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Population and Water Resources: A Delicate Balance

subject to drought, extreme seasonal fluctuations in rainfall, and other water resource problems. Many of these countries also have rapidly growing populations that must compete for limited water resources. This *Population Bulletin* explains how environmental preconditions, like climate and geography, limit human access to water; and how human activities affect the global water systems. With a harsh hydroclimate and growing population pressure, arid and semi-arid regions of Africa are already living on the hydrological margin. By 2025, over 1 billion people worldwide will be living in areas subject to extreme water scarcity. Slower population growth, conservation, appropriate agricultural policies, and increased storage facilities are among the many ways water-scarce areas can maintain the balance between population and water resources.

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Population and Water Resources: A Delicate Balance

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Their colleagues Irene Johansson and Lina Berglöff also made valuable contributions to this publication.

This Population Bulletin *is an edited, abridged version of a longer manuscript, "Water—A Finite Resource," by Malin Falkenmark and Carl Widstrand.*

Water is one of our most plentiful resources. Covering more than two-thirds of the Earth, water travels from the sea into the air to the land and back to the sea in a seemingly endless cycle of renewal. Yet water is a finite resource, and the tiny fraction suitable for drinking or irrigating crops is distributed unevenly throughout the world's regions. At the same time, the human need for water is escalating because of rapid population growth and industrialization, especially in the world regions where water is most scarce.

The world's population lives at the mercy of the water cycle. Human innovative talents can make the best possible use of the water that passes through the territory of a country, but technology cannot influence the rate at which water is naturally renewed from the global water circulation system. Further, human activities, such as the clearing of land, disposal of wastes, and withdrawal of freshwater, introduce disturbances in the water cycle that resonate throughout the Earth's environmental systems. These disturbances are accelerated by the world's continuing population growth. Nearly one-third of the world's inhabitants live in countries with severe water problems. The world's most poverty-stricken countries tend to lie within the climatic zones most subject to drought and other water problems.[1] These regions also boast some of the highest rates of population growth. The populations of Kenya, Ethiopia, and Iran may well double within 25 years. Yet, the amount of water available to these countries will remain the same.

In water-scarce countries, population size and consumption patterns will determine the quality of life. Where population pressure on available water is too high, it sets off a risk spiral which diminishes the water available per person, and may degrade water quality, and threaten human health. Scarcity of water also limits the ability to develop economically and to attain self-sufficiency in food production. Water is a necessary lubricant for industry; the lack of it may also be the ultimate constraint.

Getting enough water has always been a challenge. Access to water has

FAO/J. Issac

Box 1

Myths About Water

Myth: Water is an endlessly renewable resource.

Fact: Water is renewed within the global cycle, but the renewal rate of water is fixed and extremely slow. The amount of water entering an area each season depends on its geography and climate. There are no untapped reserves of water, but there may be unused flows that could be developed.

Myth: Water is a static resource.

Fact: Water is a dynamic, not static resource. The renewal rate, not the global volume of water at a given time determines how much water is available for use. The volume of water in a lake gives no information on the amount of water that can be withdrawn from that lake.

Myth: Water and the availability of water is a purely technical issue.

Fact: Many of our economic and resource problems have been solved by technology, but water is not solely a technological issue. If technology makes it possible to produce rain over one country, a neighboring country is deprived of its rainfall. If Ethiopia builds a dam near the source of the Nile and withdraws water for agriculture and other uses, the supply of water for Egypt, thousands of miles downstream, will diminish.

Myth: The availability of water is mainly an economic question. It is governed by market forces.

Fact: Ninety percent of the world's available water is not amenable to metering and thus eludes current market economics. However, the management of the water that is piped to users may be an economic issue subject to market forces.

generated political and military conflicts throughout world history. Often people have devised some technological wonder to overcome these problems—by building dams, canals, and pipelines to bring water from far away, or by making sea water drinkable. But such solutions are expensive, especially for the low-income countries suffering the worst shortages. And ultimately even the most ingenious methods may not supply enough water for the number of people expected to inhabit the Earth's thirstiest regions in coming decades.

The management of water scarcity is further complicated by the tendency to treat water as a commodity rather than as a finite natural resource. Engineers and politicians, not physical scientists, traditionally govern the use or misuse of water, often with little understanding of the intricacies of the water cycle or the long-term environmental impacts of their projects.

In the scientific community, population and water, along with other resources, are studied within separate disciplines, each with their own terminology and priorities. This dispersion of effort has caused a kind of scientific paralysis which has blocked progress in solving current and impending water problems.

An integrated, interdisciplinary approach to water management would allow the traditional question "how much water do we need and how much will it cost to get it", to be more appropriately reformulated as "how much water is available, and how can we use it most efficiently?"

Most water management systems were developed in the relatively water-abundant temperate climates of the industrialized countries. The wholesale transfer of these methods and technologies to the fragile hydroclimates of the tropical Third World denotes a type of "water blindness" and "temperate bias" among the development specialists who so often advise developing country governments and industries.

This *Population Bulletin* looks at water's role in the Earth's life systems, and how it relates it to human society.

It shows how society is both a manipulator of the water cycle and a consumer dependent on a constant supply; and how its needs vary with population size and consumption patterns.

Lifeblood of the Biosphere

Water is the lifeblood of the biosphere—that part of the Earth and its atmosphere in which all living things exist. Life on Earth exists within one of its three main systems: the atmosphere, the land, and water (including both the oceans and bodies of freshwater). Life is only possible because of the solar-driven circulation of water from the ocean to the atmosphere, from the atmosphere to the land, and back to the ocean.

Water has many remarkable physical and chemical characteristics. Within the human body, water carries nutrients to the cells and evacuates their waste products. It fulfills similar functions for plants and other animals. Its capillarity and surface tension leave water hanging between the mineral particles in the soil, making moisture accessible to plant roots. Water's ability to absorb heat makes it not only a cooling agent for plants and animals, but also gives it great influence over the world's climate. Its properties as a unique solvent and of underground mobility make water a carrier of nutrients and minerals from land into the groundwater, rivers, lakes, and other water bodies.

Water is also a carrier of disease. Human and animal wastes flowing into rivers or reservoirs introduce pathogens that cause a myriad of serious water-related diseases, including typhoid, cholera, amoebic infections, bacillary dysentery, and diarrhea. These account for over three-quarters of all disease in developing countries, and a large share of deaths. Treatment of water destined for household consumption can eliminate these diseases, but safe water for drinking and personal hygiene and sewage systems to control waste are a luxury in much of the world. In many developing countries, less than 20 percent of the population has access to clean drinking water.[2]

Water and Civilization

Not only is water necessary for humans to live, close proximity to water may have been a precondition for the earliest human settlements. Large waterways like the Nile and the Euphrates and Tigris, the Indus, and the Danube Rivers have been the source for agricultural and drinking water for millennia. Energy generated by differences in the water levels in rivers and streams was used to operate mills and factories, providing an early base for small industries. Lakes, rivers and oceans provided food and offered humans their most efficient means of transport.

The problem of getting enough water for growing populations and increasing agriculture and industry has frequently caused conflict. Irrigation systems in Mesopotamia and ancient Egypt, in the Roman Empire, China, and Medieval Europe all faced similar problems of distribution of water, of communal labor and collective responsibility for water courses. Conflicts over water use and extraction and over water rights occupied Roman lawyers and medieval judges in Valencia's *Tribunal de las Aguas*—a tribunal which has met nearly every Thursday for almost 900 years! For centuries, government plans for central control of waterways and irrigation water have been in conflict with farmers and their ideas of agriculture. Bickering over irrigation water was a permanent factor in Chinese life and quarrels over the measurement of irrigation time were not unheard of in medieval Spain.[3]

After the Romans designed methods of lifting water or conducting it from distant sources, Roman subjects were able to congregate in denser settlements. The Roman aqueducts made the use of marginal land possible but their construction ushered in political and logistical problems of their operation and maintenance.

The history of water and populations is also a history of power in society. There is extensive debate among social and political scientists about the connection between irrigation systems, political organization, and modes of

Environmental conditions, along with political unrest, limit water access in Somalia.

production.[4] The importance of water to the societies that developed along the Euphrates, the Tigris, and the Nile led historian Karl Wittfogel to propound a theory that control of water was a foundation for early civilizations. Wittfogel defended and promoted the argument that waterworks for agricultural purposes were so extensive and important that a well-organized cooperative effort was needed for their construction, administration, and maintenance.[5] This, in turn, led to a need for centralized decisions from which a certain type of political centralization and hierarchy developed.

Other researchers have proposed, conversely, that power is the basis for control of water rather than the control of water being the basis for power.[6] Some argue that the managerial functions implicit in irrigation may be performed through community leadership rather than a central authority.[7]

Political conflicts about the control of water and waterways are with us today. Almost 150 of the world's 200 major river systems are shared by at least two countries.[8] Conflicts over international rivers such as the Danube or the Rhine encompass both extraction and pollution. The 1991 war in the Persian Gulf underscored the strategic position of Turkey in controlling the sources of the Tigris and Euphrates Rivers. Recent irrigation/agriculture developments in Turkey, such as the Southeastern Anatolia Project will cut the flow of the Tigris by 20 percent and that of the Euphrates by some 40 percent. The Tigris carries about 17 billion cubic meters of water into Iraq and the Euphrates about 31 million cubic meters into Syria.

Limits on Human Access to Water

As numbers of people multiply and agricultural and industrial activities intensify, the amount of water used by society escalates. But access to this most vital resource is limited by environmental preconditions, such as the climate and geography, and through human activities that pollute or otherwise disturb the water systems. The key to understanding how population affects and is affected by the global water systems is an understanding of how the water system operates.

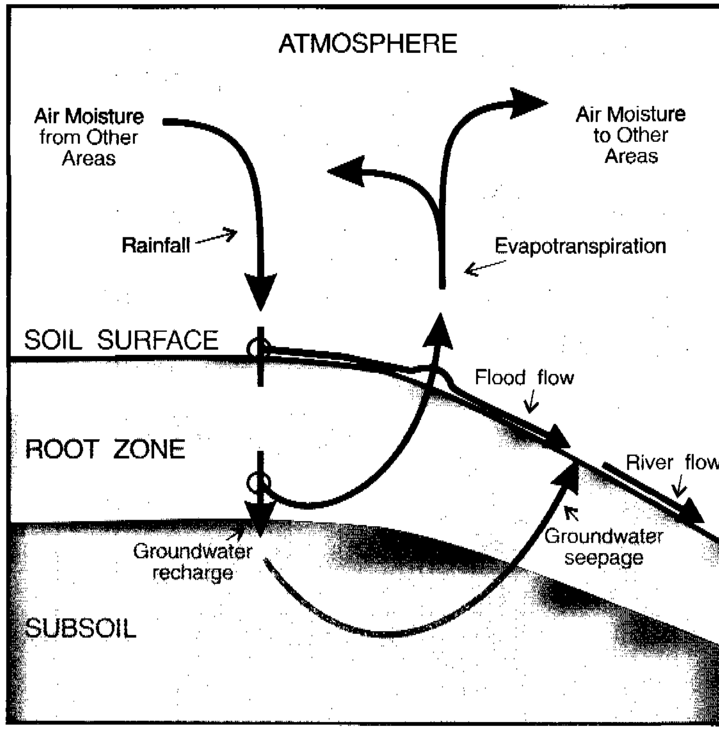
Understanding the Water Cycle

The presence of the water cycle is the fundamental difference between Earth and the other planets.[9] Water binds together and dominates many of

Earth's subsystems. About 113,000 cubic kilometers of water fall on the continents each year.[10] This precipitation is then partitioned into a long or short branch of the water cycle (see Figure 1). Most of the water remains in the short branch, returning quickly to the atmosphere from the surface of the Earth where it evaporates from moist surfaces and water bodies or is consumed by plants whose leaves return it to the air.

Water in the long branch of the cycle seeps into the soil and replenishes the underground aquifers, joining underground flows, and finally the rivers and seas. Groundwater eventually seeps to the surface in springs, or flows into rivers. The groundwater table may lie fairly close to the surface, where it is easily pumped out, or remain trapped in rock formations far under the earth. Some aquifers contain enormous amounts of water deposited thousands of years ago. The world's largest known aquifer, the Ogallala, lies beneath eight states in the central plains of the United States. Water pumped from the Ogallala helped transform a vast prairie into America's most productive farmland.

Figure 1
How Water Enters and Leaves the Landscape



○ Partitioning points for longer and shorter branches of the water cycle.

Source: Adapted from Malin Falkenmark, "Fresh-Water—Time for a Modified Approach," *Ambio* 15, no. 4 (1986): 192-200.

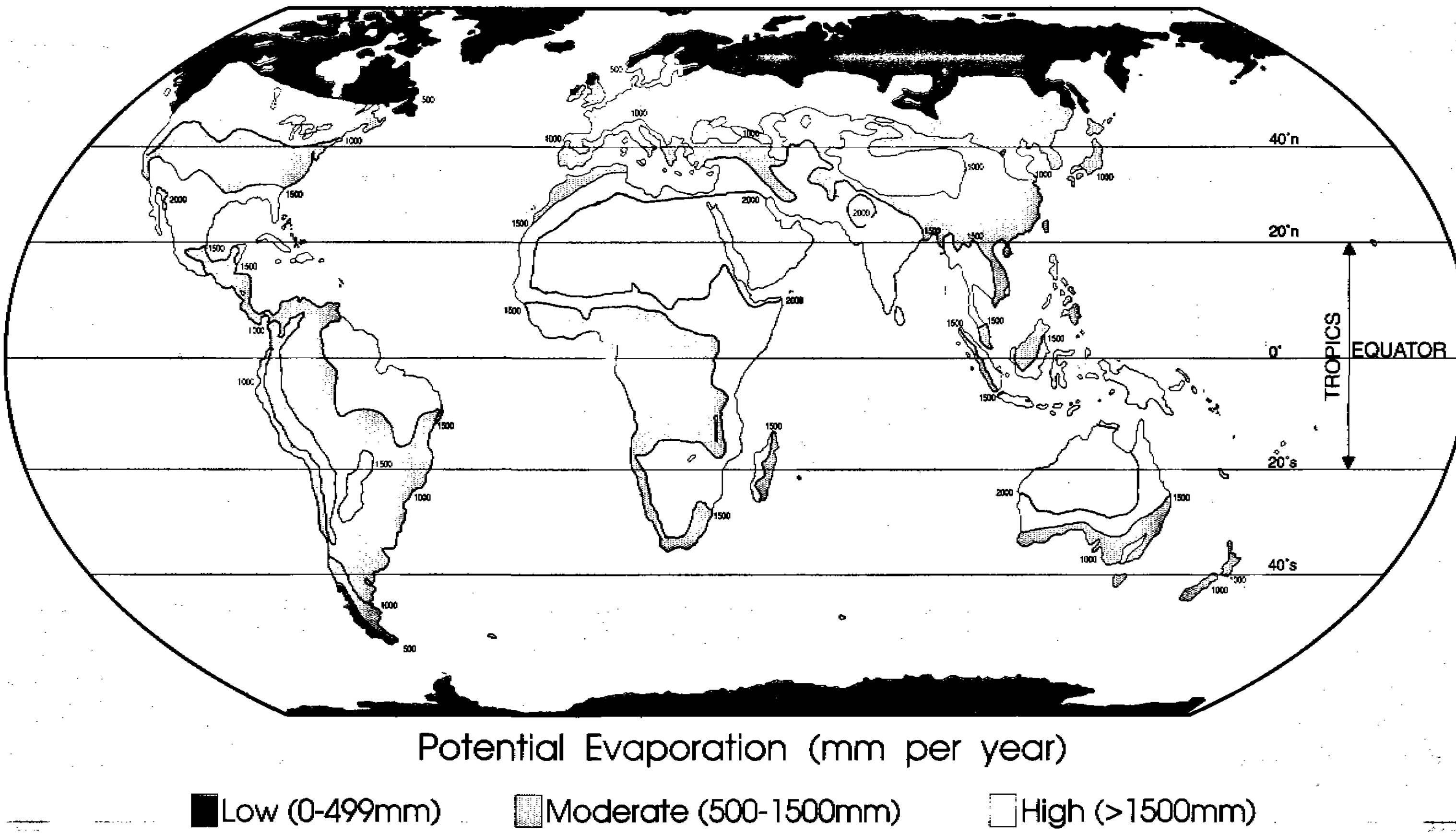
Environmental Limits

Society's access to water is complicated by the inequitable distribution of fresh water throughout the globe. The amount of renewable freshwater that passes through the aquifers and rivers of a country and is available for human use is defined by that country's position in the global water cycle and is composed of two complementary components: endogenous and exogenous. Endogenous water is produced locally from rain or snow. Most local precipitation is returned to the atmosphere as evaporation from wet surfaces and the transpiration of vegetation. Any surplus water goes to recharge the groundwater or flows into rivers or streams. Exogenous water is produced from rain or snow elsewhere and carried into a region by rivers or groundwater systems.

The share of water that enters and remains in an area naturally (that is, without human intervention) is governed by the characteristics of the landscape: rock formations beneath the surface, soil type, mountain ridges, vegetation. Most of all, it is regulated by the hydroclimate, especially the timing of the annual precipitation, the risk of recurrent droughts, and the evaporative demand of the atmosphere. Evaporative demand is a measure of the maximum amount of moisture that the atmosphere can absorb. Its value depends primarily on the temperature and latitude of a given area. Generally, evaporative demand is higher in warm areas, and is especially high at certain latitudes, as shown in Figure 2.

Because the temperature is higher in the Earth's low latitudes surrounding the equator—which receive the full brunt of the sun's rays—evaporative demand is higher there. But even in the warmest latitudes, the amount of water consumed in the production of vegetation, or biomass, varies between wet and

Figure 2
Evaporative Demand



Note: Evaporative demand is the potential or maximum amount of moisture a region's atmosphere can absorb (in millimeters of water per year). One millimeter (mm) equals 0.04 inches.

Source: Malin Falkenmark and Tom Chapman, eds., *Comparative Hydrology: An Ecological Approach to Land and Water Resources* (Paris: UNESCO, 1989).

dry climates. In the humid tropics supporting layers of lush foliage, only some 200 cubic meters of water returns to the atmosphere for every ton of biomass produced. In the arid tropics, where the atmosphere is hot and dry and the vegetation sparse, about 1,000 cubic meters of moisture are consumed per ton of biomass produced.

In the Scandinavian hydroclimate in the northern latitudes, for example, fewer than 500 millimeters of moisture per year evaporate into the atmosphere. The evaporative demand is twice this level in southern Europe and three times as large in the Sahel region of Africa. As a result, 1,000 millimeters of rainfall could create quite wet conditions in Scandinavia, but dry conditions in the Sahel.

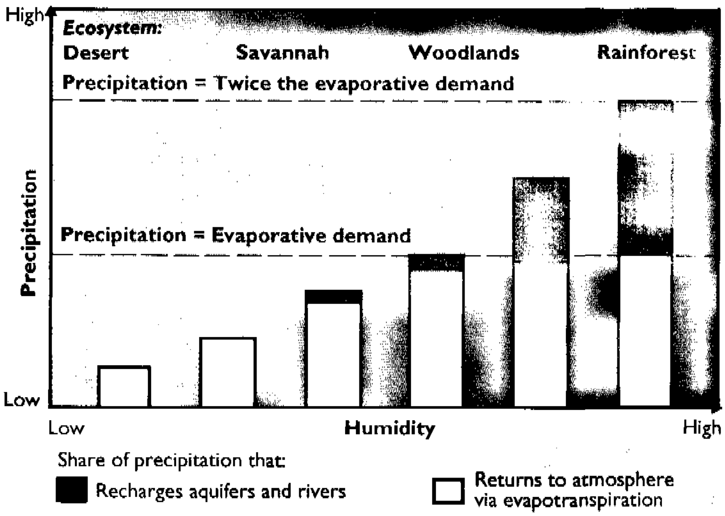
Also, the annual precipitation is evenly distributed throughout the year in areas such as Sweden or the Pacific Northwest of the United States. But in other regions, especially in the dry tropics, a year's worth of rain may fall within a few weeks. In India, for example, 90 percent of the annual rainfall occurs between June and September, the monsoon season.[11] In monsoon areas, weeks of heavy, intensive rain often follow a very dry period. The parched soil can absorb only a small portion of the rainfall and much of the area's annual water supply escapes downstream, often causing severe floods and heavy siltation in downstream regions.

The risk of drought varies greatly by region. Low latitude climates are often characterized by highly fluctuating amounts of rainfall.[12] While most world regions occasionally experience dry years or even severe drought, tropical and sub-tropical areas often suffer from recurring drought years. These droughts and fluctuations are linked to atmospheric conditions and global weather patterns. For example, unusually warm surface currents in the Pacific Ocean—dubbed the El Niño current—occur in intermittent years and create a pool of warm water that disrupts weather patterns throughout the countries in the Pacific region, and, possibly, throughout the globe.[13] El Niño may cause flooding in normally arid areas, such as in western South America, and drought in normally humid areas, such as Indonesia. Possibly linked to the El Niño weather phenomenon, more than 20 African countries experienced drought in 1984 and 1985, contributing to widespread famine.[14] Renewed drought hit southern and eastern Africa during the 1991-1992 growing season, ensuring enormous deficits in grain and other foods. Kenya, which usually exports food, will have to import 500,000 tons of food in 1992. There have been reports of people begging for water from passing vehicles in western Kenya, which is suffering the brunt of the drought. In parts of Zimbabwe, drought has caused industries to shut down. Collapse of the water system in the Zimbabwean city of Bulawayo may cause residents to be evacuated. And poor rains in Ethiopia will affect not only that country, but also Egypt, because the major source of the Nile River is in western Ethiopia.[15] Drought has exacerbated already excruciating conditions in war-torn Somalia—forcing thousands of Somalis to leave their homes, many moving across national borders.

The hydroclimate, along with the soil, geographic features and the latitude, dictate the type of native vegetation a landscape can support. Depending on the amount of rainfall, evaporative demand, and temperature, the landscape may support forests, grasslands (savannahs), or deserts (see Figure 3, page 10). An area's groundwater systems are replenished from any surplus water.

The vegetation growing within each type of ecosystem varies with local geologic conditions as well as the latitude. Forests range from the lush rainforests of Brazil containing thousands of species of plants and animals to the less diverse evergreen forests of the Canadian Rockies. Where water is insufficient to support forest growth, less dense woodlands grow, which give way to grasslands as conditions become more dry. Grasslands or savannahs may consist entirely of grasses, or may be interspersed with shrubs and trees. Where water is scarce, the entire landscape may be desert.

Figure 3
Share of Rainfall Going to Recharge Groundwater



The transition regions between the tropics and temperate climates, latitudes of about 20 to 30 degrees north and south of the equator tend to be the driest on Earth. Included in this band south of the equator are the Kalahari Desert in southern Africa, the deserts of central and western Australia, and the Atacama Desert in northern Chile. Between 20 and 30 degrees north of the equator lie the Sahara Desert in Africa and the Chihuahua Desert in Mexico.

At these latitudes, dry cool air transferred from the atmosphere above the equator falls from the upper atmosphere leaving little moisture for precipitation in those areas. The high evaporative demand, limited and fluctuating rainfall, and risk of drought in these regions constitute environmental preconditions that limit the capacity to produce lucrative agricultural products for export and frustrate the search for self sufficiency in food. As a glance at Figure 4 will show, the countries with the lowest index of human development are disproportionately concentrated in the semi-humid to arid tropics. Often these areas also have the greatest constraints on available water and the fastest growing populations.

Human-Induced Limits

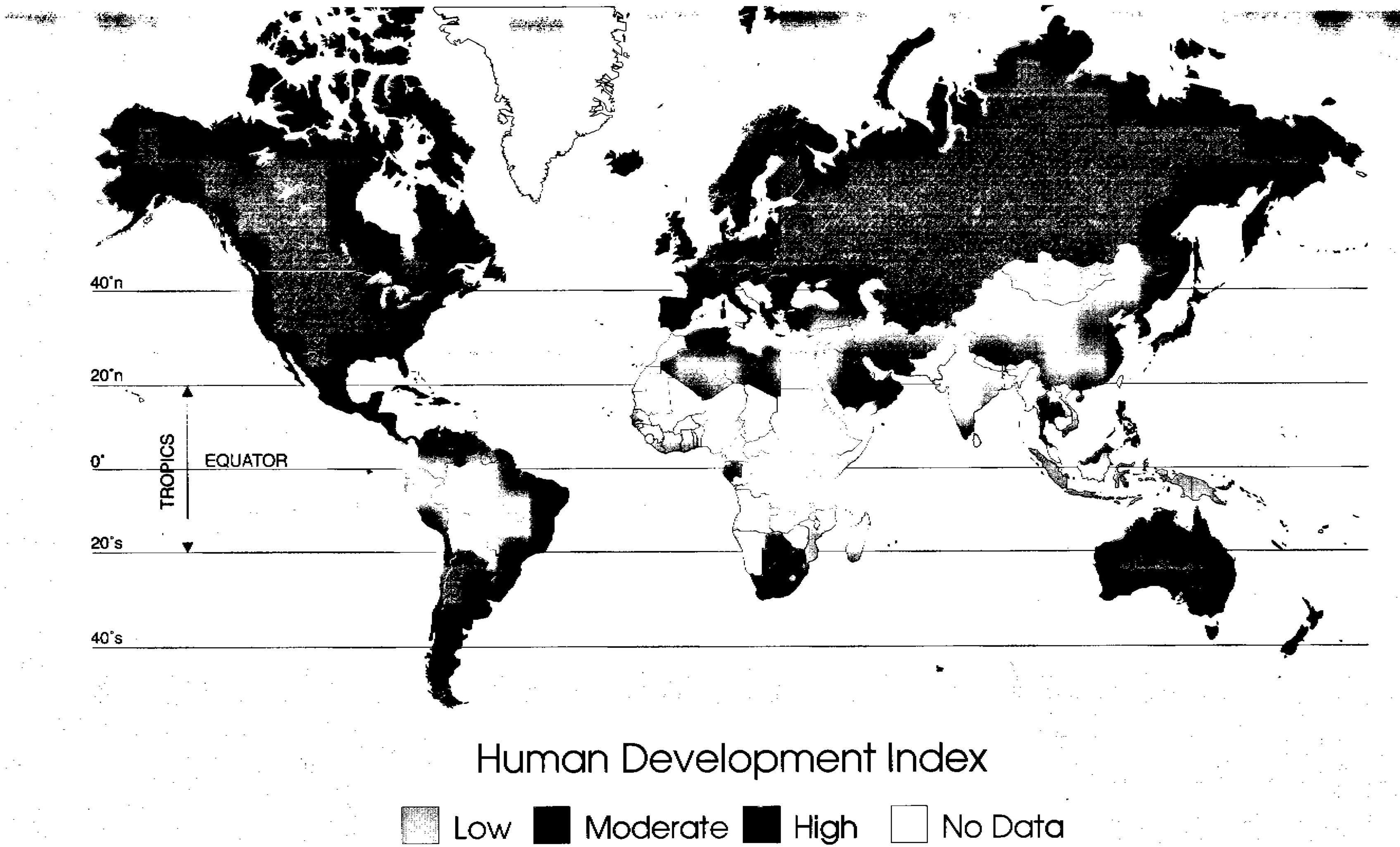
Hydrological preconditions place absolute limits on society's access to water resources. However, society's activities create another form of limitation to water quality and supply. Human civilization requires the manipulation of natural systems. To obtain food and shelter and to manufacture tools and other products, men and women have always tilled the soil, dug wells, and cut trees to harvest timber and fuelwood. Just as during the first millennia of human life on Earth, further economic and social development will require use of water and other natural resources. While some manipulation of the environment is unavoidable to meet domestic, industrial, and agricultural needs, certain human interventions are technologically driven and can be avoided. Avoidable human interventions that harm the environment can be identified and mitigated by policy.

The United States and other industrial countries have long faced water quality and quantity problems created by their own waste and industrial and agricultural activities. These relatively rich countries have begun to clean up some of the old man-made problems and are attempting to head off or at least minimize future disruption of their freshwater systems. But the task remains a formidable one.

Many developing countries have only begun large-scale alteration of their natural environment in the attempt to achieve security in food production, modernize their economies, and improve their standards of living. With the importation of technology, pesticides, and fertilizers from the already developed countries, the magnitude and environmental impacts of these development projects are escalating.

All these human interventions have higher order effects on flora and fauna; first, through the water cycle, which propagates any disturbance onward like a chain reaction, and second, because life is based on a myriad of water flows. Chemical or physical disturbance of these flows has ecological effects on the flora and fauna. In many less developed

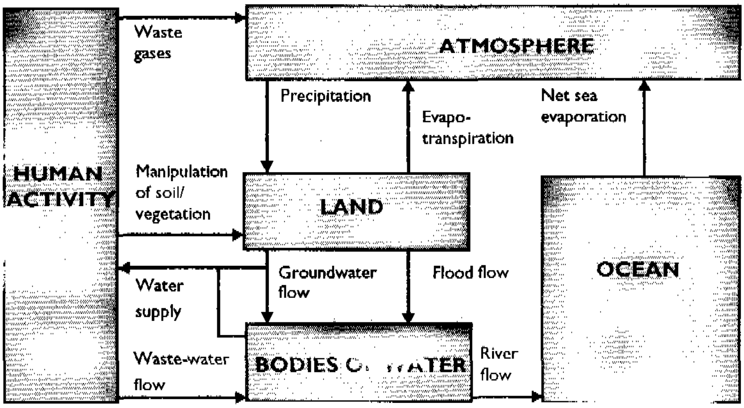
Figure 4
Levels of Human Development



Note: The Human Development Index is computed from measures of life expectancy, educational attainment, and gross domestic product per capita for each country.

Source: United Nations, *Human Development Report 1992* (New York: Oxford University Press, 1992), Table 1.

Figure 5
How Human Activities Disturb the Water Cycle



Source: Adapted from Malin Falkenmark, "The Ven Te Chow Memorial Lecture," *Water International* 16, no.4 (1991): 229-240

countries, the incipient poverty and rush to modernize in the face of continuous population increase has encouraged the adoption of the cheapest, most expedient methods of extracting minerals, raising crops, building dams or roads. Concern about environmental degradation generated by these actions is often pushed to the background.

Human activities that disturb the circulation and character of water are propagated through the water cycle as depicted in Figure 5. They cause secondary effects on the groundwater table, the fertility of the soil, the seasonality of river flows, and the chemical and biological characteristics of the moving water.

A common example of a chemical disturbance with far-reaching effects is the overuse of nitrogen-rich fertilizers to increase agricultural yields. The dissolved surplus nitrate is carried to groundwater aquifers, lakes, and rivers, generating rapid growth of algae, robbing the water of oxygen, and creating water supply problems. Eventually the water cannot support the native fish population and other indigenous aquatic life. Once the nutrient-enriched river flow reaches estuaries and coastal waters, the same process—termed eutrophication—begins there. The Baltic and North Seas are showing the effects of this process, raising public concerns about the water quality and fishing industry in Scandinavian countries.

Acid rain is another man-induced chemical disturbance that enters the water cycle from the atmosphere rather than the landscape. Energy production, traffic, and other human activities produce acidifying gases that dissolve in water droplets in the atmosphere, transforming the precipitation into a dilute acid. Once on the land, the acid water seeps into the root zone, damaging the vegetation and contributing to forest dieback. This process has harmed forest growth in the Adirondack Mountains of the northeastern United States and ravaged the forests of Czechoslovakia.

Once the buffering capacity of the soil has been surpassed, an "acid front" moves down into the groundwater, dissolving metals and other ph-sensitive materials in the soil and washing them into the water systems. In Scandinavia and Canada, acids that accumulate all winter in the snow pack are released all at once during the snow-melt, sending a shock to the river systems. These acid floodwaters also carry aluminum dissolved from the soil, which, in combination with the high acidity, is toxic to fish.

Air pollution also affects the water cycle through the warming effect of "greenhouse gases" building up in the Earth's atmosphere. One of the most prevalent of these is carbon dioxide created by the burning of fossil fuels in automobiles and factories. The future effects of global warming, indeed the estimated extent of it, are vigorously debated, but some change is certain to occur. Warmer temperatures could intensify the evaporation from the ocean and thereby increase the amount of water vapor carried toward the land. The shifting paths of atmospheric water vapor would alter precipitation patterns over the continents. The evaporative demand of the atmosphere may rise—some areas will become wetter, others drier.

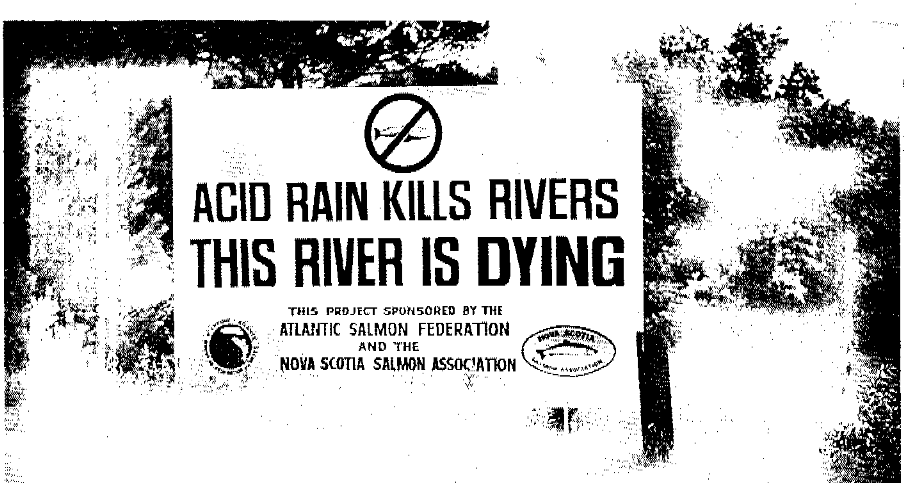
Changes in the moisture content of the soil would alter biological systems; groundwater recharge and therefore water tables would be affected. Eventually the water levels of rivers, lakes, and other water bodies will be changed. The chemical composition of ground and surface water could be affected, eventually influencing the aquatic and coastal ecosystems. The type and yield of agricultural production will most certainly change—especially in areas that are heavily dependent on irrigation.

Overpumping of groundwater can also set off a chain of events. When water is pumped from the ground faster than it can be renewed, the water table sinks and aquifers are depleted. This process is occurring with the Ogallala aquifer in the United States. Some experts estimate that the aquifer may be depleted within the next quarter century. In India's Tamil Nadu region, excessive pumping has lowered the local water table by 30 meters in just a few decades.

Agricultural practices, especially the traditional burning and clearcutting relied on in many developing societies, can alter the water systems. When land is cleared or overgrazed, water that would otherwise infiltrate the soil to feed the plants, remains on the surface, often carrying away nutrients and soil with it. This desiccation, or extreme drying, of the land may create desert-like conditions.

Storing water behind some man-made barrier is another intentional manipulation of the water cycle to improve the accessibility of water for social use. Water stored behind dams can be used when needed to grow dry season crops or generate electricity, for example. The building of dams often involves flooding a river valley which alters natural habitat and the composition of animal and plant species both behind and downstream from the dam. Alteration of groundwater systems and river deltas is an unavoidable outcome of building a dam. However, other negative effects commonly associated with large dams and reservoirs can be lessened or avoided altogether. These include the spread of water-borne diseases affecting humans and livestock and salinization or waterlogging of soil downstream. The rapid silting of reservoirs which can shorten the useful life span of a dam, can also be avoided. With proper foresight, dam reservoirs can provide new desirable habitats. Fisheries, boating, flood control, and recreational activities can be developed in conjunction with the building of a dam and hydropower plant, counterbalancing the unavoidable side-effects of this form of human intervention.

In sum, human manipulation of the water cycle is unavoidable, but many of the most harmful effects of human activity can be avoided. How much water does human society need? Again, the answer depends on both the environmental preconditions, the way a given society uses water, and of course the numbers of people to be served.



Air pollutants can enter the water through acid rain, harming flora and fauna.

Patterns of Water Use

Irrigated agriculture consumes most of the water used by people—nearly 70 percent worldwide. Industry accounts for about 23 percent of worldwide water use; and households only about 8 percent. Within a specific area, the relative importance of each of these three competing uses depends on the hydroclimate, population size, and the nature of economic activities. The amount of water used also varies with cultural expectations and demands. In Asia, 82 percent of the estimated water withdrawals from rivers or aquifers is used to irrigate crops. Irrigated agriculture accounts for 68 percent of water use in Africa, 41 percent in the United States, and 30 percent in Europe.[16] The amount used for industry increases with development level and by type of industry, but also can reflect changes in industrial processes.

Domestic or household use nearly always accounts for the smallest share of water used, except in the few countries with little agriculture or industry. In the city-state of Singapore, for example, domestic use accounts for 45 percent of the water used, and industry 51 percent.

Domestic water use is the only category that has a practical minimum. To assure adequate health, people need a minimum of about 100 liters of water per day for drinking, cooking, and washing. Of course many times this amount is necessary to carry out the activities necessary to sustain an economic base in a community. In water-abundant or affluent societies, people use many times the personal daily minimum.

Industry is the next largest usage category for water. Water has long been a basic lubricant of industrial development. Water is used in factories for cooling, processing, generating steam to run equipment, and as a transporting agent. Certain industries are particularly water intensive. Pulp and paper manufacturing, petroleum refining, and food processing are prime examples. But depending on the methods used, especially the reuse of water within the plant, the amount of water needed to

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People need a minimum of 100 liters of water per day for personal health and hygiene.

manufacture a given product can vary by a factor of 40. In Sweden, industrial water use declined markedly in the 1970s because new economic incentives motivated industries to introduce in-plant recirculation of water.[17]

Agriculture, which accounts for the largest share of water use, is also the least efficient. In the 1980s, approximately 270 million hectares of land were irrigated,[18] almost half of it in the developing countries. But a large share of irrigation water is wasted. It is not uncommon for 70 to 80 percent of the water diverted to irrigation systems to be lost to the atmosphere or seep into the ground before reaching the fields. In the lower Colorado River basin in the United States, about half of the irrigation water is wasted in this manner.

Country Use Patterns

The amount of water per capita used in a specific region depends not only on how much is easily accessible, but also on the nature of water needs and the living standards of the population. Irrigation consumes the lion's share of water resources. It is no surprise that water usage would be highest in countries that must irrigate agriculture most of the year, such as in Middle Eastern countries.

Data on water availability and demand from the time of the UN 1977 Water Conference in Mar del Plata, Argentina, indicate that, in the 1970s, Iraq used 4,400 cubic meters per year per person, while Pakistan used 2,200; Syria, 1,200; Egypt, 1,200; and India, 800. Israel stands out as an industrialized country in a semi-arid zone with a low gross water-demand level on a relative scale. By practicing efficient water management, Israel uses only 500 cubic meters annually per person.[19]

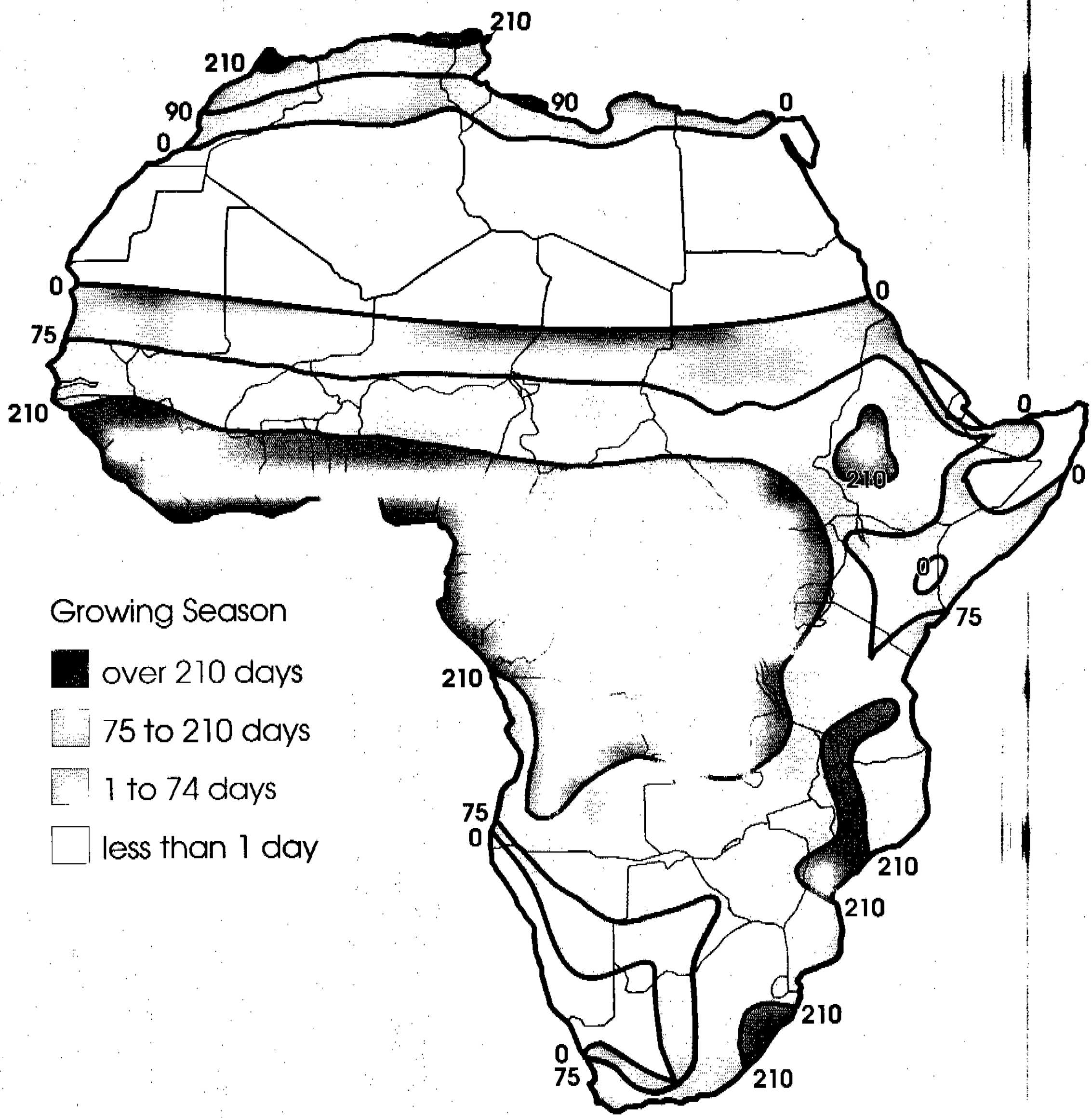
For countries in these arid zones, access to exogenous water—specifically, freshwater flowing into a country from rivers—can determine whether they are self-sufficient in agriculture. In semi-arid areas with no exogenous water, such as Libya and Saudi Arabia, agricultural production is limited by the amount of water in the root zone unless irrigation is possible. Soil moisture, replenished during the rainy season, determines the length of the growing season. A growing season of three months (about 75 to 90 days) is considered the lower limit for crop cultivation. Where the soil contains less moisture than required for a three-month growing season, only pasture is possible. Where the atmosphere is hot and dry, as it is in the dry tropics, it is capable of reabsorbing some 100 to 150 millimeters of water per month, or at least 300 to 450 millimeters during the growing period. In areas where the amount of water in the root zone limits the growing season to three to seven months (90 to 210 days), agriculture is highly vulnerable to droughts.

Large stretches of land in Africa have so little root-zone water available that little or no agriculture can be practiced. While some countries, such as Sudan and Ethiopia, have access to irrigation water, most of these areas must adapt to low levels of farming or raising livestock (see Figure 6, page 16).

In these areas, crop yield can be increased by drought-proofing agriculture through rainwater harvesting, runoff collection, and catchment management. Irrigation can be minimized by limiting it to critical periods during the growing season. Experiments with such water conservation methods are being carried out in India.[20] Some areas pump water from groundwater trapped in aquifers, a practice known as "mining" groundwater. But this is a temporary solution. The renewal rate of aquifers is so slow that groundwater mining can quickly deplete an aquifer.

The situation can be quite different in arid regions that have access to large rivers, such as Egypt. In such regions, irrigated crop growth may be practiced for as many seasons as the water flow may support. Since early human history, farmers have made skillful use of exogenous water to irrigate crops, thereby expanding the growing season. Ancient Mesopotamian, Egyptian, and Chinese cultures provide classic examples of how access to drought-proofing water made social development possible.

Figure 6
Growing Seasons and Drought Risk in Africa



Note: Where the growing season is negligible or less than 75 days, (90 days in North Africa) vegetation tends to be drought-prone pastureland. No agriculture is possible without irrigation. Where the growing season is 75 to 210 days, agriculture is limited by recurrent droughts and large seasonal fluctuations in rainfall.

Source: UN Food and Agriculture Organization (FAO), *Irrigation and Water Resources Potential for Africa* ALG/MISC/11/87 (Rome: FAO, 1987).

The presence of exogenous water explains the different situations of the Sahel, in northern Africa, and the Punjab, in India. Both regions have arid climates, yet the Sahel relies on endogenous water produced by local rainfall. The Punjab is enriched by exogenous water generated by rain and snow on the Himalayan slopes, miles away. Egypt's access to the Nile River gives it a great advantage over Libya, for example, which has no large rivers (see Table 1). Dramatic increases in agricultural production in southern Asia during the past few decades may in fact largely be due to the widespread access to exogenous water in that region.

Humid areas fed by local rainfall have different sorts of water management problems (see Table 2). They must deal with drainage problems and eutrophication, that is, the depletion of water's oxygen content from excessive organic matter. Eutrophication is often generated by the leaching of excess fertilizers from agricultural land. Humid landscapes largely fed by exogenous water sources often suffer from water pollution introduced upstream. The water supply for the Netherlands, for example, is vulnerable to huge amounts of pollutants carried in by the Rhine River from the upstream countries of Switzerland, France, and Germany.

While all areas face water management challenges, absolute water scarcity threatens the large group of low latitude countries whose climates place them on the hydrological margin. Their problems have somewhat different origins, predict a very different future, and dictate unique remedies.

Table 1
Selected Countries by Source of Available Water

Share of water from endogenous sources \ Share of water from exogenous sources	Small	Medium	Large
Small	Saudi Arabia Australia Tunisia Libya	Niger Iraq Pakistan	Mauritania Egypt Botswana
Medium	China Spain Mexico	Paraguay	Gambia
Large	Norway Colombia	Yugoslavia Uruguay Congo	Hungary Netherlands

Table 2
Management Approaches for Different Water Source Combinations

Share of water from endogenous sources \ Share of water from exogenous sources	Small	Medium	Large
Small	storage; rainwater harvesting; protective irrigation; runoff collection	irrigation	irrigation
Medium	reduce causes of eutrofication	irrigation	irrigation
Large	introduce effective drainage systems	international cooperation to control water pollution	international cooperation to control water pollution

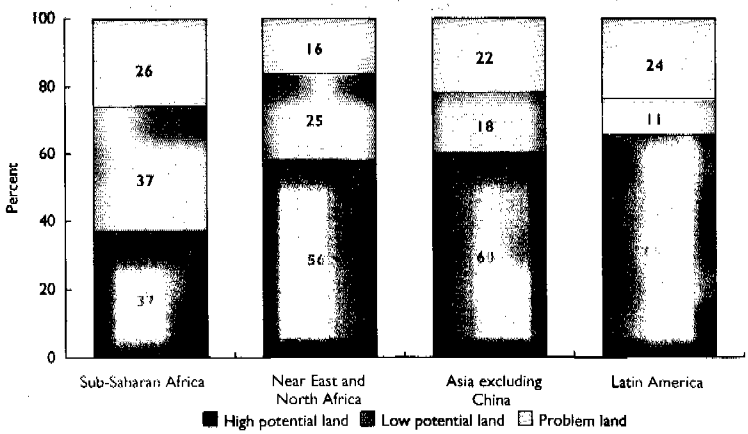
Note: Exogenous water is imported from elsewhere, such as a river water. Edogenous water is from local precipitation.

Living on the Hydrological Margin

The hydroclimate of much of the Third World makes it particularly subject to "genuine" water scarcity stemming from environmental conditions and the hydrological cycle (see Box 2, page 18). At the same time, overgrazing, overcutting of woodlands, traditional agricultural methods, and growing population pressure in these same areas often create an ideal environment for human-induced modes of scarcity.

The severe drought and widespread famine in Africa during 1984 and 1985 can be linked to both genuine and human-induced water scarcity. The genuine water scarcity, exacerbated by drought, created a "hunger crescent" through part of sub-Saharan Africa, passing through the gradient zone between the arid desert and the humid tropics. The most critically affected countries, such as Mali, Kenya, or Tanzania, are located in a region that

Figure 7
Agricultural Potential of Land in Developing Regions



Source: Adapted from data in UN Food and Agriculture Organization, *World Agriculture: Toward 2000* (London: Belhove Press, 1989).

has, first, a short growing season, making crops particularly vulnerable to recurrent droughts, and second, a shortage of water in aquifers and rivers.

The hydroclimate and environmental preconditions make these arid and semiarid landscapes particularly vulnerable to the deterioration of soil permeability. Soil in tropical and subtropical areas deteriorates easily from either chemical or physical disturbances. The virulent action of intensive monsoon rains washes away topsoil, especially where the plant cover has been cleared by overgrazing, deforestation, or fuelwood harvesting. In certain areas, the chemical makeup of the soil helps the topsoil become nearly impermeable to rainwater and easily eroded. Where the rainwater cannot infiltrate, the main avenue for recharging local groundwater that provides water during the dry season is blocked. This deterioration of the soil aggravates the genuine, or natural, water supply problems.

Because there is so little surplus of water (that is, water left after evaporation) in these regions, limited changes in vegetation can produce noticeable shifts in the surplus available for recharging aquifers and watercourses.

Box 2
Genuine vs. Human-Induced Water Scarcity

The water scarcity predicament facing society may be expressed in four different modes. Two modes are natural or genuine in that they are related to the hydroclimate. These are 1) the short growing season and 2) intermittent droughts. The other two are human-induced: 3) desiccation, or extreme drying, of the land so that the soil can no longer absorb water, and 4) high population pressure with limited water availability.

The production of vegetation—and therefore self reliance in food, livestock fodder, fuelwood, and timber—is limited by the genuine water scarcity linked to the hydroclimate. Unless irrigation water from elsewhere is available, both modes of water scarcity dictate planting drought-resistant crops and storing grain or water surplus from wet years for use during dry years.

Biomass production is also harmed by the third, human-induced, type of water scarcity: soil desiccation. When the soil surface becomes impermeable to water infiltration, the root zone dries out; nothing grows and groundwater is not recharged. The water table in local wells decreases and local populations experience what they think is a drought. This phenomenon is widespread—not only in dry regions, where it is known as dryland degradation, or less precisely as desertification—but also in water-rich areas like the Ethiopian highlands or the Himalayan slopes. Inhabitants may complain of drought despite ample rainfall.

Human water supply is also threatened by population expansion in areas with limited water availability. In such areas, rapid population growth constitutes a particular threat to both biomass production and human water supply, lessening the ability to be self sufficient. Overcoming these threats poses great challenges to all those involved with water management.

In parts of Australia and South Africa, large-scale vegetation changes severely altered the recharge rates of aquifers and rivers. In southwestern Australia the salinity of streams has increased as former woodlands are cleared for agricultural development, especially in areas that receive the least rainfall.[21] In South Africa, reforestation is considered a major water consumer, evaporating water that would otherwise feed the local rivers.[22]

The experiences in water-scarce areas drive home the point that development following the model of the water-abundant northern countries is inappropriate in areas living on the hydrological margin. Sub-Saharan Africa is a prime example of such an area. The Food and Agriculture Organization (FAO) estimates that over 35 percent of the total harvested land in Africa is "low potential land," primarily because of its limited and uncertain rainfall. The share of low potential land is greater in Africa than in other major developing regions (see Figure 7). Almost half the land could not support its population given the low-yield agricultural techniques generally practiced. In 1975, 22 African countries were not self-supporting in agriculture.[23] Agricultural production must at least double within 20 years in order to just reduce famine and keep pace with population growth.

Population Pressure on Water Resources

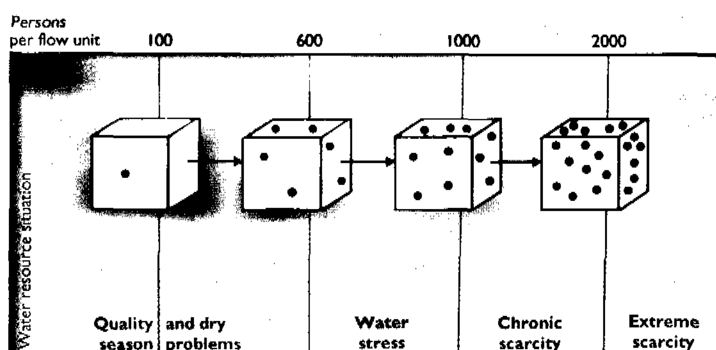
We have seen that water availability is limited by certain environmental preconditions—more severe in some areas than others—and by man-induced alterations of the natural water systems. Population size also governs the amount of water available on a per capita basis.

The number of flow units of water in a given country (where one flow unit equals 1 million cubic meters of water per year) fluctuates between wet and drought years and between the rainy and dry seasons, but as long as the climate does not change, the average remains finite. The point at which a country passes into a position of water scarcity or stress is related to population pressure as well as water consumption patterns.

If the population per flow unit remains low—below 100, the lowest category in Figure 8—water supply is generally not a problem. As population pressure increases, better water management is required to assure quality and equal distribution. Central and southern European countries are subject to this level of water resource competition—about 300 persons per flow unit. As the amount of water per capita dwindles, however, especially where there are more than 600 persons per flow unit, signs of stress begin to appear—unless water is efficiently managed. When there are over 1,000 persons per flow unit, a country invariably experiences chronic water shortage. Under current technology, extreme scarcity occurs if the ratio exceeds 2,000. The crucial issue in such countries is the amount of water that can be used for irrigation—relatively little is needed for domestic use, and often even that can be reused in agriculture.

In Africa and southern Asia, rapid population growth will push many countries into higher stress zones and eventually to chronic water shortages. In some countries, the population is expected to double between 1990 and

Figure 8
Population Pressure and Water-Resource Problems



Note: 1 flow unit = 1 million cubic meters per year

Source: Adapted from Malin Falkenmark, "The Ven Te Chow Memorial Lecture," *Water International* 16, no. 4 (1991): 229-240

Table 3

Population and Water Resources in World Regions and Selected Countries, 1990 and 2025

Region	Population (millions) 1990	Population (millions) 2025	Renewable water (m^3)	Persons per 1 million m^3 1990	Persons per 1 million m^3 2025
North Africa	**140**	**280**	**85,000**	**1,650**	**3,290**
Egypt	52	73	57,000[a]	900	1,600
Libya	5	13	1,000	6,500	18,400
Sub-Saharan Africa	**492**	**1,276**	**3,575,000**	**140**	**360**
Kenya	24	64	15,000	1,590	4,310
Somalia	9	23	12,000	760	2,040
Zaire	37	105	1,019,000	40	100
North America	**276**	**360**	**5,379,000**	**50**	**70**
Central America/ Caribbean	**147**	**250**	**1,330,000**	**110**	**190**
El Salvador	5	10	19,000	270	510
Mexico	84	137	357,000	240	390
South America	**294**	**452**	**10,377,000**	**30**	**40**
Brazil	149	220	5,190,000	20	30
Peru	22	37	40,000	540	930
Western Asia	**132**	**286**	**253,000**	**520**	**1,130**
Turkey	56	93	196,000	420	690
Southern Asia	**1,191**	**2,100**	**3,980,000**	**300**	**530**
Afghanistan	17	46	50,000	330	920
Bangladesh	114	223	1,357,000	50	100
Other Asia	**1,794**	**2,476**	**8,737,000**	**200**	**280**
Europe	**509**	**542**	**2,321,000**	**220**	**230**
Oceania	**27**	**41**	**2,011,000**	**10**	**20**
Former USSR	**281**	**344**	**4,384,000**	**60**	**80**

Note: 1 cubic meter (m^3) = 1.35 cubic yards

Source: UN, *World Population Prospects: The 1992 Revision* (New York: UN, 1992); and World Resources Institute, *World Resources 1992-1993* (New York: WRI, 1992), Table 21.

2025 (see Table 3). Because of Kenya's expanding population, its population per flow unit grew from 905 in the 1970s to 1,600 in 1990. This index will easily surpass the 2,000 threshold by 2025 when Kenya's population will be nearly five times the 1975 figure. By 2025, over 1 billion people in Africa and southern Asia will live under conditions of water scarcity. Many North African and Middle Eastern countries are already faced with absolute water scarcity. In Jordan and Israel, over 3,000 people compete for every flow unit of renewable water. By 2025, virtually all North African countries will be faced with high levels of population pressure on their scarce water resources. And, except for Turkey, all of Western Asia will also experience the highest levels of water scarcity.

These high growth rates are driven by the persistently high birth rates in most of these countries. In sub-Saharan Africa, women have an average of six children each; in southern Asia, they average between four and five children each. Because death rates have fallen in many parts of the developing world—in large part as a result of immunization campaigns, antibiotics, and other imported health technologies—the traditionally high fertility levels caused the growth rate to escalate in the 1960s. Growth rates have fallen only slightly since then.

Although birth rates have declined in recent years, the young age structure of the population—created by decades of high fertility—provides a tremendous momentum for future growth. About 45 percent of sub-Saharan Africans are under age 15, compared with 20 percent in Europe (see Table 4). These young people will be starting their own families within the next quarter century. Even if the average number of children per couple declined immediately to two—the "replacement level"—the populations of these countries will continue to grow for decades because such a large share of the population will be moving into the childbearing ages.

Africa's population is expected to grow by at least 2.8 percent annually until the end of the century. The total is projected to more than double between 1990 and 2025, expanding from 650 million to 1.6 billion, even assuming a rise in mortality from the AIDS epidemic and a further decline in birth rates. The population of western Asia could expand from 139 million to 313 million, and that of southern Asia from 1.2 billion to 2.2 billion over the same time period.

The average water resource competition levels for these broad regions mask the total number of people subject to water scarcity because of wide fluctuations in precipitation or water flows over the year, or between drought and wet years. In the humid zones, a competition level of 600 might signal the beginning of water allocation

Table 4
Demographic Indicators for World Regions, 1992

	Population 1992 (millions)	Annual growth rate (percent)	Total fertility rate (TFR)	Life expectancy in years	Percent under age 15	Percent urban	1990 GNP per capita
North Africa	147	2.6	4.8	61	42	43	$1,070
Sub-Saharan Africa	507	3.1	6.5	52	45	26	520
Western Asia	139	2.8	4.7	66	41	62	–
Southern Asia	1,231	2.2	4.3	58	38	26	440
Southeast Asia	451	1.9	3.4	62	37	29	–
East Asia	1,386	1.2	2.1	71	27	34	2,910
North America	283	0.8	2.0	76	21	75	21,580
Latin America	453	2.1	3.4	67	36	70	2,170
Europe	511	0.2	1.6	75	20	75	12,990
Former USSR	284	0.7	2.2	70	26	66	–
Oceania	28	1.2	2.6	72	26	71	13,190

Note: Total fertility rate (TFR) = average total number of children born per woman under current birth rates.
Source: Carl Haub and Machiko Yanagishita, *1992 World Population Data Sheet* (Washington, DC: PRB, 1992).

problems. In arid conditions, the problem is more complex because of considerable seasonal variations in rainfall. The largest need for irrigation water is during the dry season when the water accessible to people can be as low as 10 percent of the annual flow. Even countries with an average annual competition level of only 50, such as Bangladesh, have considerable allocation problems during the dry season when the water competition level might rise to 500 persons per flow unit.[24]

But national figures do not reflect the stress on water resource quality in local areas exerted by rapid urbanization and industrialization. The average population pressure on water resources appears moderate in most Latin American countries, for example. But a majority of Latin Americans live in cities, which are often plagued by serious water pollution from industrial and household wastes. Recurrent drought in northeastern Brazil has contributed to the rapid urbanization in that country. Unable to eke out a living from land degraded by decades of drought and poor farming techniques, farmers have flocked to Brazil's cities, reflecting the pattern of rural to urban migration that is occurring throughout the Third World. By the end of the century, a majority of the Earth's inhabitants will live in urban areas, with most of the growth occurring in the developing countries.

The most immediate impact of this stream of migration into urban areas is the growth of informal squatter settlements, or shantytowns. A lack of housing and jobs forces many recent migrants, as well as longer-term residents, to fashion shelters on vacant land, often land deemed unsuitable for housing or development. These shantytowns have no sanitation or other services—both contributing to and suffering from the health consequences

WFP/F. Mattioli

Ecuador has ample water, but not always where it is most needed.

Box 3

Urban Population Growth, Pollution, and Safe Water

Thanks to both international and domestic efforts, clean drinking water was made available to 1.3 billion people and sanitation services to an additional 748 million people in the 1980s. These efforts grew, in part, out of the United Nations commitment to improving access to safe water, demonstrated by the declaration of the 1980s as the Clean Water Decade.

These efforts were most successful in the rural areas of the Third World. In urban areas, the number of residents without access to water grew by 31 million during that decade, while those without sanitation grew by 85 million. By 1990, at least 377 million urbanites lacked basic sanitation services. Given the rapid urbanization in the developing world, these numbers are expected to swell.

The lack of adequate safe drinking water and sanitation is one of the major health and economic consequences of surging world urbanization. Increasing population concentration in urban areas has contributed to the depletion and contamination of fresh water. The costs of treating and providing clean water has escalated exorbitantly in many Third World cities. The Haungpu River, Shanghai's major source of drinking water has become so polluted near the urban area that the water transmission main had to be moved 40 kilometers upstream—at a cost of US$450 million. In Lima, Peru, upstream pollution has increased treatment costs by 30 percent. The rivers passing through many major cities have become open sewers devoid of aquatic life.

Much of the pollution is tied to the explosive growth of the informal squatter settlements on the periphery of most Third World cities. These settlements often spring up on low-lying land and along waterways, their wastes flowing directly into the urban water source. In Manila, a recent assessment showed that the most important sources of urban pollution were the uncollected solid waste, flooding, and river bank erosion around the squatter settlements that contain some 38 percent of the metropolitan population.

Many municipal governments have avoided improving the services to these poor communities, either because they simply could not afford it or because they did not want to encourage or legitimize these illegal settlements. The shantytown residents often pay inflated prices for water brought in by enterprising vendors and suffer high rates of infant mortality and parasite infestation directly resulting from the unsanitary living conditions.

These health and environmental problems spill over into the wider community. The low-income settlements of Lima, for example, were the origin of a cholera epidemic in 1991 that eventually spread throughout the region. In addition to higher health-care costs, the epidemic cost Peru an estimated US$460 million in tourism. Protecting the health of the urban poor in illegal squatter settlements through the provision of basic services may appear to be prohibitively expensive, but the health and environmental consequences of allowing these populations to live in squalor will eventually prove even more expensive.

Reference

UN Center for Human Settlements, "Urbanization: Water Supply and Sanitation Sector Challenges." Paper presented at the Water Supply and Sanitation Collaborative Council Forum, Oslo, Norway, 18-20 September 1991.

of an unsafe water supply (see Box 3). Between 30 and 60 percent of the urban populations of developing countries live in such informal settlements. At current rates these shantytown populations will double every 10 to 15 years.[25]

Urban growth in the Third World has created new megalopolises that are surpassing the size of the world capitals in developed countries. In 1960, only 3 of the world's 10 largest cities were in the developing countries: Shanghai, Buenos Aires, and Calcutta. In 1990, all except three (Tokyo, New York, and Los Angeles) were in the developing world. Although urbanization is spreading throughout the Third World, the urban scene in many developing countries is dominated by a few large cities. About one-quarter of Nigeria's city dwellers live in either Lagos or Ibadan, for example, and one-half of Egypt's urban population reside in Alexandria or Cairo.[26] The populations of such cities are soaring because of the rapid natural increase and the constant stream of migrants from the countryside. This explosive growth is exacerbating the problems of providing clean drinking water and disposing of human and industrial wastes.

Unless per capita consumption declines, the ratio of population to water reaches stressful levels either because people dwell in areas with extremely scarce resources or because the population increase is too rapid for the available water resources. The countries in the worst position are, of course, those experiencing both predicaments as demonstrated in Box 4, page 24.[27]

The pressure of rising populations sets off a cycle that reinforces the effects of other sources of water scarcity: fluctuating rainfall, short growing seasons, and land degradation. Without better management, this risk spiral can cause a complete collapse of basic services and food supplies during recurrent droughts. For example, severe famine occurred during the African drought in 1984 and 1985. At least four types of risks warrant attention:

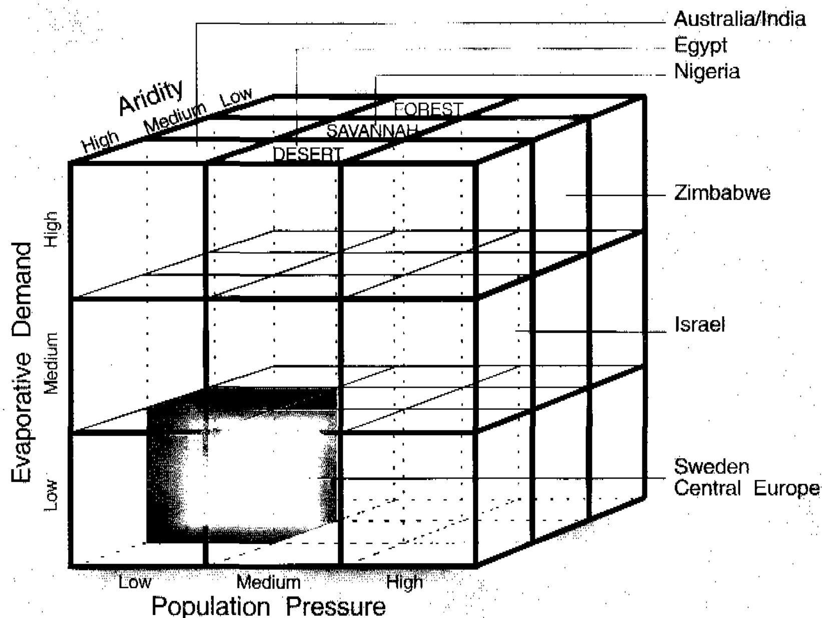
1. **Inadequate water quantity.** When growing expectations cannot be met, frustration mounts among regions and population groups. Disputes and conflicts arise concerning access to water.
2. **Deteriorating water quality.** With growing populations, industrial and other waste-water pollution increases the risk of water-borne or water-related diseases. The poor generally absorb the brunt of these problems,


EPA

Even water-abundant countries face problems of water quality.

Box 4

The Population and Water Predicament



The interplay between the three factors most affecting the water availability in a given country may be visualized in the three dimensional cube above, depicting evaporative demand, aridity of the hydroclimate, and population pressure. Evaporative demand of the atmosphere in an area (the vertical axis) governs the efficiency of an area's rainfall. For example, where the evaporative demand is low as it is in Scandinavia (below 500 millimeters per year), 1,000 millimeters of precipitation corresponds to quite wet conditions. Where evaporative demand is high as it is in the tropics—often above 1,500 millimeters per year—that same 1,000 millimeters of rainfall falls short of the annual evaporative demand.

In more arid climates, evaporative demand exceeds by far the annual precipitation. The result is desert or semi-desert. Where it is subhumid and only part of the year remains arid, grasslands or savannah grow. Where it is humid, forests are the natural vegetation.

Population pressure on available water is the third major variable determining a country's water situation. While the other variables are expected to remain constant, population pressure may increase, moving some countries to higher stress levels over time.

If we visualize the cube as a house, many of the industrialized countries could be said to have developed in the humid/subhumid corner of the basement. Their hydroclimate and environmental conditions favored economic development.

The most water-stressed of more developed countries, such as Israel, are on the second floor. Most of the Third World countries are in the hot attic of the predicament house. In these Third World countries, highly efficient water use is required for development to occur *in spite of* high evaporative demand—a legacy of their hydroclimate—and increasing population pressure—a result of high birth rates and stable or declining death rates.

especially in urban areas. Without adequate sanitation, population growth in these environments increases morbidity, as well as human suffering.

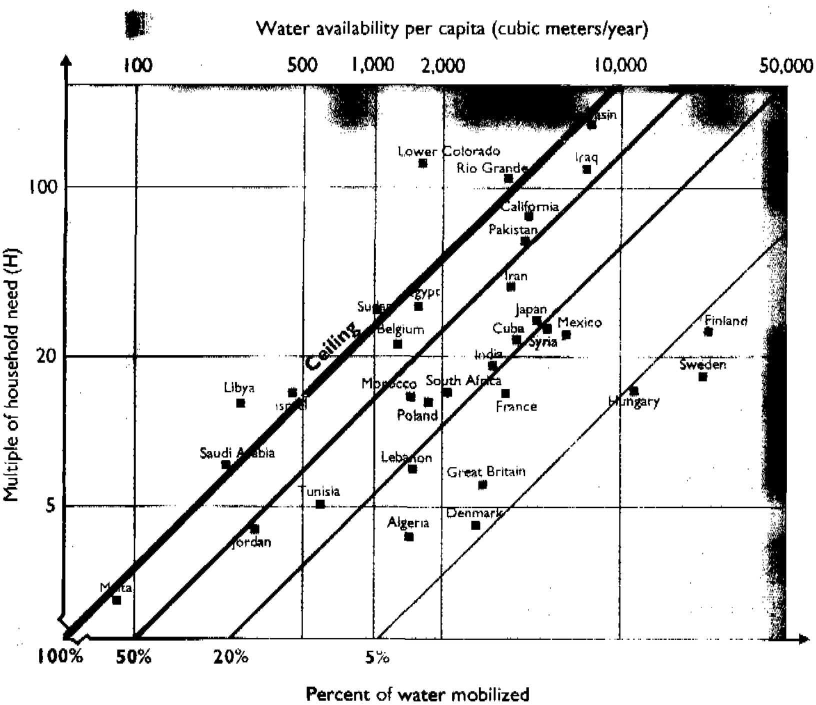
3. **Failures in food security.** During dry years, crop yields may collapse. Unless there is an organized system for food distribution, large scale famine can follow.
4. **Land degradation.** When population pressure increases, manipulation of the land intensifies. Without proper management this can lead to desiccation of the soil, lowering of water tables, erosion, and consequent siltation and flooding of downstream areas.

How can this risk spiral be avoided? Slowing population growth can head off a future crisis in some areas; however, it cannot relieve pressure from current population size. And even with slower growth rates the number of people continue to swell, especially in Third World countries with young populations. Slowing population growth is only part of the solution.

Water Availability vs. Demand

Population pressure can be eased by either accepting a lower per capita demand or increasing the percentage of water accessible. As Figure 9 depicts, demand is ultimately constrained by a finite availability ceiling: the water resources available in each country through the global water cycle. Estimates of the amount of annually renewable water available in a country

Figure 9
Water Availability and Demand



Notes:
1. Countries above the ceiling are using more water than is renewed each year through rainfall or inflow from upstream countries. This excess water may come from ancient, nonrenewable aquifers or be transported from other areas.
2. Household need (H)equals 100 liters per day, per person.
3. Reservoir storage allows countries to mobilize more than 100 percent of the available water.

Source: Based on data from J. Forkasiewicz and J. Margat, *Tableau Mondial de Données Nationales D'Economie de L'Eau, Resources et Utilisations* (Department Hydrogéologie, 79 SGN 784 HYD, Orléans, 1980).

include both internally produced surface and groundwater and river water flowing into an area from another country. Deep underground aquifers are important sources of water in some areas, but the extremely slow renewal rate may classify these as nonrenewable resources.

Seldom is all available water in a country used, either because there is more water than needed, or because the costs of extraction are higher than the potential economic benefits of the additional water. There is an upper limit to the amount available, but this ceiling is reached only if every flow unit of water in aquifers and rivers can be used, or "mobilized." A 100 percent mobilization level can be achieved only if all the water surplus during wet seasons and wet years can be stored and put to use during the dry seasons or drought years, when the demand is highest. The possibility of mobilizing 100 percent of the water depends on topography (which limits location of reservoirs), climate (which affects water losses from reservoirs), and geology (which may permit or prohibit more efficient underground water storage). In hot countries with a flat landscape, 20 to 30 percent mobilization of available water may be the upper limit under present technology.

The position of Tunisia on Figure 9, page 25, for example, shows that about 35 percent of the available water is being utilized. This allows an average water demand of only five times the personal minimum, less than 200 cubic meters per person. This is only one-tenth the typical water demand in developing countries that irrigate agricultural land.

In a few countries, with favorable geology, the mobilization level of available water can reach 100 percent. But it is seldom realistic to use all potentially available water. Where topography is flat, dams cannot be built. Where the climate is hot and dry, large reservoirs are not cost-effective because they lose so much water to evaporation. Water storage below ground eliminates the loss through evaporation, but such underground water must be easily retrievable to be practical.

Economics is another limiting factor. Large dams are costly to build. The size of a dam is determined by the size of the river, usually a function of the climate and the drainage basin, and of how far up a river's valley or basin a dam is built. The huge Aswan Dam in Egypt is an example of the enormous size of dam required so far down in a large river basin.

The mobilization level needed to satisfy the demand for water also reflects the overall water availability situation (see Table 5). In a water-rich country such as Sweden, a mere 3 percent of available water need be mobilized to provide a high standard of living for the country's 8 million inhabitants. Many developing countries have relatively low per capita water demands compared with Sweden. These countries could still remain far below the availability ceiling and absorb the much higher water use

World Bank/Ray Witlin

Seldom does a country use all of its available water.

needed to facilitate socioeconomic growth. They may, in other words, still be in a state of water underuse. The potential increase in overall water use in a society will be limited by irrigation and industrial needs as well as population growth in coming decades.

At the same time, other areas are overusing their available water. Libya uses more than 100 percent of its renewable water. It is buying time by mining groundwater from its huge Nubian Aquifer. This can continue only until the aquifer is depleted or pumping becomes too expensive. In southern California, cities are green gardens in a desert climate. Thirsty crops, such as cotton and alfalfa, form an important part of the region's economic base. Decades of subsidized water have allowed the area to plant inappropriate crops and use more than twice the available water resources.

Table 5

Water-Resource Situation by Distance to Water Availability Ceiling

Demand level	Distance to ceiling	Situation	Solution	Example
High	Low	Critical	Reduce demand by rationing/conservation	California
High	High	Approaching critical	Develop water resources to maintain current demand level	Mexico
Low	Low	Highly critical	Enlarge storage	Jordan
Low	High	No immediate danger	No change necessary	Denmark
High	Above	Unsustainable	Ration/conserve	Libya

Source: Based on data and concepts in Figure 9, page 25.

Ways Out of the Predicament

As populations continue to grow, water is becoming scarce—often critically scarce—in arid countries. Even humid areas are caught in the population and water predicament because human activities threaten both the quality and amount of the water available.

There is no doubt that the scarcity of water and the deterioration of water quality severely complicate socioeconomic development and efforts to improve living standards. And it contributes to the rampant poverty encountered in large parts of the developing world. The tropical and subtropical climates of much of the Third World, in combination with recurrent risk of droughts, make them highly vulnerable environments. The traditional slash-and-burn agricultural practices and reliance on wood for fuel in many countries contribute to the degradation of soils by disturbing the plant cover.

The problematic environments of developing countries must be accepted as givens and treated as challenges. These environmental preconditions are not in themselves problems because they are the norm for those populations. However, they are new to the technical assistance personnel from temperate countries that advise developing country governments. Often these personnel do not fully appreciate the consequences of hydroclimatic differences between the tropical and temperate zones.

In areas where there are already water-supply difficulties and land fertility is already degraded, major threats to both quality of life and basic health are mounting. The threats are twofold: insufficient food supply and increased pollution. Where local governments cannot treat the increased waste and cannot provide safe household water and food supplies, an area can slip into what some scholars have labeled the demographic trap.[28] They warn that, as population pressure continues to mount, health will deteriorate because of poor sanitation and malnutrition. Ultimately, slower population growth will result, but at the cost of increasing death rates. Such doomsday scenarios often overstate the case in an attempt to force the public and policymakers to pay attention to the very real problems. One danger of this approach is that it can be counterproductive, causing widespread feelings of defeat and hopelessness. On

Better management of waste water helped clean up the Potomac River, which flows past Washington, D.C.

the other hand, a balanced assessment of the situation may not create enough drama to interest the media, and the message is ignored. Also ignored are the signs of slow progress in dealing with the population/water predicament.

Slow Progress

Serious work in water-resources management, sanitation and public hygiene, and family planning have improved the balance between water and population in many areas. Progress in these fields is slow and often frustrating. Lasting improvements often begin at the local levels and involve local decisionmakers and nongovernmental organizations, a fact that is only now gaining recognition at the top levels of development organizations. But support and cooperation at all levels of government and throughout society are necessary to balance population needs and water resource availability.

Limiting Population Pressure

A crucial step in averting a water crisis is to slow the unprecedented population growth occurring in so many of the world's countries. Many countries now have explicit policies to slow population growth as well as to improve the health and longevity of their citizens. In 1976, 61 percent of governments surveyed by the United Nations provided direct support for family planning, whether it was for health reasons or expressly to lower birth rates. In 1989, some 72 percent of country governments provided such support.[29]

Several nations have set target birth rates and death rates. Nigeria had a 1990 total fertility rate (TFR—the average total number of children per woman) just above six. The government hopes to achieve a TFR of four children per woman by 2000, and at the same time lower its infant mortality. Uganda is also touting the advantages of limiting family size to four children. While this average seems high by American and European standards, where the TFR in most countries has been below four for most of the 20th century, such a reduction would avert millions of births. Meeting these goals by the end of the millennia, however, are optimistic and unlikely. Large families are highly valued in many traditional cultures and such deeply rooted social norms are slow to change. Couples require both the motivation and means to limit their family size.

Governments and other community organizations can encourage couples to have small families and ensure access to family planning information and methods. They can support better educational and job opportunities for women, factors related to lower fertility rates. But population growth rates will not fall until individuals change their behavior. Few countries will follow the stringent population-control policies of China, which lowered that country's average family size to just over two children in the 1980s from about six in the 1960s.[30]

In much of the developing world, family planning has become more acceptable and available. Fertility rates—the driving force in the population boom—have fallen. In India, which was the first country to formally promote family planning, nearly one-half of the couples used a family planning method in the late 1980s. India's fertility has fallen since the 1960s, but it leveled off at about 4.5 children per woman on average in the 1970s and 1980s. Recent evidence indicates that Indian fertility may be declining further. Nevertheless, its current growth rate ensures a total population greater than 1 billion by the year 2000.[31]

In Africa, where contraceptive use was practically nil thirty years ago, nearly 20 percent of couples use family planning in the early 1990s. Fertility has fallen in a few countries, offering some hope that the region can avert the worst consequences of the crisis in food and water availability. In Kenya, the average fertility rate is still nearly six children per woman in the early 1990s, down from about an eight-child average before 1980. About 27 percent of Kenyan women of reproductive age were using contraception in 1989, well below the level even of India.

In the Middle East, already suffering from severe water stress, the specter of continuous waves of new people paint an especially bleak picture (see Box 5). Adding to these problems, some countries favor continued population growth in hopes of outnumbering their political rivals.

Egypt, which has long relied on the Nile for the vast majority of its water, has slowed its population growth rate. However, the population is still increasing by over 1 million per year. Eighty percent of the growth occurs in the relatively few urban areas. The huge cities of Cairo and Alexandria are encroaching on the limited supply of good agricultural land. At the same time, countries upstream in the Nile basin may begin siphoning off more of Egypt's freshwater.

In the long term, slowing population growth will help avoid or at least slow the risk spiral of resource depletion and soil degradation. But demographic change occurs slowly—in part because a country's age structure contains momentum for continuing growth, and in part because change originates at the household level. In the short term, the impending crisis can be ameliorated by adopting management techniques to increase the amount of accessible water and use water more efficiently.

Water Management Solutions

Where growing numbers of people depend on limited water availability, societies seek the most efficient ways to manage their water resources. Even where water is relatively abundant, they must find ways to avoid polluting their clean water or disrupting local water systems. The type of management approach that is appropriate depends on the local conditions. The approach adopted is often dictated by the political and economic situation.

How can water use be adapted to its availability in countries trying to develop economically, or trying at least to achieve agricultural self-sufficiency?

In semi-arid countries with only seasonal shortage problems and rapid population increase, the main task is storing water during the dry seasons. Sri Lanka, Iran, and Pakistan, with 300 to 500 persons per flow unit, are examples of developing countries with these characteristics. Water conservation by rainfall accumulation, infiltration, and underground storage seems to be the ideal instrument to supply areas in countries far from rivers. In the southwestern United States, water from the Colorado and other large rivers is stored

Box 5

The River Jordan Basin: The Politics of Sharing a Scarce Resource

The Middle East has less water available per capita than any other major world region. Control of the Jordan River, which collects the rain from four countries, is at the center of a political controversy.[1] The limited rainfall in the northern and central parts of the river basin falls mainly in the winter. The south remains dry year round. Rain falling over northern Lebanon, Syria, and Israel drains into the Sea of Galilee and flows into the Dead Sea, a closed lake basin. Rain over the eastern parts of the river basin in Jordan and southwestern Syria drain into the main river through the Yarmouk, a tributary that forms the border between these two countries.

The plans for sharing the Jordan River's water have caused conflict for millennia, but perhaps never so violently as during the past 50 years, after the splitting of Palestine and the creation of the states of Israel and Jordan. After gaining independence in 1948, Israel immediately started to develop the water supply of the new state, envisaging large-scale immigration and agricultural expansion. The central trunk of Israel's system is the National Water Carrier, a pipeline bringing water from the Sea of Galilee down the coastal plain toward the Negev Desert. Israel secured control of the Yarmouk River, the Jordan's largest tributary, all the way to the water divide after the 1967 war—a conflict sparked, in part, by water resource disputes.[2] Later, Israel expanded its control to include the remaining tributaries.

The West Bank of the Jordan River, occupied in the same war, was an important recharge area for the mountain aquifer that brings groundwater to 3 million urban inhabitants along the coast. To protect its urban water supply, Israel restricts the Palestinians in the West Bank from drilling new wells or irrigating crops, adding to the frustration and turmoil in the occupied territory.

The past and even present disputes may appear minor in the future. It is difficult to foresee a water sharing scheme that will satisfy all parties. No country has surplus water, and all are subject to rapid population increase: Israel from immigration, the others from high birth rates.

Israel's water use per capita is very low for such a developed country. Water conservation is recognized as a matter of national defense. But Israel's water demands already exceed its available supply, and the nation faces a 30 percent water deficit within a decade, threatening its political security.[3] The severe drought in the early 1970s generated an avalanche of internal criticism and charges of mismanagement of Israel's national water system.[4]

in reservoirs and redistributed to arid areas through canals and pipelines. The viability of such efforts in other regions is limited by economic costs and technology, as well as climate and topography.

Countries with chronic shortages are the most difficult to manage. Under conditions of water scarcity, smaller amounts may be allocated for each individual. In addition, each unit of water will have to be reused as many times as possible. Sequential water use involves capturing, treating, and removing pollutants from water used in one sector so that it can be directed to other uses. Because domestic use requires the cleanest water, the ideal order of reuse would be household first, then industry, then agriculture. Agricultural use would be last because, even in water-efficient irrigation, most irrigation water returns to the atmosphere through evapotranspiration.

Population Pressure in Jordan River Basin Countries

	Persons per 1 million cubic meters 1990s	2025	Current water use circa 1990 (cubic meters)	Water use ceiling (cubic meters) 1990s	2025
Israel	3,070	4,600	375	310	217
Jordan	3,910	11,910	200	256	84
Syria	350	910		2,840	1,100
West Bank	4,000	(>13,300)	140	250	(<75)

Note: 1 cubic meter = 1.35 cubic yards.
Sources: World Resources Institute, *World Resources 1991-92* (New York: Oxford University Press, 1991); and J. Forkasiweicz and J. Margat, *Tableau Mondial de Données Nationales D'Economie de L'Eau, Ressources et Utilisations* Departement hydrogéologie, 79 SGN 784 HYD, Orléans, 1980.

The increasing population pressure on water resources in Jordan River basin countries hastens the need to find additional sources of water, better storage facilities, and more efficient water use.

Possible remedies to the region's water problems include temporary solutions such as a pipeline from the Nile to the Gaza strip and the Negev for a defined period of 50 years. With Nile River water to meet the extreme water deficits predicted for the near future, longer-term projects might include a peace pipeline transferring river water from some of Turkey's rivers to Israel, Jordan, and the Palestinian communities. Another longer term solution could include construction of a desalinization plant. Any of these solutions will require unprecedented cooperation among the fiercely independent political factions.

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Reducing the waste incurred in irrigation offers the greatest single reduction of water demand in many areas. Since 85 percent of water used in California goes into irrigation, for example, even a limited improvement in irrigation efficiency would save huge amounts of water for municipal and industrial use.[32] Overall demand could be brought down to equal current supply and still allow ample water for irrigating crops.

Various agricultural techniques can reduce the amount of water needed for irrigation and conserve the soil. These include planting drought-resistant crops, capturing and reusing runoff from irrigation systems, and dryland plowing. A strain of chickpea that needs only one half the usual amount of water has been introduced successfully in the Middle East.[33] In the drought-stricken Maharashtra State of India, a socio-technical system for rainwater harvest-

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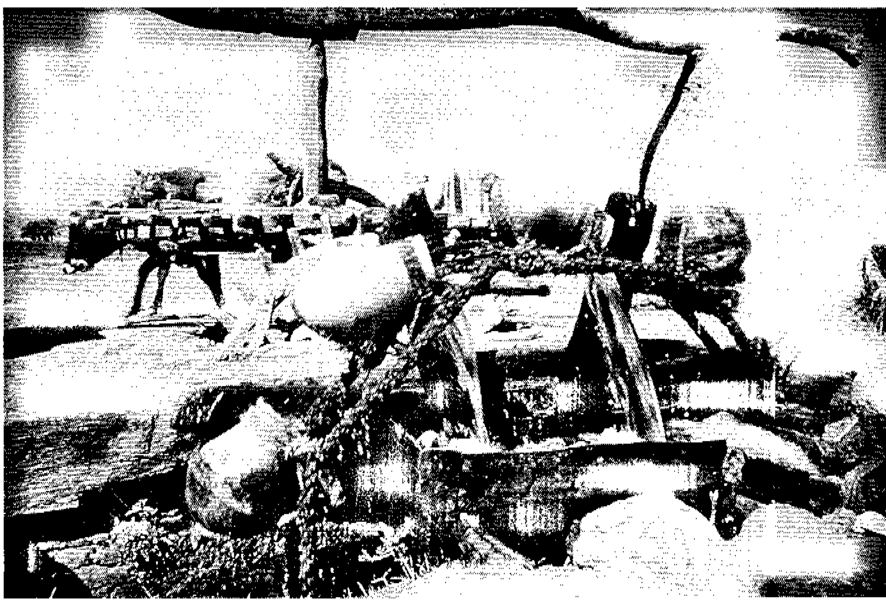

More efficient techniques can cut down on the water needed for irrigation.

ing, accumulation, artificial aquifer recharge, wells for retrieving the stored water, and allocation of water in relation to family size has been quite successful. Subsistence food security has been achieved for the local population in an area that receives only 150 millimeters of rainfall annually.[34]

Countries with chronic water shortages must also resort to nonconventional methods to augment freshwater availability. The massive desalinization projects in several Arab countries and in southern California are a current example. Under present methods and technology, however, desalinization is too costly for widespread use. Water from desalination accounts for a minor share of all water even in the areas that use it.[35] New methods of transporting water are being explored. A system of towing water to some Mediterranean countries is being developed, for example.[36]

Some countries with a chronic scarcity of endogenous water are favored by international rivers which provide the core of their water resources. Egypt is the classic example; Jordan is another such case. But these countries are prisoners of upstream countries. Large-scale agricultural development in Ethiopia or Sudan, for example, is likely to divert water from the Nile and could seriously reduce the flow to Egypt. For these countries, water management must involve international cooperation.

Conclusion

There are many ways to soften the effects of both the current crisis in selected world regions and the more widespread problems that loom ahead. These require active management of existing water resources and a slowing of the population growth in water-scarce areas. Water systems transcend national boundaries. Their management will require the cooperation and commitment of local, national and international governments, industries, and other organizations.

In every country, development—indeed all human activities—must involve careful and successful balancing of unavoidable manipulations of the landscape and the likewise unavoidable "environmental impacts" of those manipulations. Conditions of environmental sustainability[37] must encompass, for instance, protection of land productivity, groundwater potability, and biodiversity. These factors may restrain development, but they must be dealt with either in the short term, by adopting methods to protect natural systems, or in the long term, by correcting the damage already done and minimizing future problems.

Balancing society's growing needs for clean water with the finite amount of water available also requires an understanding of the demographic forces at work in each country. Rapid rural to urban migration, high fertility rates, and shifting patterns of international population movement will affect future water needs at regional, national, and local levels. With a heightened awareness of the global water systems and demographic trends, as well as the active management of resources, the delicate balance between population and water can be maintained.

United Nations

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Discussion Questions

1. Outline the environmental conditions and human activities that limit access to clean water in your community.

2. Discuss the impact that rural to urban migration may have on water use, water availability, and water quality in both urban areas and rural areas in developing countries.

3. The authors describe a series of water scarcity risks that may be exacerbated by population growth. Give examples of regions or countries that are experiencing any or all of these problems. Provide background on environmental conditions and human activities that contributed to this outcome.

4. How will economic development in poorer countries alter the demand for water and change water-use patterns?

5. During the United Nation's Clean Water Decade (1981-1990), the number of residents in urban areas without access to drinking water grew by 31 million even though clean drinking water was made available to 1.3 billion people. What led to this phenomenon?

6. Give examples of how population growth in specific countries (i.e., Kenya, United States, China) might affect the different phases of the water cycle as outlined in Figure 5.

7. Examine the relationship between water scarcity and poverty. Is it positive or negative? Is there a direct correlation?

8. The authors state that about 150 of the world's 200 major river systems are shared by at least two countries. Consider conflicts involving water rights, within or between countries. What roles does population growth play in such conflicts?

Prepared by Kimberly A. Crews

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