Chapter 9

Implications for the Future: Meeting the Challenge of Water Scarcity

Irrigation is, and will remain, the largest single user of water, but its share of world water consumption is projected to decline from 80 percent in 1995 to 72 percent in 2025 under the business-as-usual scenario (BAU). Economic expansion, population growth, and urbanization will drive demand in the non-irrigation sectors including domestic, industrial, and livestock water demand, which will increase by 62 percent over 1995 levels. In developing countries, non-irrigation water demand will grow even faster, increasing 100 percent between 1995 and 2025. Irrigation water consumption will grow by only 9 percent globally and 12 percent in developing countries because of limited growth in water supply and priority allocation for drinking water and industrial water uses. For the first time in world history, water demand for nonagricultural uses is growing more rapidly in absolute terms than water demand for agriculture. Compared with 1995, global water withdrawal in 2025 declines by 3 percent under the sustainable water use scenario (SUS) and by 36 percent under the water crisis scenario (CRI), according to our projections.

Growing water scarcity in response to rapid domestic and industrial water demand growth, particularly in the developing countries, is worsened by often severe constraints on the water supply. These constraints can be caused, first, by source limits—meaning absolute constraints on water supply—in some dry and highly developed regions including areas of northern China, northwestern India, the western United States, and much of West Asia and North Africa (WANA),[1] and, second, by economic constraints that slow the growth of new water supply infrastructure including dams and water distribution systems. These economic constraints are the result of the high financial, social, and environmental costs of dams, irrigation infrastructure, and domestic and industrial water supply.

Given water supply growth is limited but domestic and industrial water demand is growing rapidly, a significant share of the additional water for domestic and industrial uses will come from the irrigation sector. This transfer will lead to a substantial increase in water scarcity for irrigation, shown by the irrigation water supply reliability index (IWSR), which measures the availability of water relative to full water demand for irrigation. In developing countries, IWSR values decline from 0.81 in 1995 to 0.75 in 2025 under BAU, and in water-scarce basins the decline will be steeper. Increasing water scarcity for agriculture not only limits crop area expansion but also slows irrigated cereal yield growth in developing countries. This fall in the relative crop yield represents an annual yield loss through increased water stress of 0.68 metric tons per hectare in 2025, or an annual cereal production loss of 130 million metric tons. The increasing water scarcity—especially for irrigation—occurs virtually worldwide, but hotspots of extreme water scarcity increases exist including the Indus river basin in India, the Haihe and Yellow river basins in northern China, basins in northwestern China, Egypt, and WANA, and important U.S. food producing basins including the Colorado, Rio Grande, and Texas Gulf basins. Nationally and locally, the decline in irrigated production growth is projected to create food deficits and income losses in regions that depend heavily on irrigation. Globally, the decline reduces the contribution of irrigated production to future food production growth. Under BAU, irrigated production contributes 50 percent of the additional food produced between 1995 and 2025.

Water scarcity could severely—and easily—worsen if policy and investment commitments from national governments and international donors and development banks weaken further. The low investment scenario (LINV) leads to significant declines in irrigation water supply reliability and rising food prices; the water crisis scenario (CRI), under which current trends in water policy and investment deteriorate more broadly, results in the breakdown of domestic water service for hundreds of millions of people, devastating losses of wetlands, dramatic reductions in food production, and skyrocketing food prices that force declining per capita food consumption in much of the world. Uncertainty about increases in industrial and domestic demand, in terms of water-saving technology improvements, policy reform, and political will, could induce non-irrigation water demand to grow even faster than projected, further compounding water scarcity.

Water scarcity can induce increases in food prices and, hence, decreases in food demand. As shown under CRI, major cereal crop prices could more than double BAU projections, significantly reducing food demand especially in developing countries; per capita cereal demand in developing countries could actually drop below 1995 levels. Moreover, price increases have an even larger impact on low-income consumers because food represents such a large proportion of their real incomes and therefore can lead to increased malnutrition as well. Developing countries may experience additional impacts from food price increases through pressure on foreign exchange reserves, inflation, and impacts on macroeconomic stability and investment. Policy reform including agricultural research and management in rainfed areas and changes in the management of irrigation and water supplies would help to circumvent these price effects.

Excessive flow diversion and groundwater overdrafting have already caused environmental problems in many regions of the world. Our analysis shows that problems—locally and globally—will likely worsen in the future. Under current investment plans and with the continuation of recent trends in the water and food sectors, further expansion of environmental uses of water would require reductions in consumption of irrigation water and/or domestic and industrial water. Thus, in the absence of policy and investment reform, water for the environment and for food production will increasingly conflict in many parts of the world. The global decrease in environmental flows under CRI is about 1,490 cubic kilometers compared with SUS—equivalent to five times the annual flow of the Mississippi River and 20 times the annual flow of the Yellow River.

The criticality ratio—the ratio of water withdrawal to total renewable water—is a broad indicator of environmental water stress. High criticality ratios (values above 0.40) signify more intensive use of river basin water, a high probability of lower water availability and quality, and absolute water shortages during low flow periods. This ratio is globally low—only 0.08 in 1995 and 0.10 in 2025—because the global value includes water abundant countries such as Brazil and Canada that together account for 25 percent of the world's renewable freshwater. But environmental water stress is much higher, and is increasing rapidly, in critical areas in China, India, the United States, WANA, and elsewhere at local levels. In the U.S. Rio Grande and Colorado basins, the 1995 criticality ratio is close to 1.5 and remains constant at that high level until 2025 under BAU projections. In China, between 1995 and 2025, the Yellow River basin ratio increases from 0.9 to 1.2, the Haihe basin increases from 1.4 to 1.6, the Indus basin in India increases from 0.7 to 0.9, and in WANA the ratio increases from 0.7 to 0.9.

Even small increases in the criticality ratio may have large impacts on the environment given that usable water for both environmental purposes and offstream consumption is only a small fraction of the total renewable water in some regions because most natural runoff is inaccessible even with large water storage. In addition, the real conflict between water uses and committed environmental flows often occurs in dry periods or periods with large water requirements when the criticality ratio is higher than the annual average.

Nevertheless, the analysis here also points to cause for hope. The various scenarios explored in this book point to three broad strategies that could address the challenge posed by the increasing water scarcity for food production:

1) Increasing the supply of water for irrigation, domestic, and industrial purposes through investment in infrastructure;

2) Conserving water and improving the efficiency of water use in existing systems through water management and policy reform; and

3) Improving 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.

INVESTMENT IN INFRASTRUCTURE AND WATER SUPPLY

Although the financial, environmental, and social costs are high for new water supply projects, the selective expansion of water supply capacities, including storage and withdrawal capacities, is still necessary in some regions, especially in developing countries. Storage and water distribution systems such as water lift projects and canals are particularly needed for Sub-Saharan Africa (SSA), some countries in South and Southeast Asia (such as India, Bangladesh, and Viet Nam), and some countries in Latin America. In Bangladesh, storage is needed to reduce the high variance in water supply reliability. Infrastructure constraints will cause water shortages of as much as 60–70 percent in some basins in western and northwestern India after 2015, especially because of insufficient reservoir storage, and the same problem may occur in some basins in south and east India where internal rainfall distribution is uneven. Latin American countries such as Mexico and Argentina will require more storage for intra and interyear regulation after 2010. Thus, hard infrastructure investment has a role to play in the future in some regions but a reduced one compared with past trends, when dam-building and expansion of irrigated area drove rapid increases in irrigated area and crop yields particularly in developing countries.

New investments are increasingly expensive and politically sensitive, however, and appear to have relatively low payoffs. Still, some of the increasing demand for water must be met from carefully selected, economically efficient development of new water, both through impoundment of surface water and sustainable exploitation of groundwater resources, and through expansion in the development of nontraditional water sources.[2] Future construction of irrigation and water supply projects will require balanced development approaches that are acceptable to diverse constituencies. The full social, economic, and environmental costs of development must be considered, but so must the costs of failure to develop new water sources. Project design must ensure comprehensive accounting of full costs and benefits, including not only irrigation benefits but also health, household water use, and catchment improvement benefits. Of utmost importance is improved design and implementation of compensation programs for those who are displaced or negatively affected by water projects.

Sustainable development of groundwater resources also offers significant opportunities for many countries and regions where groundwater extraction remains below natural recharge, including southern China; central, western, and eastern SSA; much of Southeast Asia; and localized regions elsewhere. Groundwater irrigation is more flexible than surface water irrigation and can be used in conjunction with surface water to improve water use efficiency. Conjunctive use of surface and groundwater could be expanded significantly by (1) using wells for supplemental irrigation when canal water is inadequate or unreliable to reduce moisture stress and maximize irrigated crop yields; (2) pumping groundwater into canals to augment the canal water resources, lower the water table, and reduce salinity; and (3) viewing a canal command and its imbedded tubewells as an integrated system thereby optimizing joint use of canal and groundwater resources (Oweis and Hachum 2001; Frederiksen, Berkoff, and Barber 1993). But care must be taken in any expansion of groundwater because the actual extent of groundwater storage and recharge is poorly understood in most developing countries. In many regions, increased investment in exploration and evaluation of aquifer properties such as geometry, boundary and hydraulic characteristics, and recharge rates (including spatial and temporal variability) would have high payoffs.

WATER MANAGEMENT AND POLICY REFORM

Our results show that the most promising avenue for addressing water shortfalls into the future is water management and incentive policy reform to enhance the efficiency of existing water use, supported by infrastructure investment to modernize and upgrade existing irrigation and water delivery systems. As is shown in this book, feasible improvements in basin-scale irrigation water use efficiency can compensate—on a global scale—for reduced irrigation resulting from (1) phasing out groundwater overdraft worldwide; (2) increasing committed environmental flows; (3) raising water prices for agricultural use; and (4) reducing irrigated area development. Further, improving irrigation water use efficiency is shown to be an effective measure for increasing 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.

The institutional, technical, and financial feasibility of significant improvements in river basin efficiency in specific river basins requires site-specific research and analysis. Basin efficiency depends on improvements in water-saving technologies and infrastructure and in the institutions governing water allocation, water rights, and water quality. In the industrial sector in developing countries, the amount of water used to produce a given amount of output is far higher than in developed countries. Industrial water recycling could be a major source of water savings in many countries, however. Many industrial water users may be able to decrease their water use by at least 50 percent through water recycling methods (Beekman 1998). Cooling water accounts for more than half the industrial water used and has been one of the major sources for water recycling. Greater adoption of technology for re-circulation of cooling water in developing country factories would reduce the amount of water needed in many industrial processes. In many cases, the cooling water can then be decontaminated and used again for other purposes such as cleaning or landscape irrigation (Beekman 1998). Progress has been made in the urban areas of some water-scarce developing countries. In Beijing, for example, the rate of water recycling increased from 61 percent in 1980 to 72 percent in 1985; and between 1977 and 1991, total industrial water use declined steadily while output increased by 44 percent in real terms (Nickum 1994). Aggressive adoption of such recycling technology could be encouraged by regulations on allowable industrial water discharge and increased prices for water.

In the domestic water sector as well, considerable potential exists for improving water use efficiency. This may include anything from leak detection and repair in municipal systems to installation of low flow showerheads and low water or waterless toilets. It is sometimes argued that water savings from domestic water consumption are not possible because the fraction of water withdrawn actually consumed is small, and most of the water "lost" from systems is reused elsewhere. But a reduction in withdrawals directly saves consumptive use of water in coastal cities—which account for a significant share of the developing (and developed) world's population—where water withdrawn is lost to the oceans. Reduced water withdrawals, which reduce water reuse, also improve water quality, which effectively increases water supply by preventing a proportion of water from reaching such poor quality that it cannot be reused. Reducing withdrawals also generates economic benefits from reduced water treatment and recycling costs as it flows through the river basin (Gleick et al. 2002; Rosegrant 1997).

Reuse of domestic wastewater also has the potential to save freshwater and improve basin efficiency. Treated wastewater can be used for a variety of nonpotable purposes including landscape and recreational irrigation, maintaining urban stream flows and wetlands, and toilet flushing. Other important uses can include wastewater-fed aquaculture and the irrigation of agricultural and forest crops, which can be beneficial in fertilizing crops with wastewater nutrients, reducing overall amounts of chemical fertilizer used and reduce the need for additional pollution control.

Shuval (1990) points to the possible positive economic effects of wastewater reuse for agricultural irrigation by assisting in (water and nutrient) resource conservation, and helping to reduce environmental pollution. Although the reuse of reclaimed wastewater for irrigation has potential benefits, great caution is needed to ensure that water quality is acceptable and that poor quality water is not used to irrigate food for human consumption (particularly those foods that are eaten raw). The rate of expansion of treated wastewater reuse will depend on the quality of the wastewater, public acceptance, and cost-effectiveness. Given the relatively high cost of wastewater treatment, it is likely that treated wastewater could contribute an important share of agricultural water supply only in arid regions where the cost of new water supplies has become very high; nonagricultural uses of treated wastewater are likely to grow faster for the foreseeable future.

Improvements in the irrigation sector to increase water use efficiency must 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, such as computer monitoring of crop water demand. Managerial improvements can include the adoption of demand-based irrigation scheduling systems and improved equipment maintenance. Institutional improvements may involve establishing effective water user associations and water rights, the introduction of water pricing, and improvements in the legal environment for water allocation.

Key to inducing higher water efficiency gains in all sectors is introducing market (or market-style) incentives into water use decisionmaking. Incentive prices for water could have a major impact on water withdrawals and consumptive use in irrigation and urban water uses, thus freeing water for environmental use. As the high price scenario (HP) shows in Chapter 6, even though the water price elasticity of demand is quite low for irrigation, increasing water prices from the low levels prevailing in most countries generates substantial water savings because the total amount of water used in irrigation is so high. The results show that significant water savings are also possible from domestic and industrial uses. A large backlog of water-saving technology for industry in developing countries could come into play with the right incentives. Water savings through incentive policies could provide a significant increase in water for environmental uses. In most regions, the reduction of irrigation water supply through high prices could be balanced with increased irrigation water use efficiency at the basin scale, eliminating the negative impact of high prices on food security.

Nevertheless, implementing policies to increase water prices is politically difficult and could have negative impacts on poor consumers and farmers if badly designed or implemented. But in the domestic and industrial sectors, improving both efficiency and equity through increased water prices is feasible and would provide incentives for conservation, cover the costs of delivery, and generate adequate revenues to finance the needed growth in supplies and expanded coverage of clean piped water. Generalized subsidies should be replaced with subsidies targeted to the poor; other policies, such as increasing block tariffs, could help to ensure water availability to low-income users without direct subsidies. This type of tariff structure has a very low per unit price for water up to a specified volume, after which users pay a higher price for volumetric blocks up to the highest level of consumption. In this way, high-income households that use more water cross subsidize low-income users.

The design of effective and equitable water pricing for agriculture is more difficult. Imposing large increases in administered water prices does not work. High water prices are likely to reduce farm incomes severely (Rosegrant et al. 2000; Perry 2001; Löfgren 1996). Moreover, in existing irrigation systems, the prevailing (formal or informal) water rights significantly increase the value of irrigated land. Water rights holders correctly perceive the imposition of water prices, or an increase in existing prices, as expropriation of those rights, reducing the value of land in established irrigation farms. Attempts to establish or increase water prices are thus met with strong opposition from irrigators (Rosegrant and Binswanger 1994). Finally, implementation of water prices at the farm level is difficult because, with irrigation in much of the developing world consisting of large systems that serve many small farmers, measuring and monitoring deliveries to large numbers of end users—as would be required to charge by volume of water use—is too costly.

Despite these difficulties, it is feasible to design and implement water pricing systems based on water rights that would introduce incentives for efficient water use, recover at least O&M costs, and at the same time protect and even increase farm incomes. For example, a "charge-subsidy" scheme (Pezzey 1992) would establish incentives to use water efficiently without reducing farm incomes and appears to be politically and administratively feasible. A base water right would be established at major turnouts to water user groups or privately run irrigation sub-units (rights could be assigned directly to individual irrigators where administratively feasible). The user group would be responsible for internal water allocation. Subsequently, the base water right would be set based on historical allocation—but likely somewhat lower than the historical allocation in water-scarce basins. A fixed base charge would be applied to this quantity, sufficient to cover O&M and longer term asset replacement (depreciation) costs. For demand greater than the base water right, users would be charged an efficiency price equal to the value of water in alternative uses; for demand below the base right, the same price would be paid to the water user.

The establishment of base water rights would increase the political feasibility of water pricing by formalizing existing water rights rather than being seen as an expropriation of these rights. With efficiency prices paid only on marginal demand above or below the base right, nonpunitive incentives are introduced. Reliance on water user associations to manage water "below the turnout" improves local accountability, transparency, and the flexibility of water allocation. Information costs would be reduced because local irrigators with expert knowledge of the value of water would bear the costs and generate the necessary information on the value and opportunity costs of water below major turnouts. Reform of water pricing policy in developing countries faces many technical, administrative, and political constraints, but with increasing water scarcity and declining financial resources available for irrigation and water resource development, reform of water pricing is essential. For both urban and agricultural water, innovative and pragmatic water pricing reform that introduces incentives for efficient use and enhances cost recovery while improving equity in water allocation is feasible. Agricultural water pricing reform that establishes water rights for users, such as suggested above, would be particularly beneficial, protecting farmers against capricious changes in water allocation, ensuring that they benefit from more efficient water use, and in the longer term providing a basis for water trading among farmers and across sectors, further enhancing water use efficiency.

CROP PRODUCTIVITY AND RAINFED AGRICULTURE

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. Results under BAU show that rainfed agriculture will continue to play an important role in cereal production, contributing half the total increase of cereal production between 1995 and 2025. SUS shows an even higher contribution to the total increase of cereal production by rainfed agriculture. Improved water management and crop productivity in rainfed areas would relieve considerable pressure on irrigated agriculture and on water resources; however, this would be contingent on increased investment in research and technology transfer for rainfed areas.

Water harvesting has the potential in some regions to improve rainfed crop yields, and could provide farmers with improved water availability and increased soil fertility in some local and regional ecosystems, as well as environmental benefits through reduced soil erosion. However, greater involvement of farmers from the planning stages and the use of farmers for maintenance and data collection and provision of appropriate educational and extension support are still needed to expand the contribution of water harvesting.

The rate of investment in crop breeding targeted to rainfed environments is crucial to future crop yield growth. Strong progress has been made in breeding for enhanced crop yields in rainfed areas, even in more marginal rainfed environments. Continued application of conventional breeding and recent developments in nonconventional breeding offer considerable potential for improving cereal yield growth in rainfed environments. Cereal yield growth in rainfed areas could be further improved by extending research both downstream to farmers and upstream to the use of tools derived from biotechnology to assist conventional breeding, and, if concerns over risks can be solved, to the use of transgenic breeding.

Higher priority for agricultural extension services and access to markets, credit, and input supplies should be given in rainfed areas because successful development of rainfed areas is likely to be more complex than in high-potential irrigated areas given their relative lack of access to infrastructure and markets, and their more difficult and variable agroclimatic environments. Progress may also be slower than in the early Green Revolution because new approaches will need to be developed for specific environments and tested on a small scale prior to broad dissemination. Investment in rainfed areas, policy reform, and transfer of technology, such as water harvesting, will therefore require stronger partnerships between agricultural researchers and other agents of change, including local organizations, farmers, community leaders, NGOs, national policymakers, and donors.

SUMMARY

A large part of the world is facing severe water scarcity. With a continued worsening of water supply and demand trends and water policy and investment performance, water scarcity could become a fully fledged crisis with severe impacts on food production, health, nutrition, and the environment. But solutions to potential water crisis are available, including increasing the supply of water for irrigation, domestic, and industrial purposes through highly selective investments in infrastructure. Even more important, however, are water conservation and water use efficiency improvements in existing irrigation and water supply systems through water management reform, policy reform, and investment in advanced technology and infrastrucure; and improving crop productivity per unit of water and land through integrated efforts in water management and agricultural research and policy, emphasizing crop breeding and water management in rainfed agriculture. The appropriate mix of water policy and management reform and investments, and the feasible institutional arrangements and policy instruments to be used must be tailored to specific countries and basins and will vary across underlying conditions and regions including levels of development, agroclimatic conditions, relative water scarcity, level of agricultural intensification, and degree of competition for water. These solutions are not easy, and will take time, political commitment, and money. One thing is certain; the time to act on fundamental reform of the water sector is now.

NOTES

1. In low rainfall years, for example, water withdrawal in WANA will be significantly higher than the total renewable water in the region, including inflows from other regions.

2. As noted in the opening chapter, nontraditional water sources such as desalination of salt water and brackish water are highly unlikely to make a large contribution to the global water supply over the next several decades. Even an extremely high 20 percent growth in production of desalinated water per year would only account for 1.5 percent of water withdrawal by 2025. Desalination will play an important role in alleviating local water shortages, but even with declining production costs, desalination growth will primarily provide drinking water in coastal regions of countries that are both highly water scarce and relatively wealthy.