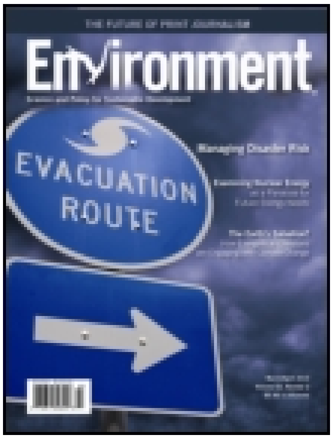


Environment: Science and Policy for Sustainable Development
Publication details, including instructions for authors and subscription information:
http://www.tandfonline.com/loi/venv20

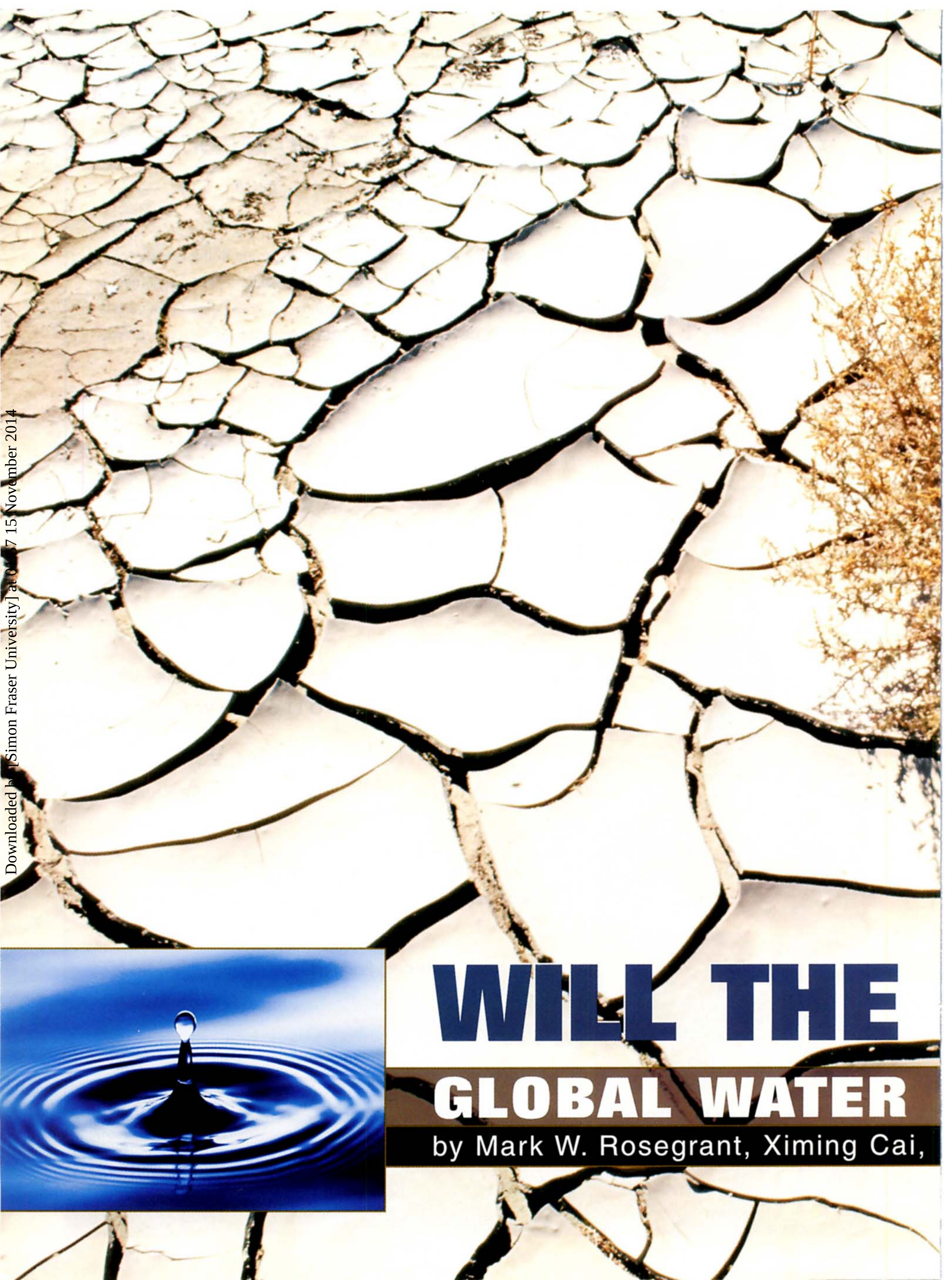
Will The World Run Dry? Global Water and Food Security

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

Published online: 30 Mar 2010.

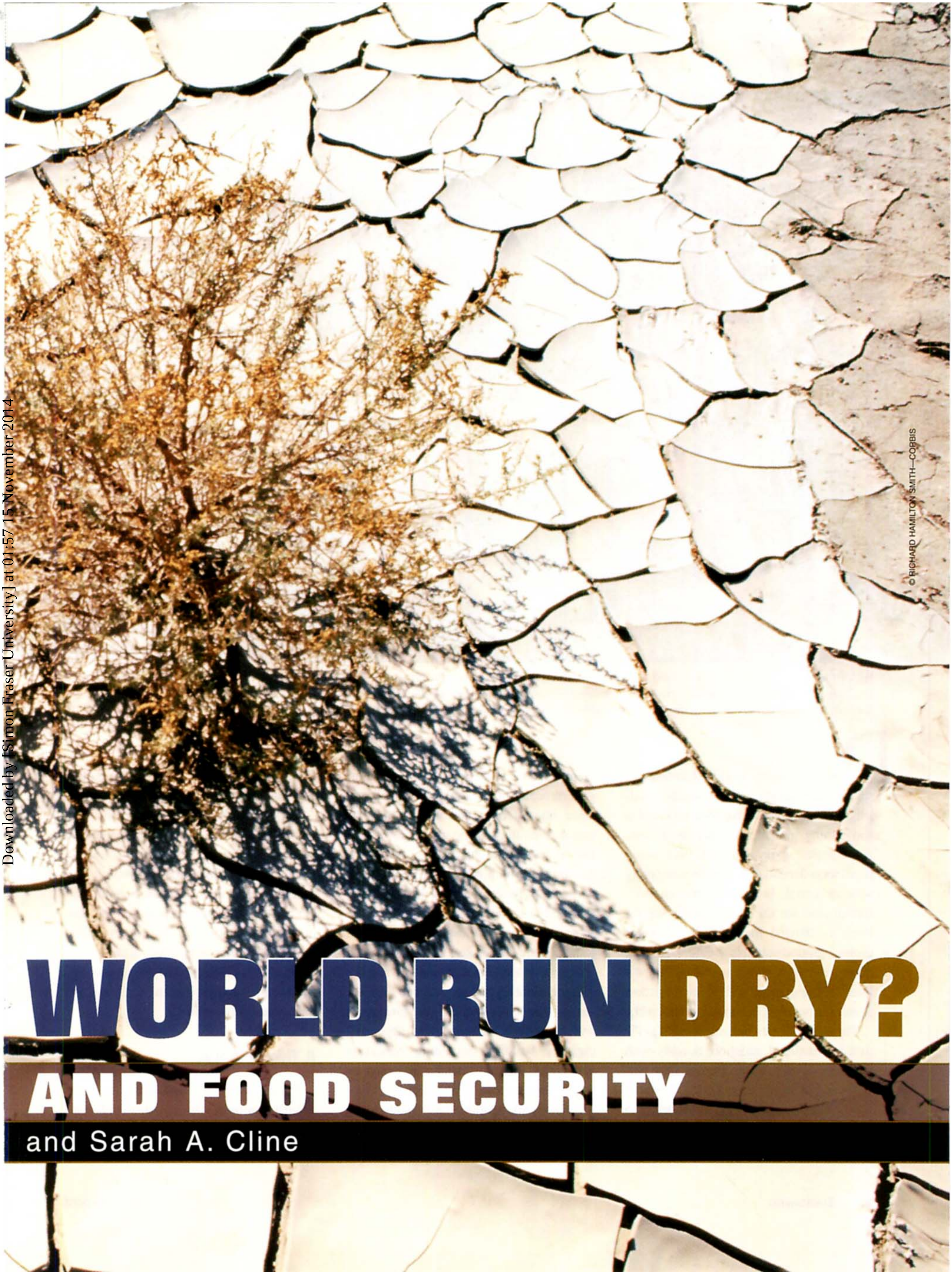
To cite this article: Mark W. Rosegrant , Ximing Cai & Sarah A. Cline (2003) Will The World Run Dry? Global Water and Food Security, Environment: Science and Policy for Sustainable Development, 45:7, 24-36, DOI: 10.1080/00139150309604555

To link to this article: http://dx.doi.org/10.1080/00139150309604555



WILL THE GLOBAL WATER

by Mark W. Rosegrant, Ximing Cai,



WORLD RUN DRY?

AND FOOD SECURITY

and Sarah A. Cline

Water today is a scarce resource facing heavy and unsustainable demand from users of all kinds. In many areas, such as this drought-stricken village in western India, groundwater supplies are depleted before the water table can recharge, and access to clean water is limited. Such scenarios underscore the formidable challenges of meeting the world's water needs.

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 becoming more costly.

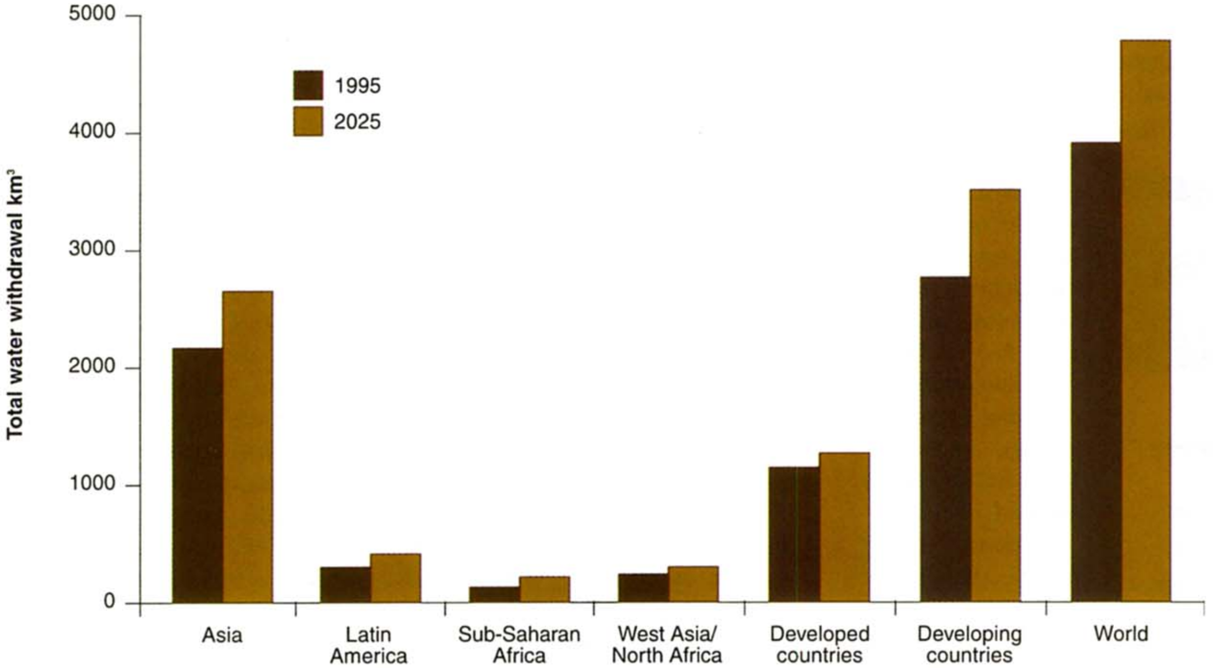
These challenges are receiving significant international attention, notably with the third World Water Forum that was convened in Japan from 16 to 23 March 2003. This meeting was the third in a series of meetings held every three years, bringing together water experts, government leaders, representatives from nongovernmental organizations (NGOs), and other interested parties to examine the major dilemmas facing the water sector and to seek solutions to these problems. The third forum hosted more than 24,000 participants from more than 180 countries and held sessions focusing on many of the most crucial water issues facing the world today. Some of the key issues addressed include the need for safe, clean water for all individuals; good governance in water management, including an integrated water resources management approach; capacity building, including education and access to information; financing of water resources infrastructure; and increased participation of all stakeholders, including women and the poor. More than 100 commitments on water were made during the forum, based primarily on the key water issues.

But despite this attention, the challenge of meeting both water and food security remains formidable. Planning of how to meet the increasing needs of various water users depends upon an understanding of the current situation and potential impacts of policy decisions. To this end, a global model of water and food supply and demand was developed to examine long-term prospects for water and food security under alternative policies.

A Thirsty World

Water development underpins food security, people's livelihoods, industrial growth, and environmental sustainability throughout the world. In 1995

Figure 1. Total water withdrawal by region in 1995 and business-as-usual projections for 2025



SOURCE: M. W. Rosegrant, X. Cai, and S. A. Cline, *Global Water Outlook to 2025: Averting an Impending Crisis* (Washington, D.C.: International Food Policy Research Institute, 2002), 2.

the world withdrew 3,906 cubic kilometers (km^3) of water for these purposes (see Figure 1 on this page). 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, in turn constraining food production.[1]

About 250 million hectares are irrigated worldwide today, nearly five times more than at the beginning of the twentieth 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. 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.[2]

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.[3] Although the domestic and industrial sectors use far less water than agriculture, the growth in water consumption in these sectors has been rapid.

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.

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 collective choices of 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. Three alternative futures for global water and food show the very different outcomes that policy choices produce.[4]

Business-As-Usual Scenario

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

Policy decisions—and the actions of billions of individuals—determine fundamental, long-term drivers of water and food supply and demand.

Over the coming decades, the area of land devoted to cultivating food crops would grow slowly in most of the world because of urbanization, soil degradation, and slow growth in irrigation investment, as well as the fact that a high proportion of arable land is already cultivated. Moreover, steady or declining real prices for cereals would make it unprofitable for farmers to expand harvested area. As a result, greater food production would depend primarily on increases in yield. Yet growth in crop yields would 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 and would not easily be repeated.

In the water sector, the management of river basin and irrigation water would become more efficient, but slowly. Governments would continue to transfer management of irrigation systems to farmer organizations and water-user associations. Such transfers would increase water efficiency if 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 would adopt more efficient irrigation practices. Economic incentives to induce more efficient water management, however, would 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 would 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.

In the business-as-usual scenario, public investment in expanding irrigation and reservoir storage would 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 would construct dams, and reservoir water for irrigation would increase moderately.

With slow growth in irrigation from surface water, farmers would 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, and West Asia and North Africa—would continue to do so.[5]

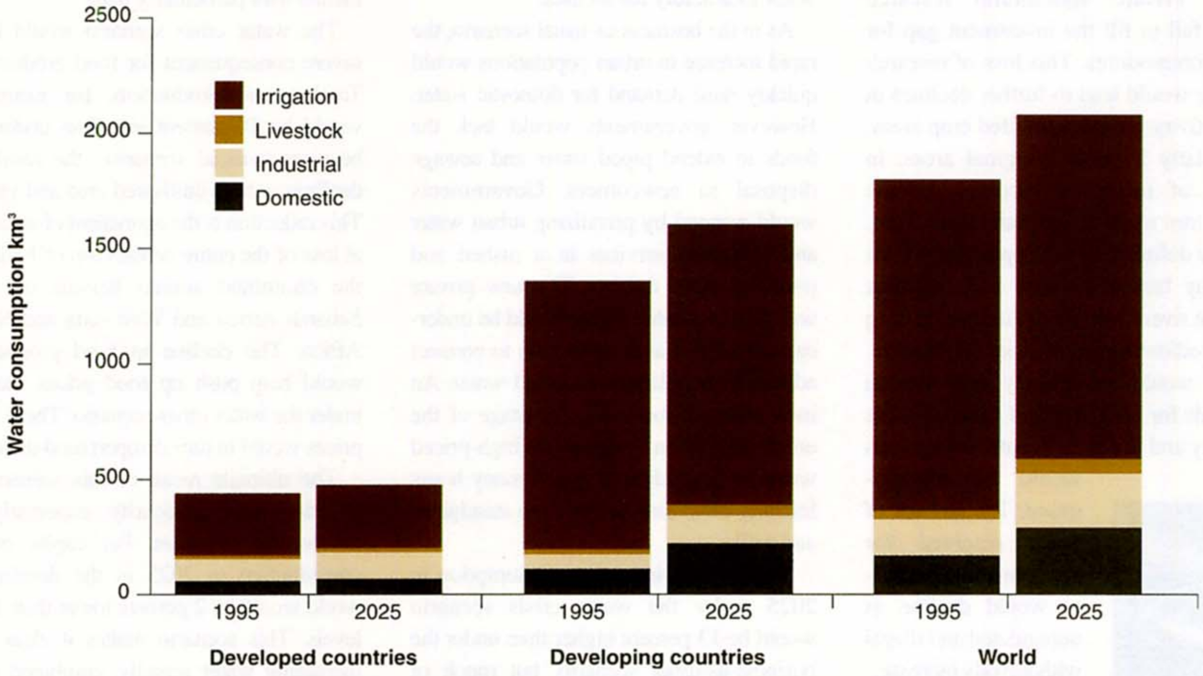
The cost of supplying water to domestic and industrial users would rise dramatically. Better delivery and more efficient home water use would lead to some increase in the proportion of households connected to piped water. Many households, however, would remain unconnected. Small price increases for industrial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

Environmental and other interest groups would 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 would not increase.

Almost all users would place heavy demands on the world's water supply under the business-as-usual scenario. Together, consumption of water for domestic, industrial, and livestock uses—that is, all nonirrigation uses—would increase dramatically, rising by 62 percent from 1995 to 2025 (see Figure 2 on page 29). Because of rapid population growth and rising per capita water use, domestic consumption would increase by 71 percent, more than 90 percent of which would be in developing countries. Industrial water use would grow much faster in developing countries than in developed countries. The intensity of industrial water use would 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 would 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. 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.

Water scarcity under the business-as-usual scenario would lead to slower growth of food production and substantial shifts in where the world's food is grown. Farmers would find themselves unable to raise crop yields as quickly as in the past in the face

Figure 2. Water consumption by sector and region in 1995 and business-as-usual projections for 2025



SOURCE: M. W. Rosegrant, X. Cai, and S. A. Cline, *Global Water Outlook to 2025: Averting an Impending Crisis* (Washington, D.C.: International Food Policy Research Institute, 2002), 6.

of a decline in relative water supply. Crop-harvested area is expected to grow even more slowly than crop yield in the coming decades, with all of the growth projected to occur in developing countries.

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.[6] Under the business-as-usual scenario, developing countries would dramatically increase their reliance on food imports by 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 policy makers concerned with 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.

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 would worsen. Governments would 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, would cause water prices for irrigators to rise. Water users would fight price increases, and conflict would spill over to local management and cost-sharing arrangements. Spending on the operation and maintenance of secondary and tertiary systems would fall dramatically, and deteriorating infrastructure and poor management would lead to falling water-use efficiency. Likewise, attempts to organize river basin organizations to coordinate water management would fail because of inadequate funding and high levels of conflict among water stakeholders within the basin.

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

A moderate worsening of many of the current trends in water and food policy and in investment could build to a genuine water crisis.

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

In the attempt to get enough water to grow their crops, farmers would 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 would begin to fail. With declining water tables, farmers would find the cost of extracting water too high, and a big drop in groundwater extraction from these regions would further reduce water availability for all uses.

As in the business-as-usual scenario, the rapid increase in urban populations would quickly raise demand for domestic water. However, governments would lack the funds to extend piped water and sewage disposal to newcomers. Governments would respond by privatizing urban water and sanitation services in a rushed and poorly planned fashion. The new private water and sanitation firms would 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.

Total worldwide water consumption in 2025 under the water crisis scenario would be 13 percent higher than under the business-as-usual scenario, but much of this water would be wasted and of no benefit to anyone. Virtually all of the increase would go to irrigation, mainly because farmers would use water less efficiently and withdraw more water to compensate for water losses. The supply of irrigation water would be less reliable, except in regions where so much water is diverted from environmental uses to irrigation that it balances the lower water-use efficiency.

For most regions, per capita demand for domestic water would be significantly lower than under the business-as-usual scenario, in both rural and urban areas. The result is that people would not have access to the water they would need for drinking and sanitation. Compared with outcomes under the business-as-usual scenario, the total domestic demand under the water crisis scenario would be 28 percent less in developing countries, 7 percent less in developed countries, and 23 percent less globally (see Figure 3 on page 31).

The water crisis scenario would also have significant impacts on other water users. Demand for industrial water would increase, owing to failed technological improvements and economic measures. With water diverted to make up for less efficient water use in other sectors, the water crisis scenario would hit environmental uses particularly hard.

The water crisis scenario would have severe consequences for food production. Total cereal production, for example, would be 10 percent less than under the business-as-usual scenario—the result of declines in both cultivated area and yields. This reduction is the equivalent of an annual loss of the entire cereal crop of India, or the combined annual harvest of sub-Saharan Africa and West Asia and North Africa. The decline in food production would help push up food prices sharply under the water crisis scenario. These high prices would in turn dampen food demand.

The ultimate result of this scenario is growing food insecurity, especially in developing countries. Per capita cereal consumption in 2025 in the developing world would be 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 would take a significant bite out of the real income of poor consumers. Malnutrition would increase substantially, given that the poorest people in low-income developing countries spend more than half their income on food. Sharp price increases could 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 would 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 would directly target these rainfed areas. Improved policies and increased investment in rural infrastructure would help link remote farmers to markets and reduce the risks of rainfed farming.

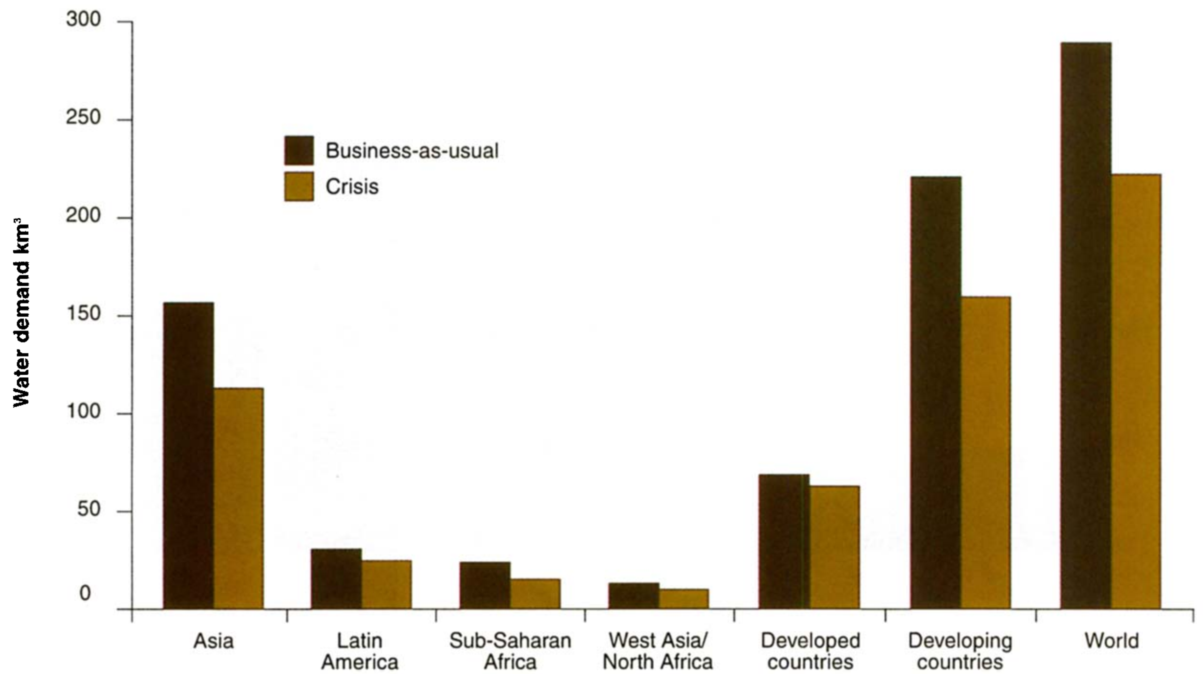
To stimulate water conservation and free up agricultural water for environmental, domestic, and industrial uses, the effective price of water to the agricultural sector would be gradually increased. Agricultural water price increases would be implemented through incentive programs that provide farmers 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 would be twice as high in developed countries and three times as high in developing countries compared with the business-as-usual scenario. The government would 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 would 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 would increase their on-farm investments in irrigation and water management technology, and the efficiency of irrigation systems and basin water use would improve significantly.

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

Farmers would 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 would 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 would

Figure 3. Domestic consumption of water by region, business-as-usual and crisis scenarios, 2025



SOURCE: M. W. Rosegrant, X. Cai, and S. A. Cline, *Global Water Outlook to 2025: Averting an Impending Crisis* (Washington, D.C.: International Food Policy Research Institute, 2002), 11.

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 would be canceled, but others would proceed with support from civil society groups. Yet new storage capacity would be less necessary because rapid growth in rainfed crop yields would help reduce rates of reservoir sedimentation from erosion due to slash-and-burn cultivation.

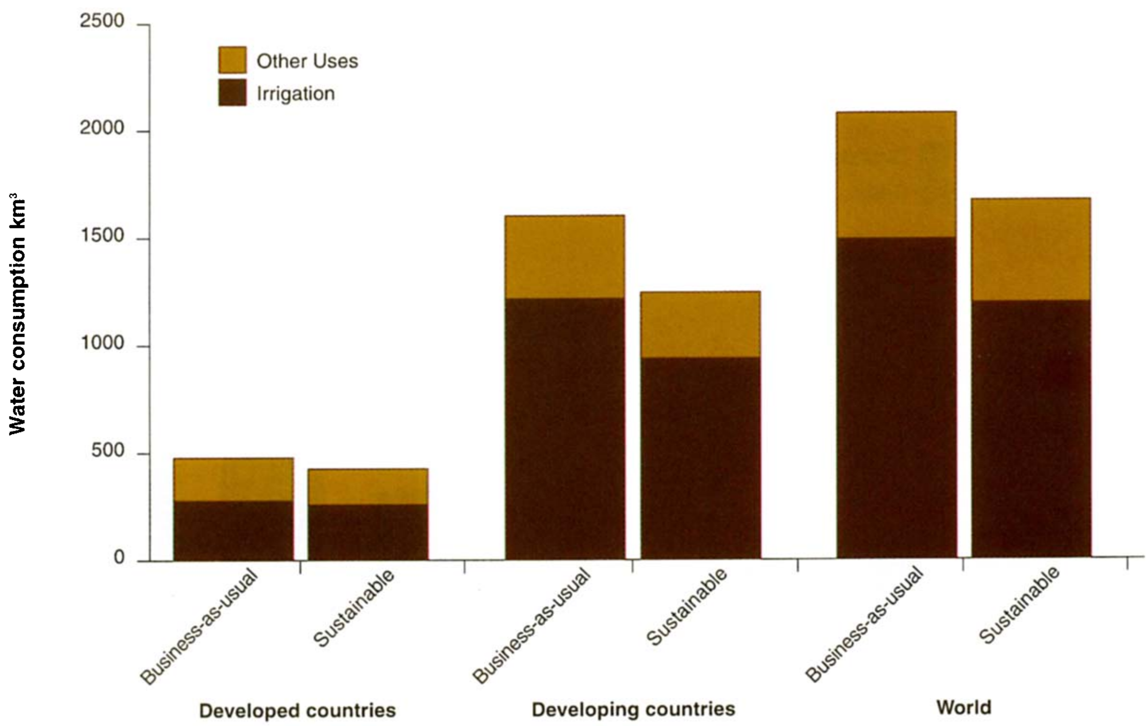
Policy toward groundwater extraction would change significantly. Market-based approaches would assign rights to groundwater based on annual withdrawals as well as the renewable stock of groundwater. This step would be combined with stricter regulations and better enforcement of such tigher controls.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

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

With strong societal pressure for improved environmental quality, allocations for environmental uses of water would increase. Moreover, the reforms in agricultural and nonagricultural water sectors would reduce pressure on wetlands and other environmental uses of water. Greater investments and better water management would 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, would be allocated to instream environmental uses.

In the sustainable water scenario, the world consumes less water but reaps greater benefits than under the business-as-usual scenario, especially in developing countries. In 2025, total worldwide water consumption would be 20 percent lower under the sustainable scenario than under the business-as-usual scenario (see Figure 4 on this page). This reduction in consumption would free up water for environmental uses. Higher water prices and higher water-use efficiency would reduce consumption of irrigation water by 296 km^3 compared with the business-as-usual scenario. The reliability of irrigation water supply would be reduced slightly in the sustainable scenario—as compared with the business-as-usual scenario—because of a higher priority on environmental flows. Over time, however, more

Figure 4. Total and irrigation water consumption, by region, business-as-usual and sustainable scenarios, 2025



SOURCE: M. W. Rosegrant, X. Cai, and S. A. Cline, *Global Water Outlook to 2025: Averting an Impending Crisis* (Washington, D.C.: International Food Policy Research Institute, 2002), 14.

efficient water use in this scenario would counterbalance the transfer of water to the environment and would result in an improvement in the reliability of supply of irrigation water by 2025.

This scenario would improve the domestic water supply through universal access to piped water for rural and urban households. Other water sectors would also be affected under the sustainable water scenario. Industrial water demand would be reduced under the sustainable water scenario through technological improvements and effective economic incentives. The environment would be 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.

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 would be slightly lower than under the business-as-usual scenario, owing to less water for irrigation and slightly lower crop prices. With faster growth in rainfed yields making up for slower growth in harvested area and irrigated yields, total cereal production in 2025 would be 19 million tons more (a 1 percent difference) under the sustainable water scenario 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 would be 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.

Implications for the Future

In the sustainable water scenario, the world consumes less water but reaps greater benefits, especially in developing countries.

Water scarcity will get much worse if policy and investment commitments from national governments, 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, a devastating loss of wetlands, serious reductions in

Strategies to mitigate the effects of water scarcity, such as this method to retain dew and irrigation water for a melon crop near Seville, Spain (above, left), may offer a sustainable future. Without such strategies, drought-ravaged landscapes (right) could be more the norm.

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 projected, further worsening water scarcity.

Water scarcity will get much worse if policy and investment commitments from national governments, international donors, and development banks weaken further.

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. The 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 here point to three broad strategies that can address the challenge posed by water scarcity for food production:

- investment in infrastructure to increase the supply of water for irrigation, domestic, and industrial purposes;
- conservation of water and improvements in the efficiency of water use in existing systems, through reforms in water management and policy, including stronger incentives for water conservation; and
- improvements in 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 Vietnam), and some countries in Latin America. These countries must consider

© ROSEMARY GREENWOOD—ECOSCENE/CORBIS

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. Feasible improvements in the efficiency of basin-scale irrigation water use can, on a global scale, compensate for irrigation reduction resulting from the phasing out of groundwater overdraft worldwide, increased committed environmental flows, higher prices for agricultural water use (which themselves encourage investments in improved efficiency), and low irrigated area development. In addition, 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 seek alternative means to compensate for the negative impact of growing water scarcity on agriculture, 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 is a 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.

Mark W. Rosegrant is senior research fellow at the International Food Policy Research Institute (IFPRI) and principal researcher at the International Water Management Institute (IWMI). Rosegrant has extensive experience in research and policy analysis in agriculture and economic development, with an emphasis on critical water issues as they impact world food security, rural livelihoods, and environmental sustainability. He also developed IFPRI's International Model for Policy Analysis of Agricultural Commodities and Trade (IMPACT) and the IMPACT-WATER models. He continues to lead the team that maintains the models, which have been used to examine key policy options concerning food prices, food security, livestock and fisheries demand, agricultural research allocation, water resources, environment, and trade. He also currently coordinates a joint modeling team between IFPRI and IWMI, developing integrated global water and food models, and has written and edited numerous publications on agricultural economics, water resources, and food policy analysis. He can be reached via e-mail at m.rosegrant@cgiar.org. Ximing Cai is a research fellow at IFPRI and a researcher with IWMI. Cai's current research interests include water resource planning and management, operations research and their application to integrated water resources, and agricultural and economic systems. He can be reached via e-mail at x.cai@cgiar.org. Sarah A. Cline is a research analyst with IFPRI. Cline's work at IFPRI focuses on water resources policy and management, as well as global food supply, demand, and trade issues. She can be reached via e-mail at s.cline@cgiar.org.

NOTES

1. The source of these data is the 2002 IMPACT-WATER assessments and projections. IMPACT-WATER is a global modelling framework 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). 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).

2. Food and Agricultural Organization of the United Nations (FAO), *FAOSTAT Database 2000* (Rome: FAO, 2000), accessible via http://apps.fao.org/.

3. World Health Organization (WHO) and United Nations Children's Fund (UNICEF), *Global Water Supply and Sanitation Assessment 2000 Report* (Geneva: UN, 2000).

4. For a more detailed analysis of these and other scenarios and a detailed discussion of methodology, see M. W. Rosegrant, X. Cai, and S. A. Cline, *Global Water Outlook to 2025: Averting an Impending Crisis* (Washington, D.C.: International Food Policy Research Institute, 2002); and Rosegrant, Cai, and Cline, note 1 above.

5. West Asia and North Africa is one of the regional groupings used in the IMPACT-WATER model. The region consists of the following countries: Egypt, Turkey, Algeria, Cyprus, Iran, Iraq, Jordan, Kuwait, Lebanon, Libya, Morocco, Saudi Arabia, Syria, Tunisia, United Arab Emirates, and Yemen.

6. 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, Sixteenth Congress on Irrigation and Drainage, Cairo (New Delhi: International Commission on Irrigation and Drainage, 1996), 117–32.