Changing diets lead to changing water use in agriculture

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2 Trends in water and agricultural development

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Overview

To meet the objectives of increasing food production and alleviating poverty and hunger in an environmentally sustainable manner will require a renewed focus on agricultural water management and institutional innovations for managing water. In some areas of the world demand for water for various uses exceeds supply. But for much of the world there is a pending crisis of water supply not because of a shortage of water but because of mismanagement of water resources. This report defines water scarcity from the perspective of individual water users who lack secure access to safe and affordable water to consistently satisfy their needs for food production, drinking, washing, or livelihoods.

About 2.8 billion people, more than 40% of the world's population, live in river basins where water scarcity must be reckoned with [competing explanations]. About 1.6 billion people live in areas of economic water scarcity where human, institutional, and financial capital limit access to water even though water in nature is available locally to meet human demands. Symptoms of economic water scarcity include lack of or underdeveloped water infrastructure, whether small-scale (water harvesting structures) or large-scale (reservoirs, distribution networks); high vulnerability to short- and long-term drought; and difficult access to reliable supplies, especially for rural people. These conditions are prevalent in much of South Asia and Sub-Saharan Africa. Another 1.2 billion people live under conditions of physical water scarcity in river basins where water resources development has exceeded sustainable limits. In these cases symptoms include environmental degradation and competition for water. While it is possible with good management to treat the symptoms of water scarcity, it is also possible with bad management to create water problems in areas of no water scarcity.

Throughout the developing world income and nutrition levels are improving in aggregate, but poverty and malnutrition persist in many regions, including Asia, Sub-Saharan Africa, and parts of Latin America. There has been a steady increase in the per capita consumption of food, including fruits, vegetables, and animal products, leading to better nutrition for many and a decrease in famines. The average global per capita daily food supply increased from 2,400 kilocalories (kcal) in 1970 to 2,800 kcal in 2000, which means that enough food was produced globally to feed the growing population. Fish and meat consumption is rising, increasing reliance on aquaculture and industrial livestock production, with some positive well-being and income benefits, but greater pressure on water resources and the environment. However, pockets of food insecurity remain. The average daily per capita food supply in South Asia (2,400 kcal) and Sub-Saharan Africa (2,200 kcal), while slowly rising, was below the world average of 2,800 kcal in 2000.

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Key trends and their drivers

During the second half of the 20th century the global food system was able to respond to the doubling of world population by more than doubling food production [well established]. From 1963 to 2000 food production grew more rapidly in developing countries than in developed countries, with growth in food production exceeding growth in population, except in Africa. However, there was wide variability in food production within and across regions. Intensification and yield growth have been the dominant factors, and irrigated agriculture has played a major role. Nearly all the growth in cereal production since 1970 has been from higher yields. Yield increases have come at different times in different regions of the world. In some areas yields have reached their upper limits and are showing signs of leveling off.

Globally, about 80% of agricultural water use (evapotranspiration) is directly from green water (rainfall stored in soil moisture), with the rest from blue water sources (water withdrawals from rivers, reservoirs, lakes, and aquifers) [well established]. There is considerable variation across regions. Irrigation is relatively important in Asia and North Africa, while rainfed agriculture dominates in Sub-Saharan Africa. Groundwater levels are declining in many areas where there is a high dependence on groundwater for agriculture and population demands are high. Demand for water for industrial and domestic uses is growing relative to demand for agriculture. As competition for water intensifies, agriculture can expect to receive a decreasing share of developed freshwater resources.

Despite dramatic increases in large-scale irrigation infrastructure over the past half century, the bulk of the world's agricultural production still comes from predominantly rainfed lands [well established]. Some 55% of the gross value of crop production is grown under rainfed agriculture on 72% of harvested land.[1] Many people dependent on rainfed agriculture are highly vulnerable to both short-term dry spells and long-term drought and thus are reluctant to invest in agricultural inputs that could increase yields. In developing countries growth in both productivity improvements and area expansion has been slower in rainfed agriculture than in irrigated agriculture. The potential exists for raising the productivity of many rainfed systems in Sub-Saharan Africa, but this potential has been exceptionally difficult to realize.

The world's harvested land increased by about 24% from 1961 to 2003 to 1.2 billion hectares (ha), 28% of it irrigated, while the area equipped for irrigation[2] *nearly doubled, from 139 million ha to 277 million ha, funded initially by investments by international development banks, donor agencies, and national governments but later increasingly by small-scale private investments* [established but incomplete]. Irrigation water was essential to achieve the gains from high-yielding fertilizer-responsive crop varieties. Approximately 70% of the world's irrigated land is in Asia, where it accounts for almost 35% of cultivated land. By contrast, there is very little irrigation in Sub-Saharan Africa. Globally, donor spending on agricultural water reached a peak of more than $1 billion a year in the late 1970s and early 1980s and then fell to less than half that level by the late 1980s. Benefit-cost ratios deteriorated with falling cereal prices and rising construction costs. Recognition of the poor performance of large-scale irrigation systems spread, and opposition mounted to the environmental degradation and social dislocation sometimes caused by large dams. Today, there appears to be consensus that the appropriate scale of infrastructure should be determined by the specific environmental, social, and economic conditions and goals, with the participation of all stakeholders.

The potential exists for raising the productivity of many rainfed systems, but this potential has been exceptionally difficult to realize in many areas

Biological diversity is in rapid decline in all the world's major biomes [well established]. Loss of biodiversity is greatest among freshwater-dependent species—almost twice as fast as for marine or terrestrial species. The majority of biomes have been greatly modified, with 20%–50% of 14 global biomes transformed to croplands. For terrestrial ecosystems the most important direct driver of change in the past 50 years has been land cover change. Further land use changes causing habitat loss are associated primarily with the additional expansion of agriculture. For freshwater ecosystems the most important direct drivers of change include direct physical changes to freshwater habitat, such as draining wetlands and building dams, and modification of water regimes through water extraction and pollution. Many indirect drivers of change work through the impacts of land use arising from agriculture-related activities

The two major factors contributing to increased food demand, and thus to increased water use for food production, are population growth and changes in diets as living standards improve [well established]. Rising incomes lead not only to increasing consumption of staple cereals, but also to a shift in consumption patterns among cereal crops and away from cereals toward livestock products, fish, and high-value crops. A growing, wealthier population requires more food per person, and richer and more varied diets. The amount of water needed to produce food depends on diets and how the food is produced.

Rapid rural to urban migration in developing countries influences farming practices and water demand [established but incomplete]. In the 1960s two-thirds of the world's population lived in rural areas, and 60% of the economically active population worked in agriculture. Today, half of the people live in rural areas, and just a little more than 40% of the economically active population depend directly on agriculture. In absolute terms the rural population will start to decline in the next few years, and by 2050 two-thirds of the world's people will live in cities. In many poor countries in South Asia and Sub-Saharan Africa, however, the rural population will continue to grow until about 2030, and the number of people depending on agriculture will continue to rise. Cities are rapidly increasing their claim on water at the expense of rural uses such as farming. Urban centers represent a source of pollution that has impacts on downstream irrigation and aquatic ecosystems.

Farmers need to adjust to the agricultural transformation that occurs as economies develop, incomes rise, and urbanization spreads. Agriculture grows but not as fast as the nonagricultural sector, and food habits shift toward richer and more varied diets. Some farmers will shift from staples to higher value horticultural crops, livestock, and fisheries. Others will specialize in export crops. Farmers who continue to grow staple food crops will need to boost their productivity. The next step in agricultural transformation is access to value-added supply chains in the modern retail sector. In many parts of the developing world groups of professional farmers are emerging whose incomes come almost entirely from farming. Many more farm households are augmenting their incomes from nonfarm activities as labor has become more mobile. The way this transformation unfolds has implications for water investments to reduce poverty. In the early stages investments in water to increase productivity can be quite effective in reducing poverty. But as economies grow, this impact diminishes. Later, livelihood diversification becomes an important strategy. Ultimately, this could lead to an exit from agriculture, another means of escape from rural poverty *[competing explanations]*.

> Cities are rapidly increasing their claim on water at the expense of rural uses such as farming

Benefits and costs

Investments in water for agriculture have made a positive contribution to rural livelihoods, food security, and poverty reduction [established but incomplete]. The positive impact is felt through employment gains, affordable food prices, and more stable outputs. Through a multiplier effect investments in irrigation lead to a rise in crop yields and farm incomes that results in higher demand for goods and services in the nonfarm sector—multiplying the benefits of the original investment. A handful of studies indicate that the multiplier effect of investment in irrigation is in the range of 2.5 to 4. The additions to employment in the local nonfarm sector can be as high as twice that for the farm sector, with a major impact on poverty reduction.

Poorly conceived and implemented water management interventions have incurred high social and environmental costs [well established]. Social costs have included inequity in the allocation of benefits and loss of livelihood opportunities. Common property resources such as rivers and wetlands, important for poor fishers and resource gathers, have been appropriated for other uses, resulting in a loss of livelihood opportunities. Communities have been displaced, especially in areas behind dams, without adequate compensation. A large proportion of irrigation's negative environmental effects arise from the diversion of water away from natural aquatic ecosystems, such as rivers, lakes, oases, and other groundwater-dependent wetlands. Direct and indirect negative impacts have been well documented, including salinization, channel erosion, declines in biodiversity, introduction of invasive alien species, reduction of water quality, genetic isolation through habitat fragmentation, and reduced production of floodplain and other inland and coastal fisheries.

Changing responses over time to the water-food-environment challenge

Farmers, fishers, and pastoralists and their communities, often supported by community-based organizations, have responded to water scarcity with or without government support [established but incomplete]. The failure of large-scale public irrigation systems to provide water where and when farmers needed it spurred many to invest in individual pumps and other private irrigation systems. Where opportunities permit, farmers are benefiting from more flexible and reliable supplies or from small storage coupled with irrigation. However, local responses do not always meet the broader water-food-environment challenge because the primary focus is generally to enhance local food production and livelihoods. Particularly in semiarid areas unregulated exploitation of groundwater can lead to falling water tables or to rising water tables and increased salinity. The development of private facilities may further disadvantage poor farmers, who cannot afford the investment costs, and undermine farmer irrigation associations.

Responses at the national level generally express a broader view, but still reflect specific perspectives and priorities [competing explanations]. Often, institutional development did not keep pace with rapid infrastructure development, undermining the efficiency of investments and failing to adapt to changing economic, environmental, and social conditions. Many of today's water bureaucracies were set up to construct major water infrastructure facilities. This heavy focus on infrastructure sometimes led to institutions and practices that were well suited for construction, but less well suited for the adaptive management needed to operate long-lived, multipurpose water infrastructure. Today, despite repeated calls for integration, government responses tend to remain mostly sectoral. Management of water allocation between sectors remains fragmented and highly politicized in most countries. Even within agriculture irrigation receives the most attention while rainfed agriculture, fisheries, and livestock are rarely considered in discussions of water resources.

Good practice in agriculture is increasingly sensitive to the role of ecosystems, and the environmental community has become increasingly aware of the importance of water, food, and livelihood issues

Although some people argue that water is essentially a local issue, global issues affect global water use, and thus global actions are necessary to resolve them [competing explanations]. Global issues of trade, energy, and subsidies have an impact on water use, but water is rarely a main topic of global discussions and agreements on these topics. The Second World Water Forum in 2000 was instrumental in mobilizing thinking around key global issues of the water crisis: water supply, agriculture, environment, and livelihoods. A divide in thinking was clearly illustrated by reports on water for food and rural development and reports on water and nature. With water again at the forefront of global issues, discussions are occurring in a more balanced context, with more consideration of the social and environmental tradeoffs that water management and development decisions entail.

In agricultural water new paradigms call for considering water management within a basin context and for including rainfed agriculture, fisheries, and livestock in water discussions. There is more attention to integration across sectors and to the appropriate roles of public and private sectors. Good practice in agriculture is also increasingly sensitive to the role of ecosystems, recognizing the importance of watershed protection, environmental flows, and sustainable management of aquatic ecosystems, springs, and aquifers. At the same time there has been an increasing awareness within the environmental community of the importance of water, food, and livelihoods issues.

The water situation today—is there a water crisis?

While the global quantity of freshwater is constant, the world population and therefore freshwater demand are growing. There is enough land, water, and human capacity in the world to produce sufficient food in aggregate for a growing population over the next

50 years, so in that sense water is not a constraint to global food production. So why is there talk of a water crisis?

There are many local crises that taken together could constitute a global water crisis. In some areas of the world demand for water for various uses exceeds supply. But for much of the world there is a pending crisis not because of a shortage of water but because of mismanagement of water resources. Avoiding this crisis will require institutional innovations that allow focusing simultaneously on the goals and tradeoffs in food security, poverty reduction, and environmental sustainability.

For much of the world there is a pending crisis not because of a shortage of water but because of mismanagement of water resources

Water scarcity today

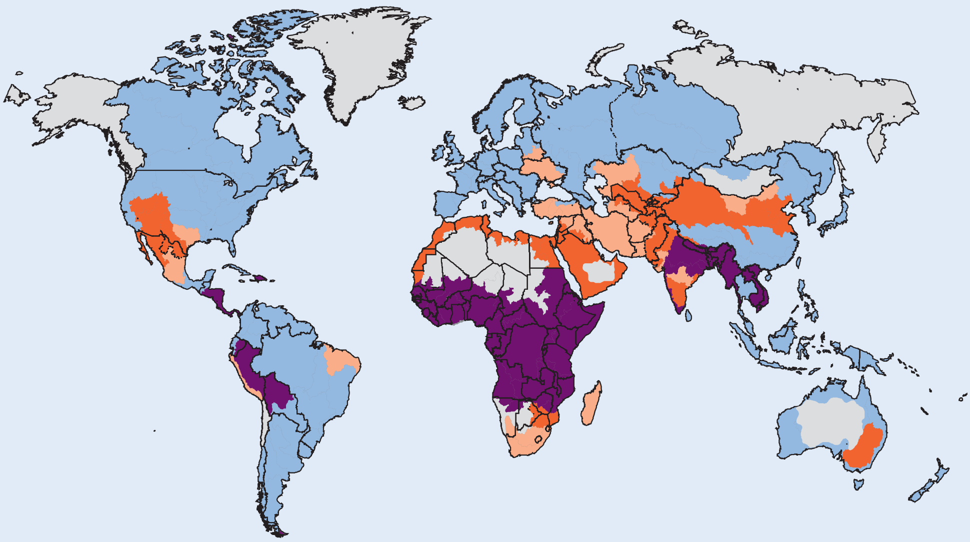
What is water scarcity? We define scarcity from the perspective of individual water users rather than the hydrology of an area. Individuals are water insecure when they lack secure access to safe and affordable water to consistently satisfy their needs for drinking, washing, food production, and livelihoods. An area is water scarce when a large number of people are water insecure (Rijsberman 2006).

Access to water is difficult for millions of people for reasons that go beyond the physical resource base. About 2.8 billion people live in areas facing water scarcity, and more than 1.2 billion of them—one fifth of the world's population—live in areas of physical water scarcity. Another 1.6 billion people live in basins that face economic water scarcity, where human capacity or financial resources are likely to be insufficient to develop adequate water resources even though adequate water in nature is available to meet human needs (map 2.1). Within these regions poor people suffer most from symptoms of scarcity. Lack of finance, lack of human capacity, poor management, and a lack of good governance all contribute to water scarcity.

Physical water scarcity. Physical water scarcity occurs when available water resources are insufficient to meet all demands, including minimum environmental flow requirements (see chapter 16 on river basins; photo 2.1). Arid regions are most often associated with physical water scarcity, but an alarming new trend is an artificially created physical water scarcity, even where water is apparently abundant. This is due to the overallocation and overdevelopment of water resources, leaving no scope for making water available to meet new demands except through interbasin transfers. There is not enough water to meet both human demands and environmental flow needs.

Symptoms of physical water scarcity include severe environmental degradation, such as river desiccation and pollution; declining groundwater tables; water allocation disputes; and failure to meet the needs of some groups. Some 1.2 billion people live in river basins where the physical scarcity of water is absolute (human water use has surpassed sustainable limits). And another 500 million people live in river basins that are fast approaching this situation. While physical scarcity introduces complex problems, investments in good management can mitigate many of them.

Economic water scarcity. Economic water scarcity occurs when investments needed to keep up with growing water demand are constrained by financial, human, or institutional map **2.1** | **Areas of physical and economic water scarcity**



Definitions and indicators

- *Little or no water scarcity.* Abundant water resources relative to use, with less than 25% of water from rivers withdrawn for human purposes.
- *Physical water scarcity (water resources development is approaching or has exceeded sustainable limits).* More than 75% of river flows are withdrawn for agriculture, industry, and domestic purposes (accounting for recycling of return flows). This definition—relating water availability to water demand—implies that dry areas are not necessarily water scarce.
- *Approaching physical water scarcity.* More than 60% of river flows are withdrawn. These basins will experience physical water scarcity in the near future.
- *Economic water scarcity (human, institutional, and financial capital limit access to water even though water in nature is available locally to meet human demands).* Water resources are abundant relative to water use, with less than 25% of water from rivers withdrawn for human purposes, but malnutrition exists.

Source: International Water Management Institute analysis done for the Comprehensive Assessment of Water Management in Agriculture using the Watersim model.

capacity (photo 2.2). Much of the scarcity felt by people is due to the way institutions function—favoring one group over another, not listening to the voices of women and disadvantaged groups. Symptoms of economic water scarcity include inadequate infrastructure development, so that people have trouble getting enough water for agriculture and domestic purposes; high vulnerability to seasonal water fluctuations, including floods and long- and short-term drought; and inequitable distribution of water even though infrastructure exists. Much of Sub-Saharan Africa experiences economic water scarcity, and there are many pockets across the globe where water resources are inequitably distributed. Further water development could ease problems of poverty and inequality.

Poverty and undernourishment remain

Throughout the developing world income and nutrition levels are improving in aggregate. However, while food production has outpaced population growth globally and food

Photo by Karen Conniff

Photo 2.1 Physical water scarcity—water development is approaching or has exceeded sustainable limits

Photo by Mats Lannerstad

Photo 2.2 Economic water scarcity: water exists in nature, but access is difficult

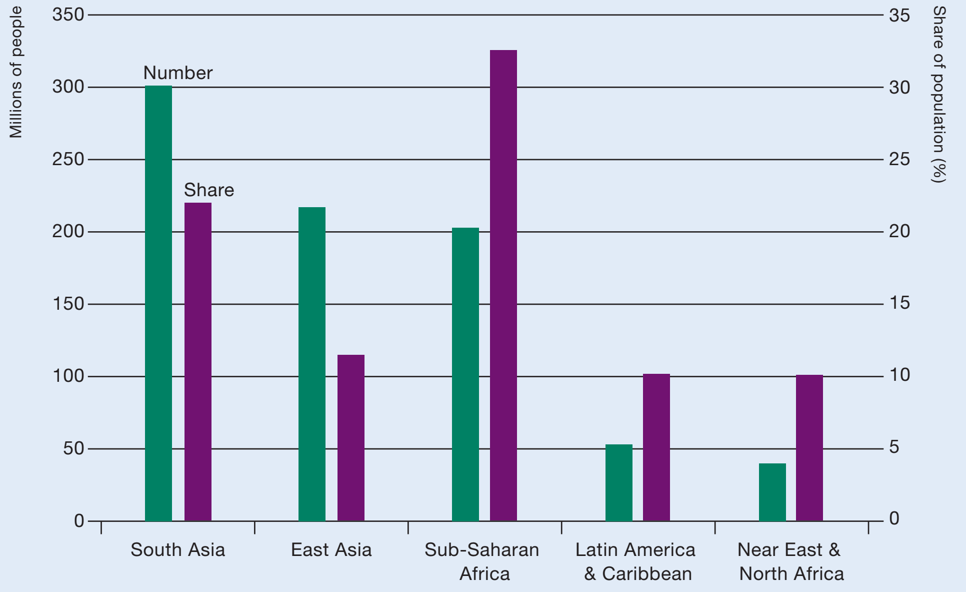
prices have declined, poverty and malnutrition persist in many regions including Asia, Sub-Saharan Africa, and parts of Latin America. It is clear that the benefits of the gains made in agriculture have been unequally distributed.

The poverty statistics are bleak:

- More than 1 billion people lived below the $1 a day poverty line in 2001 (UNDP 2005).
- 1.5 billion people live on between $1 and $2 a day.
- The majority of people living in abject poverty are women and children (UN 2006a).
- 1.1 billion people had no access to clean water in 2004 (WHO and UNICEF 2006).
- 2.6 billion people had no access to improved sanitation in 2004 (WHO and UNICEF 2006).
- 850 million people are undernourished, 815 million of them in developing countries representing 17% of the population of these countries (FAO 2004).

Many poor people either do not produce sufficient food for their own consumption or do not earn enough to buy the food they need. The share of undernourished people in the developing world varies from about 10% in the Near East and North Africa and Latin America and the Caribbean regions to almost 33% in Sub-Saharan Africa (figure 2.1).

By optimistic projections the number of undernourished people in the world is expected to decline to 610 million by 2015 (Bruinsma 2003), still far greater than the 1996 World Food Summit target of 400 million (FAO 1997) and the Millennium Development figure 2.1 **Both the share and number of undernourished people vary greatly by region, 2000–02**



Source: FAO 2006c.

Goals target of halving, between 1990 and 2015, the proportion of people who suffer from hunger (UN 2006a).

The 850 million undernourished people (FAO 2004) depend on water for agriculture in different ways:

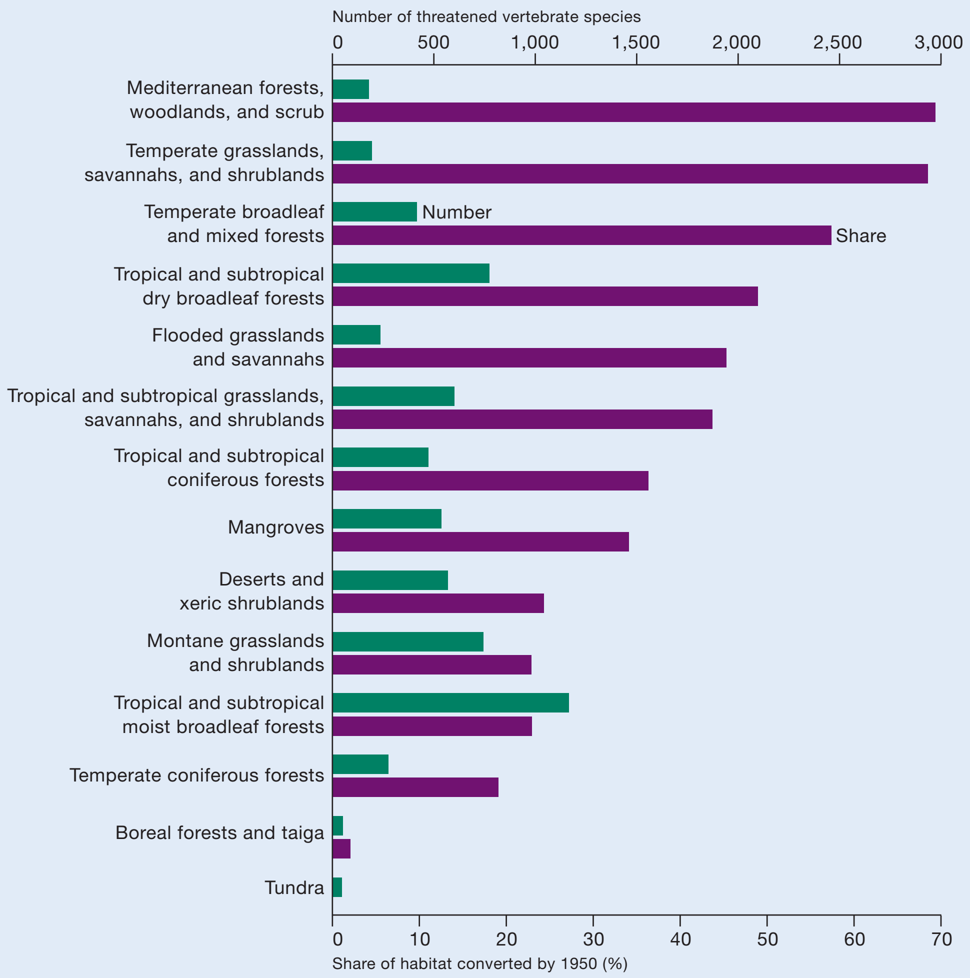
- Smallholder farmers (50%) depend on access to secure water supplies for food production, nutrition, income, and employment.
- The urban poor (20%) have benefited from the lower food prices made possible through productivity gains in agriculture. There is also a growing pattern of urban-rural family linkages, as part of the family, usually men, migrate to cities and support remaining family members back in the villages—often the elderly, women, and children.
- The rural landless (20%) could gain by employment and income brought about by agriculture.
- The remaining undernourished (10%) include pastoralists vulnerable to drought and climate change, fishers vulnerable to water pollution and river water depletion, and forest-dependents vulnerable to clearing of land for agriculture, road construction, and eventually deforestation.

Many more people are vulnerable to changes in water quantity, quality, and timing brought about by increased competition, climate change, floods, and droughts.

Agricultural development as a driver of ecosystem change and biodiversity loss

The Millennium Ecosystem Assessment (MEA 2005a,b) has reported that many ecosystems globally have been transformed as a consequence of human activities. A major driver in this change has been the doubling in world population, from 3 billion in 1959 to 6 billion in 1999. More land was converted to cropland in the 30 years after 1950 than in the 150 years between 1800 and 1950, with some 24% of the earth's land area now occupied by cultivated systems. Between 1960 and 2000 reservoir storage capacity quadrupled, changing the natural flow of rivers. Approximately 35% of mangrove forests have been lost

figure **2.2** **Threatened vertebrate species in 14 global biomes**



Source: MEA 2005b.

(based on countries with adequate data, which encompass about half the mangrove area), due mainly to transformation to agriculture or aquaculture. More than half of the 14 biomes (regional groupings of similar plants, animals, and climates on a global scale) assessed had experienced a 20%–50% conversion to human use, with temperate and Mediterranean forests and temperate grasslands the most affected (figure 2.2)

Key trends and their drivers: how did we get here?

What have been the key changes and ways of thinking, especially about agricultural development and the use of water, that have brought people to think about water as a scarce resource?

During the second half of the 20th century the global food system was able to respond to the doubling of world population by more than doubling food production

Agricultural productivity

During the second half of the 20th century the global food system was able to respond to the doubling of world population by more than doubling food production. Thus, food demand could be met if food supplies were evenly distributed. From 1963 to 2000 food production grew more rapidly in developing countries than in developed countries, with food production growth exceeding population growth, except in Africa (figure 2.3 and table 2.1). However, there was wide variability in food production within and across regions. And kilocalories per person per day, which in 2000 averaged 2,800 globally, ranged from 2,200 in Sub-Saharan Africa and 2,400 in South Asia to 2,850 in Latin America and 2,875 in East Asia, to a high of 3,450 in industrial countries (FAO 2006c).

This growth in crop production was achieved through a combination of expansion in arable land, increase in cropping intensities (multiple cropping or shorter fallow periods), and increases in yield. The increases in arable land were small, with much of the expansion onto marginal lands as urbanization spread onto good quality agricultural lands (Penning de Vries and others 2002). The amount of cropland per person is currently about 0.25 ha, compared with 0.45 ha in 1961. Intensification and yield growth have been the dominant factors in production growth, and irrigated agriculture has played a major role. Nearly all the growth in cereal grain production since 1970 has been from higher yields (see table 2.1). In developing countries growth accelerated in the 1970s with the introduction and spread of the high-yielding varieties of rice and wheat under irrigation—the green revolution.

Yield increases have come at different times in different regions of the world. For example, maize yields started rising before the 1940s in the United States, in the 1960s in China, in the 1970s and again in the 1990s in Latin America, but have not yet taken off in Africa (see figure 6 in summary; FAO 2006b). In some areas yields have reached their upper limits and are showing signs of leveling off.

Green and blue water use in agriculture

Agriculture uses water through evapotranspiration (transpiration by plants and evaporation from soils). A distinction can be made between the withdrawal of water from rivers, reservoirs, lakes, and aquifers (blue water) and the direct use of rainwater stored in the figure **2.3** **Growth in food production outpaced growth in population between 1963 and 2000 in all regions but Africa**

Note: Numbers in parentheses are average annual growth rates for 1963–2000.
Source: FAO 2006b; Hayami 2005.

table **2.1** **Global cereal production, 1970–2005**

Year	Area (millions of hectares)	Yield (metric tons per hectare)	Production (millions of metric tons)
1970	676	1.77	1,192
1980	717	2.16	1,550
1990	708	2.75	1,952
2000	674	3.06	2,060
2005	686	3.27	2,240

Source: FAO 2006b; Falcon and Naylor 2005.

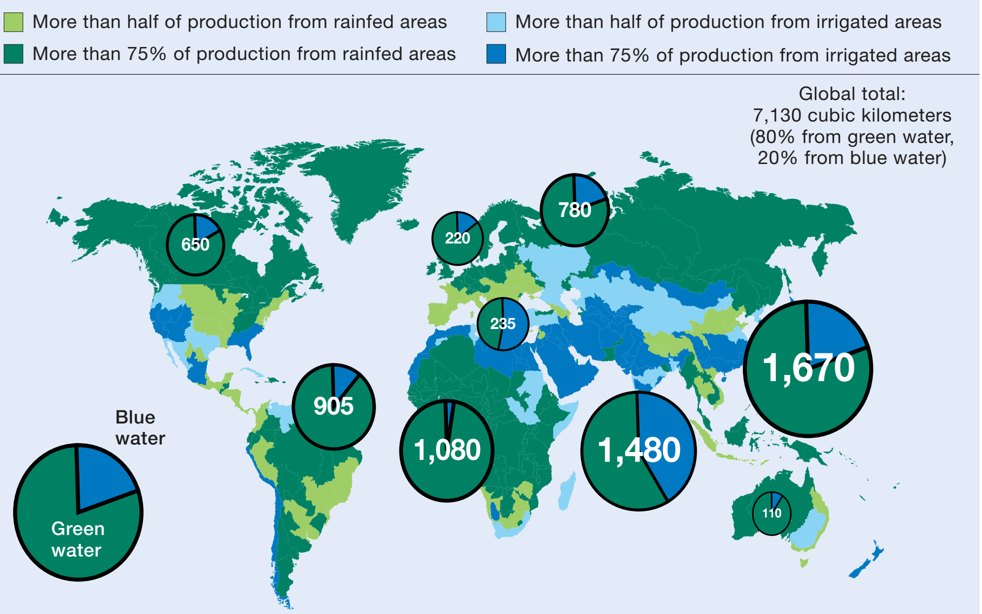
soil (green water). There is a range of options for using blue and green water for crop production. Pure rainfed agriculture uses only green water. Practices to upgrade rainfed agriculture supplement rainwater with blue water. Irrigation uses blue water in addition to green water to maintain adequate soil moisture levels, allowing crops to fulfill their yield potential. Blue water is the measured and managed freshwater resource that is also used to meet domestic, industrial, and hydropower demands and that sustains aquatic ecosystems in rivers and lakes (UN 2006b).

Globally, about 80% of agricultural evapotranspiration is directly from green water, with the rest from blue water sources (map 2.2). There is considerable variation between regions. Irrigation is relatively important in Asia and North Africa, while rainfed agriculture dominates in Sub-Saharan Africa.

The implications of green and blue water use are quite different (see chapter 6 on ecosystems). Increased evapotranspiration from blue water sources reduces stream flow and groundwater levels. Increased evapotranspiration from green water sources is usually due to expansion of agricultural land area, a terrestrial impact, but has less impact on blue water flows. Still, any change in land use can affect river flows. In South Africa recognition of the effects of “streamflow-reducing activities” has led to initiatives to control commercial forestry and to remove invasive tree species in order to reduce evapotranspiration and increase river flow (Hope 2006).

Global blue water withdrawals are estimated at 3,830 cubic kilometers, 2,664 cubic kilometers (70%) of which are for agriculture, including losses (table 2.2; FAO 2006a). The net evapotranspiration from irrigation is 1,570 cubic kilometers, while the remainder of the 7,130 cubic kilometers used is directly from rain. About 1,000 cubic kilometers (25%–30%) of the 3,830 cubic kilometers withdrawn originate from groundwater (see chapter 10 on groundwater), mostly for drinking water and irrigation. Groundwater levels are declining in areas of China, India, Mexico, Egypt, and other parts of North Africa, where dependence on groundwater for agriculture and population demands are high. Demand for water for industrial and municipal uses, including for energy generation, is growing relative to demand for agriculture (figure 2.4). As competition for water from these other sectors intensifies, agriculture can expect to receive a decreasing share of developed freshwater resources.

map **2.2** | **Food crop evapotranspiration from rain and irrigation**



Note: Production refers to gross value of production. The pie charts show total crop water evapotranspiration in cubic kilometers by region.

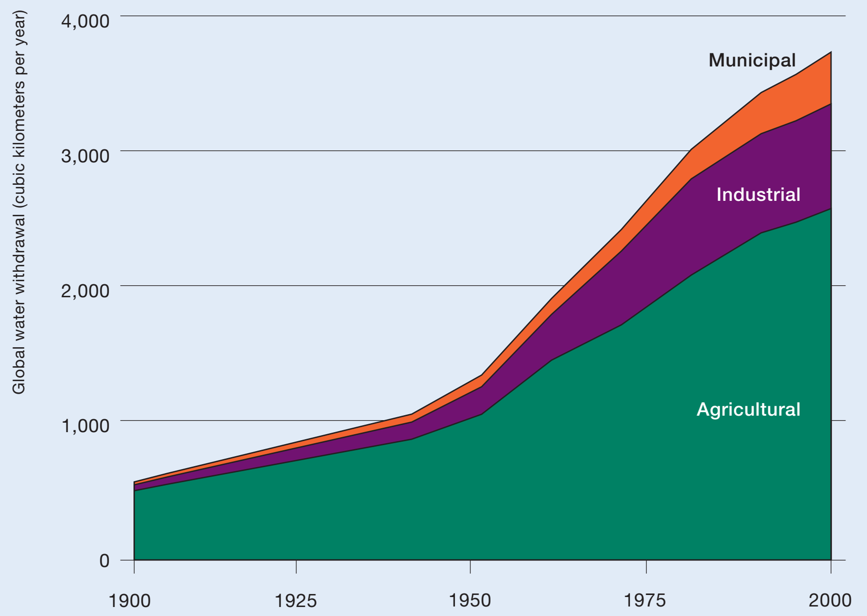
Source: International Water Management Institute analysis done for the Comprehensive Assessment for Water Management in Agriculture using the Watersim model.

table **2.2** | **Freshwater resources and withdrawal, 2000**
(cubic kilometers per year unless otherwise indicated)

Region	Renewable freshwater resources	Total freshwater withdrawal	Freshwater withdrawals: Agriculture Amount	Agriculture Share (%)	Industry Amount	Industry Share (%)	Municipalities Amount	Municipalities Share (%)	Withdrawal as share of renewable resources (%)
Africa	3,936	217	186	86	9	4	22	10	5.5
Asia	11,594	2,378	1,936	81	270	11	172	7	20.5
Latin America	13,477	252	178	71	26	10	47	19	1.9
Caribbean	93	13	9	68	1	9	3	23	14.4
North America	6,253	525	203	39	252	48	70	13	8.4
Oceania	1,703	26	19	72	3	10	5	18	1.5
Europe	6,603	418	132	32	223	53	63	15	6.3
World	43,659	3,830	2,664	70	785	20	381	10	8.8

Source: FAO 2006a.

figure **2.4** **Sectoral competition is increasing for blue water withdrawals for human uses**



Source: Shiklomanov 2000.

Rainfed agriculture

Despite dramatic increases in large-scale irrigation infrastructure over the past half century the bulk of the world's agricultural production still comes from predominantly rainfed lands.[3] Some 55% of the gross value of crop production is grown under rainfed agriculture on 72% of harvested land (table 2.3; see also chapter 3 on scenarios). There are large regional differences in the percentage of rainfed cultivated land, from almost 95% in Sub-Saharan Africa and almost 90% in Latin America, to less than 70% in the Near East and North Africa and less than 60% in South Asia. In Southeast Asia the picture is more mixed.

Rainfed areas support both permanent crops such as rubber, tea, and coffee and annual crops such as wheat, maize, and rice. Some crops such as tubers, which are a staple crop of much of Sub-Saharan Africa, have been largely overlooked by the green revolution. In developing countries severe poverty is found in areas where the unpredictability of rainfall and flooding creates great uncertainty. Many people dependent on rainfed agriculture are highly vulnerable to both short-term (two to three weeks) dry spells and long-term (seasonal) drought and thus are reluctant to invest in agricultural inputs that could increase yields. This situation will become worse for many small farmers with climate change.

In developing countries growth in both productivity improvements and area expansion has been slower in rainfed agriculture than in irrigated agriculture (see below). Most irrigation has been installed on already cultivated rainfed land rather than on new land. In table **2.3** **Global water and land statistics**

Water (cubic kilometers)			Land (millions of hectares)	
Use	**Statistics**		**Use**	**Statistics**
	Total precipitation over continents 110,000			Total terrestrial land 13,000
	Vapor flow back to the atmosphere 70,000	Runoff to the oceans 40,000		
	Evapotranspiration	Withdrawals		
Biomass consumed by grazing livestock	840		Grazing lands	3,430
Rainfed crops	4,910		Rainfed harvested lands	860
Irrigated crops	Irrigation 1,570 Rainfall 650	2,664	Irrigated cultivated lands	Harvested 340[a]
Municipal use	53	381		
Industrial use	88	785		
Reservoirs	208			

a. Of which 277 are equipped.

Source: For water withdrawal statistics and equipped irrigation area, FAO 2006a; for evapotranspiration, International Water Management Institute analysis using the Watersim model; for harvested irrigated crop area, chapter 3 on scenarios; for biomass consumed by grazing livestock, Stockholm Environment Institute calculations for the Comprehensive Assessment of Water Management in Agriculture; for municipal, industrial, and reservoir use, Shiklomanov 2000; for land statistics, FAO 2006b.

temperate regions with relatively reliable rainfall and good soils rainfed agriculture generates high yields, especially when supplemental irrigation practices are applied (see chapter 8 on rainfed agriculture). The potential exists for raising the productivity of many rainfed systems (in particular for maize, sorghum, and millet) in Sub-Saharan Africa, but this potential has been difficult to realize.

Irrigated agriculture

In the past half century there have been massive investments in large-scale public surface irrigation infrastructure as part of efforts to increase world staple food production and ensure food self-sufficiency. Irrigation water was essential to achieve the gains from high-yielding fertilizer-responsive crop varieties. These investments by international development banks, donor agencies, and national governments to develop and expand irrigation systems established the foundation of food security in much of the developing world. During this period more than half the agricultural budget in many countries, particularly in Asia, and more than half of World Bank agricultural lending was devoted to irrigation (Rosegrant and Svendsen 1993). At the same time irrigation demand dominated steadily increasing water withdrawals.

While the world's cultivated land increased by about 13% from 1961 to 2003 (from 1,368 million ha to 1,541 million ha), equipped irrigated area (photo 2.3) almost doubled, from 139 million ha to 277 million ha, an increase from 10% to 18% of cultivated area.

Harvested irrigated area, which includes double cropping, is estimated at 340 million ha (see table 2.3 and chapter 3 on scenarios). New incomplete evidence suggests that the harvested irrigated area might actually be higher because of a higher cropping intensity and unreported, often informal, groundwater or private irrigation (Thenkabail and others 2006). Approximately 70% of the world's irrigated land is in Asia (figure 2.5), where it accounts for 34% of cultivated land. China and India alone account for more than half of irrigated land in Asia. Over time Asia, with its high population densities, has come to rely increasingly on irrigated agriculture to boost agricultural productivity and thus to ensure domestic food security. More than two-thirds of the increase in cereal grain has come from irrigated land.

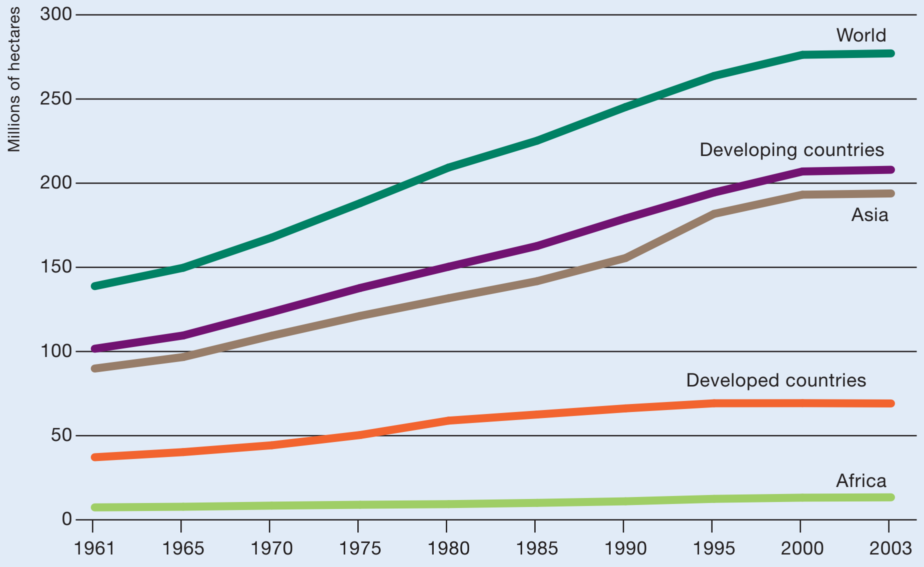
While the world's cultivated land increased by about 13% from 1961 to 2003, equipped irrigated area almost doubled

By contrast, there is very little irrigation in Sub-Saharan Africa. Several large publicly funded irrigation schemes were commissioned in the 1960s and 1970s, mostly as settlement schemes funded through bilateral loans. Water application methods were largely surface irrigation, and little was done to improve water productivity. Decisionmaking was centralized, and profitability was low. Many of the schemes became unsustainable, and some closed. World Bank lending for irrigation and drainage fell sharply after 1985 (Donkor 2003).

During the 1990s most countries in East and Southern Africa emphasized implementation of poverty reduction strategies, which allocated inadequate budgets for agriculture, particularly water management. Meanwhile, as the costs of inputs escalated and inflation grew, the prices of farm produce plummeted. Even though lending for irrigation and drainage partially recovered in the late 1990s, lending for 2002–05 was still less than half the level for 1978–81, very low compared with lending in other regions. Also, investment in agricultural water in Sub-Saharan Africa has been only a small proportion of the total for the water sector—just 14% of African Development Bank lending to the water sector as a whole during 1968–2001, for example (Peacock, Ward, and Gambarelli forthcoming).

Photo by TWilliam Critchley

Photo 2.3 Large sprinkler system used in irrigated agriculture figure **2.5** | **The area equipped for irrigation is growing faster in developing countries than in developed countries, except in Africa**



Source: FAO 2006b.

Globally, donor spending on irrigation reached a peak of more than $1 billion a year (in 1980 US dollars) in the late 1970s and early 1980s and then fell to less than half that level by the late 1980s (Rosegrant and Svendsen 1993). Four factors contributed to the decline in public investments in irrigation in the 1980s. First, there was a sharp drop in cereal prices in the 1980s. Second, there was growing recognition of the poor performance of irrigation systems.[4] Third, there was a rise in construction costs of irrigation infrastructure, although it is now decreasing (Inocencio and others forthcoming). Falling grain prices and rising construction costs reduced benefit-cost ratios, discouraging further investments. Fourth, there was growing opposition to large dams and to the environmental degradation and social dislocation they sometimes caused. Reflecting these environmental concerns, the World Commission on Dams, created in 1997, reviewed the experience with large dams and established a framework for decisionmaking regarding new large-scale dam projects (WCD 2000).

Recently, there has been renewed interest in investment in agricultural water management. The World Bank's new *Water Resources Sector Strategy*, for example, calls for a principled but pragmatic approach to balanced investment in both infrastructure and institutions and spells out a strategy for re-engaging in agricultural water management (World Bank 2004, 2006).

Two major investment trends exist today. One is the emergence of mega-projects such as the south-north diversion project in China and the interlinking rivers project in India, which intend to transfer water from water-abundant to water-scarce areas. The other is extensive individual and small-scale investments in irrigation and groundwater (photos 2.4 and 2.5).

Private and community-based irrigation systems in developing countries, particularly groundwater pumping (figure 2.6), have grown rapidly since the 1980s, propelled by the availability of cheap drilling technology, rural electrification, subsidized energy, and inexpensive small pumps that farmers can afford to purchase themselves. Pumping enabled small-scale irrigation to develop within rainfed systems and to supplement other sources of irrigation water. In India, with 26 million pump owners, irrigation from groundwater now exceeds irrigation from surface water systems. One consequence has been accelerating rates of groundwater decline.

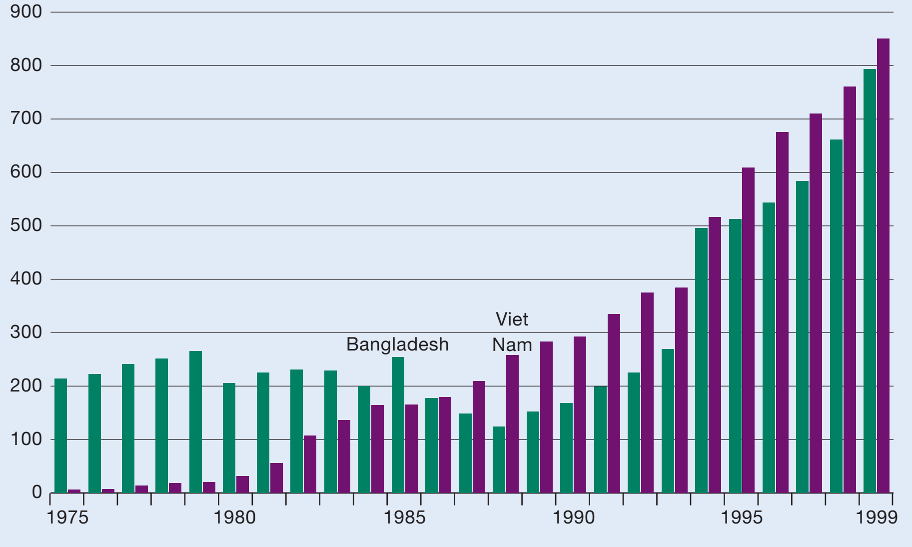

Photo by Mats Lannerstad

Photo 2.4 One major investment trend is the emergence of mega-projects


Photo by Tushaar Shah

Photo 2.5 Another is extensive individual investment in irrigation and groundwater

figure **2.6** **The number of irrigation pumps in Bangladesh and Viet Nam has risen rapidly since the 1980s**



Source: Bangladesh Ministry of Agriculture 2000; Viet Nam General Statistics Office 2001.

A fairly polarized debate has arisen in some circles over the relative benefits of large- and small-scale infrastructure. In reality, the appropriate scale of infrastructure should be determined in the context of the specific environmental, social, and economic conditions and goals, with the participation of relevant stakeholders.

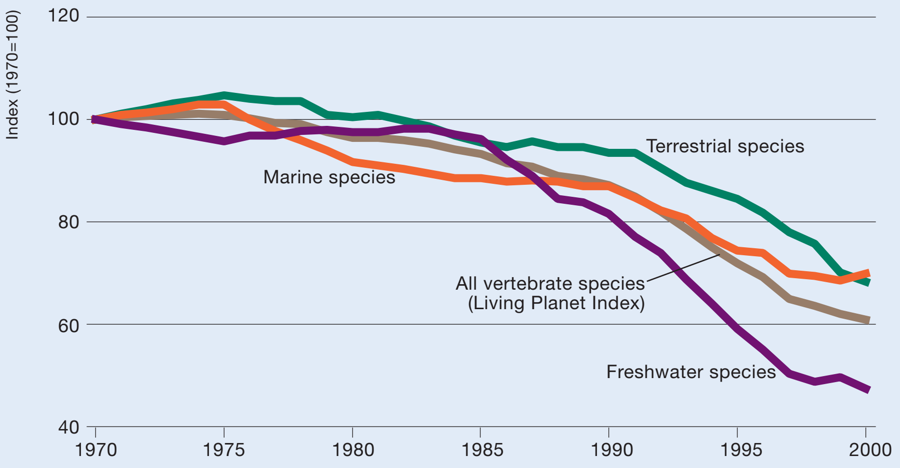
Drivers of biodiversity loss and ecosystem change

Biological diversity is in rapid decline in all the world's major biomes. While rates of loss differ between regions and biomes, loss of biodiversity is greatest among freshwater-dependent species—almost twice as fast as for marine and terrestrial species (figure 2.7). This has happened because biodiversity associated with inland waters is concentrated within limited areas, because many inland water-dependent species are especially vulnerable to changes in environmental conditions, and because freshwater is subject to rapidly escalating threats from land-based impacts as demands placed on water to meet growing populations and development pressures rises (MEA 2005a).

Many factors contribute to biodiversity change. The most important direct drivers of biodiversity loss are habitat change (land use change, physical modification of rivers, water withdrawal from rivers, damage to sea floors from trawling), climate change, invasive alien species, species overexploitation, and pollution. For most ecosystems the impacts are constant or growing.

- *Habitat transformation and fragmentation.* This includes the impact of land cover change, such as the conversion to agriculture and the release of nutrients into rivers, and of water withdrawals for irrigation.

figure **2.7** **The Living Planet Index shows that biodiversity is declining most rapidly in freshwater-dependant species**



Note: The index incorporates data on the abundance of 555 terrestrial species, 323 freshwater species, and 267 marine species around the world. While the index fell by some 40% between 1970 and 2000, the terrestrial index fell by about 30%, the freshwater index by about 50%, and the marine index by about 30%.

Source: MEA 2005b.

- *Modifications to water regimes.* Many rivers have been fragmented through the construction of dams and barrages. River-regulating structures have changed flow regimes (the quantity and timing of flow in rivers).
- *Spread of invasive alien species.* Increased trade and travel have contributed to the spread of invasive alien species (and disease organisms). The introduction of non-native invasive species is now a major cause of species decline in freshwater systems. While measures are increasingly being taken to control some of the pathways through which invasive species make inroads, many pathways remain inadequately regulated.
- *Nutrient loading.* Since 1950 anthropogenic increases in nitrogen, phosphorus, sulfur, and other nutrient-associated pollutants have emerged as one of the most important drivers of change in terrestrial, freshwater, and coastal ecosystems. Humans now produce more reactive (biologically available) nitrogen than all natural pathways combined.

The majority of biomes have been greatly modified, with 20%–50% of 14 global biomes transformed to croplands. For terrestrial ecosystems the most important direct driver of change in the past 50 years has been changes in land cover. Further land use changes causing habitat loss are associated primarily with the additional expansion of agriculture and secondarily with the expansion of cities and infrastructure.

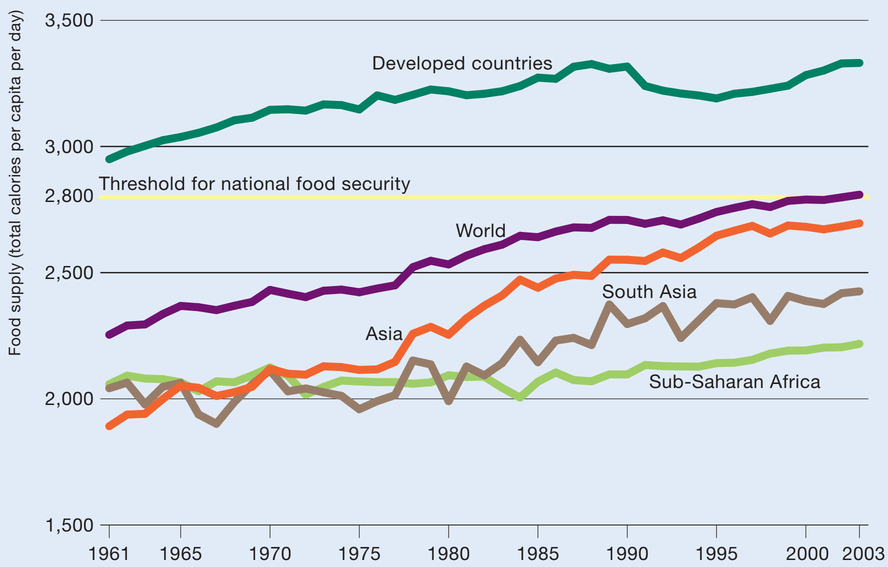
For freshwater ecosystems the most important direct drivers of change in the past 50 years include direct physical changes to freshwater habitat, such as draining wetlands and building dams, and deliberate modification of water regimes through, for example, water extraction and pollution. All these factors are also influenced indirectly through the impacts of land use; for example, excessive erosion leads to sedimentation in rivers, estuaries, and lakes. Invasive species are also an important driver. Many of these drivers arise due to agriculture-related activities (including livestock, fisheries, and aquaculture).

People and diets

The two major factors contributing to increased food demand, and thus to increased water use for food production, are population growth and changes in diets as living standards improve. Global population is projected to grow from 6.1 billion in 2000 to 7.2 billion in 2015, 8.1 billion in 2030, and 8.9 billion in 2050 (UN 2003b), before leveling off (except in Sub-Saharan Africa). Rising incomes lead not only to increasing consumption of staple cereals, but also to a shift in consumption patterns among cereal crops and away from cereals toward livestock products, fish, and high-value crops.

The key variable used for measuring and evaluating the evolution of the world food situation is kilocalories per person per day (FAO 2006c). The world food supply increased from about 2,400 kcal per person per day in 1970 to 2,800 kcal per person per day in 2000.[5] However, large differences exist. In developed countries food supply increased from 3,050 kcal to 3,450 kcal per person per day over that period, while in Sub-Saharan Africa it increased from 2,100 kcal to about 2,200 kcal (figure 2.8).

The growth in per capita food consumption has been accompanied by significant changes in commodity composition. Cereals continue to be the most important source of figure **2.8** | **There has been a steady increase in global nutritional status since the 1960s, but developing countries still lag behind**



Source: FAO 2006b.

total food consumption in the world, but there are large regional differences in the commodity composition of the diet (figure 2.9). In Sub-Saharan Africa roots and tubers are by far the most important component and are expected to remain so for some time. In all regions except Sub-Saharan Africa there has been a significant increase in the consumption of vegetable oils over the last three decades. Meat consumption increased in all regions except Sub-Saharan Africa. The industrial countries are by far the largest meat consumers, at 103 kilograms per person per year, a trend that is projected to continue for the next 50 years. The same pattern applies to dairy products.

A growing, wealthier population requires more food per person, and richer and more varied diets. The amount of water needed to produce food depends on diets and how the food is produced (see chapter 7 on water productivity). It is estimated that in 2000 crop production to feed 6.1 billion people used about 7,130 cubic kilometers of water through evapotranspiration (see chapter 3 on scenarios), excluding evaporation from grazing lands. About 1,570 cubic kilometers of the evapotranspiration was met using blue water from the 2,664 cubic kilometers withdrawn from rivers, lakes, and aquifers (see table 2.2). Crop evapotranspiration thus roughly corresponds to about 3,000 liters of water to feed one person per day, or 1 liter of water to produce 1 calorie. But this varies by water productivity and diet. A diet without meat requires an estimated 2,000 liters of water per day to produce, while a diet high in grainfed beef requires about 5,000 liters of water (Renault and Wallender 2000; see chapter 7 on water productivity).

figure 2.9 | Major diet components vary by region—and over time

a. Includes Australia, Austria, Belgium, Canada, Denmark, Finland, France, Germany, Greece, Iceland, Ireland, Israel, Italy, Japan, Luxembourg, Malta, the Netherlands, New Zealand, Norway, Portugal, South Africa, Spain, Sweden, Switzerland, the United Kingdom, and the United States.

Source: FAO 2006c.

It is clear then that as more people add more animal products to their diets, more water will be required for agriculture. But that is not necessarily bad for water. Pasture-fed and free-roaming livestock do not use additional blue water, and in many places animals graze on land where no other form of agriculture can take place. Moreover, for many malnourished people livestock products are important for a balanced diet, while livestock rearing and fisheries are extremely important livelihood activities for many poor people.

> The amount of water needed to produce food depends on diets and how the food is produced. Crop evapotranspiration roughly corresponds to about 3,000 liters of water to feed one person per day, or 1 liter to produce 1 calorie

Consumption and production of animal products are growing at about 2.5%–4% a year in developing countries, but at less than 0.5% a year in developed countries (see chapter 13 on livestock). But annual per capita meat consumption in developing countries is still lower than it was in developed countries 30 years ago and will remain so for the next 30 years. Most of the increased production will be met through mixed and industrial livestock systems, which depend on feed rather than grazing. More crops—and thus more water—will be needed for feed.

Freshwater fish consumption has been growing at a rate of 3.3% a year between 1970 and 2000 and 4.5% a year between 1990 and 2000. Fish, including shellfish and crustaceans, provide about 16% of animal protein consumed worldwide and are a valuable source of minerals and fatty acids. While fish harvests from marine capture have barely increased since the 1990s, annual freshwater fish production (from capture fisheries and aquaculture) doubled between 1990 and 2000.

Because both oceanic and freshwater capture fisheries have reached their limits of sustainability in many locations, the rising demand for fish will have to come from aquaculture. Aquaculture has been growing at a rate of 8% a year since 1980 and has increased its share in world fish supplies to 43% (FAO 2006d). Aquaculture in the coastal zone has been the method for meeting the increasing demand on fisheries and is also the fastest growing food sector in the world, with an output of 37.9 million metric tons in 2001 (Kura and others 2004). Aquaculture, like industrial livestock systems, requires freshwater to produce feed, and inland aquaculture has additional water requirements, adding to the competition for water resources.

Urbanization and migration

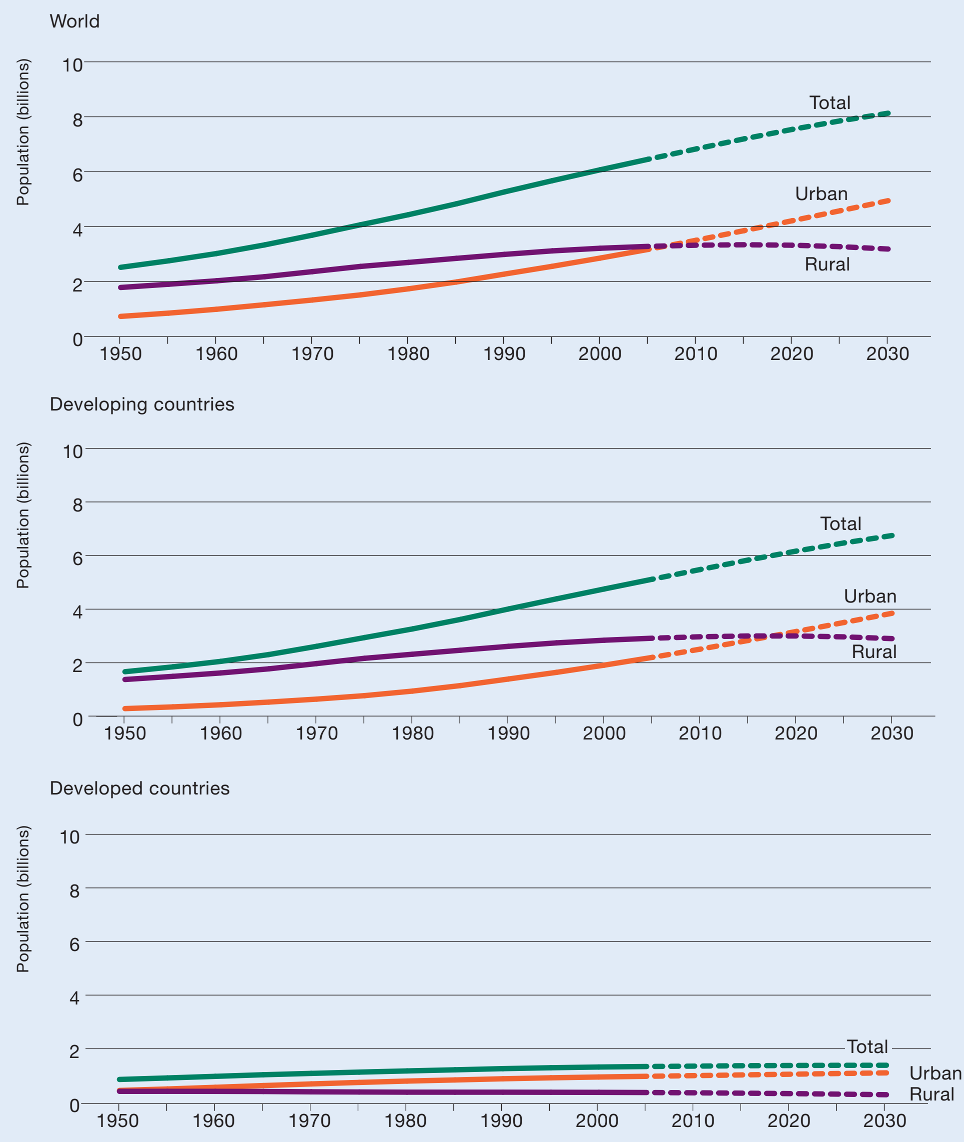
In the 1960s two-thirds of the world's population lived in rural areas (figure 2.10), and 60% of the economically active population worked in agriculture. Today, half of the people live in rural areas, and just a little more than 40% of the economically active population depend directly on agriculture. In absolute terms the rural population will start to decline in the next few years. By 2030 more than 60% of the world's people will live in cities. But, again, global averages mask considerable regional variation. In many poor countries in South Asia and Sub-Saharan Africa the rural population will continue to grow until about 2030, and the number of people depending on agriculture will continue to rise.

Rapid rural to urban migration in developing countries influences farming practices and water demand. Also, it is often the men who migrate to cities, leaving women, older people, and children behind in rural areas. As a consequence, in developing countries women's share in the economically active population in agriculture is growing, rising from

39% in 1961 to 44% in 2004, while in developed countries it is falling, dropping from 44% to 35% (FAO 2006b).

Cities are rapidly increasing their claim on water at the expense of rural uses such as farming. Furthermore, urban centers represent a source of pollution that has impacts on

figure **2.10** **The world's population is shifting to the cities**



Source: FAO 2006b.

downstream irrigation and aquatic ecosystems. City wastewater, often untreated, is an increasing source of irrigation water, especially in noncoastal cities. Wastewater use has its own unique set of health and environment considerations (see chapter 11 on marginal-quality water).

Agricultural transformations

Economic development typically begins with the development of agriculture. In the early stages of development agriculture provides labor and capital (often in the form of export earnings) to the industrial sector and in turn provides a market for industrial products. As the economy develops agriculture grows but not as fast as the nonagricultural sector. Agriculture's share of GDP declines. With rising incomes and urbanization, food habits change toward richer and more varied diets.

> The next step in agricultural transformation is access to value-added supply chains in the modern retail sector in the form of higher quality, timeliness, food safety, and labor standards in production

This agricultural transformation will take different forms in different countries or regions. To adapt to changes in consumer demand some farmers will shift from staples to higher value horticultural crops, livestock, and fisheries. Others will specialize in export crops. Farmers who continue to grow staple food crops will need to boost their productivity. Low-cost food grains will be important to poor people both because grains constitute a large share of their budgets and because the low wages made possible by cheap food make labor-intensive activities more profitable (Timmer 2005).

The next step in agricultural transformation is access to value-added supply chains in the modern retail sector, where the added value comes in the form of higher quality, timeliness, food safety, and labor standards in production (Timmer 2005). It is difficult to judge how fast this transition is occurring, but in many parts of the developing world groups of professional farmers are emerging whose incomes come almost entirely from farming. They are more innovative than conventional farmers, have larger farms, and have better access to resources such as credit and new marketing structures. Supermarkets play an increasingly important role as intermediaries in these value-added supply chains, ensuring quality, environmental standards, and market access.

A much larger number of farm households in developing countries are involved in transformation of a different sort, increasingly augmenting their incomes through nonfarm activities. Labor has become more mobile. The distinction between rural and urban is becoming blurred, as households move between both rural and urban worlds and earn a living in both agricultural and nonagricultural activities (Rigg 2005).

Management of water resources for agriculture will be shaped by this ongoing transition. For example, families with incomes essentially from nonfarm activities or those who invest in pumps to obtain water on demand will have less interest in assuming responsibilities for operation and maintenance of irrigation systems.

The way this transformation unfolds has implications for water investments to reduce poverty. In the early stages of the transformation investments in water to increase productivity can be quite effective in reducing poverty, especially through a multiplier effect. But as economies grow, this impact diminishes. Furthermore, other opportunities open up for the rural poor, including job opportunities in the cities. Later in the transformation livelihood diversification becomes an important strategy. It is hard to gain much wealth from agriculture alone unless farm sizes are large enough. Ultimately, this could lead to an exit from agriculture, another escape from rural poverty. But throughout the transformation there will be pockets of rural poverty, where more targeted investments in water for food can make a difference in the nutrition, income, and health of the rural poor.

Benefits and costs, winners and losers

From a global perspective the economic benefits from investments in water for agriculture over the last 50 years have far exceeded the costs, but the gains could have been much more equitably distributed. Furthermore, the social and environmental costs have sometimes been severe, were often neglected in cost-benefit analyses, and could have been reduced with appropriate attention.

From a global perspective the economic benefits from investments in water for agriculture over the last 50 years have far exceeded the costs, but the gains could have been much more equitably distributed

Gains in food security, economic growth, poverty reduction, and environmental sustainability

The major objectives of large-scale irrigation investments have been economic growth, food security, and poverty alleviation. Due largely to the expansion of irrigation and the adoption of green revolution technologies, global food grain prices have fallen dramatically. The growth dividend made possible by productivity gains has been shared between producers through higher incomes and consumers through lower prices. But consumers benefited much more than producers, particularly the poor who receive half or more of their calories from cereal grains.

Research shows that investments in water for agriculture have made a positive contribution to rural livelihoods, food security, and poverty reduction (Lipton, Litchfield, and Faurès 2003; Hasnip and others 2001; Hussain 2005). The positive impact is felt through employment gains, affordable food prices, and more stable outputs. Through a multiplier effect the investment in irrigation leads to a rise in crop yields and farm incomes that results in higher demand for goods and services in the nonfarm sector that multiplies the benefits of the original investment. A handful of studies on the multiplier effects of investment in irrigation indicate a range of 2.5 to 4 (Bhattarai, Barker, and Narayanamoorthy forthcoming). Mellor (2002) notes that the additions to employment in the local nonfarm sector can be as high as twice that for the farm sector, with a major impact on poverty reduction.

Water management practices have also contributed to environmental sustainability. Development of intensive irrigation has reduced the amount of land required for agriculture. Wetlands and agriculture have coexisted for 10,000 years, shaping many adaptations of biodiversity (Bambaradeniya and Amerasinghe 2004). Galraith, Amerasinghe, and Huber-Lee 2005 find that in recent years irrigation and water storage have created new habitats for water birds in Asia, leading to an increase in their population.

Social and environmental costs

Poorly conceived and implemented water management interventions have incurred high social and environmental costs. Social costs have included inequity in the allocation of benefits and loss of livelihood opportunities. Differential access to benefits has been common, especially between more and less powerful members of society: landed and landless, rich and poor, men and women, large and small landholders. Some projects have benefited upstream users at the expense of downstream users, who lose access to some or all good-quality water. Common-property resources such as rivers and wetlands, important for poor fishers and resource gathers, have been appropriated for other uses, resulting in a loss of livelihood opportunities (Gowing, Tuong, and Hoanh 2006). Communities have been displaced, especially in areas behind dams, without adequate compensation (WCD 2000).

A large proportion of irrigation's negative environmental effects arise from the diversion of water from natural aquatic ecosystems, such as rivers, lakes, oases, and other groundwater-dependent wetlands. Direct and indirect negative impacts have been well documented (for example, Richter and others 1997; Revenga and others 2000; WCD 2000; Bunn and Arthington 2002; MEA 2005a,b; see chapter 6 on ecosystems for details), including salinization, channel erosion, declines in biodiversity, introduction of invasive alien species, reduction of water quality, genetic isolation through habitat fragmentation, and reduced production of floodplain and other inland and coastal fisheries.

> A large proportion of irrigation's negative environmental effects arise from the diversion of water from natural aquatic ecosystems

Poor irrigation practices result in the buildup of salinity in the soil, though there is uncertainty about how much. Available but highly unreliable data suggest that some 20–30 million ha of irrigated land in the arid and semiarid zones are seriously affected by salinity—about 10% of all irrigated land and 20% of irrigated land in these susceptible regions. Current estimates are that about 0.25–0.5 million ha are lost from production every year as a result of salt buildup (FAO 2002), much less than the often quoted figure of 1–2 million ha. There has been a great slowdown in the growth in salinization as the development of new large-scale irrigation has slowed. Often, in new irrigation projects water tables rise rapidly, causing waterlogging and salinization, but eventually they drain or reach equilibrium. Much of the newer irrigation development comes from groundwater, which tends to drain lands.

Changing responses over time to the water-food-environment challenge

Meeting the water-food-environment challenge requires reducing poverty by producing food in an environmentally sustainable manner and by managing any negative consequences when tradeoffs must be made. Individuals, communities, governments, and the international community have all been responding to water problems, but in different ways over time.

Local responses by farmers and communities

Farmers, fishers, and pastoralists and their communities, often supported by community-based organizations, have responded to water scarcity with or without government support (Noble and others 2006). The failure of large-scale public irrigation systems to provide water where and when farmers needed it spurred many to invest in individual pumps and other private irrigation systems. This informal irrigation sector blossomed in many areas. Examples include water harvesting using age-old systems (such as the revival of *johads* in Rajastan, India; Shah and Raju 2002) or adapting systems to the local situation. Peri-urban irrigators use wastewater as a key source (Drechsel and others 2006; see also chapter 11 on marginal-quality water). Where opportunities permit, farmers are benefiting from more flexible and reliable supplies or from small storage coupled with micro, or localized, irrigation to shift from cereal grains to higher value crops.

However, local responses do not always meet the broader water-food-environment challenge because the primary focus is generally to enhance local food production and livelihoods. Farmers and communities, for example, do not bear all of the costs of their actions with regard to the environment or downstream impacts. Particularly in semiarid areas, unregulated exploitation of groundwater can lead to falling water tables (see chapter 10 on groundwater). Upstream development of water sources can decrease water availability downstream. Furthermore, the development of private facilities may further disadvantage poor farmers, who cannot afford the investment costs, and undermine farmer irrigation associations. Many have argued that uniting these local actions into larger programs or establishing regulatory policies could reduce the negative impacts.

The focus on water infrastructure sometimes led to institutions and practices well suited for construction, but less well suited for the adaptive management needed to operate long-lived, multipurpose water infrastructure

National government responses

Responses at the national level generally express a broader view, but they still reflect specific perspectives and priorities. Governance in the water sector has often been the root cause of success or failure at the national level. Often, institutional development failed to keep pace with rapid infrastructure development, undermining the efficiency of investments and failing to adapt to changing economic, environmental, and social conditions. Many of today's water bureaucracies were set up to construct major water infrastructure facilities. This heavy focus on infrastructure sometimes led to institutions and practices that were well suited for construction, but less well suited for the adaptive management needed to operate long-lived, multipurpose water infrastructure (see chapters 9 on irrigation and 5 on policies and institutions).

In the 1990s investment in water infrastructure fell sharply as the focus shifted to water management. Efforts emphasized demand management, rationalized water allocation, institutions and capacity building, and market tools for promoting more efficient use and operations of existing water supplies.

A global consensus (discussed below) was emerging during this period on good practice in integrated water resources management, environmental water needs, and ecosystems approaches. It was increasingly being recognized that agricultural water management needs to be more integrated, looking at the full range of water resources, water uses, and management and supply development options. Important changes were gradually being made, such as the South African Water Law, which included the first designation of environmental allocations for water.

But despite repeated calls for integration, government responses remain mostly sectoral. Management of water allocation across sectors remains fragmented and highly politicized in most countries. Even within agriculture, irrigation receives the most attention while rainfed agriculture, fisheries, and livestock are rarely considered in discussions of water resources.

Global and regional responses

There is no global convention on water, unlike for desertification, wetlands, and biodiversity. Some argue that water is essentially a local issue, and thus there is no need for global action. But global issues affect global water use, and thus global actions are necessary to resolve them.

Consider recent events in Asian cereal grain production and trade. Food grain production in the Punjab region of India and Pakistan and the North China Plain, two of the breadbaskets of Asia, increased dramatically in the 1970s and 1980s. Today, however, the exploitation of water resources exceeds sustainable levels because more groundwater is being pumped for irrigation than is being recharged. A recent report notes that the threat to irrigation in the temperate regions of northern China could cause China to import a large share of its wheat needs, which would have a substantial impact on global production and trade (Lohmar and others 2003). In an effort to avert this outcome and to boost rural incomes, China instead introduced national cereal grain subsidies in 2004. This may result in extending the wheat-growing area further south in China into more humid climates, as occurred in eastern India and Bangladesh.

National management of water allocation across sectors remains fragmented and highly politicized in most countries

The United Nations Conference on Environmental Development in Rio de Janeiro (Earth Summit) in 1992 was a milestone in the global call to action for better water management. A consensus emerged on global good practice in water management based on the Dublin Principles (ICWE 1992): freshwater is a finite and vulnerable resource, essential to sustain life, development, and the environment; water development and management should be based on a participatory approach, involving users, planners, and policymakers at all levels; women play a central part in the provision, management, and safeguarding of water; and water has an economic value in all its competing uses, and should be recognized as an economic good. There was also recognition of the urgency of the challenge, which many considered an impending water crisis, a crisis of water management as much as of water scarcity.

The Second World Water Forum in 2000 was instrumental in mobilizing thinking around key global issues of the water crisis: water supply, agriculture, environment, and livelihoods (HRH Prince of Orange and Rijsberman 2000). A divide in thinking was clearly illustrated by reports on water for food and rural development (van Hofwegen and Svendsen 2000) and reports on water and nature (IUCN 2000). Numerous programs, meetings, organizations, and activities were mobilized to address the issues that make up the global water crisis—the Global Water Partnership, UN–Water,[6] the World Water Council, World Water Week in Stockholm, the Consultative Group on International Agricultural Research Challenge Program on Water and Food, and this Comprehensive Assessment of Water Management in Agriculture.

With water again at the forefront of global issues, discussions are occurring in a more balanced context, with more consideration of the social and environmental tradeoffs that water management and development decisions entail (SIWI and IWMI 2004; World Bank 2004).

New paradigms call for considering agricultural water management within a basin context and for including rainfed agriculture, fisheries, and livestock in water discussions. There is more attention to integration across sectors and to the appropriate roles of public and private sectors. Good practice in agriculture is also increasingly more sensitive to the role of ecosystems, recognizing, for example, the importance of watershed protection, environmental flows, and sustainable management of aquatic ecosystems, springs, and aquifers.

At the same time there has been an increasing awareness within the environmental community of the importance of water, food, and livelihoods issues. This awareness builds on the Ramsar Convention on Wetlands' emphasis on the wise use of wetlands, which has long recognized that wetlands are being used for agriculture, but that this should be done in a sustainable manner. This dialogue about a balanced ecoagriculture to meet the needs of both societies and ecosystems can evolve still further, with wider all round benefits.

Reviewers

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Notes

1. Harvested area includes cropping intensity. Thus if two crops per year are grown on the same 100 hectares, the harvested area is 200 hectares.

2. Area equipped for irrigation refers to areas where irrigation infrastructure has been developed. Area actually irrigated may differ from area equipped for irrigation, and equipped area does not include cropping intensity.

3. The distinction between rainfed and irrigated agriculture is blurred, with rainfed areas receiving supplemental irrigation.

4. Improving irrigation management to overcome problems of poor irrigation performance was the motivation behind the establishment of the International Irrigation Management Institute, which later expanded its mandate and became the International Water Management Institute.

5. A dietary energy supply value of 2,800 kcal per person per day is usually taken as a threshold for national food security, considering dietary energy requirements (typically between 1,900 kcal and 2,500 kcal per person per day), inefficiencies in the food distribution chain, and inequalities in access to food through a national distribution function of dietary energy consumption.

6. UN–Water is the interagency mechanism established to follow up on the water-related decisions of the World Summit on Sustainable Development and the Millennium Development Goals concerning water.

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