INTERNATIONAL FOOD POLICY RESEARCH INSTITUTE
sustainable options for ending hunger and poverty
IFPRI

2020 VISION

IWMI
International Water Management Institute

FOOD POLICY
REPORT

GLOBAL WATER OUTLOOK TO 2025

Averting an Impending Crisis

Mark W. Rosegrant, Ximing Cai, and Sarah A. Cline

THE INTERNATIONAL FOOD POLICY RESEARCH INSTITUTE (IFPRI)

IFPRI was established in 1975 to identify and analyze national and international strategies and policies for meeting the food needs of the developing world on a sustainable basis, with particular emphasis on low-income countries and poor people; to make the results of its research available to all those in a position to use them; and to help strengthen institutions conducting research and applying research results in developing countries.

While IFPRI's research is geared to the precise objective of contributing to the reduction of hunger and malnutrition, the factors involved are many and wide-ranging, requiring analysis of underlying processes and extending beyond a narrowly defined food sector. The Institute's research programs reflect worldwide collaboration with governments and private and public institutions interested in increasing food production and improving the equity of its distribution.

A 2020 VISION FOR FOOD, AGRICULTURE, AND THE ENVIRONMENT is an initiative of IFPRI launched in 1993 in collaboration with partners around the world. The 2020 Vision Initiative seeks to develop and promote a shared vision for how to meet the world's food needs while reducing poverty and protecting the environment and seeks to generate information and encourage debate to influence action by all relevant parties.

The 2020 Vision Initiative gratefully acknowledges support for its general activities from the following donors: Canadian International Development Agency (CIDA), Danish International Development Agency (DANIDA), Swedish International Development Cooperation Agency (SIDA), and Swiss Agency for Development Cooperation (SDC).

THE INTERNATIONAL WATER MANAGEMENT INSTITUTE (IWMI)

IWMI's mission is: improving water and land resources management for food, livelihoods, and nature. IWMI works to: (1) identify the larger issues related to water management and food security that need to be understood and addressed by governments and policymakers; (2) develop, test, and promote management practices and tools that can be used by governments and institutions to manage water and land resources more effectively and address water scarcity issues; (3) clarify the link between poverty and access to water and help governments and the research community better understand the specific water-related problems of poor people; and (4) help developing countries build their research capacities to deal with water scarcity and related food security issues.

IWMI's agenda is to put research into action through five research themes: Integrated Water Resources Management for Agriculture, Sustainable Smallholder Land and Water Management, Sustainable Groundwater Management, Water Resource Institutions and Policies, and Water, Health, and Environment.

The Institute leads three international programs that bring together the expertise of a number of Future Harvest Centers and other partners, including national research systems and NGOs: the Comprehensive Assessment of Water Management in Agriculture; the SIMA Malaria and Agriculture initiative; and the CGIAR Challenge Program on Water and Food.

FUTURE HARVEST

IFPRI and IWMI are two of 16 food and environmental research organizations known as the Future Harvest Centers. The centers, located around the world, conduct research in partnership with farmers, scientists, and policymakers to help alleviate poverty and increase food security while protecting the natural resource base. The Future Harvest Centers are principally funded by governments, private foundations, and regional and international organizations, most of which are members of the Consultative Group on International Agricultural Research (CGIAR).

Global Water Outlook to 2025

Averting an Impending Crisis

Mark W. Rosegrant
Ximing Cai
Sarah A. Cline

A 2020 Vision for Food, Agriculture, and the Environment Initiative
International Food Policy Research Institute
Washington, D.C., U.S.A.

International Water Management Institute
Colombo, Sri Lanka

September 2002

ISBN 0-89629-646-6

Contents

Preface

For some time, experts have argued about the Earth's capacity to support ever larger human populations. Can the Earth produce enough food to feed 8 billion people? 10 billion? It now appears that one of the main factors limiting future food production will be water. This scarce resource is facing heavy and unsustainable demand from users of all kinds, and farmers increasingly have to compete for water with urban residents and industries. Environmental uses of water, which may be key to ensuring the sustainability of the Earth's water supply in the long run, often get short shrift.

Based on a global model of supply and demand for food and water, this report shows that if current water policies continue, farmers will indeed find it difficult to meet the world's food needs. Hardest hit will be the world's poorest people. The results from the model used in this report also show the consequences of changing the course of water policy. Further inattention to water-related investments and policies will produce a severe water crisis, which will lead in turn to a food crisis. A commitment to sustainable use of water, through appropriate policies and investments, however, will lead to a more water- and food-secure world. Water may be a scarce resource, but humans have developed many ways of using it more efficiently—that is, getting more from each unit of water. But water-saving policies, practices, and technologies are of no help if they are not used. Inappropriate incentives and institutions often hinder effective use of water. This report spells out the future results of our current choices.

Many more details about the scenarios described in this report are available in a book called *World Water and Food to 2025: Dealing with Scarcity,* by Mark W. Rosegrant, Ximing Cai, and Sarah A. Cline, also available from IFPRI.

Introduction

Demand for the world's increasingly scarce water supply is rising rapidly, challenging its availability for food production and putting global food security at risk. Agriculture, upon which a burgeoning population depends for food, is competing with industrial, household, and environmental uses for this scarce water supply. Even as demand for water by all users grows, groundwater is being depleted, other water ecosystems are becoming polluted and degraded, and developing new sources of water is getting more costly.

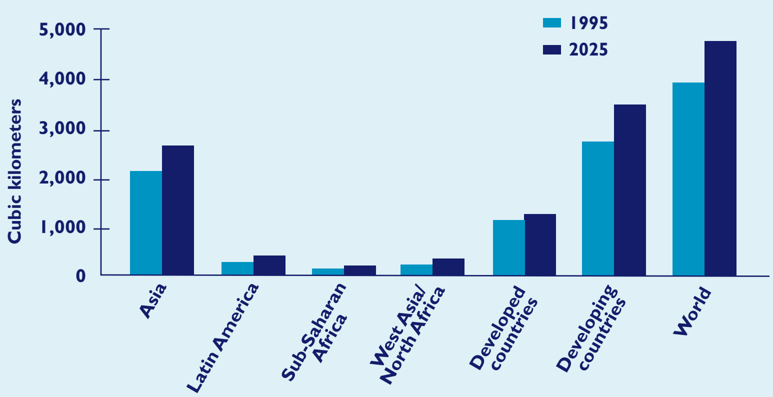
Will there be enough water to grow food for the almost 8 billion people expected to populate the Earth by 2025? It is impossible to answer that question without an understanding of the evolving relationship between water availability and food production. This understanding will allow decisionmakers to look squarely at the consequences of the choices they make to balance water supply and demand among all users in the years to come.

To spell out these consequences, we have developed a global model (see box on page 26) of water and food supply and demand to address the following questions: How are water availability and water demand likely to evolve by the year 2025? What impact will various water policies and investments have on water availability for the environment, domestic and industrial uses, and irrigation? What steps can policymakers take to ensure a sustainable use of water that meets the world's food needs?

A Thirsty World

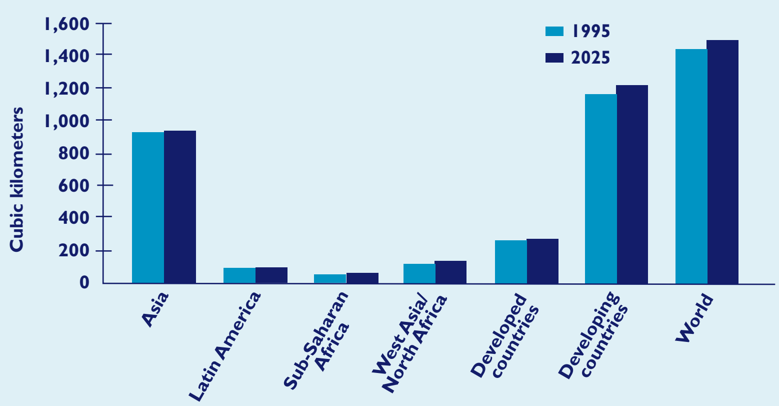
Water development underpins food security, people's livelihoods, industrial growth, and environmental sustainability throughout the world. In 1995 the world withdrew 3,906 cubic kilometers (km^3) of water for these purposes (Figure 1). By 2025 water withdrawal for most uses (domestic, industrial, and livestock) is projected to increase by at least 50 percent. This will severely limit irrigation water withdrawal, which will increase by only 4 percent, constraining food production in turn.

Figure 1 Total water withdrawal by region, 1995 and 2025



SOURCE: Authors' estimates and IMPACT-WATER projections, June 2002.
NOTE: Projections for 2025 are for the business as usual scenerio.

Figure 2 Total irrigation water consumption by region, 1995 and 2025



SOURCE: Authors' estimates and IMPACT-WATER projections, June 2002.
NOTE: Projections for 2025 are for the business as usual scenerio.

About 250 million hectares are irrigated worldwide today, nearly five times more than at the beginning of the 20th century. Irrigation has helped boost agricultural yields and outputs and stabilize food production and prices. But growth in population and income will only increase the demand for irrigation water to meet food production requirements (Figure 2). Although the achievements of irrigation have been impressive, in many regions poor irrigation management has markedly lowered groundwater tables, damaged soils, and reduced water quality.

Water is also essential for drinking and household uses and for industrial production. Access to safe drinking water and sanitation is critical to maintain health, particularly for children. But more than 1 billion people across the globe lack enough safe water to meet minimum levels of health and income. Although the domestic and industrial sectors use far less water than agriculture, the growth in water consumption in these sectors has been rapid. Globally, withdrawals for domestic and industrial uses quadrupled between 1950 and 1995, compared with agricultural uses, for which withdrawals slightly more than doubled.[1]

Water is integrally linked to the health of the environment. Water is vital to the survival of ecosystems and the plants and animals that live in them, and in turn ecosystems help to regulate the quantity and quality of water. Wetlands retain water during high rainfall, release it during dry periods, and purify it of many contaminants. Forests reduce erosion and sedimentation of rivers and recharge groundwater. The importance of reserving water for environmental purposes has only recently been recognized: during the 20th century, more than half of the world's wetlands were lost.[2]

Alternative Futures for Water

The future of water and food is highly uncertain. Some of this uncertainty is due to relatively uncontrollable factors such as weather. But other critical factors can be influenced by the choices made collectively by the world's people. These factors include income and population growth, investment in water infrastructure, allocation of water to various uses, reform in water management, and technological changes in agriculture. Policy decisions—and the actions of billions of individuals—determine these fundamental, long-term drivers of water and food supply and demand.

To show the very different outcomes that policy choices produce, we present three alternative futures for global water and food, followed by an assessment of specific policy options.[3]

Business As Usual Scenario

In the business as usual scenario current trends in water and food policy, management, and investment remain as they are. International donors and national governments, complacent about agriculture and irrigation, cut their investments in these sectors. Governments and water users implement institutional and management reforms in a limited and piecemeal fashion. These conditions leave the world ill prepared to meet major challenges to the water and food sectors.

Over the coming decades the area of land devoted to cultivating food crops will grow slowly in most of the world because of urbanization, soil degradation, and slow growth in irrigation investment, and because a high proportion of arable land is already cultivated. Moreover, steady or declining real prices for cereals will make it unprofitable for farmers to expand harvested area. As a result, greater food production will depend primarily on increases in yield. Yet growth in crop yields will also diminish because of falling public investment in agricultural research and rural infrastructure. Moreover, many of the actions that produced yield gains in recent decades, such as increasing the density of crop planting, introducing strains that are more responsive to fertilizer, and improving management practices, cannot easily be repeated.

In the water sector, the management of river basin and irrigation water will become more efficient, but slowly. Governments will continue to transfer management of irrigation systems to farmer organizations and water-user associations. Such transfers will increase water efficiency when they are built upon existing patterns of cooperation and backed by a supportive policy and legal environment. But these conditions are often lacking.

In some regions farmers will adopt more efficient irrigation practices. Economic incentives to induce more efficient water management, however, will still face political opposition from those concerned about the impact of higher water prices on farmers' income and from entrenched interests that benefit from existing systems of allocating water. Water management will also improve slowly in rainfed agriculture as a result of small advances in water harvesting, better on-farm management techniques, and the development of crop varieties with shorter growing seasons.

Public investment in expanding irrigation systems and reservoir storage will decline as the financial, environmental, and social costs of building new irrigation systems escalate and the prices of cereals and other irrigated crops drop.

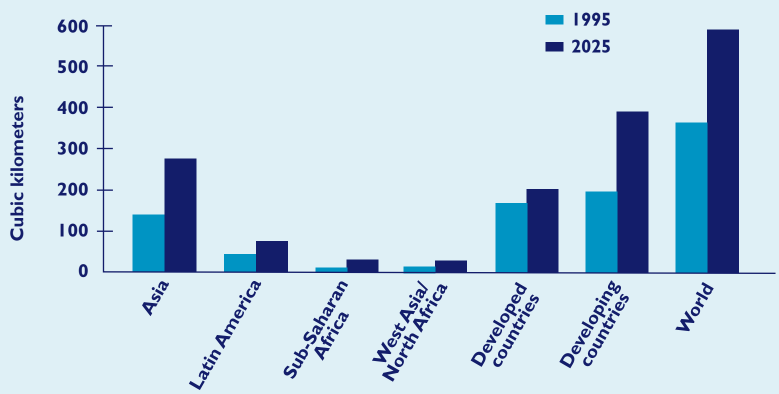
Nevertheless, where benefits outweigh costs, many governments will construct dams, and reservoir water for irrigation will increase moderately.

With slow growth in irrigation from surface water, farmers will expand pumping from groundwater, which is subject to low prices and little regulation. Regions that currently pump groundwater faster than aquifers can recharge, such as the western United States, northern China, northern and western India, Egypt, and West Asia and North Africa, will continue to do so.

The cost of supplying water to domestic and industrial users will rise dramatically. Better delivery and more efficient home water use will lead to some increase in the proportion of households connected to piped water. Many households, however, will remain unconnected. Small price increases for industrial water, improvements in pollution control regulation and enforcement, and new industrial technologies will cut industrial water use intensity (water demand per $1,000 of gross domestic product). Yet industrial water prices will remain relatively low and pollution regulations will often be poorly enforced. Thus, significant potential gains will be lost.

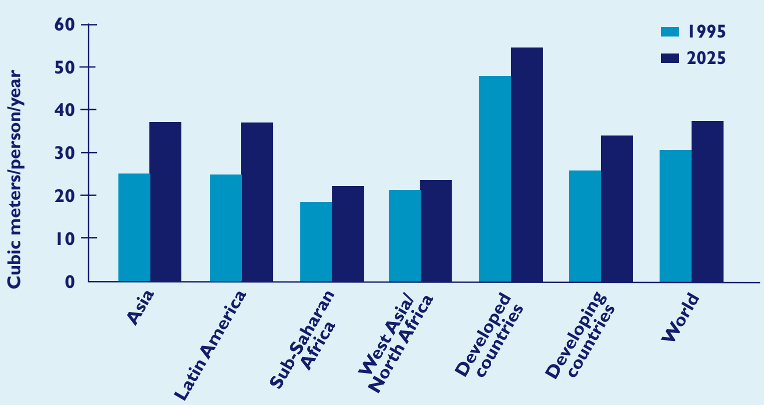
Environmental and other interest groups will press to increase the amount of water allocated to preserving wetlands, diluting pollutants, maintaining riparian flora and other aquatic species, and supporting tourism and recreation. Yet because of competition for water for other uses, the share of water devoted to environmental uses will not increase.

Figure 3 Total nonirrigation water consumption by region, 1995 and 2025



SOURCE: Authors' estimates and IMPACT-WATER projections, June 2002.
NOTE: Projections for 2025 are for the business as usual scenerio.

Figure 4 Per capita domestic water consumption by region, 1995 and 2025



SOURCE: Authors' estimates and IMPACT-WATER projections, June 2002.
NOTE: Projections for 2025 are for the business as usual scenerio.

The Water Situation

Almost all users will place heavy demands on the world's water supply under the business as usual scenario. Total global water withdrawals in 2025 are projected to increase by 22 percent above 1995 withdrawals, to 4,772 km^3 (see Figure 1, page 2).[4] Projected withdrawals in developing countries will increase 27 percent over the 30-year period, while developed-country withdrawals will increase by 11 percent.[5]

Together, consumption of water for domestic, industrial, and livestock uses—that is, all nonirrigation uses—will increase dramatically, rising by 62 percent from 1995 to 2025 (Figure 3). Because of rapid population growth and rising per capita water use (Figure 4), total domestic consumption will increase by 71 percent, of which more than 90 percent will be in developing countries. Conservation and technological improvements will lower per capita domestic water use in developed countries with the highest per capita water consumption.

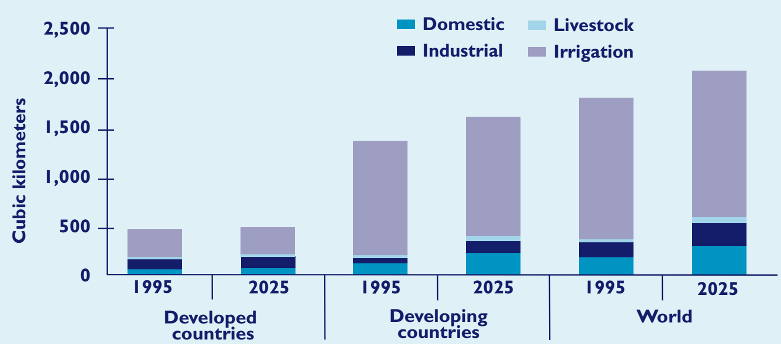
Industrial water use will grow much faster in developing countries than in developed countries. In 1995 industries in developed countries consumed much more water than industries in the developing world. By 2025, however, developing-world industrial water demand is projected to increase to 121 km^3, 7 km^3 greater than in the developed world (Figure 5). The intensity of industrial water use will decrease worldwide, especially in developing countries (where initial intensity levels are very high), thanks to improvements in water-saving technology and demand policy. Nonetheless, the sheer size of the increase in the world's industrial production will still lead to an increase in total industrial water demand.

Direct water consumption by livestock is very small compared with other sectors. But the rapid increase of livestock production, particularly in developing countries, means that livestock water demand is projected to increase 71 percent between 1995 and 2025. Whereas livestock water demand will increase only 19 percent in the developed world between 1995 and 2025, it is projected to more than double in the developing world, from 22 to 45 km^3.

Although irrigation is by far the largest user of the world's water, use of irrigation water is projected to rise much more slowly than other sectors. For irrigation water, we have computed both potential demand and actual consumption. Potential demand is the demand for irrigation water in the absence of any water supply constraints, whereas actual consumption of irrigation water is the realized water demand, given the limitations of water supply for irrigation (Figure 6). The proportion of potential demand that is realized in actual consumption is the irrigation water supply reliability index (IWSR).[6] An IWSR of 1.0 would mean that all potential demand is being met.

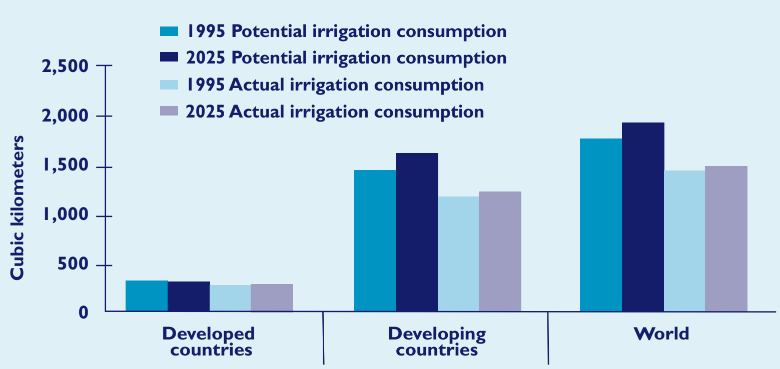
Potential irrigation demand will grow by 12 percent in developing countries, while it will actually decline in developed countries by 1.5 percent. The fastest growth in potential demand for irrigation water will occur in Sub-Saharan Africa, with an increase of 27 percent, and in Latin America,

Figure 5 Water consumption by sector, 1995 and 2025



SOURCE: Authors' estimates and **IMPACT-WATER** projections, June 2002.
NOTE: Projections for 2025 are for the business as usual scenerio.

Figure 6 Potential and actual consumption of irrigation water, 1995 and 2025



SOURCE: Authors' estimates and **IMPACT-WATER** projections, June 2002.
NOTE: Projections for 2025 are for the business as usual scenerio.

Table 1 Irrigation water supply reliability by region, 1995 and 2025

	IRRIGATION WATER SUPPLY RELIABILITY INDEX	
REGION	1995	2025
Asia	0.81	0.76
Latin America	0.83	0.75
Sub-Saharan Africa	0.73	0.72
West Asia/North Africa	0.78	0.74
Developed countries	0.87	0.90
Developing countries	0.81	0.75
World	0.82	0.78

SOURCE: Authors' estimates and IMPACT-WATER projections, June 2002.

NOTE: Projections for 2025 are for the business as usual scenario.

with an increase of 21 percent. Each of these regions has a high percentage increase in irrigated area from a relatively low 1995 level. India is projected to have the highest absolute growth in potential irrigation water demand, 66 km^3 (17 percent), owing to relatively rapid growth in irrigated area from an already high level in 1995. West Asia and North Africa will increase by 18 percent (28 km^3, mainly in Turkey), while China will experience a much smaller increase of 4 percent (12 km^3). In Asia as a region, potential irrigation water demand will increase by 8 percent (100 km^3).

Water scarcity for irrigation will intensify, with actual consumption of irrigation water worldwide projected to grow more slowly than potential consumption, increasing only 4 percent between 1995 and 2025. In developing countries a declining fraction of potential demand will be met over time. The IWSR for developing countries will decline from 0.81 in 1995 to 0.75 in 2025, and in dry river basins the decline will be steeper (Table 1). For example, in the Haihe River Basin in China, which is an important wheat and maize producer and serves major metropolitan areas, the IWSR is projected to decline from 0.78 to 0.62, and in the Ganges of India, the IWSR will decline from 0.83 to 0.67.

In the developed world, the situation is the reverse: the supply of irrigation water is projected to grow faster than potential demand (although certain basins will face increasing water scarcity). Increases in river basin efficiency will more than offset the very small increase in irrigated area. As a result, after initially declining from 0.87 to 0.85 in 2010, the IWSR will improve to 0.90 in 2025 thanks to slowing growth of domestic and industrial demand (and actual declines in total domestic and industrial water use in the United States and Europe) and more efficient use of irrigation water.

The Food Situation

Water scarcity under business as usual will lead to slower growth of food production and substantial shifts in where the world's food is grown.

Farmers will find themselves unable to raise crop yields as quickly as in the past in the face of a decline in relative water supply. The global yield growth rate for all cereals is projected to decline from 1.5 percent per year from 1982 to 1995 to 1.0 percent per year from 1995 to 2025. In developing countries, average crop yield growth will decline from 1.9 percent per year to 1.2 percent.

The projected relative crop yields for irrigated cereals show that scarce water is a significant cause of the slowdown in cereal yield growth in developing countries. Relative crop yield is the ratio of the actual projected crop yield to the economically attainable yields at given crop and input prices under conditions of zero water stress. The relative crop yield for cereals in irrigated areas in developing countries is projected to decline from 0.86 in 1995 to 0.75 in 2025 (Figure 7). This fall in the relative crop yield represents an annual loss in crop yields forgone due to increased water stress of 0.68 metric tons per hectare in 2025, or an annual loss of cereal production of 130 million metric tons, equivalent to the annual rice crop in China in late 1990s and double the U.S. wheat crop in the same period.[7]

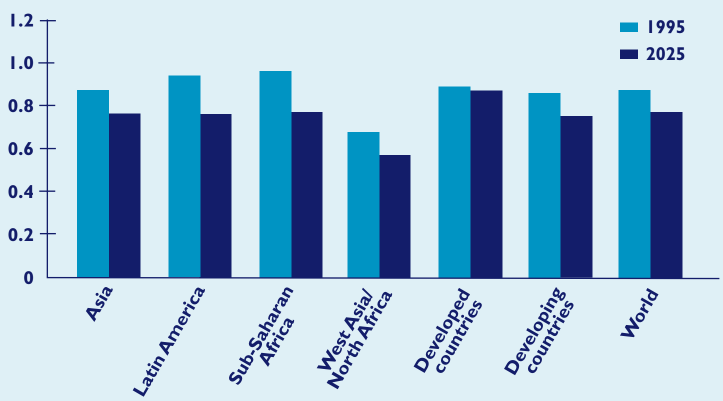
Crop-harvested area is expected to grow even more slowly than crop yield in the coming decades. Cereal-harvested area will rise by only 64 million hectares by 2025, from 687 million hectares in 1995. All of this growth is projected to occur in developing countries, with a slight decline in cereal-harvested area in developed countries.

Growth in food demand will be concentrated in developing countries, where rising incomes and rapid urbanization will also cause people to change the kinds of food they demand. Consumers will shift from maize and coarse grains to wheat and rice, livestock products, and fruits and vegetables. In much of Asia, an additional shift will occur from rice to wheat. The projected strong growth in meat consumption, in turn, will substantially increase cereal consumption in the form of animal feed, particularly maize. Total world cereal demand is projected to grow by 828 million tons, or 47 percent.

With slowing production growth, the prices of most food commodities are projected to decline, but far more slowly than in the past two decades. Maize prices will increase slightly, while rice, wheat, and other cereals will all decline in price. Rice prices show the biggest decline, a drop of $64 per ton, or 22 percent, between 1995 and 2025, but this is still far below the rate of decline in the past three decades. Real world prices of wheat, rice, and maize fell by 47, 59, and 61 percent respectively, between 1970 and 2000.

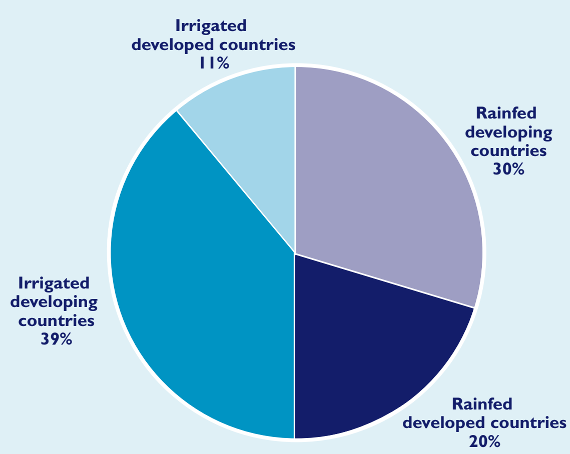
Under the business as usual scenario, irrigated and rainfed production will each account for about one-half the increase in production between 1995 and 2025 (Figure 8). The large contribution to production from rainfed areas may surprise some observers. But more than 80 percent of cereal area in developed countries is rainfed, and much of this area is highly productive maize and wheat land. The average rainfed cereal yield in developed countries was 3.2 tons per hectare in 1995, virtually as high as irrigated cereal yields in developing countries, and is projected to grow to 4.0 tons per hectare by 2025. Moreover, whereas rainfed cereal yields in developing countries are projected to increase only from 1.5 tons per hectare to 2.1 tons per hectare by 2025, rainfed area in developing countries will

Figure 7 Relative cereal yield by region, 1995 and 2025



SOURCE: Authors' estimates and IMPACT-WATER projections, June 2002.
NOTE: Projections for 2025 are for the business as usual scenerio.

Figure 8 Share of irrigated and rainfed production in cereal production increase, 1995 and 2025



SOURCE: Authors' estimates and IMPACT-WATER projections, June 2002.
NOTE: Projections for 2025 are for the business as usual scenerio.

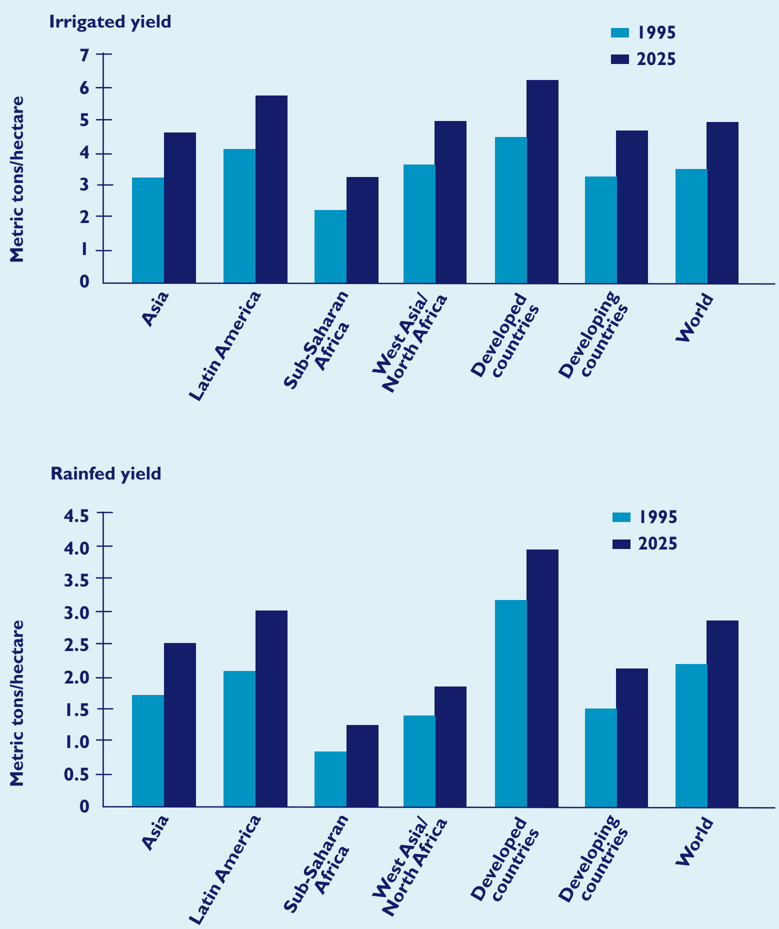
account for 62 percent of total cereal area in developing countries (Figure 9).

By substituting cereal and other food imports for irrigated agricultural production (so-called imports of virtual water), countries can effectively reduce their agricultural water use.[8] Under business as usual, developing countries will dramatically increase their reliance on food imports from 107 million tons in 1995 to 245 million tons in 2025. The increase in developing-country cereal imports by 138 million tons between 1995 and 2025 is the equivalent of saving 147 km^3 of water at 2025 water productivity levels, or 8 percent of total water consumption and 12 percent of irrigation water consumption in developing countries in 2025.

The water (and land) savings from the projected large increases of food imports by the developing countries are particularly beneficial if they are the result of strong economic growth that generates the necessary foreign exchange to pay for the food imports. But even when rapidly growing food imports are primarily a result of rapid income growth, national policymakers concerned about heavy reliance on world markets often see them as a signal to set trade restrictions that can slow growth and food security in the longer term. More serious food security problems arise when high food imports are the result of slow agricultural and economic development that fails to keep pace with basic food demand driven by population and income growth. Under these conditions, countries may find it impossible to finance the required imports on a continuing basis, causing a further deterioration in the ability to bridge the gap between food consumption and the food required for basic livelihood.

"Hot spots" for food trade gaps are Sub-Saharan Africa, where cereal imports are projected to more than triple by 2025 to 35 million tons, and West Asia and North Africa, where cereal imports are projected to increase from 38 million tons in 1995 to 83 million tons in 2025. The reliance on water-saving cereal imports in West Asia and North Africa makes economic and environmental sense, but it must be supported by faster nonagricultural growth. It is highly unlikely that Sub-Saharan Africa could finance the projected level of imports internally; instead international financial or food aid would be required. Failure to finance these imports would further increase food insecurity and pressure on water resources in this region.

Figure 9 Irrigated and rainfed cereal yield by region, 1995 and 2025



SOURCE: Authors' estimates and IMPACT-WATER projections, June 2002.
NOTE: Projections for 2025 are for the business as usual scenerio.

Water Crisis Scenario

A moderate worsening of many of the current trends in water and food policy and in investment could build to a genuine water crisis. In the water crisis scenario, government budget problems worsen. Governments further cut their spending on irrigation systems and accelerate the turnover of irrigation systems to farmers and farmer groups but without the necessary reforms in water rights. Attempts to fund operations and maintenance in the main water system, still operated by public agencies, cause water prices to irrigators to rise. Water users fight price increases, and conflict spills over to local management and cost-sharing arrangements. Spending on the operation and maintenance of secondary and tertiary systems falls dramatically, and deteriorating infrastructure and poor management lead to falling water use efficiency. Likewise, attempts to organize river basin organizations to coordinate water management fail because of inadequate funding and high levels of conflict among water stakeholders within the basin.

National governments and international donors will reduce their investments in crop breeding for rainfed agriculture in developing countries, especially for staple crops such as rice, wheat, maize, other coarse grains, potatoes, cassava, yams, and sweet potatoes. Private agricultural research will fail to fill the investment gap for these commodities. This loss of research funding will lead to further declines in productivity growth in rainfed crop areas, particularly in more marginal areas. In search of improved incomes, people will turn to slash-and-burn agriculture, thereby deforesting the upper watersheds of many basins. Erosion and sediment loads in rivers will rise, in turn causing faster sedimentation of reservoir storage. People will increasingly encroach on wetlands for both land and water, and the integrity and health of aquatic ecosystems will be compromised. The amount of water reserved for environmental purposes will decline as unregulated and illegal withdrawals increase.

The cost of building new dams will soar, discouraging new investment in many proposed dam sites. At other sites indigenous groups and nongovernmental organizations (NGOs) will mount opposition, often violent, over the environmental and human impacts of new dams. These protests and high costs will virtually halt new investment in medium and large dams and storage reservoirs. Net reservoir storage will decline in developing countries and remain constant in developed countries.

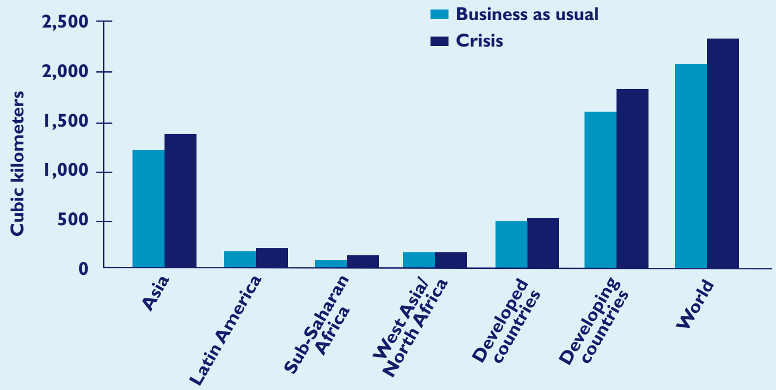
In the attempt to get enough water to grow their crops, farmers will extract increasing amounts of groundwater for several years, driving down water tables. But because of the accelerated pumping, after 2010 key aquifers in northern China, northern and northwestern India, and West Asia and North Africa will begin to fail. With declining water tables, farmers will find the cost of extracting water too high, and a big drop in groundwater extraction from these regions will further reduce water availability for all uses.

As in the business as usual scenario, the rapid increase in urban populations will quickly raise demand for domestic water. But governments will lack the funds to extend piped water and sewage disposal to newcomers. Governments will respond by privatizing urban water and sanitation services in a rushed and poorly planned fashion. The new private water and sanitation firms will be undercapitalized and able to do little to connect additional populations to piped water. An increasing number and percentage of the urban population must rely on high-priced water from vendors or spend many hours fetching often-dirty water from standpipes and wells.

The Water Situation

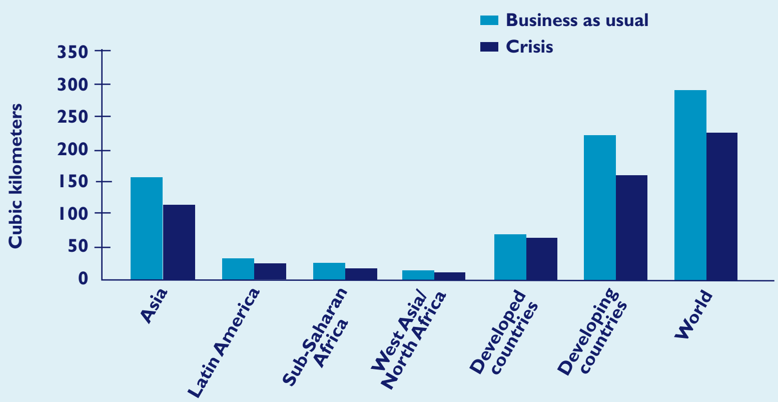
The developing world will pay the highest price for the water crisis scenario. Total worldwide water consumption in 2025 will be 261 km^3 higher than under the business as usual scenario—a 13 percent increase—but much of this water will be wasted, of no benefit to anyone (Figure 10).

Figure 10 Total water consumption by region, business as usual and crisis scenarios, 2025



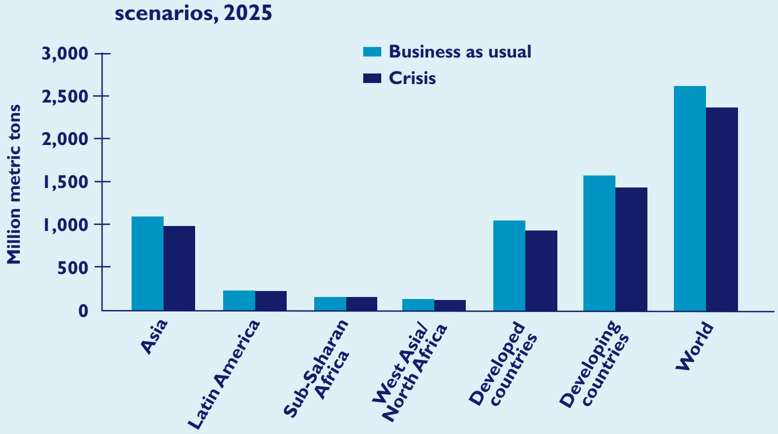
SOURCE: Authors' estimates and IMPACT-WATER projections, June 2002.

Figure 11 Domestic consumption of water by region, business as usual and crisis scenarios, 2025



SOURCE: Authors' estimates and IMPACT-WATER projections, June 2002.

Figure 12 Total cereal production by region, business as usual and crisis scenarios, 2025



SOURCE: Authors' estimates and IMPACT-WATER projections, June 2002.

Virtually all of the increase will go to irrigation, mainly because farmers will use water less efficiently and withdraw more water to compensate for water losses. The supply of irrigation water will be less reliable, except in regions where so much water is diverted from environmental uses to irrigation that it compensates for the lower water use efficiency.

For most regions, per capita demand for domestic water will be significantly lower than under the business as usual scenario, in both rural and urban areas. The result is that people will not have access to the water they need for drinking and sanitation. The total domestic demand under the water crisis scenario will be 162 km^3 in developing countries, 28 percent less than under business as usual; 64 km^3 in developed countries, 7 percent less than under business as usual; and 226 km^3 in the world, 23 percent less than under business as usual (FIgure 11).

Demand for industrial water, on the other hand, will increase, owing to failed technological improvements and economic measures. In 2025 the total industrial water demand worldwide will be 80 km^3 higher than under the business as usual scenario—a 33 percent rise—without generating additional industrial production.

With water diverted to make up for less efficient water use, the water crisis scenario will hit environmental uses particularly hard. Compared with business as usual, environmental flows will drop significantly by 2025, with 380 km^3 less environmental flow in the developing world, 80 km^3 less in the developed world, and 460 km^3 less globally.

The Food Situation

The water crisis scenario will have severe consequences for food production. Total cereal production under water crisis, for example, will be 249 million metric tons, or 10 percent, less than business as usual—the result of declines in both cultivated area and yields (Figure 12). This reduction is the equivalent of annually losing the entire cereal crop of India, or the combined annual harvest of Sub-Saharan Africa and West Asia and North Africa.

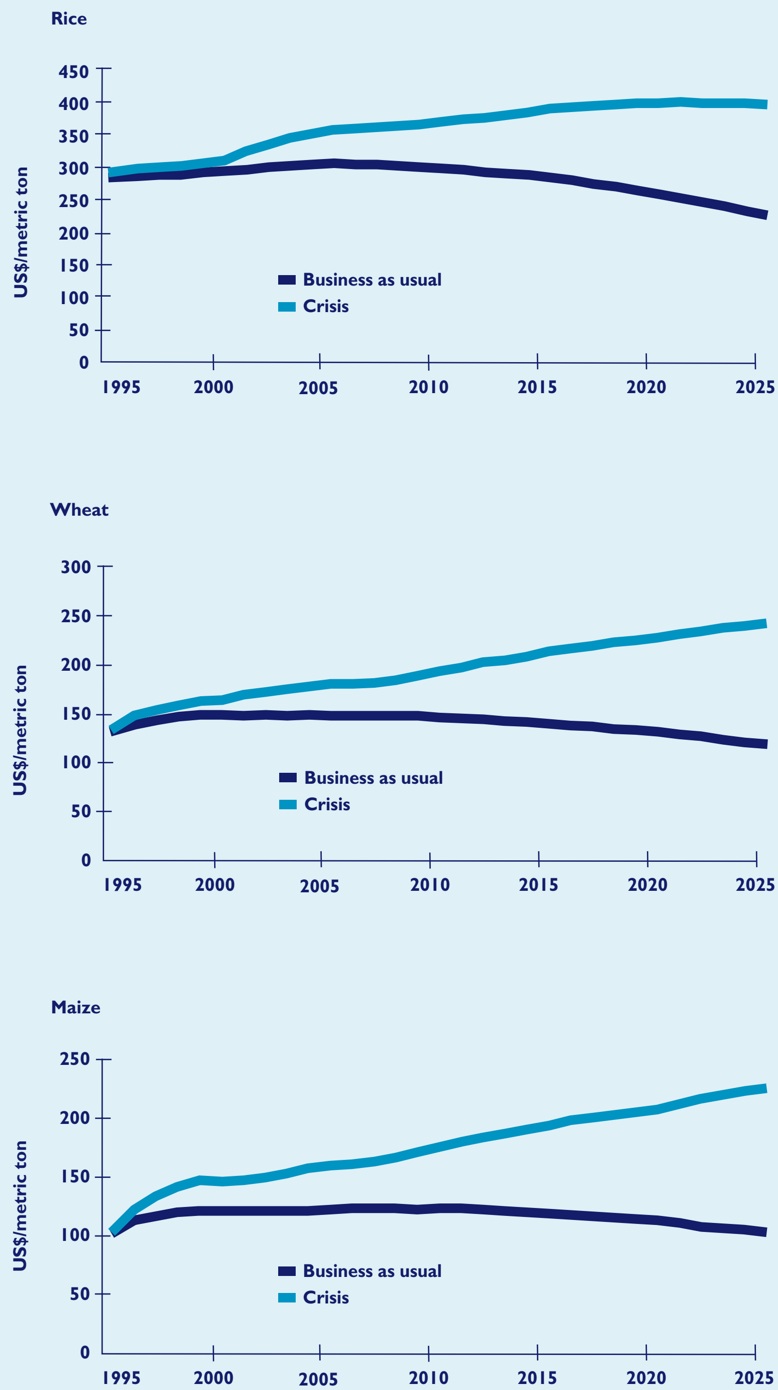
Compared with business as usual, the total cereal-harvested area under the water crisis scenario is 17.7 million hectares, or 3 percent, lower than business as usual in the developing world, 8.9 million hectares, or 4 percent, lower in the developed world, and 26.6 million hectares, or 4 percent, lower globally

Yields will fall for both irrigated and rainfed crops. The average total cereal yield in 2025 is 216 kilograms per hectare, or 6 percent, lower under the water crisis scenario than under business as usual. Because the supply of irrigation water in most regions is less reliable under the water crisis scenario, the average yield of irrigated cereals will be lower for developing and developed countries and the world as a whole in 2025. Globally, irrigated cereal yields will be 4 percent lower under water crisis than under business as usual.

Since farmers fail to harvest more rainfall and crop research cutbacks slow yield growth, rainfed crops will yield 191 kilograms per hectare less than business as usual, a 7 percent decrease from 1995 to 2025.

The decline in food production will help push up food prices sharply

Figure 13 World prices for rice, wheat, and maize, business as usual and crisis scenarios, 1995–2025



SOURCE: Authors' estimates and IMPACT-WATER projections, June 2002.

under the water crisis scenario (Figure 13, previous page). The price of rice will rise by 40 percent, wheat by 80 percent, maize by 120 percent, other coarse grains by 85 percent, soybeans by 70, and potatoes, sweet potatoes, and other roots and tubers by 50 to 70 percent. Crop prices under the water crisis scenario in 2025 are 1.8 times that of business as usual for rice, 1.7 times for potatoes, 1.6 times for soybeans, and more than double for all other crops.

These high prices will dampen food demand. Under the water crisis scenario, cereal demand in 2025 will decline by 55 million tons, or 7 percent, compared with the business as usual scenario in the developed world, and 192 million tons, or 11 percent, in the developing world.

Compared with business as usual, net trade will decline in the water crisis scenario. Developing countries will import 58 million tons, or 23 percent, less cereal than under business as usual. This decline implies that high prices dampen crop demand and thus lead to trade reductions.

The ultimate result of this scenario is growing food insecurity, especially in developing countries. Per capita cereal consumption in 2025 in the developing world is 2 percent lower than 1995 levels.

This scenario makes it clear that increasing water scarcity, combined with poor water policies and inadequate investment in water, has the potential to generate sharp increases in cereal food prices over the coming decades. Price increases of this magnitude will take a significant bite out of the real income of poor consumers. Malnutrition will increase substantially, given that the poorest people in low-income developing countries spend more than half their income on food. Sharp price increases can also fuel inflation, place severe pressure on foreign exchange reserves, and have adverse impacts on macroeconomic stability and investment in developing countries.

Sustainable Water Scenario

A sustainable water scenario would dramatically increase the amount of water allocated to environmental uses, connect all urban households to piped water, and achieve higher per capita domestic water consumption, while maintaining food production at the levels described in the business as usual scenario. It would achieve greater social equity and environmental protection through both careful reform in the water sector and sound government action.

Governments and international donors will increase their investments in crop research, technological change, and reform of water management to boost water productivity and the growth of crop yields in rainfed agriculture. Accumulating evidence shows that even drought-prone and high-temperature rainfed environments have the potential for dramatic increases in yield. Breeding strategies will directly target these rainfed areas. Improved policies and increased investment in rural infrastructure will help link remote farmers to markets and reduce the risks of rainfed farming.

To stimulate water conservation and free up agricultural water for environmental, domestic, and industrial uses, the effective price of water to the agricultural sector will be gradually increased. Agricultural water price increases will be implemented through incentive programs that provide farmers income for the water that they save, such as charge-subsidy schemes that pay farmers for reducing water use, and through the establishment, purchase, and trading of water use rights. By 2025 agricultural water prices will be twice as high in developed countries and three times as high in developing countries as in the business as usual scenario. The government will simultaneously transfer water rights and the responsibility for operation and management of irrigation systems to communities and water user associations in many countries and regions. The transfer of rights and systems will be facilitated with an improved legal and institutional environment for preventing and eliminating conflict and with technical and organizational training and support. As a result, farmers will increase their on-farm investments in irrigation and water management technology, and the efficiency of irrigation systems and basin water use will improve significantly.

River basin organizations will be established in many water-scarce basins to allocate mainstream water among stakeholder interests. Higher funding and reduced conflict over water, thanks to better water management, will facilitate effective stakeholder participation in these organizations.

Farmers will be able to make more effective use of rainfall in crop production, thanks to breakthroughs in water harvesting systems and the adoption of advanced farming techniques, like precision agriculture, contour plowing, precision land leveling, and minimum-till and no-till technologies. These technologies will increase the share of rainfall that goes to infiltration and evapotranspiration.

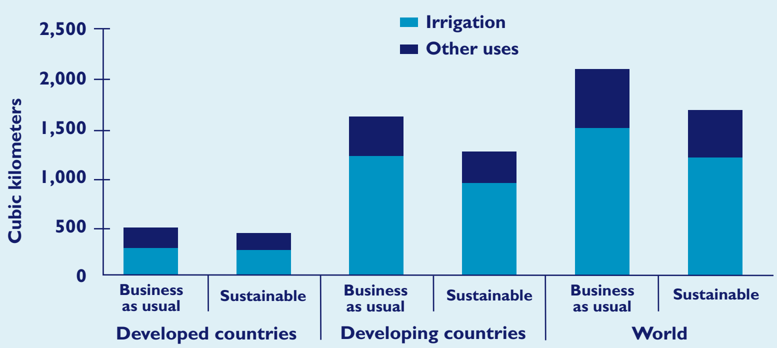
Spurred by the rapidly escalating costs of building new dams and the increasingly apparent environmental and human resettlement costs, developing and developed countries will reassess their reservoir construction plans, with comprehensive analysis of the costs and benefits, including environmental and social effects, of proposed projects. As a result, many planned storage projects will be canceled, but others will proceed with support from civil society groups. Yet new storage capacity will be less necessary because rapid growth in rainfed crop yields will help reduce rates of reservoir sedimentation from erosion due to slash-and-burn cultivation.

Policy toward groundwater extraction will change significantly. Market-based approaches will assign rights to groundwater based on both annual withdrawals and the renewable stock of groundwater. This step will be combined with stricter regulations and better enforcement of these regulations. Groundwater overdrafts will be phased out in countries and regions that previously pumped groundwater unsustainably.

Domestic and industrial water use will also be subject to reforms in pricing and regulation. Water prices for connected households will double, with targeted subsidies for low-income households. Revenues from price increases will be invested to reduce water losses in existing systems and to extend piped water to previously unconnected households. By 2025 all households will be connected. Industries will respond to higher prices, particularly in developing countries, by increasing in-plant recycling of water, which reduces consumption of water.

With strong societal pressure for improved environmental quality, allocations for environmental uses of water will increase. Moreover, the reforms in agricultural and nonagricultural water sectors will reduce pressure on wetlands and other environmental uses of water. Greater investments and better water management will improve the efficiency of water use, leaving more water instream for environmental purposes. All reductions in domestic and urban water use, due to higher water prices, will be allocated to instream environmental uses.

Figure 14 Total and irrigation water consumption, by region, business as usual and sustainable scenarios, 2025

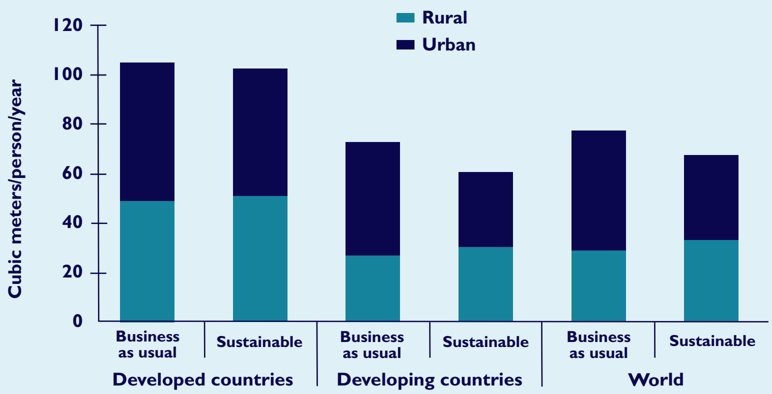


SOURCE: Authors' estimates and IMPACT-WATER projections, June 2002.

The Water Situation

In the sustainable water scenario the world consumes less water but reaps greater benefits than under business as usual, especially in developing countries. In 2025 total worldwide water consumption is 408 km^3, or 20 percent, lower under the sustainable scenario than under business as usual (Figure 14). This reduc-

Figure 15 Potential per capita domestic water consumption by connected rural and urban households, business as usual and sustainable scenarios, 2025



SOURCE: Authors' estimates and IMPACT-WATER projections, June 2002.

tion in consumption frees up water for environmental uses. Higher water prices and higher water use efficiency reduces consumption of irrigation water by 296 km^3 compared with business as usual. The reliability of irrigation water supply is reduced slightly in the sustainable scenario compared with business as usual, because this scenario places a high priority on environmental flows. Over time, however, more efficient water use in this scenario counterbalances the transfer of water to the environment and results in an improvement in the reliability of supply of irrigation water by 2025.

This scenario will improve the domestic water supply through universal access to piped water for rural and urban households. Globally, potential domestic water demand under the sustainable water scenario will decrease 9 percent compared with business as usual, owing to higher water prices. However, potential per capita domestic demand for connected households in rural areas will be 12 percent higher than that under business as usual in the developing world, and 5 percent higher in the developed world. This increase is accomplished by expanding universal access to piped water in rural areas even with higher prices for water. And in urban areas, potential per capita water consumption for poor households sharply improves through connection to piped water, while the initially connected households reduce consumption in response to higher prices and improved water-saving technology (Figure 15).

Through technological improvements and effective economic incentives, the sustainable water scenario will reduce industrial water demand. In 2025 total industrial water demand worldwide under the sustainable scenario will be 85 km^3, or 35 percent, lower than under business as usual.

The environment is a major beneficiary of the sustainable water scenario, with large increases in the amount of water reserved for wetlands, instream flows, and other environmental purposes. Compared with the business as usual scenario, the sustainable scenario will also result in an increase in the environmental flow of 850 km^3 in the developing world, 180 km^3 in the developed world, and 1,030 km^3 globally. This is the equivalent of transferring 22 percent of global water withdrawals under business as usual to environmental purposes.

The Food Situation

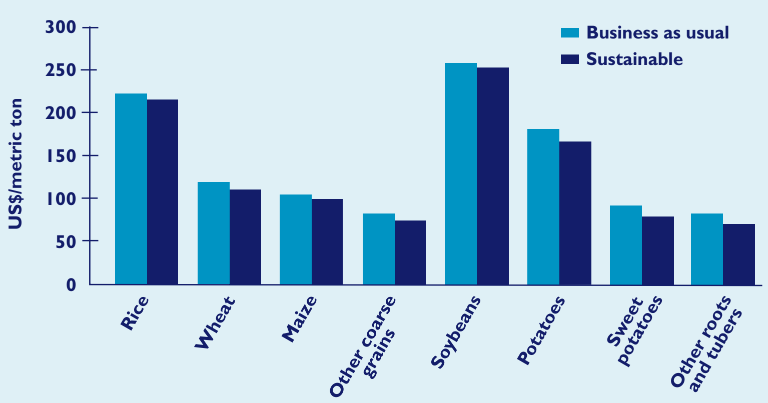
The sustainable water scenario can raise food production slightly over the business as usual scenario, while achieving much greater gains for domestic water use and the environment.

The total harvested area under the sustainable water scenario in 2025 will be slightly lower than under business as usual owing to less water for irrigation and barely lower crop prices. Because the supply of irrigation water will be less reliable under the sustainable water scenario than under business as usual, the yield of irrigated cereals will be 2 percent lower for the world as a whole in 2025. On the other hand, global rainfed yields under the sustainable water scenario will be 7 percent higher than business as usual, owing to higher agricultural research investment and a larger improvement in rainfall harvesting. With the faster growth in rainfed yields making up for slower growth in harvested area and irrigated yields, total cereal production in 2025 will be 19 million tons, or 1 percent, more under the sustainable scenario than under business as usual. Crop prices under this scenario will decline slowly from 1995 to 2025 except for slight increases for maize and soybeans due to heavy demand for livestock feeds (Figure 16).

As in the water crisis scenario, net trade in the sustainable scenario is lower than that under business as usual, with cereal imports from the developing world declining by 14 million tons, or 6 percent. This decline reflects the different rates of adjustment of food production between food-importing and -exporting countries. Cereal production under the sustainable water scenario is 10 million tons less in developed countries and 29 million tons more in developing countries than under the business as usual scenario.

The sustainable scenario shows that with improved water policies, investments, and rainfed cereal crop management and technology, growth in food production can be maintained while universal access to piped water is achieved and environmental flows are increased dramatically. Compared with the water crisis scenario, the increase in environmental flows under the sustainable water scenario is about 1,490 km^3, equivalent to 5 times the annual flow of the Mississippi River, 20 times the annual flow of the Yellow River, and 4 times the annual flow of the Ganges River.

Figure 16 World food prices, business as usual and sustainable scenarios, 2025



SOURCE: Authors' estimates and IMPACT-WATER projections, June 2002.

Consequences of Key Policy Changes

If policymakers do not make a holistic change in water policies and investments but simply change certain key factors, could this produce substantial benefits? We examine what would happen if policymakers and water users raised water prices, shifted to sustainable groundwater use, or better exploited the potential of rainfed agriculture.

Raising Water Prices

Raising water prices seems to make sense for several reasons. Higher water prices not only encourage all users to use water more efficiently, but also could generate funds to maintain existing water infrastructure and to build new infrastructure. Yet because of perceived political risks and concern that higher prices would hurt poor farmers and consumers, there have been few attempts to implement higher water prices. In fact, in most instances the poor suffer from current subsidized water prices because water subsidies in most countries go disproportionately to the better off: urban water users connected to the public system and irrigated farmers.

Well-designed price hikes for water can create incentives for people to use water efficiently and recover at least operation and maintenance costs, while protecting and even increasing farm incomes. But would such water price increases save significant amounts of water that could be left instream for environmental purposes without reducing food production?

To address this question, we examine two scenarios with higher water pricing. One implements higher water prices but with water use efficiency remaining the same as under the business as usual scenario. The other scenario assumes higher water prices but also assumes that higher water prices induce improvements in basin efficiency through better crop water management and investments in new irrigation technology compared with the business as usual scenario. Under both scenarios, water prices for agriculture, industry, and connected households are assumed to increase gradually over the period from 2000 to 2025. By 2025 water prices for industrial water use are 1.75 times higher than prices under the business as usual scenario in developed countries and 2.25 times higher in developing countries. For domestic water uses, water prices are 1.5 times higher in developed countries and double in developing countries. For agricultural water uses, prices double by 2025 in developed countries and triple in developing countries compared with the business as usual prices.

The higher-price scenarios result in a reduction of water withdrawals of 839 km^3 (18 percent) and of total water consumption of 287 km^3 (14 percent) compared with business as usual, with more than half of the reduction occurring in developing countries. Withdrawals and consumption are the same in the two scenarios; higher efficiency influences the proportion of withdrawals and consumption that are used beneficially. The impact on water withdrawal is even greater in some regions, with reductions of more than 20 percent in China, Southeast Asia, Latin America, and West Asia and North Africa, and between 14 and 20 percent in other countries and regions. The reduction in withdrawals and consumption thus represents a major benefit for the environment, dramatically increasing environmental flows.

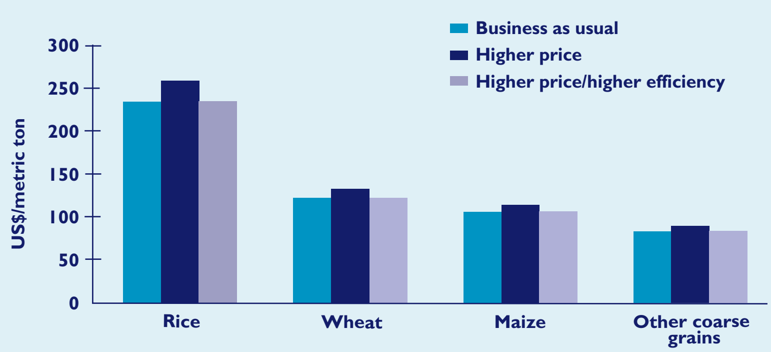
Demand for water for all nonirrigation uses—that is, for industrial, domestic, and livestock use—falls dramatically under the higher-price scenarios compared with business as usual. Total nonirrigation consumption of water falls from 599 km^3 under the business as usual scenario to 449 km^3 globally, from 395 km^3 to 285 km^3 in developing countries, and from 204 km^3 to 164 km^3 in developed countries. Water withdrawals for these purposes also fall significantly.

Total consumption of irrigation water under both the higher-price and the higher-price/higher-efficiency scenarios is about 100 km^3 less than under the business as usual scenario. Yet because of more efficient water use in the higher-price/higher-efficiency scenario, more of the irrigation water is consumed beneficially by crops. Whereas cereal production declines by about 5 percent in the higher-price scenario compared with business as usual, under the higher-price/higher-efficiency scenario the change in cereal production is slight.

With the decline in production under the higher-price scenario, world food prices increase, with the greatest increase for rice (10 percent) and price increases of 4–8 percent for other cereals. When water prices induce higher basin efficiency, however, food prices are the same or lower (Figure 17).

These results show that higher water prices for industry, domestic, and agricultural sectors would result in large water savings that can be used for environmental purposes. Making water use more efficient in conjunction with higher prices is critical to maintaining or increasing the reliability of irrigation water supply and food production compared with business as usual.

Figure 17 World cereal prices under business as usual and alternative water price scenarios, 2021-25



SOURCE: Authors' estimates and IMPACT-WATER projections, June 2002.

Shifting to Sustainable Groundwater Use

A number of basins and countries are pumping groundwater in excess of natural recharge rates. These include the Rio Grande and Colorado River Basins in the western United States, the Yellow and Haihe River Basins in northern China, and several river basins in northern and western India, Egypt, and West Asia and North Africa. What would happen to water and food if these regions stopped overpumping and returned to sustainable water use?

The low-groundwater-pumping scenario assumes that all countries and regions will phase out unsustainable groundwater overdraft over the next 25 years. Areas with more plentiful groundwater will increase their pumping almost as much as in the business as usual scenario. Total global groundwater pumping will fall to 753 km^3 in 2021–25, a decline from the 1995 value of 817 km^3 and from the 2025 business as usual value of 922 km^3. Compared with business as usual, global consumptive water use will decline 5.6 percent in the irrigation sector, 0.5 percent in the livestock sector, 0.1 percent in the domestic sector, and 0.1 percent in the industrial sector, with most of this change occurring in developing countries. Virtually no change in consumption will occur in other sectors.

In 2021–25 the total area planted to cereals will be 730,000 hectares less under the low-groundwater scenario than under business as usual. Although rainfed area will increase, it will not be enough to offset the large decline in irrigated area. Most of the change in irrigated area will occur in developing countries, especially in China. In most regions yields for irrigated cereals will fall and yields for rainfed cereals will rise slightly.

Total cereal production will decline by an annual average of 18 million tons from business as usual projections in 2021–25. The fall in irrigated cereal production will lead to price increases that stimulate increased rainfed production, but, once again, the increase will not be enough to overcome the decline in irrigated cereal production. Crop prices under the low-groundwater scenario are projected to be 5–10 percent higher in 2021–25 than under business as usual projections. Although total developing-country cereal production will decline in the low-groundwater scenario compared with business as usual in 2021–25, these price rises will actually cause farmers in developed countries to produce more cereals and thus lead to an overall increase in cereal production there compared with business as usual.

Not surprisingly, the low-groundwater scenario projects the biggest drops in cereal production to be concentrated in the basins that currently experience large overdrafts, especially China and India. As a result, the developing world as a whole will increase its net imports, with major increases concentrated in China and India, and developed countries will increase their net exports.

These country-level shortfalls in demand and increases in imports could be serious, but they may be a worthwhile trade-off for restoring sustainable groundwater supplies. More important, countries must combine a phase-out of groundwater overdrafting with policies to mitigate the impacts on the overdrafting regions in order to maintain income growth. Countries should increase their agricultural research investments, and, particularly in the hardest-hit river basins, make investments and implement policy reforms to increase basin efficiency, and encourage diversification from irrigated cereals to crops that give more value per unit of water.

Exploiting the Potential of Rainfed Agriculture

Could more rapid growth in rainfed cereal production—through either research and technology-driven growth in cereal yield and area or through increased rainfall harvesting—compensate for significant reductions in irrigation and water supply investment compared with business as usual? We explore these questions in two alternative scenarios.

The low-investment scenario assumes that basin efficiency will not increase above 1995 levels, that the rate of increase in potential irrigated area will be about one-third of the rate under the business as usual scenario, that the increase in reservoir storage will be 40 percent of business as usual, and that increases in maximum allowable water withdrawals will be 30 percent as high. This reduction in investment in infrastructure and management seriously constrains growth in food production, causing an annual drop in irrigated cereal production of 120 million tons (11 percent) in 2021–25 and driving cereal prices up by 25–35 percent.

We then estimate the required rainfed area and yield increases to offset the reduction of irrigated production and maintain essentially the same international trade prices. A larger increase is assigned to rainfed yield than area (because of limited potential for area expansion), and a larger increase is assigned to those basins, countries, or regions where irrigation effects are greater.

Under this scenario the international price will maintain approximately the same level as the business as usual scenario for all cereal crops except rice. It proved impossible to fully compensate for the loss of rice production, which has a high proportion of irrigated area.

Compared with business as usual, this scenario results in a decline in global irrigation water consumption of 240 km^3, or 16 percent, and a decline in irrigated cereal production of 153 million tons. Rainfed area, however, increases by

10 million hectares, mostly in developing countries. Rainfed yields increase by 11 percent, and rainfed production increases by 187 million tons compared with business as usual. The share of the world's cereal produced on rainfed lands will increase significantly, to 62 percent globally, 51 percent in developing countries, and 78 percent in developed countries, compared with 56, 43, and 74 percent, respectively, under business as usual.

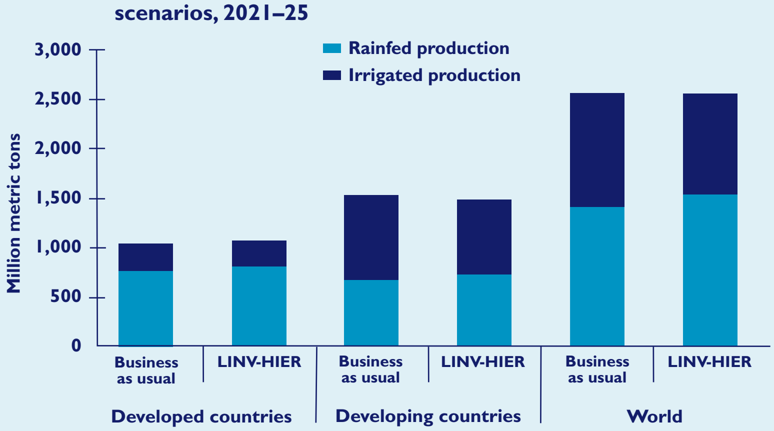
The second scenario looks at the possibility of increasing effective rainfall use through water harvesting, conservation tillage, and precision farming to counteract the reduction of irrigated production due to low investment in irrigation development and water supply. Effective rainfall use increases by 10–15 percent above 1995 levels from 1995 to 2025 in those basins and countries with rainwater shortages for crop production, including river basins in the western United States, northern and western China, northern and western India, and countries in West Asia and North Africa. An increase ranging from 5 to 10 percent is projected for other regions. These rates compare to 3–5 percent increases under business as usual.

Under this scenario world cereal prices (especially for rice) are higher than those under business as usual. The projected increase in effective rainfall water use cannot fully compensate for the irrigation decline. Although the global production of rainfed cereals is 126 million tons more than under business as usual, irrigated production is 131 million tons lower (Figure 18). Developing countries are harder hit, with a shortfall in total cereal production of 42 million tons (2.8 percent) that causes a reduction in demand of 26 million tons and an increase in imports of 16 million tons. Nevertheless, the results show significant benefits from better management that generates higher effective rainfall.

These scenarios show that there is significant potential for increasing rainfed production to compensate for lower investment in irrigation. Appropriate investments and policy reforms, however, will be required to enhance the contribution of rainfed agriculture. In some regions water harvesting has the potential to improve rainfed crop yields. But crop breeding for rainfed environments is crucial to future cereal yield growth. Strong progress has been made in breeding for enhanced crop yields in rainfed areas, even in the less favorable environments. The continued application of conventional breeding and the recent developments in nonconventional breeding offer considerable potential for improving cereal yield growth in rainfed environments. Progress could be hastened by extending research to farmers and by using tools derived from biotechnology to assist conventional breeding (Table 2).

Governments must also combine crop research targeted to rainfed areas with increased investment in rural infrastructure and policies to close the gap between potential and actual yields in rainfed areas. Important policies include higher priority for rainfed areas in agricultural extension services and access to markets, credit, and input supplies.

Figure 18 Rainfed and irrigated cereal production, business as usual and lower irrigation investment and higher effective rainfall use scenarios, 2021–25



SOURCE: Authors' estimates and IMPACT-WATER projections, June 2002.
NOTE: LINV-HIER stands for lower irrigation investment and higher effective rainfall use.

Table 2 Rainfed and irrigated cereal yield by region, for three scenarios: business as usual, lower irrigation investment and higher rainfed area and yield, and lower irrigation investment and higher effective rainfall use, 2021–25

	Rainfed yield (metric tons/hectare)			Irrigated yield (metric tons/hectare)		
REGION	BAU	LINV-HRF	LINV-HIER	BAU	LINV-HRF	LINV-HIER
Asia	2.46	2.96	2.49	4.50	4.05	4.13
Latin America	2.92	3.13	3.08	5.46	4.85	4.92
Sub-Saharan Africa	1.19	1.22	1.30	3.08	2.95	2.99
West Asia/North Africa	1.75	1.93	1.89	4.86	4.55	4.61
Developed countries	3.89	4.24	3.95	5.97	5.54	5.59
Developing countries	2.08	2.36	2.18	4.53	4.09	4.16
World	2.77	3.07	2.86	4.80	4.37	4.43

SOURCE: Authors' estimates and IMPACT-WATER projections, June 2002.

NOTE: BAU stands for business as usual, LINV-HRF stands for lower irrigation investment and higher rainfall area and yield, and LINV-HIER stands for lower irrigation investment and higher effective rainfall use.

Implications for the Future

Water scarcity will get much worse if policy and investment commitments from national governments and international donors and development banks weaken further. The water crisis scenario—predicated on the worsening of a number of already evident trends—would lead to a breakdown in domestic water service for hundreds of millions of people, devastating loss of wetlands, serious reductions in food production, and skyrocketing food prices that would force declining per capita food consumption in much of the world. Failure to adopt water-saving technology improvements and policy reforms could make demand for nonirrigation water grow even faster than we projected, further worsening water scarcity.

Water scarcity can lead to declining food demand and increasing food prices. As shown in the water crisis scenario, major cereal crop prices may be more than double the projections under the business as usual scenario, and at the same time food demand may be significantly reduced, especially in developing countries. Moreover, price increases can have an even larger impact on low-income consumers.

Excessive diversion of water flows and overdraft of groundwater have already caused environmental problems in many regions around the world. Our analysis shows that the problems, from a local to a worldwide scale, will likely be even more serious in the future. If current investment plans and recent trends in the water and food sectors continue, expanding the environmental uses of water would require reducing the consumption of irrigation water or domestic and municipal water or both. Thus, in the absence of policy and investment reform, competition over water between households and industries and between farmers and environmental uses will increase in many parts of the world.

With water becoming increasingly scarce, continued high flow diversions would become self-defeating. Excess extraction speeds the recession of ecological systems and lowers water quality, finally reducing the qualified water supply for human uses. This has already occurred in the Aral Sea Basin in Central Asia. Groundwater overdraft can likewise lead to the loss of an important water source for human uses, as is already happening in many regions.

However, the analysis also reveals cause for hope. The scenarios explored in this report point to three broad strategies that can address the challenge posed by water scarcity for food production:

1. invest in infrastructure to increase the supply of water for irrigation, domestic, and industrial purposes;
2. conserve water and improve the efficiency of water use in existing systems through reforms in water management and policy; and
3. improve crop productivity per unit of water and land through integrated water management and agricultural research and policy efforts, including crop breeding and water management for rainfed agriculture.

Although the financial, environmental, and social costs of new water supply projects are high, in some regions, especially in developing countries, it is still crucial to selectively expand water supply, storage, and withdrawal capacities. Storage and water distribution systems (such as water lift projects and canals) are particularly needed for Sub-

Saharan Africa, some countries in South and Southeast Asia (such as Bangladesh, India, and Viet Nam), and some countries in Latin America. These countries must consider not only the full social, economic, and environmental costs of development, but also the costs of failure to develop new water sources. Projects must be designed to account for full costs and benefits, including not only irrigation benefits, but also health, household water use, and catchment improvement benefits. It is also essential to improve compensation programs for those who are displaced or negatively affected by water projects.

Expanding water supplies can help alleviate water scarcity, but the results show that the most promising avenue is likely to be water management reforms, incentive policies, and investments in infrastructure and technology to enhance efficiency in existing uses. Throughout this report, we have shown that feasible improvements in the efficiency of basin-scale irrigation water use can, on a global scale, compensate for irrigation reduction resulting from (1) the phasing out of groundwater overdraft worldwide; (2) increased committed environmental flows; (3) higher prices for agricultural water use (which themselves encourage investments in improved efficiency); and (4) low irrigated area development. We have also shown that improving irrigation water use efficiency is an effective way to increase water productivity.

In severely water-scarce basins, however, relatively little room exists for improving water use efficiency, and food production and farm incomes could fall significantly if water for irrigation is transferred to other uses. In these basins, governments will need to compensate for the negative impact of growing water scarcity on agriculture by alternative means, such as investing in agriculture to obtain more rapid growth in crop yields, promoting the diversification of farming into less water-intensive crops, and diversifying the economy to reduce the economic role of agriculture over time.

Making big improvements in river basin efficiency in specific river basins will require site-specific analysis and implementation. Basin efficiency depends on improvements both in water-saving technologies and in the institutions governing water allocation, water rights, and water quality. Industrial water recycling, such as recirculation of cooling water, can be a major source of water savings in many countries. Much potential also exists for improving the efficiency of domestic water use. Steps may include anything from detecting and repairing leaks in municipal systems to installing low-flow showerheads and low-water or waterless toilets. Treated wastewater can be used for a variety of nonpotable purposes including landscape and recreational irrigation, maintenance of urban stream flows and wetlands, wastewater-fed aquaculture, and toilet flushing. To encourage water-saving innovation, domestic and industrial water prices should be increased. Generalized subsidies should be replaced with subsidies targeted to the poor. Water providers should charge low prices for a basic entitlement of water, with increasing prices for greater amounts of water.

Improvements in the irrigation sector can be made at the technical, managerial, and institutional levels. Technical improvements include advanced irrigation systems such as drip irrigation, sprinklers, conjunctive use of surface and groundwater, and precision agriculture, including computer monitoring of crop water demand. Managerial improvements include the adoption of demand-based irrigation scheduling systems and improved equipment maintenance. Institutional improvements involve the establishment of effective water user associations and water rights, the creation of a better legal environment for water allocation, and the introduction of higher water prices. Great care must be taken in designing a water pricing system for agriculture. Direct water price increases are likely to be punitive to farmers because water plays such a large role in their cost of production. Better alternatives would be pricing schemes that pay farmers for reducing water use, and water rights and water trading arrangements that provide farmers or water user associations with incentives to reduce wasteful water use.

Rainfed agriculture emerges from the analysis as a potential key to sustainable development of water and food. Rainfed agriculture still produces about 60 percent of total cereals, and its role remains very important in both the business as usual and the sustainable water scenarios. Improved water management and crop productivity in rainfed areas would relieve considerable pressure on irrigated agriculture and on water resources. Exploiting the full potential of rainfed agriculture, however, will require investing in water harvesting technologies, crop breeding targeted to rainfed environments, agricultural extension services, and access to markets, credit, and input supplies in rainfed areas.

A large part of the world is facing severe water scarcity, but the impending water crisis can be averted. The precise mix of water policy and management reforms and investments, and the feasible institutional arrangements and policy instruments to be used, must be tailored to specific countries and basins. They will vary based on level of development, agroclimatic conditions, relative water scarcity, level of agricultural intensification, and degree of competition for water. But these solutions are not easy, and they take time, political commitment, and money. Fundamental reform of the water sector must start now.

Notes

1. W. J. Cosgrove and F. Rijsberman, *World Water Vision: Making Water Everybody's Business* (London: World Water Council and World Water Vision and Earthscan, 2000); I. A. Shiklomanov, "Electronic Data Provided to the Scenario Development Panel, World Commission on Water for the 21st Century" (State Hydrological Institute, St. Petersburg, Russia, 1999), mimeo.
2. E. Bos and G. Bergkamp, "Water and the Environment," in *Overcoming Water Scarcity and Quality Contraints*, 2020 Focus 9, ed. R. S. Meinzen-Dick and M. W. Rosegrant (Washington, D.C.: International Food Policy Research Institute, 2001).
3. The business as usual, crisis, and sustainable scenarios are compared using average 2025 results generated from 30 hydrologic scenarios. The other scenarios are compared with business as usual based on a single 30-year hydrologic sequence drawn from 1961–90, and results are shown as the average of the years 2021–25.
4. Water demand can be defined and measured in terms of withdrawals and actual consumption. While water withdrawal is the most commonly estimated figure, consumption best captures actual water use, and most of our analysis will utilize this concept.
5. The global projection is broadly consistent with other recent projections to 2025, including the 4,580 km^3 in the medium scenario of J. Alcamo, P. Döll, F. Kaspar, and S. Sieberg, *Global Change and Global Scenarios of Water Use and Availability: An Application of Water GAP 1.0* (Kassel, Germany: Center for Environmental System Research, University of Kassel, 1998), the 4,569 km^3 in the "business-as-usual" scenario of D. Seckler, U. Amarasinghe, D. Molden, S. Rhadika, and R. Barker, *World Water Demand and Supply, 1990 to 2025: Scenarios and Issues*, Research Report Number 19 (Colombo, Sri Lanka: International Water Management Institute, 1998), and the forecast of 4,966 km^3 (not including reservoir evaporation) of Shiklomanov, "Electronic Data."
6. Compared with other sectors, the growth of irrigation water potential demand is much lower, with 12 percent growth in potential demand between 1995 and 2025 in developing countries and a slight decline in potential demand in developed countries.
7. All tons mentioned in this report are metric tons.
8. J. A. Allan, "Water Security Policies and Global Systems for Water Scarce Regions," in *Sustainability of Irrigated Agriculture—Transactions*, Vol. 1E, special session: The Future of Irrigation under Increased Demand From Competitive Uses of Water and Greater Needs for Food Supply—R.7 in the symposium on Management Information Systems in Irrigation and Drainage, 16th Congress on Irrigation and Drainage, Cairo (New Delhi: International Commission on Irrigation and Drainage, 1996).

The IMPACT-WATER Model

To explore the relationships among water, environment, and food production, we developed a global modeling framework, IMPACT-WATER, that combines an extension of the International Model for Policy Analysis of Agricultural Commodities and Trade (IMPACT) with a newly developed Water Simulation Model (WSM).[1] IMPACT is a partial equilibrium model of the agricultural sector, representing a competitive agricultural market for crops and livestock. Demand is a function of prices, income, and population growth. Growth in crop production in each country is determined by crop and input prices and the rate of productivity growth. World agricultural commodity prices are determined annually at levels that clear international markets. IMPACT generates projections for crop area; yield; production; demand for food, feed, and other uses; prices; and trade. For livestock, IMPACT projects numbers, yield, production, demand, prices, and trade.

For this study we integrated the IMPACT model with WSM, a basin-scale model of water resource use, to create a linked model, IMPACT-WATER. We made the linkage by (1) incorporating water in the crop area and yield functions; and (2) simultaneously determining water availability at the river basin scale, water demand by irrigation and other sectors, and crop production. IMPACT-WATER divides the world into 69 spatial units, including macro river basins in China, India, and the United States and aggregated basins over other countries and regions. Domestic and industrial water demands are estimated as a function of population, income, and water prices. Water demand in agriculture is projected based on irrigation and livestock production growth, water prices, climate, and water use efficiency for irrigation at the basin level. Then water demand is incorporated as a variable in the crop yield and area functions for each of eight major food crops: wheat, rice, maize, other coarse grains, soybeans, potatoes, yams and sweet potatoes, and cassava and other roots and tubers. Water requirements for all other crops are estimated as a single aggregate demand.

We treat water availability as a stochastic variable with observable probability distributions. WSM simulates water availability for crops at a river basin scale, taking into account precipitation and runoff, water use efficiency, flow regulation through reservoir and groundwater storage, nonagricultural water demand, water supply infrastructure and withdrawal capacity, and environmental requirements at the river basin, country, and regional levels. Environmental impacts can be explored through scenario analysis of committed instream and environmental flows, salt leaching requirements for soil salinity control, and alternative rates of groundwater pumping.

[1] For a more detailed description of the integrated model, see M.W. Rosegrant, X. Cai, and S.A. Cline, *World Water and Food to 2025: Dealing with Scarcity* (Washington, D.C.: International Food Policy Research Institute, 2002).

2020 VISION INITIATIVE
INTERNATIONAL ADVISORY COMMITTEE

IFPRI

INTERNATIONAL FOOD POLICY RESEARCH INSTITUTE

2033 K Street, NW
Washington, DC 20006-1002 USA
Telephone: 001-202-862-5600
Fax: 001-202-467-4439
Email: ifpri@cgiar.org

Website: www.ifpri.org

ABOUT THE AUTHORS

Mark W. Rosegrant is a senior research fellow in the Environment and Production Technology Division of the International Food Policy Research Institute (IFPRI) and principal researcher at the International Water Management Institute (IWMI). Ximing Cai is a research fellow at IFPRI and a researcher at IWMI. Sarah A. Cline is a research analyst at IFPRI.

Also available from the 2020 Vision Initiative:

Rosegrant, Mark W., Ximing Cai, and Sarah A. Cline. 2002. *World water and food to 2025: Dealing with scarcity*. IFPRI-2020 Vision/International Water Management Institute book. Washington, D.C. U.S.A.: International Food Policy Research Institute.

Rosegrant, Mark W., Michael S. Paisner, Siet Meijer, and Julie Witcover. 2001. *2020 Global food outlook: Trends, alternatives and choices.* 2020 Vision Food Policy Report. Washington, D.C., U.S.A.: International Food Policy Research Institute.

Meinzen-Dick, Ruth S., and Mark W. Rosegrant, eds. 2001. *Overcoming water scarcity and quality constraints.* 2020 Vision Focus 9. Washington, D.C., U.S.A.: International Food Policy Research Institute.

FUTURE HARVEST

ISBN 0-89629-646-6
9 780896 296466