WATER SERVICES

Water availability is an increasingly critical constraint to expanding food production in many of the world's agroecosystems. Agriculture accounts for the greatest proportion of withdrawals from the world's surface- and groundwater resources. And agriculture is the most consumptive user of water; that is, it returns the highest proportion of each cubic meter withdrawn to the atmosphere by evaporation and transpiration via plants. Thus, agriculture can profoundly affect the hydrological cycle of the watersheds in which it is practiced, and, consequently, the quantity and timing of available water resources. Additionally, and of growing concern, are the changes in water quality that agricultural production often entails. These range from increases in suspended solids—soil particles entering the surface water system through rainwater erosion of cultivated soils—to water pollution by the leaching of fertilizers, pesticides, and animal manure, to the accumulation of dissolved salts (salinization). These quantity and quality consequences of agricultural water use directly affect aquatic ecosystems and generate water-mediated impacts on a range of environmental, economic, and recreational goods and services as well as on human health.

Thus, we assess the relationship between agroecosystems and water-related goods and services in two ways. First, we consider water as a primary input to food, feed, and fiber production; second, we review the potential impacts of agriculture on water quantity and quality.

In keeping with the global agroecosystem characterization *(see section on Agricultural Extent and Agricultural Land Use Changes)*, the role of water in generating agricultural goods and services is divided into two distinct categories: rainfed systems, and extraction of ground- and surface water for irrigated systems.

Condition of Rainfed Agroecosystems

Around 95 percent of all agricultural land, some 83 percent of cropland, depends on rainfall as the sole source of water. In these rainfed agroecosystems, the interaction of rainfall and evapotranspiration as mediated by crop and soil properties determines the availability of water for plant growth. As a measure of water availability, we used data from the FAO/IIASA Global Agroecological Zone database including temperature, rainfall, evapotranspiration, soil moisture holding capacity, and the length of growing period (LGP) for each year from 1960 to 1990 (FAO/IIASA 1999). LGP is the number of days per year in which moisture and temperature conditions will support plant growth. Map 4 shows the global variation in the average annual LGP within the PAGE global extent of agriculture, while Map 15 shows the year-to-year variability in length of growing period over the 30-year period. The regional patterns of growing season length and variability, both key factors in determining

Table 21

Water Availability within the PAGE Agricultural Extent[a]

	Area Share by Region[b]										
	North America	Latin America and the Caribbean	Europe	Former Soviet Union	West Asia/ North Africa	Sub-Saharan Africa	South Asia	Southeast Asia	East Asia	Oceania	World
						(percentage)					
Rainfall (mm per year)[c]											
0-300	1.3	0.8	0.0	17.5	12.5	0.7	5.4	0.0	5.6	7.2	4.8
300 - 600	30.7	7.9	28.4	62.4	63.8	18.6	9.5	0.0	27.9	61.0	27.5
600 - 1000	35.0	24.9	56.6	19.7	23.5	37.0	37.2	0.0	19.7	19.8	29.2
1000 - 1500	31.8	32.8	12.3	0.3	0.1	33.3	32.0	17.8	30.2	3.9	23.0
1500 - 2000	1.1	24.9	2.3	0.0	0.0	7.4	8.5	22.5	15.3	3.8	9.5
> 2000	0.0	8.7	0.4	0.0	0.0	2.9	7.4	59.7	1.4	4.1	6.1
Region Total	*100.0*	*100.0*	*100.0*	*100.0*	*100.0*	*100.0*	*100.0*	*100.0*	*100.0*	*100.0*	*100.0*
Length of Growing Period (days per year)[c]											
Arid (0–74)	20.8	5.3	0.0	29.3	12.9	6.3	10.9	0.0	5.5	14.6	11.7
Dry Semiarid (75–119)	6.1	5.2	0.5	14.7	30.2	12.3	15.2	0.0	9.9	21.6	9.8
Moist Semiarid (120–179)	12.0	13.4	13.3	32.3	37.3	33.3	47.6	0.4	19.0	29.9	23.2
Subhumid (180–269)	42.7	41.4	76.6	23.5	19.5	34.4	20.7	38.6	18.0	20.2	35.2
Humid (270–365)	18.4	34.7	9.6	0.1	0.0	13.8	5.6	61.0	47.7	13.7	20.1
Region Total	*100.0*	*100.0*	*100.0*	*100.0*	*100.0*	*100.0*	*100.0*	*100.0*	*100.0*	*100.0*	*100.0*
Year-to-Year Length of Growing Period Variability (coefficient of variation)[c]											
0 - 0.05	6.2	17.1	20.8	11.4	0.6	17.5	2.1	45.1	32.5	9.4	16.2
0.05 - 0.1	22.2	35.2	32.7	17.2	13.8	45.4	34.1	44.3	25.8	9.0	29.8
0.1 - 0.2	34.2	24.0	38.5	28.4	61.8	21.7	44.9	10.7	27.0	22.2	29.3
0.2 - 0.5	27.7	19.3	7.9	42.4	18.4	11.0	13.4	0.0	11.9	42.6	20.3
0.5 - 1.0	8.4	3.2	0.0	0.7	2.3	3.8	1.2	0.0	2.0	16.1	3.3
> 1.0	1.3	1.3	0.0	0.0	3.1	0.6	4.2	0.0	0.7	0.7	1.1
Region Total	*100.0*	*100.0*	*100.0*	*100.0*	*100.0*	*100.0*	*100.0*	*100.0*	*100.0*	*100.0*	*100.0*

Source: IFPRI calculation based on: (a) GLCCD 1998; USGS EDC 1999. (b) ESRI 1996, and (c) FAO/IIASA 1999.
Note: These are not proposed as short- to medium-term indicators of agroecosystem condition. They are, however, good indicators of the rainfed production potential. Because they are relatively stable over time and not influenced directly by agroecosystem management decisions, they are useful as agroecosystem characterization or stratification variables *(see section on agroclimatic factors).*

agroecosystem output and management options, are summarized in Table 21. Regions with low and variable rainfall often support pastoral systems, while regions with high and stable rainfall favor high investments of labor and capital, improved pastures, and annual and permanent crops.

In rainfed agroecosystems, rainfall, LGP, and LGP variability are factors over which farmers have no control and that are not *directly* affected by agroecosystem management decisions. They are not, therefore, suitably responsive indicators of agroecosystem condition for the purposes of this study.[19] At a regional scale and over longer time periods, however, they do serve as intermediate indicators of the likely impacts of global climate change on agriculture (for example, Fischer et al. 1996), and as measures of the exposure of farmers to climatological risk. At a local scale, however, farmers do have management options for improving water availability (denser canopy, mulching, reduced tillage, soil conservation, and more water-efficient cropping systems).

Condition of Irrigated Agroecosystems

Between 30 and 40 percent of the world's crop output comes from the 17 percent of the world's cropland that is irrigated, some 264 million hectares (WMO 1997:9; FAOSTAT 1999). This output includes nearly two thirds of the world's rice and wheat production. In India, for example, irrigated areas (one third of all cropland) account for more than 60 percent of total production (Rosegrant and Ringler 1997:10). Over the past 20 years, irrigated areas have steadily grown at approximately 1.5 to 2.0 percent per year (FAOSTAT 1999).

EXTENT AND CHANGE IN IRRIGATED AREA

Expansion of irrigation not only signifies increasing water demands, but also implies more intensive land use with regard to other production inputs, such as fertilizers and pesticides. Extent can be expressed as an absolute area or as a share of total cropland. National time series data on irrigated area are available from FAOSTAT (1999). Two digital spatial sets containing irrigated land variables were available to this study: the University of Kassel Global Irrigation Area (Döll and Siebert 1999), and Global Land Cover Characterization Database (GLCCD 1998; USGS EDC 1999a). Both have shortcomings, but since the USGS data was particularly unreliable in detecting irrigated areas in South America, Africa, and Oceania, and the Kassel map was calibrated to FAO irrigation area statistics at the national level, the Kassel data source was preferred *(see Map 16)*. Format and resolution issues precluded combining the data sets, but for comparative purposes the independently constructed maps were overlaid revealing significant areas of mismatch.[20] Given the importance of irrigated areas from an agricultural and environmental perspective, there is much to be done to improve our knowledge of their location and extent.

IRRIGATION INTENSITY

There are many forms of irrigation at different scales of operation, but all share the objective of compensating for low rainfall by delivering sufficient water to the root zone to satisfy crop growth needs and, in some cases, to prevent the accumulation of dissolved salts. Crop water needs are large. Potato plants take up about 500 kg of water to produce 1 kg of potatoes, and in the cases of wheat, maize, and rice the corresponding requirements are 900 kg, 1400 kg, and 2000 kg of water respectively. Tropical crops, such as sugar cane and bananas, are even more demanding (Klohn and Appelgren 1998).

Of the 9,000 to 12,500 km^3 of water estimated to be available globally for use each year (Postel et al. 1996:786; UN 1997), between 3,500 and 3,700 km^3 was being extracted in 1995 (Shiklomanov 1996:69). Of that total, around 70 percent, some 2,450 to 2,700 km^3 (WMO 1997:9; Postel 1993:58), is extracted for irrigation. High-income countries, mostly lying in the subhumid and humid temperate and subtropical regions, tend to have more abundant water resources—both per hectare and per capita. Poorer countries tend to have scarce water resources and relatively larger agricultural demands. According to the World Bank (2000:132), the share of extracted water used for agriculture ranges from 87 percent in low-income countries, through 74 percent in middle-income countries, to 30 percent in high- income countries.[21] So while the 206 m^3 per capita withdrawn annually for agriculture by Africans represents 85 percent of their total withdrawals, the average of 1029 m^3 per capita withdrawn by North Americans represents just 47 percent (WRI 2000: 276).

The simplest measure of irrigation intensity is the amount of irrigation water withdrawn (or applied) per year. This is most usefully expressed as an equivalent water depth, that is, cubic meters of water per year divided by hectares irrigated. For regional and global assessment, national estimates of the volume of freshwater extraction for agriculture are available from WRI (1998), and irrigated areas from FAOSTAT (1999). Using these data Seckler et al. (1998:32-38) calculated the depth of irrigation. Across all 118 countries covered, the mean depth of irrigation water extracted in 1990 was just under one meter—about the same as the average for China and a little less than the 1.1 meters for India (Seckler et al. 1998:32).

IRRIGATION EFFICIENCY

Most irrigation systems use water inefficiently primarily because of the lack of incentives for farmers to treat water as a scarce resource. Efficiency is generally defined as the ratio of water actually used by crops (that is, returned to the atmosphere via transpiration) to the gross amount of water extracted for irrigation use. Extracted water is lost by direct evaporation from irrigation canals or the soil surface or by subsurface leakage. Global estimates of irrigation efficiency vary but average around 40 percent (Postel 1993:56; Seckler et al. 1998:25; Faurès 2000). At a watershed or basin level, however, these efficiencies can be misleading as a significant proportion of the subsurface leakage may be returned to surface- or groundwater resources elsewhere. If irrigation efficiency could be improved, less irrigation water would need to be extracted from rivers and aquifers per ton of food, feed, or fiber produced. Improved efficiency is being pursued in a number of ways: through policies that foster water markets or other regulatory arrangements; through technologies such as field leveling, low-energy precision application, drip irrigation, soil moisture monitoring; and through more water-efficient crops and cropping systems. There is also evidence of success through institutional reform and devolution that engage farming communities more directly in the improved management of water resources (Postel 1997; Subramanian et al. 1997).

Efficiency estimates were calculated based on country-specific, crop-related water use factors from Seckler et al. (1998) and FAO and WRI data were used for determining irrigation depth. Seckler et al.'s estimates suggest that arid agroecosystems have more efficient irrigation, e.g., 54 and 58 percent efficiency for the two driest groups of countries, compared to around 30 percent for the least water-constrained group. China and India show irrigation efficiencies of around 40 percent. They strongly influence the global average of around 43 percent (Seckler et al. 1998:25).

Table 22 summarizes the above irrigation indicators by region. Although there are many other potentially important indicators of irrigated agroecosystem condition, such as the pro-

Table 22

Regional and Global Summary of Irrigation Indicators

	1990 Irrigation Indicators					
			Included in the Seckler et al. Analysis			
Region	Total Irrigated Area[a]	Area Growth Rate[a]	Irrigated Area[c]	Irrigation Abstraction[c]	Av. Irrigation Depth[b,d]	Av. Irrigation Efficiency[b]
	(000 ha)	*(%/year)*	*(000 ha)*	*(cubic km/yr)*	*(meters)*	*(percent)*
North America	21,618	0.90	21,618	202	0.93	53
Latin America and the Caribbean	16,182	2.38	16,111	163	1.17	45
Europe	16,743	0.59	16,272	103	0.90	56
West Asia/ North Africa	22,570	2.45	21,805	219	1.17	60
Sub-Saharan Africa	4,773	1.20	4,604	53	1.59	50
South Africa	1,290	0.77	1,290	15	1.16	45
Asia	154,449	1.87	136,564	1,324	1.02	39
India	45,144	2.73	45,144	484	1.07	40
China	47,965	1.31	47,965	463	0.97	39
Rest of Asia	61,340	1.70	43,455	377	0.92	32
Oceania	2,113	3.57	2,112	6	0.29	66
World	243,028	1.57	220,376	2,086	0.95	43

Source: (a) compiled from FAOSTAT 1999. (b) IFPRI calculations based on Seckler et al. (1998:32-38). (c) Seckler et al. (1998:32-38). (d) Gross equivalent depth-abstraction divided by area. Seckler et al. provide summaries for countries grouped by water scarcity. Total global irrigation abstraction in 1990 is estimated at 2,353 cubic kilometers (Seckler et al. 1998:32).

ductivity of irrigated areas per unit of irrigated land, cropped area, or irrigation water, the additional crop-specific data they require are usually unavailable at a macro level (see Molden et al. 1998 for a discussion of other relevant indicators).

SALINIZATION AND WATERLOGGING

Two significant environmental consequences of irrigation are salinization and waterlogging. Salinization occurs through the accumulation of salts deposited when water is evaporated from the upper layers of the soil. Although salinization can occur naturally, irrigation promotes so-called "secondary" salinization because it artificially increases the supply of water to surface layers of the soil in typically more arid climates where evaporation rates are higher. This accelerates the build-up of salts. Because most crops are not tolerant of high levels of salinity, salinization of land and water can in extreme cases lead to the abandonment of irrigated areas, but is more usually reflected in declining yields. The problem is particularly acute in arid and semiarid areas, such as in Pakistan and Australia, where soil evaporation rates are much higher and natural leaching and drainage are inhibited. In the case of Australia, salinization occurs chiefly in rainfed areas where natural water tables have been rising since settlers first began clearing the natural bush vegetation, primarily for grazing land.

Waterlogging is more prevalent in humid environments and in irrigated areas where excessive amounts of water are applied to the land and the water table rises. Waterlogging is often a precursor to salinization. Both salinization and waterlogging most often arise from poor irrigation management and inadequate drainage. A review of estimates of land damaged by salinization put the global total at around 45Mha, representing some 20 percent of the world's total irrigated land (Ghassemi et al. 1995:42). Rough estimates of the annual impacts of degradation in irrigated areas, primarily through salinization, are losses of around 1.5Mha of irrigated land in the world's dry areas (Ghassemi 1995:41 quoting Dregne et al. 1991), and approximately US$11 billion from reduced productivity globally (Postel 1999:92). These losses represent just under 1 percent of the global totals of both irrigated area and annual value of production, but are much more significant in affected areas.

Agricultural Effects on Water Quality

Both rainfed and irrigated agriculture can markedly affect the quality of water in ways other than salinization. Poor crop cover, field drainage, and cultivation operations, particularly on sloping land, can lead to increased levels of water-induced soil erosion. Generally, increases in water-borne suspended solids negatively affect downstream aquatic ecosystems, as well as cause siltation on downstream channels, reservoirs, and other hydraulic infrastructure. Analysts estimate that around 22 percent of the annual storage capacity lost through siltation of reservoirs in the United States is due to soil erosion from cropland (Gleick 1993:367). But the linkages between land use practices, erosion, and sedimentation in rivers are complex. Box 3 summarizes some recent findings on this issue.

High external-input systems are prone to generate significant environmental externalities—typically, pollution from fertilizer, pesticides, and animal manure leaching into ground- and surface water. In Belgium and the Netherlands, the nitrogen input to some croplands exceeds 500 kg/ha. Years of phosphate fertilizer application in parts of the United States has left many soils saturated with phosphorus (FAO 1999b:172). Leaching of excess nutrients from farms into water sources causes eutrophication, which consequently damages aquatic plant life and fauna through algal blooms, depressed oxygen levels, and increased water treatment costs. In addition, excess nitrates pose direct human health threats. The depletion of river flows exacerbates such water quality problems by reducing the dilution capacity of rivers and downstream water bodies. Box 4 describes an example of an agricultural water pollution controversy in the United States, and the difficulties faced in dealing with it, even when environmental regulations and enforcement measures are well established.

Monitoring water for nutrients, ions (salinity), solids, persistant organochlorine pollutants (POPs—originating in pesticides and related compounds), and others, remains the most reliable means of tracing changes in water quality. But even though cheaper, simpler means of field testing are continually being developed, water quality monitoring remains technically and financially demanding. For example, it is necessary to correct some observations for water temperature, pH, and flow rate effects. Even with reliable water quality data, it is often difficult, especially in watersheds having significant human populations and commercial activities, to clearly relate changes in such quality indicators to the (generally diffuse) effects of agricultural activity. For example, there is recent evidence from the United States of higher prevalence of pesticides and nutrients in surface runoff from urban than from agricultural catchments while, in the case of groundwater, prevalence is higher in agricultural catchments (USGS 1999).

Agricultural Effects on Water Supply

With regard to land use change, there is considerable evidence that converting forest and woodlands to agricultural uses increases available surface- and groundwater resources because of the substantial reduction in biomass and, consequently, in transpiration demands (FAO 1999b:173). However, reduced biomass and litter, coupled with intentional efforts to improve drainage, reduce the water storage capacity of agricultural land and can seriously diminish its flow regulation capacity. This increases the incidence and severity of high runoff events and, correspondingly, diminishes dry weather flows.

Box 3

Historical Decline in Soil Erosion in U.S. River Basin

One of the most intensive, longitudinal studies of soil erosion in the world was recently completed for the Coon Creek Basin, located in the humid midwestern United States. The Basin drains into the Mississippi River. The study documented changing sedimentation rates in a 360-square kilometer area, comparing original prairie soils present when European farmers arrived in the 1850s with detailed erosion studies by the U.S. Soil Conservation Service in the 1930's and resurveys of soil profiles in the 1970s and the 1990s.

Measured rates of sedimentation jumped in the late nineteenth century, skyrocketed in the 1920s and 1930s, and then dropped again as United States Department of Agriculture pressed local farmers to stop using the traditional moldboard plow and adopt conservation practices. These practices included strip-cropping and leaving plant residue and stubble in the fields year-round to inhibit run-off. Between the 1970s and the 1990s, sedimentation rates dropped to just 6 percent of their previous peak. The findings illustrate the potential for conservation practices, when widely adopted, to dramatically reduce soil degradation.

Yet, the study also found that regardless of erosion rates, the Basin tended to store and release sediment in such a way that the amount delivered to the Mississippi River remained roughly constant over the decades. Sediment eroded from upland areas is, in effect, stored around Coon Creek tributaries and other deposition sites and released later. For example, cutbanks and floodplains around the oxbows of the tributaries changed in shape and size over time and were transformed from sediment sources to sinks and back again. The findings suggest that even if materials coming off a field or group of fields are controlled, it may be some time before effects on downstream sedimentation are observed. Thus, short-term measures of downstream sedimentation may be a poor indicator of the quality of upstream farmers' land husbandry practices.

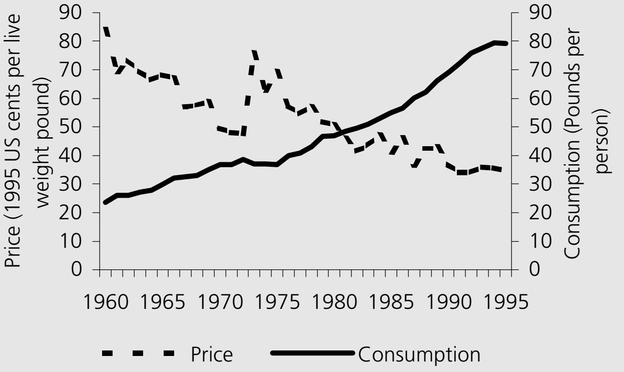
Source: Adapted from Trimble, S.W., *Science*, vol. 285, 20 August 1999, pp. 1187-89.

Decreased river flows and falling groundwater levels are pervasive in irrigated areas, because few incentives exist to not overuse water. In the United States, roughly one fifth of the irrigated area (about 4 million hectares) is estimated to be extracting groundwater at greater than the recharge rate (Postel 1993:58). Postel (1993:59) and Rosegrant and Ringler (1997:419) report water tables in the North China Plain falling by up to one meter per year, and by 25-30 meters in a decade in parts of Tamil Nadu, India. A notorious case of river water

Box 4

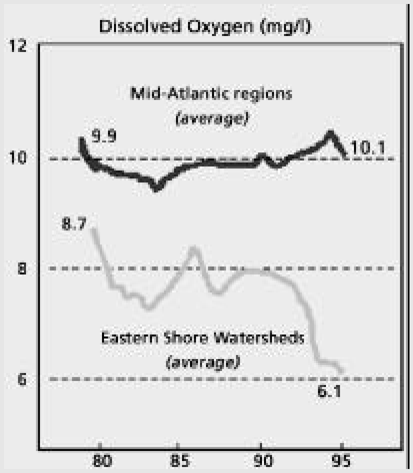
Cheaper Chicken, More Pollution

Figure A



Source: USDA/ERS, Poultry Yearbook 1996; Data downloaded from http://usda.mannlib.cornell.edu/

Figure B



Source: The Washington Post.

Between 1970 and 1996, per capita consumption of poultry meat in the United States nearly doubled. Health concerns and demographic changes stimulated demand, while increased retail competition and new chicken production techniques were responsible for the increased supply, which drove down chicken prices *(see Figure A)*. To reduce the costs of transporting feed and chickens, large, vertically-integrated producers contract with nearby farmers to raise chickens for company slaughterhouses. As more farmers enter the industry, the concentration of chickens and slaughterhouses increases, and so does the problem of manure disposal.

The chicken industry in Delmarva (the peninsula of Delaware, Maryland, and Virginia) exemplifies the problem. The area produces more than 600 million birds a year and 750,000 tons of manure—more than that produced by a city of 4 million people. Farmers have traditionally used chicken manure, which is richer in nutrients—especially nitrogen (nitrates) and phosphorous—than other livestock waste, to fertilize their fields. But, as housing development expanded into farmland, more manure was applied to less cropland and soils became saturated with nutrients. A survey conducted in the late 1980s found that one third of all groundwater in Delmarva's agricultural areas was contaminated with nitrates, confirming that excess nutrients were seeping into and polluting groundwater, wells, and other public water sources.

At the same time, company slaughterhouses disposed of millions of gallons of wastewater each day in waterways that reach the Chesapeake and coastal bays. Other creeks and streams carry surface run-off from overfertilized fields or piles of wet manure. Although wastewater should be cleaned to per-unit standards, its growing volume raises the total load of nutrients beyond acceptable levels. Treating slaughterhouse wastewater also creates sludge (minute solids filtered from the wastewater) that is injected into the ground for disposal, increasing groundwater pollution.

The Environmental Protection Agency Chesapeake Bay Program estimates that chicken manure sends more than four times as much nitrogen into the Bay as the biggest nonagricultural sources (septic tanks and run-off), and five times as much phosphorous as sewage-treatment plants. Storms exacerbate the problem, washing large amounts of nutrient-laden sediment into the Bay. The excess nitrogen and phosphorous overstimulate algae growth. As the algae die and decompose, they consume oxygen, choking fish and other water life *(see Figure B)*. Some scientists believe the toxic microbe *Pfiesteria piscicida* feeds on the excess algae and nutrients.

So far there is no agreement on who should clean up the pollution the industry produces or which methods should be used. Some companies have begun trucking manure to more distant farming areas. Others are exploring technological solutions, including adding phytase to chicken feed to help the chickens digest phosphorous and building plants to convert manure into fuel and fertilizer pellets.

Government regulation has so far failed to solve the problem. The industry's economic importance makes it difficult for local politicians to pass and enforce more stringent antipollution legislation. One study estimated that a 4 percent drop in the state's poultry production would eliminate 1,000 jobs and $74 million in economic output. In 1997, the EPA fined one company $6 million after state regulators failed to stop the discharge of excessive nutrients. The problem has pitted environmentalists, federal and state regulators, and the industry against each other. Industry leaders complain that they are caught between the demand for cheap chicken and the desire for pristine waterways.

Source: Adapted from Washington Post series *Poultry's Price: The Cost of the Bay.* August 1-3, 1999.

overextraction for irrigation is the remarkable shrinkage and salinization of the Aral Sea and the consequent loss of fish species and fishing livelihoods (Gleick 1993:5-6; Postel 1993:59).

For irrigated systems, the indicators of area, depth, and efficiency described earlier provide a broad picture of water resource use. To place that extraction in context, however, requires estimates of the renewable capacity of water resources. Only by comparing existing and likely future demands against renewable resource capacity will it become apparent how water scarce each location is, what stresses agroecosystems and other potential water users face, and what options might be available to balance demands with renewable supplies, including, for example, increased water reuse. Assessing the resource potential for surface water is relatively straightforward compared to assessing reliable groundwater yields, in many places the major source of irrigation water. This study has not attempted to assess the reliable yields of water resources.

Given these complexities and the limited scope of this study, we adopted a much simpler indicator, the proportion of a basin within the PAGE global extent of agriculture, as a guide to the potential impact of agroecosystems on water goods and services. This indicator is shown at the global scale in Map 17. The indicator is continuous, but is displayed here in just three ranges (10-30 percent, 30-50 percent, and greater than 50 percent) to simplify map presentation. Because of its simplicity, the indicator can easily be updated as new land cover or watershed boundary data become available. The map depicts the area extent of agriculture within each watershed boundary. Given that one hectare of irrigated area will likely have a much greater impact on water goods and services than one hectare of rainfed agriculture, the indicator could be further refined by differentiating between rainfed and irrigated agricultural areas within each watershed. Such a differentiation was not made here because of resolution differences among the satellite-derived agricultural extent data, the irrigation area data, and the basin boundaries.

Summary of Indicators and Data

Water has a central role within and beyond agriculture. The need to use those finite resources more effectively in the face of growing demands and greater pollution threats has already mobilized several international initiatives, such as the Global Water Partnership and the World Water Council. The most recent manifestation of the international concern was the Second World Water Forum held in The Hague, the Netherlands, in March 2000 (World Water Forum 2000). One relevant outcome from that meeting was the commitment by the UN systems to produce periodic reports on the state of the world's water resources, a so-called "water development report."

An important objective of all such initiatives is to overcome the lack of reliable and internationally comparable water information, a constraint reflected in several parts of this chapter. The proposed Millennium Ecosystem Assessment should link with and add value to the networks and resources of ongoing programs including: the Global Climate Observation System (GCOS 2000); the World Hydrological Cycle Observing System (WYCOS 2000); the Global Environment Monitoring System for Water (GEMS/Water 2000); and the Global Runoff Data Centre (GRDC 2000). Some of these resources are significant. For example, the GEMS/Water archive contains over 1.5 million data points for 710 monitoring sites globally collected since the late 1970s. Although the sampling sites are more numerous in developed countries, the standardized data sets do include several of the key nutrient, ion, solids, and organic contaminant indicators discussed above.

With specific reference to water and agriculture, the FAO/Netherlands Conference on the MultiFunctional Character of Agriculture and Land (MFCAL) held in Maastricht, the Netherlands, in September 1999 explicitly addressed the multiple goods and services of water in similar ways to those explored in this study (FAO 1999b). FAO is also responsible for the AQUASTAT initiative established specifically to compile and disseminate water information, with a strong focus on improving irrigation and drainage data (FAO 2000a). The University of Kassel compiled the irrigation map used in this study (Döll and Siebert 1999) and is continuing to refine that map (in collaboration with FAO's AQUASTAT program). In addition, it is testing global water use scenarios for the World Water Commission (Alacamo et al. 2000). This scenario development activity also involved Stockholm Environment Institute (SEI) (Gallopin and Rijsberman 1999) and IWMI (IWMI 1999) who focused on the agricultural dimensions, as well as the International Food Policy Research Institute (IFPRI) who incorporated the water scenarios into global food assessments to trace the likely consequences on food availability and prices (Rosegrant and Ringler 2000).

Field level indicators of the efficiency of rainfall use under different management practices would be valuable to local agroecosystem assessments. Satellite-derived data on rain-use efficiency (RUE) is now available (University of Maryland 1999; Prince et al. 1998) and its suitability as a regional-scale indicator of rainfed agroecosystem condition merits further investigation. A companion PAGE report, *Pilot Analysis of Global Ecosystems: Grasslands* (White et al. 2000), reviews the use of RUE as a condition indicator. Additionally, the PAGE report, *Pilot Analysis of Global Ecosystems: Freshwater* (Revenga et al. 2000) reviews and analyzes the state of the world's freshwater ecosystems.