



WATER QUANTITY

Overview

Water, used by households, agriculture, and industry, is clearly the most important good provided by freshwater systems. Humans now withdraw about 4,000 km³ of water a year, or about 20 percent of the world's rivers' base flow (the dry-weather flow or the amount of available water in rivers most of the time) (Shiklomanov 1997:14, 69). Between 1900 and 1995, withdrawals increased by a factor of more than six, which is greater than twice the rate of population growth (WMO 1997:9).

Scientists estimate that the average amount of global runoff (the amount of water that is available for human use after evaporation and infiltration takes place) is between 39,500 km³ and 42,700 km³ a year (Fekete et al. 1999:31; Shiklomanov 1997:13). However, not all of this water is available to humans. Much of the runoff occurs in flood events or is inaccessible to people because of its remote location. In addition, part of the runoff needs to remain in waterways so that aquatic ecosystems continue to function. In fact, only around 9,000 km³ is readily accessible to humans, and an additional 3,500 km³ is stored in reservoirs (WMO 1997:7).

In any case, such global averages fail to portray the details of the world's water situation. Water supplies are distributed

unevenly around the globe, with some areas containing abundant water and others a much more limited supply. For example, arid and semiarid regions receive only 2 percent of the world's runoff, even though they occupy roughly 40 percent of the terrestrial area (WMO 1997:7). In water basins with high water demand relative to the available runoff, water scarcity is a growing problem.

According to the U.N. Comprehensive Assessment of the Freshwater Resources of the World, there are close to 460 million people in the world currently suffering from serious water shortages and an additional 25 percent of the world's population may become water-stressed if current consumption levels continue (WMO 1997:9). Many experts, governments, and international organizations around the world are predicting that water availability will be one of the major challenges facing human society in the 21st century and that the lack of water will be one of the key factors limiting development (WMO 1997:5).

Water is not only becoming scarce in many regions of the world because of increased demand by industries and municipalities, but with an expected population reaching about 7.8

billion by 2025—the U.N. medium projection (UNPD 1999:2)—food production will have to increase, meaning more water resources will be needed for irrigation.

At present, irrigated agriculture accounts for 40 percent of global food production even though it represents just 17 percent of global cropland (WMO 1997:9). Agriculture is society's major user of water, withdrawing 70 percent of all water (WMO 1997:8). Most irrigation systems are relatively inefficient. Global estimates of irrigation efficiency are around 40 percent (Postel 1993:56; Seckler et al. 1998:25). Even though irrigation for food production is an increasingly important service, it is not analyzed in detail in this report because it has been examined separately under the agroecosystem component of PAGE (Wood et al. 2000).

At the same time that water demand is increasing, pollution from industry, urban centers, and agricultural runoff is limiting the amount of water available for domestic use and food production. In developing countries, an estimated 90 percent of wastewater is discharged directly to rivers and streams without any waste processing treatment (WMO 1997:11). In many parts of the world, rivers and lakes have been so polluted that their water is unfit even for industrial uses (WMO 1997:11). Threats of water quality degradation are most severe in areas where water is scarce because the dilution effect is inversely related to the amount of water in circulation. The loss of ecological services is considerable, but difficult to assess.

The Aral Sea represents one of the most extreme cases in environmental degradation of an aquatic system. Large-scale upstream diversions of the Amu Darya and Syr Darya river flow for irrigation of about seven million hectares of land, has reduced inflow to the extent that the volume of water in the Aral basin has been reduced by 75 percent since 1960 (UNESCO 2000:35; Postel 1999:94). This loss of water, together with excessive chemicals from agricultural runoff, has caused a collapse in the Aral Sea fishing industry, a loss of biodiversity and wildlife habitat, particularly the rich wetlands and deltas, and an increase in human pulmonary and other diseases in the area resulting from the high toxicity of the salt concentrations in the exposed seabed (Postel 1999:94; WMO 1997:10).

Condition Indicators of Water Quantity

Given humanity's dependence on water, one would expect that an assessment of the capacity of freshwater systems to provide this basic good would be easy to carry out. However, researchers looking into freshwater ecosystems at the global level face two major data gaps: water use and water supply at the watershed level. For some countries, reliable information on water supply and use is not even available at a national level.

To get a better understanding of the balance of water demand and supply and to better estimate the dimensions of the

global water problem, the PAGE study developed two indicators that measure the capacity of freshwater systems to provide water for human consumption. These indicators are the following:

- ▶ Per capita water supply by river basin;
- ▶ Dry season flow by river basin.

PER CAPITA WATER SUPPLY BY RIVER BASIN

To calculate water supply, the PAGE study undertook a new analysis of water scarcity using a somewhat different methodology than the 1997 U.N. assessment mentioned previously. Because country-level estimates of water availability may hide significant within-basin differences, the PAGE study calculated water supply for individual river basins, rather than at a national or state level, with the object of identifying those areas where water supply per person fell below 1,700 m³/year.

Water experts define areas where per capita water supply drops below 1,700 m³/year as experiencing “water stress”—a situation in which disruptive water shortages can frequently occur (Falkenmark and Widstrand 1992:1–33; Hinrichsen et al. 1998:4). In areas where annual water supplies drop below 1,000 m³ per person per year, the consequences can be more severe and lead to problems with food production and economic development unless the region is wealthy enough to apply new technologies for water use, conservation, or reuse.

According to the PAGE analysis, some 41 percent of the world's population, or 2.3 billion people, live in river basins under water stress, with per capita water supply below 1,700 m³/year (see *Map 9 and Table 3*). Of these, some 1.7 billion people reside in highly stressed river basins where water supply falls below 1,000 m³/year. By 2025, the PAGE analysis projects that, assuming current consumption patterns continue, at least 3.5 billion people—or 48 percent of the world's projected population—will live in water-stressed river basins (see *Map 10 and Table 3*). Of these, 2.4 billion will live under high water stress conditions. This per capita water supply calculation, however, does not take into account the coping capabilities of different countries to deal with water shortages. For example, high-income countries that are water scarce may be able to cope to some degree with water shortages by investing in desalination or reclaimed wastewater. The study also discounts the use of fossil water sources because such use is unsustainable in the long term.

The 2025 estimates are considered conservative because they are based on the United Nations' low-range projections for population growth, which has population peaking at 7.2 billion in 2025 (UNPD 1999:3). In addition, a slight mismatch between the water runoff and population data sets leaves 4 percent of the global population unaccounted for in this analysis.

Map 9 was developed by combining a global population database for 1995 that uses census data for over 120,000 admin-

Table 3

Global Annual Renewable Water Supply Per Person in 1995 and Projections for 2025

Water Supply (m ³ /person/year)	1995	1995	2025	2025
	Population (millions)	Percent of Total	Population (millions)	Percent of Total
<500	1,077	19.0	1,783	24.5
500–1,000	587	10.4	624	8.6
1,000–1,700	669	11.8	1,077	14.8
>1,700	3,091	54.6	3,494	48.0
Unallocated	241	4.2	296	4.0
Total	5,665	100	7,274	100

Source: WRI.

istrative units (CIESIN et al. 2000) and a global runoff database developed by the University of New Hampshire and the WMO/Global Runoff Data Centre (Fekete et al. 1999). The runoff database combines observed discharge data from monitoring stations with a water balance model driven by climate variables such as temperature, precipitation, land cover, and soil information. For those regions where discharged data were available, the modeled runoff was adjusted to match the observed values; for regions with no observed data the modeled estimates of runoff were used (Fekete et al. 1999).

This runoff model provides a slightly lower estimate of global runoff than previous analyses—39,500 km³/year (Fekete et al. 1999:31) instead of 42,700 km³/year (Shiklomanov 1997:13) or 47,000 km³/year (Seckler et al. 1998:3). Based on these data, the percentage of the population that is estimated to be living in conditions of water stress in 1995 is higher than previous estimates. This is due in part to the slightly lower estimate of global runoff and a more current subnational population data set for 1995 (CIESIN et al. 2000). Finally by using a river basin approach instead of a national level analysis, many within-country differences in water supply can be highlighted.

The results of this analysis also show that of those basins where the projected population is expected to be higher than 10 million by 2025, 6 basins will go from having more than 1,700 m³ to less than 1,700 m³ of water per capita per year. These basins are the Volta, Farah, Nile, Tigris and Euphrates, Narmada, and the Colorado River basin in the United States (see *Maps 9 and 10*). Another 29 basins will descend further into scarcity by 2025, including the Jubba, Godavari, Indus, Tapti, Syr Darya, Orange, Limpopo, Huang He, Seine, Balsas, and the Rio Grande (see *Maps 9 and 10*).

Other water availability projections suggest similar trends of increasing scarcity. For example, the WaterGAP model developed by the University of Kassel in Germany estimates that under a “business as usual” scenario four billion people in 2025

will live in areas experiencing severe water stress (Alcamo et al. 2000:3). The business as usual scenario assumes that “current trends in population, economy, technology, and human behavior continue up to 2025” (Alcamo et al. 2000:25). According to the model’s results, increased scarcity will be especially marked in South and Southeast Asia and southern and western Africa.

Although the estimates of percent population experiencing scarcity are similar, these results are not directly comparable with the PAGE analysis because the modeling approaches are very different. The PAGE model assumes constant water supply, with human population growth as the main cause of rising water demands. It also uses benchmarks of per capita available water to determine which watersheds will experience shortages (Falkenmark and Lindh 1993). These estimates of per capita water demand are conservative; they assume that as much as 30 to 50 percent of the freshwater runoff can be mobilized for human consumption. These benchmarks also base their agricultural water demand on a “nutritious, low-meat diet” (FAO in Postel 1997), and two-thirds of crop water being supplied by rainwater.

WaterGAP uses a very different approach that integrates climate and land cover changes into future water supply, and also factors economic growth and technological advances, as well as population growth, into water demand projections. WaterGAP uses a higher population projection for 2025 (8 billion people) and sets population and income level as the main drivers behind increases in domestic water demand. However, the largest increase in water consumption in its model comes from industry.

Global concerns about water scarcity include not only surface water sources but groundwater sources as well. More than 1 billion people in Asian cities and 150 million in Latin American cities rely on groundwater (Foster et al. 1998:xi). In addition, although there are no complete figures on groundwater

use by the rural population, many countries are increasingly dependent on this resource for both domestic and agricultural use (Foster et al. 2000:1). Currently humans withdraw approximately 600–700 km³ per year—about 20 percent of global water withdrawals (Shiklomanov 1997:53–54). Some of this water is fossil water that comes from deep sources that are isolated from the normal runoff cycle, but much groundwater comes from shallower aquifers that draw from the same global runoff that feeds freshwater ecosystems. Indeed, overdrafting of groundwater sources can rob streams and rivers of a significant fraction of their flow. In the same way, pollution of aquifers by nitrates, pesticides, and industrial chemicals often affects water quality in adjacent freshwater ecosystems. Although overdrafting and contamination of groundwater aquifers are known to be widespread and growing problems (UNEP 1996:4–5), comprehensive data on groundwater resources and pollution trends are not available at the global level.

DRY SEASON FLOW BY RIVER BASIN

These basinwide estimates mask the effect of seasonal runoff patterns, which reduce that amount of water that is available for human use. In many parts of the tropics, rainfall is highly concentrated in time. For example, it has been estimated that all of India's rainfall falls in 100 hours during the monsoon months (Seckler, personal communication, 1999). Most runs off into the sea before it can be captured for human use.

In almost every continent, river modification has affected the natural flow of the rivers to a point where, during the dry season, the outflow to the sea is nonexistent. For example, such rivers as the Colorado, Huang-He, Ganges, Nile, Syr Darya, and Amu Darya, all run dry at the mouth during the dry season (Postel 1995:10). The Amu Darya and the Syr Darya used to contribute 55 billion cubic meters of water annually to the Aral Sea prior to 1960, but this volume has been reduced to an average of 7 billion m³, or 6 percent of the total annual flow for the period 1981–90 (Postel 1995:14, 15). Most of the water is diverted for irrigation (Postel 1995:14).

To assess runoff seasonally, and its implications for water availability, base flow as a percent of total flow per person was calculated for every river basin. Base flow, the volume of runoff available during the dry season (Foster et al. 1998:10), is defined here hydrologically as the four consecutive months with the lowest cumulative runoff. Map 11 highlights basins that are either water stressed (less than 1,700m³/year per person) or have just adequate supplies of water (between 1,700 and 4,000 m³/year per person) with a pronounced dry season. Basins with a pronounced dry season are those where less than 2 percent of the total annual runoff occurs in the 4 driest months of the year. Twenty-seven of these basins had more than ten million people in 1995 (*outlined in black in Map 11*). They include the Balsas and Grande de Santiago basins in Mexico, the Limpopo in South-

ern Africa, the Hai Ho and Hong in China, the Chao Phraya in Southeast Asia, and the Brahmani, Damodar, Godavari, Krishna, Mahi, Narmada, Ponnaiyar, Rabarmarti, and Tapti in India. Here, low dry season flows have exacerbated water supply and quality problems.

Capacity of Freshwater Systems to Provide Water

Humans withdraw about one fifth of the normal (nonflood) flow of the world's rivers, but in river basins in arid or populous regions the proportion can be much higher. This has implications for the species living in or dependent on these systems, as well as for future human water supplies. Currently, more than 40 percent of the world's population lives in water-scarce river basins. With growing populations, water scarcity is projected to increase significantly in the next decades, affecting half of the world's people by 2025. Widespread depletion and pollution of groundwater sources, which account for about 20 percent of global water withdrawals, also is a growing problem for freshwater ecosystems because groundwater aquifers are often linked to surface water sources.

Water Quantity Information Status and Needs

The single greatest barrier to better analyses of how the hydrological cycle is being impacted by engineering works and land-use change is the poor quality of the hydrological data. The reliability and availability of hydrological data has deteriorated sharply since the mid-1980s when international support of national monitoring programs was reduced, particularly from U.N. agencies. The number of functioning hydrological stations has fallen significantly since 1985 (Fekete et al. 1999:8). In many parts of the developing world we know less about hydrological conditions than we did 20 years ago. As a result, major projects are being designed and in some cases implemented without the basic hydrological data needed to assess the financial—let alone environmental—impacts of these projects.

In addition, currently available statistics on water withdrawal and consumption are fraught with uncertainty because of the highly decentralized nature of water use. Our knowledge of the extent and nature of irrigated land at the continental and global levels is poor, for example, even though the agriculture sector is responsible for 93 percent of water consumption and 70 percent of withdrawals (WMO 1997:8). The irrigated area database developed by the University of Kassel and used in the PAGE agroecosystems report (Wood et al. 2000) is the only globally complete and consistent coverage that estimates area “equipped” for irrigation. However, the coarse resolution (50

kilometers) and lack of information about crop types, operations of irrigation systems, and other variables precluded its use for more detailed analyses. Even when higher resolution data are used, huge differences have been observed between remotely sensed estimates and field-based estimates. These differences are partly attributable to different definitions of irrigated land (for example, the area equipped for irrigation, the area actually irrigated, or the irrigated area multiplied by the number of crops) and underreporting by farmers (Frolking et al. 1999: 407–416).

As mentioned in previous sections, comprehensive statistics on supply and use of groundwater resources are also lacking for domestic and urban use, as well as irrigation (Foster et al. 1998:xi; Foster et al. 2000:2). In order to improve our ability to monitor the condition of freshwater systems to provide water for humans and ecosystems, better statistics on water availability and use are urgently needed—preferably at the watershed level.