the implementation of these priorities and policies would revolutionize water use and management. There is far greater risk in not trying to bring about these changes, however, than in getting started. Nothing short of fundamental change will solve the water dilemmas in which a growing portion of the world now finds itself. These challenges require that scientists, engineers, conservation practitioners, policy-makers, and citizens work together. They require leadership from many quarters. And they require action soon, because it may turn out that time to reverse the threatening trends under way is even more limited than water itself.

References

Agarwal, A., Narain, S., (Eds.), 1997. *Dying Wisdom*. Centre for Science and Environment, New Delhi, India.

Costanza R., d'Arge, R., de Groot, R., Farber, S., Grasso, M., Hannon, B., Limburg, K., Naeem, S., O'Neill, R., Paruelo, J., Raskin, R., Sutton, P., van den Belt, M., 1997. The value of the world's ecosystem services and natural capital. *Nature*, 387: 253–260.

Dudgeon, D., 2000. Large-scale hydrological changes in tropical Asia: Prospects for riverine biodiversity. *BioScience*, 50: 793–806.

Heal, G., 2000. *Nature and the Marketplace: Capturing the Value of Ecosystem Services.* Island Press, Washington, D.C.

IUCN-The World Conservation Union, 2000. *Vision for Water and Nature: A World Strategy for Conservation and Sustainable Management of Water Resources in the 21st Century.* Gland, Switzerland and Cambridge, United Kingdom.

Micklin, P., 1992. The Aral crisis: Introduction to the special issue. *Post-Soviet Geography*, 33: 269–282.

Moyle, P.B., Leidy, R.A., 1992. Loss of biodiversity in aquatic ecosystems: Evidence from fish faunas. In: Fiedler, P.L., Jain, S.K. (Eds.), *Conservation Biology: The Theory and Practice of Nature Conservation, Preservation, and Management*. Chapman and Hall, New York.

Neto, F., 2001. Alternative approaches to flood mitigation: A case study of Bangladesh. *Natural Resources Forum*, 25(4): 285–297.

Poff, N.L., Allan, J.D., Bain, M.B., Karr, J.R., Prestegaard, K.L., Richter, B.D., Sparks, R.E., Stromberg, J.C., 1997. The natural flow regime. *BioScience*, 47(11): 769–784 (December).

Polak, P., Morgan, W., Saussier, J., 1999. Increasing the productivity of the world's micro-farmers. In: *Sustainable Agricultural Solutions: The Action Report of the Sustainable Agriculture Initiative.* Novello Press, Ltd., London, pp. 140–143.

Population Reference Bureau, 2001. *2001 World Population Data Sheet.* Washington, D.C.

Postel, S., 1999. *Pillar of Sand: Can the Irrigation Miracle Last?* W.W. Norton & Company, New York.

Postel, S., Carpenter, S., 1997. Freshwater ecosystem services. In: Daily, G.C. (Ed.), *Nature's Services: Societal Dependence on Natural Ecosystems*. Island Press, Washington D.C., pp. 195–214.

Postel, S.L., Daily, G.C., Ehrlich, P.R., 1996. Human appropriation of renewable freshwater. *Science*, 271: 785–788.

Postel, S., Polak, P., Gonzales, F., Keller, J., 2001. Drip irrigation for small farmers: A new initiative to alleviate hunger and poverty. *Water International*, 26(1): 3–13.

Postel, S., Richter, B., in press. *Rivers for Life: Managing Water for People and Nature*. Island Press, Washington, D.C.

Postel, S.L., Wolf, A.T., 2001. Dehydrating conflict. *Foreign Policy*, (September–October): 60–67.

Ricciardi, A., Rasmussen, J.B., 1999. Extinction rates of North American freshwater fauna. *Conservation Biology*, 13: 1220–1222.

Rijsberman, F., Molden, D., 2001. Balancing water uses: Water for food and water for nature. Thematic background paper prepared for the International Conference on Freshwater, Bonn, Germany. December.

Republic of South Africa, 1997. White Paper on Water Policy. Department of Water Affairs and Forestry, Pretoria, South Africa.

Rosegrant, M.W., Cai, X., Cline, S.A., 2002. *World Water and Food to 2025*. International Food Policy Research Institute, Washington, D.C.

Schwartz, D., Singh, A., 1999. *Environmental Conditions, Resources, and Conflicts*. United Nations Environment Programme (UNEP), Nairobi, Kenya.

South African National Water Act No. 36 of 1998. *Government Gazette*, Volume 398, No.19182, Cape Town, August 26, 1998. Part 3: The Reserve, and Appendix 1: Fundamental Principles and Objectives for a New Water Law in South Africa.

United Nations General Assembly, 1997. Convention on the Law of the Non-Navigational Uses of International Watercourses. United Nations, New York.

Van Wilgen, B.W., Cowling, R.M., Burgers, C.J., 1996. Valuation of ecosystem services: A case study from South African fynbos ecosystems. *BioScience*, 46(3): 184–189.

Vickers, A., 2001. *Handbook of Water Use and Conservation*. WaterPlow Press, Amherst, Massachusetts.

Wallace, J.S., Batchelor, C.H., 1997. Managing water resources for crop production. Philosophical Transactions of the Royal Society of London: *Biological Sciences*, 352: 937–947.

Wolf, A.T., 1998. Conflict and cooperation along international waterways. *Water Policy*, 1: 251–265.

Wolf, A.T., Yoffe, S., Giordano, M., 2003. International waters: Identifying basins at risk. *Water Policy*, 5: 31–62.

World Commission on Dams (WCD), 2000. *Dams and Development: A New Framework for Decision-Making*. Earthscan, London.

World Health Organization, 2000. Global Water Supply and Sanitation Assessment 2000. Report, available at http://www.who.int/water_sanitation_health/Globassessment/tab2-2.gif