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Water Resources in the Twenty-First Century: Challenges and Implications for Action

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Contents

Foreword v

Acknowledgments vi

Global Water Supply and Demand 1

Challenges for the Future 3

Strategies for the Future 6

Supply Management: Development of New Water 6

Demand Management: Comprehensive Water Policy Reform 14

International Water: Conflict or Cooperation? 21

Conclusions 23

References 24

Foreword

The defining issue of the twenty-first century may well be the control of water resources. In the next 30 years it is likely that water shortages will increase dramatically. While water supplies are dwindling because of groundwater depletion, waste, and pollution, demand is rising fast. Currently 338 million people are subject to sometimes severe water shortages, and by 2025 this number is projected to jump to about 3 billion. The worsening scarcity of water threatens agricultural growth and industrial production and is likely to increase water-related health problems and degrade the environment. In light of these prospects, water issues have been a central theme of IFPRI's 2020 Vision initiative, which seeks to develop an international consensus on how to meet future world food needs while reducing poverty and protecting the environment.

In this paper, Mark W. Rosegrant assesses global water supply and demand, describes in detail the forces contributing to water scarcity, and lays out a number of strategies for managing water in the future. Any solution, Rosegrant asserts, will need to involve both the careful exploitation of new sources of water and strong measures to stimulate more efficient use of water. Policies must treat water not as a free good, as they often do now, but rather as a scarce commodity that comes at a price. Cooperation between countries sharing the same water basin will also become increasingly important as water becomes more scarce.

As Rosegrant points out, sensible and far-sighted methods of managing water resources have been adopted in some areas and have been successful in helping alleviate water shortages. But such methods will need to become much more widespread if the world is to avoid large-scale conflicts and catastrophes stemming from water shortages and competition for the scarce resource. The principles described here offer guidance on strategies to help avert these disasters.

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The world faces severe and growing challenges to maintaining water quality and meeting the rapidly growing demand for water resources. New sources of water are increasingly expensive to exploit, limiting the potential for expansion of new water supplies. Water used for irrigation, the most important use of water in developing countries, will likely have to be diverted to meet the needs of urban areas and industry but must remain a prime engine of agricultural growth. Waterlogging, salinization, groundwater mining, and water pollution are putting increasing pressure on land and water quality. Pollution of water from industrial waste, poorly treated sewage, and runoff of agricultural chemicals, combined with poor household and community sanitary conditions, is a major contributor to disease and malnutrition. In many areas water is available to users at no cost or at a heavily subsidized price. Thus neither water managers nor water users have incentives to conserve water, so water is overused and wasted instead of being treated as a scarce resource.

New strategies for water development and management are urgently needed to avert severe national, regional, and local water scarcities that will depress agricultural production, parch the household and industrial sectors, damage the environment, and escalate water-related health problems. This paper will describe existing and projected water supply and demand, discuss challenges for the future for water and irrigation management and policy, and examine the water supply and demand strategies that are essential to meet the mounting challenges now and in the future.

Global Water Supply and Demand

Global numbers on water availability give a false sense of security, because water is abundant globally but scarce locally. Total water on the earth is 1,360 million cubic kilometers, 97 percent of which is in the oceans. There are 37 million cubic kilometers of freshwater, and three-fourths of this is in glaciers and icebergs. About 8 million cubic kilometers of freshwater is stored in groundwater, and only 200,000 cubic kilometers is accounted for by lakes and rivers.

Renewable freshwater is provided by annual rainfall over land of 110,000 cubic kilometers, of which 70,000 cubic kilometers evaporates and 40,000 cubic kilometers is transformed into runoff that can replenish rivers, lakes, and groundwater aquifers. Much of this runoff is immediately lost to floods, leaving an estimated 9,000–14,000 cubic kilometers of reliable runoff annually (Clarke 1993). Given current global water use of around 4,500 cubic kilometers, even this fraction of available water would be adequate to meet growth in demand for the foreseeable future, if supplies were distributed equally across the world's population.

But freshwater is distributed unevenly across the globe. Per capita water availability is highest in Latin America and North America, while Africa, Asia, and Europe have far less water per capita (Table 1). However, these regional figures also hide the huge variability in water availability. Freshwater is poorly distributed across countries (Canada is blessed with 120,000 cubic meters per capita per year of renewable water resources; Kenya has 600 cubic meters; and Jordan 300 cubic meters); across regions within countries (although India has adequate average water availability of 2,500 cubic meters per capita, the state of Rajasthan has access to only 550 cubic meters per capita per year [Engelman and LeRoy 1993]); and across seasons (Bangladesh annually suffers from monsoon flooding followed by severe dry season water shortages).

Thus, water scarcity is region-, locale-, and season-specific. When does water scarcity become a serious problem? Countries with freshwater resources in the range of 1,000–1,600 cubic meters per capita per year face water stress, with major problems occurring in drought years. When annual internal renewable water resources are less than 1,000 cubic

Table 1—Per capita water availability by region, 1950–2000

Region	1950	1960	1970	1980	2000
			(thousand cubic meters)		
Africa	20.0	16.5	12.7	9.4	5.1
Asia (excluding Oceania)	9.6	7.9	6.1	5.1	3.3
Europe (excluding the Soviet Union)	5.9	5.4	4.9	4.6	4.1
North America and Central America	37.2	30.0	25.2	21.3	17.5
South America	105.0	80.2	61.7	48.8	28.3

Source: Ayibotele 1992.

meters per person annually, countries are considered water scarce. Below this threshold, water availability is considered a severe constraint on socioeconomic development and environmental quality. Currently, 28 countries with a total population of 338 million are considered water stressed, and 20 of these countries are water scarce. Water shortages will increase dramatically in the next 30 years: by 2025, it is projected that 46 to 52 countries with an aggregate population of around 3 billion will be water stressed (Engelman and LeRoy 1993).

Tightening supplies have been accompanied by rapid growth in demand for water. Total water use by region since 1950 is summarized in Table 2. Between 1950 and 1990, water use increased by more than 100 percent in North and Latin America, by more than 300 percent in Africa, and by almost 500 percent in Europe. In 1990, Asia accounted for 60 percent of world water withdrawals, North America for 17 percent, Europe for 13 percent, Africa for 6 percent, and Latin America for 4 percent. Global demand for water has grown rapidly, at 2.4 percent per year since 1970.

Water use can be divided into three major categories: agriculture, industry, and domestic. Domestic use includes drinking water, private homes, commercial establishments, public services, and municipal supplies. Agriculture is by far the biggest user of water, accounting for more than 70 percent of water withdrawals worldwide and more than 90 percent of water withdrawals in low-income developing countries (Table 3).

Table 2—Water use by continent, 1950–2000

	1950	1960	1970	1980	1990	2000
			(cubic kilometers per year)			
Africa	56	86	116	168	232	317
Asia	865	1,237	1,543	1,939	2,478	3,187
Europe	94	185	294	435	554	673
Latin America	59	63	85	111	150	216
North America	286	411	556	663	724	796
Total	1,360	1,982	2,594	3,316	4,138	5,189

Source: Clarke 1993.

Table 3—Sectoral water withdrawals by country income group

		Withdrawals by sector		
Country income group	Annual withdrawal per capita	Agriculture	Industry	Domestic use
	(cubic meters)		(percent)	
Low-income countries	386	91	5	4
Middle-income countries	453	69	18	13
High-income countries	1,167	39	47	14

Source: World Bank 1992.

Challenges for the Future

Countrywide, regional, and seasonal water scarcities in developing countries pose severe challenges for national governments and the international development community. The challenges of growing water scarcity are exacerbated by the increasing costs of developing new water, wasteful use of already developed water supplies, degradation of soil in irrigated areas, depletion of groundwater, water pollution and its impact on human health, and the massive subsidies and distorted incentives that govern water use.

Increasing Costs of New Water

New sources of water are increasingly expensive to exploit, limiting the potential for expansion in new water supplies. Table 4 summarizes trends in real capital costs for new irrigation systems in five Asian countries. All countries show large increases in the costs per hectare of investment over the past two decades. In India and Indonesia, the real costs of new irrigation have more than doubled since the early 1970s; in the Philippines, costs have increased by more than 50 percent; in Sri Lanka, they have tripled; and in Thailand they have increased by 40 percent. Combined with declining cereal prices, these increases in costs have resulted in low rates of return for new irrigation construction.

In Africa, irrigation construction costs have been even higher than in Asia because of numerous physical and technical constraints. The average investment cost for medium- and large-scale irrigation was estimated at US$8,300 per hectare in 1992 dollars (FAO 1992). Construction cost estimates from the World Bank, based on the analysis of "all possible projects" within each of several countries in Sub-Saharan Africa, are somewhat lower than the FAO estimates. The weighted average of irrigation costs across projects in Sudan was US$2,850 per hectare; in Botswana, US$5,900; in Kenya, US$5,600; in Zambia, US$2,000; and in Zimbabwe, US$9,500 (Olivares 1990). Both the World Bank and FAO estimates include only the direct cost for irrigation. However, the average cost of irrigation systems in Sub-Saharan Africa increases to US$18,300 per hectare if the typically high indirect costs of social infrastructure, such as roads, houses, electric grids, and public service facilities, are included (Jones 1995).

The cost of supplying water for household and industrial uses is also increasing rapidly. In Amman, Jordan, the average incremental cost of water from groundwater has been US$0.41 per cubic meter. However, with shortages of groundwater, the city has begun to rely on surface water, pumped with a lift of 1,200 meters from a site 40 kilometers from the city, at an average incremental cost of US$1.33 per cubic meter. Future schemes are estimated to cost US$1.50 per cubic meter. In Shenyang, China, the cost of new water supplies will nearly triple from US$0.04 to US$0.11 per cubic meter between 1988 and 2000 because pollution of the current groundwater source will require a shift to water conveyed by gravity from a surface source 51 kilometers from the city. In Yingkou, China, pollution of the water supply source has forced a shift to a new source that the increased average incremental cost from about US$0.16 per cubic meter to US$0.30 per cubic meter. In Lima, Peru, the average incremental cost to meet short- and medium-term needs has been US$0.25 per cubic meter. However, because of depletion of the presently used aquifer, to meet long-term urban needs a transfer of water from the Atlantic watershed is being planned, at an

Table 4—Real capital costs for construction of new irrigation systems, 1966–88

Year	India (1988 prices)	Indonesia (1985 prices)	Philippines (1985 prices)	Sri Lanka (1986 prices)	Thailand (1985 prices)	Unweighted average
			(U.S. dollars per hectare)			
1966–69	2,698	1,521	1,613	1,470	1,419	1,744
1970–74	2,368	1,681	1,882	2,056	2,584	2,114
1975–80	1,656	3,187	2,263	2,909	2,366	2,476
1981–85	4,033	3,283	2,688	5,288	2,276	3,514
1986–88	4,856	4,096	n.a.	5,776	2,812	4,385

Source: Rosegrant and Svendsen 1993.
Note: n.a. indicates not available.

estimated average incremental cost of US$0.53 per cubic meter. In Mexico City, water is currently being pumped over an elevation of 1,000 meters into the Mexico Valley from the Cutzamala River through a pipeline about 180 kilometers long, at an average incremental cost of water of US$0.82 per cubic meter, almost 55 percent more than the previous source, the Mexico Valley Aquifer (World Bank 1993).

Wasteful Use of Existing Water Supplies

One of the most important problems is that much water is wasted in existing agricultural, household, and industrial uses. Water use efficiency in irrigation in much of the developing world is typically in the range of 25 to 40 percent; that is, 25 to 40 percent of water in the system is actually used beneficially. In urban supply systems, "unaccounted-for water," much of which is direct water losses, is often 50 percent or more in major metropolitan areas in developing countries. These inefficiencies seem to imply the potential for huge savings from existing uses of water, but savings will not be dramatic in all regions or delivery systems, because some of the water "lost" from systems is reused elsewhere. However, the scope for water savings from existing uses remains large.

A particularly difficult challenge will be to improve the efficiency of agricultural water use to maintain crop productivity growth while at the same time allowing reallocation of water from agriculture to urban and industrial uses. Nearly two-thirds of world rice and wheat production is grown on irrigated land, and growth in output per unit of land and water is essential to feed growing populations. At the same time, because of the limited number of cost-effective new sources of water, the rapidly growing household and industrial demand for water will need to be met increasingly from water savings from irrigated agriculture, which generally accounts for 80 percent of water diverted for use in developing countries. Water savings in agriculture, to truly contribute to reducing water scarcity, should be accompanied by improved efficiency in urban and industrial use.

Degradation of Irrigated Cropland

The past decade has seen significant degradation of existing irrigated cropland. Data are limited and definitions of damaged area vary considerably. Estimates of annual global losses of agricultural land due to waterlogging and salinization range from 160,000–300,000 hectares (Tolba 1978; Barrow 1991) to 1.5 million hectares (Kovda 1983). Most of the waterlogging and salinization have occurred in irrigated croplands with high production potential.

Global estimates of the total area affected by salinity but still in production also vary considerably. El-Ashry (1991), Rhoades (1987), and Kayasseh and Schenck (1989) estimate that salinity seriously affects productivity in 20 to 30 million hectares of irrigated land. Barrow (1991), however, estimates that in the late 1980s roughly 30 to 46 million hectares were in a poor production state because of salinization. Thus, although estimates vary significantly, degradation of irrigated area is a significant and growing problem and will further increase the pressure on existing irrigated production.

Groundwater Depletion

Groundwater is depleted when pumping rates exceed the rate of natural recharge. Pumping of fossil water constitutes water mining, one-time extractions from a depletable reserve. While mining of both renewable and nonrenewable water resources can be an optimal economic strategy, it is clear that groundwater mining is excessive in many instances. Overdrafting, or the mining of groundwater at a rate higher than recharge, increases pumping lifts and costs because of the lowered water table, causes land to subside (sometimes irreversibly damaging the aquifer), and induces saline intrusion and other degradation of water quality in the aquifer.

In the United States, the equivalent of 4 million hectares, one-fifth of irrigated area, is watered by pumping in excess of groundwater recharge (Postel 1993). The Ogallala Aquifer, which stretches from southern South Dakota to northwest Texas, has been heavily depleted in its southern portions, where groundwater supplies dropped from 678 cubic kilometers before rapid irrigation development to 514 cubic kilometers in 1990. Only in recent years have management reforms reduced pressures on the Ogallala (Engelman and LeRoy 1993).

In parts of the North China Plain, groundwater levels are falling by as much as 1 meter per year, and heavy pumping in portions of the southern Indian state of Tamil Nadu has been estimated to reduce water levels by as much as 25–30 meters in a decade. In the western Indian state of Gujarat, overpumping in the coastal areas has caused saltwater to invade the aquifer, contaminating village drinking supplies (Postel 1993).

Fossil aquifers, which are typically deep underground and receive little or no recharge, are being used for irrigation in some arid regions of the world. Egypt is irrigating 17,000 hectares of cropland from fossil aquifers and has plans to increase these areas severalfold (Abu-Zeid and Seckler 1992). Three-fourths of Saudi Arabia's water supply comes from nonrenewable groundwater sources, and this share is expected to rise. Groundwater pumping in Saudi Arabia exceeds estimated recharge more than fivefold.

Pollution, Water Quality, and Human Health

Pollution of water from industrial effluents, poorly treated or untreated domestic and industrial sewage, runoff of agricultural chemicals, and mining wastes is a growing problem. The main contaminants found in water include detergents (soaps and solvents), pesticides, petroleum and other derivatives, toxic metals (such as lead and mercury), fertilizers and other plant nutrients, oxygen-depleting compounds (such as wastes from canneries, meat-processing plants, slaughterhouses, and paper and pulp processing), and disease-causing agents responsible for hepatitis and infections of the intestinal tract such as typhoid fever, cholera, and dysentery (Anton 1993).

Unsafe drinking water, combined with poor household and community sanitary conditions, is a major contributor to disease and malnutrition, particularly among children. Contaminated wastewater is often used for irrigation, creating significant risks for human health and well-being. In São Paulo, contaminated water from the Tiete River is used to irrigate vegetables downstream. In Chile, 62,000 hectares of vegetables are irrigated from watercourses downstream from Santiago's sewage outflow (Anton 1993). Only 217 of 3,119 towns in India have partial (209) or full (8) sewage treatment facilities. Rivers in India often have astronomical coliform counts. The Yamuna River leaving New Delhi receives 200 million liters of untreated sewage per day, with coliform counts of 25 million organisms per 100 milliliters. A safe level for drinking water is 100 organisms per 100 milliliters (Clarke 1993). Worldwide, 1 billion people are without clean drinking water, and 1.7 billion have inadequate sanitation facilities. As many as 1 billion episodes of diarrhea occur annually in developing countries. The World Bank (1992) has estimated that access to safe water and adequate sanitation could result in 2 million fewer deaths from diarrhea among young children.

Massive Subsidies and Distorted Incentives

Despite these challenges, most of the world does not treat water as the scarce resource that it is. Both urban and rural water users are provided with massive subsidies on water use; irrigation water is essentially unpriced; in urban areas the price of water does not cover the cost of delivery; capital investment decisions in all sectors are divorced from management of the resource. In Mexico, annual subsidies for operation and maintenance of water systems (that is, not including capital costs) are one-half of 1 percent of gross domestic product, far more than is spent on the agricultural research system (Rosegrant and Gazmuri Schleyer 1996). In Jordan, despite severe water scarcity, water policies encourage overuse of water, and strict rationing is often required to allocate the resulting scarcities. Overuse of irrigation water is encouraged by massive subsidies. Irrigation water developed by the public sector is priced at only one-tenth of the actual cost of water produced by the private sector (Rosegrant, Gazmuri Schleyer, and Yadav 1995). Annual irrigation subsidies are estimated at US$0.6 billion in Pakistan, US$1.2 billion in India, and US$5.0 billion in Egypt (Bhatia and Falkenmark 1993).

In most countries, water subsidies go disproportionately to the better-off: urban water users connected to the public system and irrigating farmers. Table 5 shows the ratio between the price charged for water by informal vendors and the price charged by urban water systems. The results confirm that the urban poor, who must rely on water vendors, pay many times more for water than the generally better-off residents who receive subsidized water from the public systems. The equity impacts are worsened because subsidies are often financed from regressive taxes.

With water provided by public systems at little or no cost to the user, no one in the allocation system, whether water managers, farmer-irrigators, or urban water consumers, has an incentive to conserve water. As a result, water is used to excess in all purposes, leading to inefficient cropping and production decisions, waterlogging, salinization, groundwater

Table 5—Ratio of water prices charged by vendors to prices charged by public utilities in selected cities

Country	City	Ratio
Bangladesh	Dacca	12–25:1
Colombia	Cali	10:1
Côte d'Ivoire	Abidjan	5:1
Ecuador	Guayaquil	20:1
Haiti	Port-au-Prince	17–100:1
Honduras	Tegucigalpa	16–34:1
Indonesia	Jakarta	4–60:1
	Surabaya	20–60:1
Kenya	Nairobi	7–11:1
Mauritania	Nouakchott	100:1
Nigeria	Lagos	4–10:1
	Onitsha	6–38:1
Pakistan	Karachi	28–83:1
Peru	Lima	17:1
Togo	Lomé	7–10:1
Turkey	Istanbul	10:1
Uganda	Kampala	4–9:1

Source: Bhatia and Falkenmark 1993.

overdrafting, and return flows degraded by agricultural chemicals and industrial pollutants.

Strategies for the Future

The challenges posed by growing scarcity of water can be addressed through two strategies: supply management, which involves activities to locate, develop, and exploit new sources of water, and demand management, which addresses the incentives and mechanisms that promote water conservation and efficient use of water. The distinction between these two modes of management is not clear-cut: is investment in lining an irrigation canal to reduce water losses supply management or demand management? A useful working definition is that actions and policies that affect the quantity and quality of water at the entry point into the distribution system are classified as supply management, and actions that influence the use or wastage of water after this point as demand management (UNDTC 1991; World Bank 1994).

The evidence suggests that meeting the challenges of water scarcity will require both more vigorous demand management, with comprehensive water policy reform to make better use of existing supplies, and supply management, involving highly selective development and exploitation of new water supplies. The appropriate mix of supply and demand management will vary with levels of development and water scarcity. As economies grow and competition for water and the value of water increase, the benefits from, and necessity for, demand management increase significantly. Randall (1981) argues that as "water economies" move from the expansionary phase to the mature phase, conditions for establishment of property rights emerge: the long-run supply of impounded or diverted water becomes inelastic; the demand for delivered water increases rapidly; competition for water among agricultural, industrial, urban, and instream uses increases; and externality problems, including rising water tables, land salinization, and groundwater salinization and depletion become increasingly important. All of these factors increase the value of water and therefore the benefits from efficient allocation of water, and they shift the likely balance of effort from supply management to demand management.

Supply Management: Development of New Water

The development of new water resources has slowed considerably since the late 1970s as a result of escalating construction costs for dams and related infrastructure, relatively low prices for staple cereals, and concerns about environmental and social impacts, particularly the dislocation of residents in affected communities. International donors have sharply reduced their lending for irrigation. Lending from four major donors—the World Bank, the Asian Development Bank (ADB), the United States Agency for International Development (USAID), and the Japanese Overseas Economic Cooperation Fund (OECF)—peaked in the late 1970s but fell by almost 50 percent over the next decade. Total public expenditures for irrigation for many countries in Asia also declined significantly during the 1980s. Annual expenditures in China and Sri Lanka were cut nearly in half between the late 1970s and the late 1980s. In the Philippines, annual expenditures on irrigation in the late 1980s were only one-third the level of the early 1980s. Declines in the late 1980s from peak expenditure levels in Bangladesh, India, Indonesia, and Thailand range from 15 percent to 40 percent (Rosegrant and Svendsen 1993).

These declining expenditures are reflected in declining growth in crop areas under irrigation. As shown in Table 6, the growth in irrigated area in developing countries has already dropped slightly and is likely to drop considerably further when the full lagged effects of investment declines are felt. The decline in growth in irrigated area has been much more dramatic in the developed world, where cutbacks in irrigation investment began much earlier. Overall, the growth rate in irrigated area has declined from 2.08 percent per year during 1970–82 to 1.28 percent during 1982–94.

Is the era of building new irrigation and water supply capacity over? Although a return to the construction boom of the 1970s will not occur, some of the new 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 expanded development of nontraditional sources of water.

Table 6—Irrigated area, 1970–94

Year	Developed countries	Developing countries	Total
	(thousands of hectares)		
1970	44,046	123,285	167,331
1975	49,964	137,599	187,563
1980	58,414	150,634	209,048
1981	59,655	152,696	212,351
1982	59,733	154,574	214,307
1983	60,532	157,055	217,587
1984	61,609	159,876	221,485
1985	61,975	161,186	223,161
1986	63,280	162,201	225,481
1987	62,618	164,121	226,739
1988	63,780	165,894	229,674
1989	64,882	171,046	235,928
1990	65,598	175,411	241,009
1991	65,672	177,333	243,005
1992	65,664	180,562	246,226
1993	64,709	184,026	248,735
1994	64,605	184,944	249,549
Annual growth rates (percent)			
1970–82	2.57	1.90	2.08
1982–94	0.66	1.51	1.28

Source: FAO 1996.

Irrigation

It is impossible in a survey paper such as this to identify the likely location, type, and size of new irrigation dams and systems that will be built, but some general observations can be made. Large-scale dams will be extraordinarily difficult to build, despite the fact that a review of the World Bank's experience with irrigation shows that there are in fact economies of scale in irrigation projects: the rates of return to large projects have been somewhat higher than returns to small-scale projects (Jones 1995). However, these estimated rates of return do not generally take into account the full range of externalities generated by large projects. The heightened national and international concern over the broad effects of large irrigation projects will make it very difficult to proceed with many of these projects. The controversy over the Narmada Valley Development Program in western India illustrates the issues that need to be resolved if large-scale irrigation projects are to play a role in future water development.

The Narmada project includes 30 large dams, 135 medium-sized ones, and 3,000 small ones, and covers an area from the watersheds of the Narmada River in Madhya Pradesh and Maharashtra in central India through Gujarat on the west coast and on to arid regions in Rajasthan. The main dam in the project is the Sardar Sarovar, which is designed to provide domestic water to 40 million people, generate 1,200 megawatts of electric power, and irrigate 1.8 million hectares of land (Seckler 1992). These benefits are huge, but the environmental and human costs of the construction of the dam are also large. The reservoir to be created by the Sardar Sarovar Dam would flood 37,000 hectares of forest and farmland and displace nearly 100,000 people, mostly poor tribal villagers. An additional 80,000 hectares of land would be used to construct the distribution network, affecting, in various degrees, another 140,000 people (Berger 1994).

Because of concern over environmental impacts and compensation and resettlement of those whose homes would be submerged, strong opposition to Sardar Sarovar developed from villagers in the Narmada Valley, as well as from environmentalists and human rights advocates in India and elsewhere. As a result of the controversy, an independent review was commissioned by the World Bank, which had initially approved US$450 million for Sardar Sarovar, about 8 percent of the base cost (Postel 1993). The independent review, completed in June 1992, stated that the project had never been properly assessed and that serious weaknesses existed in the planning and implementation of resettlement plans and environmental protection measures. As a result of the review, the World Bank terminated any further financial participation in the project. The Indian government, however, has proceeded with implementation of the project (Berger 1994).

What are the implications of the Sardar Sarovar dispute for future investment in large-scale irrigation? Seckler (1992) notes that the 240,000 people adversely affected and 117,000 hectares of land submerged must be weighed against the 40 million beneficiaries and 1.8 million hectares of irrigated land. A small tax on the beneficiaries could generate sufficient funding for ample compensation of those who are harmed. The critical problem is not financial but administrative: how to identify, find, and rationally compensate those persons harmed by the project. Seckler (1992) further argues that the appropriate strategy would be to proceed with Sardar Sarovar but to reform the compensation process to avoid the inequities of the current system.

Perhaps even more fundamentally, society needs to devise better means to make trade-offs between costs, which may be relatively small in aggregate but are extremely large for those who bear them, and benefits, which may be large but are more widely dispersed. Often ignored in cases such as Narmada are the costs of not proceeding with the project. The social, economic, and environmental consequences that will occur if Narmada water is not developed to support Gujarat's population and rural economy must also be taken into account. Among the likely outcomes are a major reallocation of water from agriculture to urban uses, rural-urban migration, lower agricultural production, and increased pressure on fragile environments (Frederiksen, Berkoff, and Barber 1993). Assessment of potential large-scale irrigation projects should include a comprehensive accounting of costs and benefits and must employ equitable, realistic, and practical methods for compensating those who are negatively affected. Future construction of large-scale irrigation projects will require balanced development approaches acceptable to diverse constituencies.

Controversy over the impacts of large-scale irrigation has stimulated renewed interest in the potential for small-scale irrigation, which is presumed to have fewer environmental and human costs. Sub-Saharan Africa provides a useful case study for the debate over appropriate scale in irrigation investment. In Africa, the highly mixed, and sometimes disastrous, experience with large-scale systems led to a new interest in the potential for small-scale irrigation beginning in the 1980s. Underhill (1990) summarized the potential advantages of small-scale irrigation: small-scale technology can be based on farmers' existing knowledge; it is more compatible with the existing physical and human environment; local technical, managerial, and entrepreneurial skills can be utilized; migration or resettlement of labor is not usually required; the planning and development of small-scale systems is more flexible; social infrastructure requirements are reduced; and external input requirements are lower.

The evidence on government-controlled small-scale irrigation in Sub-Saharan Africa, however, suggests that these potential advantages are often not realized. The mode of implementation has effectively eliminated the potential advantages, so that in many cases small-scale irrigation has been just "a miniature version of the technically sophisticated, fully-controlled irrigation promoted in larger projects" (FAO 1986). A comparative review of large and small government-managed irrigation systems in Kenya concluded that big and small systems often share a number of common characteristics: high capital costs per hectare and per farmer; bureaucratic, costly, and inefficient management; low technical efficiency; low settler incomes; and zero or negative returns (Adams 1990).

Can the potential advantages from small-scale irrigation be achieved more regularly than described here? There is considerable evidence that farmer-controlled small-scale irrigation has a better record of performance than government-controlled large- or small-scale systems. These farmer-owned and -managed schemes also sometimes fail, but the failed systems do not continue to operate to be observed and analyzed; they simply disappear. In Burkina Faso, small-scale irrigation covered 6,200 hectares in 1956 but declined to 1,500 hectares in 1961, before partially recovering to about 3,000 hectares in the mid-1980s (Brown and Nooter 1992). The substantial small-scale sector that does exist, generally without significant government support, indicates that these systems are economically viable.

What accounts for the relative success of farmer-controlled small-scale systems? A review of successful systems of this type identified the following common characteristics: (1) the technology is simple and low cost, usually consisting of small pumps drawing water from shallow aquifers or rivers and streams; (2) the institutional arrangements for operating the system are private and individual; (3) supporting infrastructure is adequate to permit access to inputs and to markets for the sale of surplus production; (4) the systems generate high and timely cash returns to farmers; and (5) the farmer is an active and committed participant in project design and implementation (Brown and Nooter 1992).

The experience in Sub-Saharan Africa thus shows that it is not so much the size of the irrigation system that determines its success, but a host of institutional, physical, and technical factors. Analysis for other regions supports this conclusion. An assessment of returns to irrigation in the Philippines concluded that, while average returns to small-scale irrigation were slightly higher than those to medium- and large-scale irrigation, the difference was insignificant because the variation in performance of systems within each type was so large (Rosegrant et al. 1987). Although the review of World Bank irrigation projects concluded that large-scale projects were more profitable, project size explained only 10 percent of the variation in performance (Jones 1995). The evidence indicates that, fundamentally, the small versus large distinction is not very useful. Every river basin is different, and the appropriate choice of system size and operational characteristics in any given basin is likely to be determined by conditions unique to that basin. A pragmatic approach to project design should be taken that ensures quantification of full benefits, including not only irrigation benefits, but also health, household water use, and catchment improvement benefits (Jones 1995), and full assessment of, and compensation for, negative environmental and resettlement costs. Selective development of new surface irrigation must still play a role in future water resource development.

Groundwater

Sustainable development of groundwater resources offers significant opportunities for many countries. The massive expansion of private sector tubewell irrigation in Bangladesh, India, and Pakistan is the most successful example of private sector irrigation development in the developing world. Use of private tubewells has grown most rapidly in areas with reasonably good roads, research and extension systems, and accessible credit and electric or diesel energy. Moreover, private tubewells have been installed largely in and around the command areas of large surface irrigation systems. Seckler (1990) gives three reasons for this: deep percolation losses from the surface systems recharge the aquifers for tubewells; the tubewells are often used together with surface irrigation water, which lowers pumping costs and concentrates these costs in periods of highest marginal returns; and the tubewells ride piggyback on the infrastructure created for the surface systems.

A "groundwater revolution" in Bangladesh beginning in the 1980s was a key stimulant to rapid agricultural growth in the 1980s and early 1990s. Nearly 1.5 million hectares of land were newly irrigated after 1980, in significant part from installation of shallow tubewells spurred by deregulation of tubewell imports. Although localized problems of groundwater mining have occurred, in most areas in Bangladesh there remains significant scope for further expansion of groundwater use within the bounds of natural recharge. If dry season water scarcity worsens, investments to divert wet season river flows for artificial recharge of aquifers may become feasible and could reduce wet season flooding (Rogers et al. 1994).

With careful management, the potential for groundwater use is also substantial in North Africa and the Middle East. Large aquifers underlying this region include the Eastern Erg and the Nubian Aquifers. The Eastern Erg in Algeria and Tunisia covers an area of almost 400,000 square kilometers and stores an amount of water equal to about four times the average annual renewable supply of the entire North Africa and Middle Eastern region. Only 0.04 percent of this volume is recharged annually, so this is essentially fossil water. The Nubian Sandstone Aquifer underlies parts of Egypt, Libya, and Sudan, extending over an area of 1.8 million square kilometers. The volume of stored water is nearly 20 times the average annual renewable supply for North Africa and the Middle East, and the aquifer has an annual recharge rate equal to about 2.5 percent of its volume, so this resource could be of great value if exploited prudently. However, concerns have grown over Libya's plans to transfer massive amounts of this water from southeastern Libya to the country's coastal region via the so-called Great Man-made River Project, which could substantially reduce groundwater reserves in the two other riparian countries. Because of the nature of these large fossil aquifers in North Africa, extensive investigation is required to determine their characteristics, possible exploitation rates, and the potential impacts on neighboring countries (World Bank 1994).

Much of Asia and parts of Latin America have significant untapped groundwater potential, while in Sub-Saharan Africa groundwater is likely to be of mainly local and regional significance, because aquifers in much of the region are small and discontinuous, with slow rates of recharge. A common problem for all developing regions is that the actual extent of groundwater storage and recharge is poorly understood. Sharply increased investment in exploration and evaluation of aquifers (including geometry, continuity, boundaries, and hydraulic characteristics) and recharge rates (including spatial and temporal variability) would have high payoffs.

Conjunctive Use of Surface Water and Groundwater

Conjunctive use of surface water and groundwater is often recommended but rarely practiced, except in the limited sense of farm-level water management when both surface and groundwater supplies are available (Frederiksen, Berkoff, and Barber 1993). Nevertheless, conjunctive use of surface and groundwater has several potential advantages that could be expanded significantly. For example, wells can be used as an on-demand irrigation system, to supplement inadequate or unreliable flows of canal water, reduce moisture stress, and maximize irrigated crop yields. The pumping of groundwater into the canals can augment the canal water resources, lower the water table, and reduce salinity. And a canal command and its embedded tubewells can be viewed as an integrated system for optimizing the use of canal and groundwater resources jointly. One additional feature that is important in areas such as the Gangetic basin is the capacity of alluvial aquifers to serve as storage media for highly variable river flows. The flat topography of much of eastern India and Bangladesh affords little opportunity to build conventional storage reservoirs of the type that exist in northern India and Pakistan. Shallow groundwater storage is an attractive alternative that prevents evaporative losses and offers easy and decentralized access for irrigators (Rosegrant and Svendsen 1993).

Urban Supplies

A fundamental question is the degree to which demand for urban water can be met from new sources, from savings from existing waste and inefficient water use in urban water systems, or from reallocation of water from agriculture (the last two topics are discussed briefly here and in more detail later). Whatever the mix of sources for new urban water supplies, there is general agreement that huge new investments in urban water systems will be necessary. Required investments to provide water and sewage treatment facilities for the rapidly growing urban populations in developing countries could be as high as US$500 per person (Seckler 1996). Some estimates indicate that fully meeting increased urban demand for water through the development of new water supplies would require investments of US$11–14 billion per year for the next 30 years. These requirements are double the amounts estimated to have been available for urban water supply during the 1980s. Sectoral funding of this magnitude is not likely to be available (Bhatia and Falkenmark 1993).

The almost certain inability to identify new water sources and mobilize these levels of funds to meet the rapidly growing demand for water in urban areas means that, in addition to tapping new water sources, there will almost certainly be an increase in the amount of water reallocated from agriculture to domestic and industrial uses. This type of reallocation is already taking place in developing countries, despite legal and administrative restrictions, because of the differential economic value of water in the two sectors. Thus Palanisami (1994), for example, describes the operation of informal intersectoral water markets operating in and around the major river basins in Tamil Nadu, India. Despite significant restrictions on the tradability of water in Tamil Nadu, informal water markets have developed in response to increasing water scarcity and to the differential value of water across sectors. Well owners and irrigators pumping from rivers sell water to truckers who transport the water to urban centers. The relatively well-to-do households served by the public water system pay only US$0.06 per cubic meter. By contrast, in informal markets, water is pumped by diesel or electric motors and sold by well owners for US$0.08–US$0.10 per cubic meter. Bullock carts and lorry tankers are the main modes of distribution, supplying water to households and other customers. The cost of water to final users averages around US$0.75 per cubic meter, more than 10 times the subsidized rate paid by households connected to the public distribution system. Farmers who grow crops that demand low amounts of water and sell their remaining allowance of water earn about 50 percent more net income per hectare than farmers who grow only traditional crops (Palanisami 1994).

Thus, the key question is not whether reallocation will occur, but whether it will be accomplished in a rational and equitable manner that keeps costs to a minimum or in the ad hoc manner governing most such reallocations today. Intersectoral reallocation of water can be accomplished either through supply management (with top-down reallocation of water between sectors) or through demand management, which uses incentives to induce water to move among competing demands (described in detail later). Since in most developing countries agricultural use accounts for more than 80 percent of consumptive use, relatively small transfers of water from agriculture could meet growing urban and industrial demands. For example, in Morocco a 5 percent transfer of water from agriculture would almost double the total supplies available for the domestic sector (World Bank 1994).

Nevertheless, there are understandable concerns about possible negative direct and indirect effects from water transfers. In addition to direct impacts on agricultural production, water transfers can negatively affect business activities, local government fiscal capacity, and the quality of public services in areas from which water is being transferred because of the reduction in irrigated area or production and associated reductions in agriculturally linked economic activities and in the tax base. In addition, permanent transfer of water rights may limit future economic development in the area of origin and induce out-migration.

However, the limited evidence available seems to indicate that negative effects from water transfers are manageable. One of the most important innovations of Chile's water policy is allowing cities to buy water without having to buy land or expropriate water. Growing cities now buy rights from many farmers, usually buying a small portion of each farmer's total rights. There have rarely been negative effects in the agricultural zones surrounding water-demanding urban areas, because farmers usually sell small portions of their rights and maintain agricultural production with highly efficient irrigation technology for the orchard or vegetable crops grown in those areas (Gazmuri Schleyer and Rosegrant 1996).

In California, indirect economic effects from water transfers using the 1991 California State Emergency Drought Water Bank were small. Farmers who sold water to the bank reduced farm operating costs by US$17.7 million, or 11 percent, and crop sales by US$77.1 million, or 20 percent. These reductions adversely affected the suppliers of farm inputs and the handlers and processors of farm outputs, but the effects were not large when compared with the agricultural economy in the selling region. Operating costs, crop sales, and agribusiness revenues dropped 2 to 3 percent in selling counties because of the bank (Dixon, Moore, and Schechter 1993).

Hydropower

Hydropower is produced when the energy in falling water is used directly to turn turbines, which generate electricity. Installed hydroelectricity capacity worldwide in 1990 was over 610,000 megawatts, 24 percent of total world electrical-generating capacity. More than half of all hydropower capacity is in North America and Western Europe, while only 3 percent of it is in Africa. North America and Europe have developed approximately 60 percent and 36 percent of their large-scale hydropower potential, respectively; Asia and Latin America have developed around 10 percent, and Africa only 5 percent. In 1990, hydroelectric dams generated more than 2 million gigawatt hours of electricity, or just under 7 percent of the world's primary commercial energy and 20 percent of global electricity. In South and Central America, 70 percent of all electricity comes from hydroelectric plants; Canada and the United States together meet 20 percent of their total electrical demand with hydropower (Gleick 1993b).

Global hydroelectricity production increased more than 20 percent during the 1980s, but in the industrialized nations the development of new hydroelectricity facilities has slowed greatly as the best sites have been developed and as the environmental costs of further construction rise. Indeed, the greatest development of hydroelectric facilities is now occurring in those regions that have seen little development to date. During the 1980s, hydroelectric production increased by 50 percent in Asia and more than doubled in parts of Latin America and in China (Gleick 1993b).

Although nearly all of the water used to generate hydropower can be reused, there is significant consumptive use from the evaporative loss of water from the surface of reservoirs. Evaporation from reservoirs is directly related to the surface area of the reservoir and varies with temperature, wind conditions, and humidity. Annual evaporation from standing water in the United States varies from 0.5 meter in the Northeast to more than 1.0 meter in the more arid Southwest. Evaporative losses at the Aswan Dam in Egypt have been estimated at nearly 3 meters annually, equivalent to 11 percent of reservoir capacity. Hydropower facilities, like irrigation dams, have a number of other effects on human and freshwater ecosystems. The creation of a reservoir displaces human settlements and wildlife and replaces a flowing water ecosystem with a standing water one. Hydroelectric dams are subject to the risk of catastrophic failure with extensive loss of life and property, an unusual risk associated with few other energy sources, most notably nuclear power. Estimates of the magnitude and extent of the environmental costs of hydroelectric facilities vary widely. Some analysts believe that hydropower is a benign source of electrical power generation; others have concluded that new large dams may be the worst electricity option in terms of environmental damage per unit of electricity (Gleick 1993b). Despite considerable debate in recent years, many issues remain unresolved and are likely to be resolved on a case-by-case basis.

The environmental costs and benefits must be carefully weighed in evaluating new water sources. Plans to develop hydropower in the Mekong River basin are under fire from a wide range of environmental groups and other critics. However, in Laos, forests are being rapidly depleted for fuelwood, timber sales, and slash-and-burn agriculture. New water and hydropower development on the Mekong could offer an alternative power source to fuelwood, reducing deforestation. These benefits must be weighed against the potentially harmful consequences of construction, including resettlement of indigenous people and inundation of reservoir sites (Jacobs 1994).

Desalination

The supply of freshwater through desalination is in essence infinite, but expensive. However, although desalination capacity increased 13-fold from 1970 to 1990, to more than 13 million cubic meters per day, desalinated water accounts for just one-tenth of 1 percent of freshwater use (Engelman and LeRoy 1993; Gleick 1993a). Nearly 60 percent of desalination capacity in the world is in the oil-rich, water-scarce Persian Gulf, and much of the rest of the capacity is in island nations and other arid countries (Postel 1992).

Technology for desalination is improving rapidly, but prices remain high. The cost of production (not including transport costs) ranges from US$1.00 to US$2.00 per cubic meter depending on the technology and salt loads in the water (Frederick 1993). Although this is comparable to the costs of new water supplies in some of the most arid areas of the world, it is very high compared with costs from alternative sources in most of the world. And if substantial transportation costs are incurred to pump desalinated water inland, per unit costs increase significantly. Desalination plants also have high capital and energy costs and generate substantial wastes, which could cause significant environmental problems. It is likely that use of desalinated seawater will continue to increase rapidly (from what is still a low base), but that this growth will primarily be for domestic and industrial purposes in coastal regions of countries that are both very water scarce and relatively wealthy.

Recycling and Wastewater Reuse

After being used once, freshwater can be used again in the same home or factory (usually called recycling) or collected from one or more sites, treated, and redistributed and used in another location (generally called wastewater reuse) (Postel 1992). Both of these concepts are distinct from the reuse of return flows from irrigation when only part of the water withdrawn from a stream or aquifer is consumptively used. The greatest potential for water saving is likely to be industrial recycling, although wastewater reuse can offer significant and increasing savings as the scarcity value of water increases.

Only a small fraction of industrial water used for cooling, processing, and other activities is actually consumed. Although the rest of the water may be heated or polluted, it can often be recycled within a factory or plant, thereby getting more output from each cubic meter delivered or allocated to that operation. Developed countries have greatly expanded the use of water recycling in industry. Total industrial water use in Japan reached a high in 1973 and declined by a quarter by 1989. In 1989, Japan produced industrial output worth US$77 per cubic meter of water supplied to industries, compared with US$21 per cubic meter in 1965 in real terms. In the United States, between 1950 and 1990, total industrial water use fell 36 percent while industrial output increased nearly fourfold (Postel 1992).

Pollution control laws have been a primary motivator for industrial water recycling in developed countries. The most cost-effective way to meet specific water quality standards and pollution limits has often been to recycle and reuse water a number of times before discharging it. Pollution control laws have therefore promoted conservation and more efficient water use as well as helping to clean up rivers, lakes, and streams (Postel 1992). As developing countries continue their rapid industrialization, recycling of water can play an important role in conserving water supplies.

The reuse of wastewater has been more limited. The rate of expansion of wastewater reuse depends on the final quality of the wastewater and on the public's willingness to use these supplies. Although the technology exists to upgrade wastewater for domestic consumption, it is expensive and consumer resistance has been high. In California, which has the highest rate of wastewater reuse in the United States, wastewater is being reused for industrial cooling, groundwater recharge, barriers against saltwater intrusion, and irrigation of parks, golf courses, and certain types of crops. Even in California, however, wastewater reuse accounts for less than 1 percent of the state's developed water supplies (Frederick 1993).

About 500,000 hectares of cropland worldwide are irrigated by treated municipal wastewater, amounting to only two-tenths of 1 percent of the world's irrigated area. Israel undertakes the largest wastewater reuse effort in the world, treating 70 percent of the nation's sewage to irrigate 19,000 hectares of cropland. Reclaimed wastewater is projected to supply more than 16 percent of Israel's total water needs by the start of the next century. Most of this would be used in agriculture to replace freshwater reallocated to nonagricultural uses (Postel 1992). Given the relatively high cost of wastewater treatment and transport to agricultural areas, it is likely that wastewater can constitute an important share of agricultural water supply only in arid regions where the cost of new water supplies has become very high.

Water Harvesting

Water harvesting, the capture and diversion of rainfall or floodwater to fields to irrigate crops, has been used for centuries in traditional agriculture. The improvement and expanded use of such techniques can increase production and farm income in some environments. In semi-arid areas of India and Pakistan, low earthen banks are constructed to hold back the monsoon floods and submerge and saturate the fields. Crops are then planted when the floods recede. In Bihar, India, as many as 800,000 hectares of land are planted under this system (Clarke 1993). On a different order of magnitude, farmers in the Yatenga Province in Burkina Faso in recent years have begun to use improved versions of their traditional water harvesting techniques. Farmers in this region build simple stone bunds across the slopes of their fields to reduce erosion and help store moisture in the soil. By the end of 1989, farmers in more than 400 Yatenga villages were using these techniques on 8,000 hectares. Vegetative barriers can also be used for water harvesting. Vetiver grass, native to India and known there as *khus*, has been used in both Africa and Asia. When densely planted along the contours of a sloping field, the grass forms a vegetative barrier that slows runoff, allowing rainfall to spread out and seep into the soil, much as the stone bunds do. In the Machakos District in southern Kenya, farmers use a water harvesting technique called *fanya-juu* terracing, which involves digging a ditch and throwing the soil up-slope to form an earthen wall that maximizes erosion control and rainwater retention. Average corn yields on terraced lands are estimated to be 50 percent higher than on unterraced lands (Postel 1992).

These experiences, among others, show that in some local and regional ecosystems, water harvesting can provide farmers with improved water availability, increased soil fertility, and higher crop production. Water harvesting can also provide broader environmental benefits through reduced soil erosion. However, given the limited areas where such methods appear feasible and the small amounts of water that can be captured, water harvesting techniques are unlikely to have a significant impact on global food production and water scarcity.

Demand Management: Comprehensive Water Policy Reform

Potential for Water Savings

A large share of water to meet new demand must come from water saved from existing uses through comprehensive reform of water policy. Such reform will not be easy, because both long-standing practice and cultural and religious beliefs have treated water as a free good and because entrenched interests benefit from the existing system of subsidies and administered allocations of water. Furthermore, the gains from demand management will be more difficult to achieve than is suggested by much of the literature. In some river basins, efficiency gains from existing systems may prove to be limited, because whole-basin water use efficiencies are already high as a result of reuse and recycling of drainage water, even though individual water users are inefficient.

Although individual project performances vary considerably, overall irrigation efficiencies (the product of irrigation system efficiency and field application efficiency) in developing countries are low, ranging from 25–40 percent for India, Mexico, Pakistan, the Philippines, and Thailand to 40–45 percent in Malaysia and Morocco, compared with 50–60 percent in Israel, Japan, and Taiwan (Rosegrant and Shetty 1994). These low water use efficiencies are often cited as evidence that very large savings in water use can be obtained. However, these water use efficiencies are derived from individual system evaluations rather than from basinwide assessments. Unmeasured downstream recovery of "waste" drainage water and recharge and extractions of groundwater can result in actual basinwide efficiencies substantially greater than the nominal values for particular systems. For example, estimates of overall water use efficiencies for individual systems in the Nile basin in Egypt are as low as 30 percent, but the overall efficiency for the entire Nile system in that country is estimated at 80 percent (Keller 1992).

Can real water savings be achieved through demand management? At the water basin level, the actual water losses are the water that flows to water sinks. Three water sinks are generally defined as: (1) losses of water vapor to the atmosphere through evaporation from surfaces and the evapotranspiration of plants; (2) flows of water to salt sinks, including oceans, inland seas, and saline aquifers; and (3) pollution of surface and groundwater by salts or toxic elements so that the water becomes unusable (Seckler 1996). In addition to these, it is conceptually useful to consider a fourth sink, which can be called an "economic sink." The economic sink includes water that drains from the system and seeps or percolates into groundwater or other freshwater sinks, but which it is not economically feasible to recover because the cost of reuse (that is, through the installation and operation of a tubewell) is too high. This water is physically available for reuse and thus it is not a true loss to the system, but it will not be used unless demand management is reformed. Moreover, this water can be truly lost to the system through evapotranspiration if it underlies land covered with nonproductive vegetation and weeds.

Conceptually, the economic sink is analogous to the pollution sink. The degree of pollution is a continuum: at low levels of pollution, the water remains reusable, but the effective cost per unit of that water is higher because crop yields per unit of water will be lower. Thus, at low levels of pollution, economic costs are imposed by the initially high withdrawals that lead to drainage, reuse, and pollution, but there are no physical losses of water from the system. (It could be argued, however, that there are quality-related physical losses, since it takes more polluted water to generate a unit of crop output.) However, with continued reuse, pollution passes a threshold at which the water becomes unusable and is lost to the system.

Similarly, the economic feasibility of reuse is a continuum: when the cost of reuse is relatively low, water will be reused and will not be physically lost to the system (although again, economic costs are imposed by the initially excessive withdrawal of water). However, when the cost of reusing drainage water becomes high enough (because of, for example, physical characteristics of aquifers, deep percolation, high lifts, field slopes), a threshold is passed at which the water becomes uneconomical to use and is effectively sequestered. Within any given environment, the greater the difference between the true scarcity value of water and the effective user price, the greater the loss of water to the economic sink.

The task of demand management is to generate both physical savings of water and economic savings by increasing output per unit of evaporative loss of water, increasing the utilization of water before it reaches salt sinks, reducing water pollution, reducing the loss of water to the economic sink, and restoring the existing water in the economic sink to use. It is unclear empirically how large each of these potential water savings is, and important research remains to be done on this issue. Definitive estimates of the potential for improving system performance by increasing effective water supply will require basin-specific analysis. There is probably less potential for generating savings from existing systems than nominal systemwide efficiency figures imply. Nevertheless, the potential for generating water savings and economic gains through demand management appears to be considerable.

Policy Instruments for Demand Management

The types of policy instruments available for demand management include the following (Bhatia, Cestti, and Winpenny 1995):

1. Enabling conditions, which are actions to change the institutional and legal environment in which water is supplied and used. Policies here include reform of water rights, privatization of utilities, and laws pertaining to water user associations.
2. Market-based incentives, which directly influence the behavior of water users by providing incentives to conserve on water use, including pricing reform and reduced subsidies on urban water consumption, water markets, effluent or pollution charges, and other targeted taxes or subsidies.
3. Nonmarket instruments, including restrictions, quotas, licenses, and pollution controls.
4. Direct interventions, including conservation programs, leak detection and repair programs, and investment in improved infrastructure.

The precise nature of water policy reform, and the policy instruments to be deployed, will vary from country to country depending on underlying conditions such as level of economic development and institutional capability, relative water scarcity, and level of agricultural intensification. Additional research is required to design specific policies within any given country. However, some key elements of a demand management strategy are the following.

Demand Management for Surface Irrigation. Surface water can be conserved by improving the management of administrative water allocation mechanisms, by using volumetric water prices, or by establishing markets in tradable water rights.

Administrative reforms. Administrative reforms have included modification of water distribution methods (such as shifting from continuous flow to rotational flow water allocation) and institutional reform of public irrigation bureaucracies. Reform of water management methods within existing systems has shown mixed results, with some interventions showing increases in water use efficiency and high rates of economic return (Aluwihare and Kikuchi 1991) and others appearing much less effective (Rosegrant 1989; Rosegrant and Svendsen 1993). It is unclear if real water savings have been achieved through these reforms.

Institutional reform of public irrigation agencies has received increasing attention in recent years and holds considerable promise for long-term progress in improving system performance. Possible reforms include reorganization into a semi-independent or public utility mode, applying financial viability criteria to irrigation agencies, franchising rights to operate publicly constructed irrigation facilities, and strengthening accountability mechanisms such as providing for farmer oversight of operating agencies (Rosegrant and Svendsen 1993).

Water rights, markets, and prices. The primary alternative to quantity-based allocation of water is incentive-based allocation, either through volumetric water prices or through markets in transferable water rights. The empirical evidence shows that farmers are price responsive in their use of irrigation water. The four main types of responses to higher water prices are use of less water on a given crop, adoption of water-conserving irrigation technology, shifting of water applications to more water-efficient crops, and change in crop mix to higher-value crops (Rosegrant, Gazmuri Schleyer, and Yadav 1995; Gardner 1983).

The choice between administered prices and markets should be largely a function of which system has the lowest administrative and transaction costs. Markets in tradable water rights have two major advantages compared with administered efficiency pricing. First, information costs are reduced, because the market, composed of irrigators with expert knowledge of the value of water as an input in the production process, bears the costs and generates the necessary information on the value and opportunity costs of water. Second, in existing irrigation systems, the value of prevailing usufructuary water rights (formal or informal) has already been capitalized into the value of irrigated land. Imposition of administered pricing is correctly perceived by rights holders as expropriation of those rights and creates capital losses in established irrigation farms. Attempts to establish administered efficiency prices thus meet with strong opposition from established irrigators, making it difficult to institute and maintain an efficiency-oriented system of administered prices. The establishment of transferable property rights is seen as formalizing existing rights to water rather than expropriating these rights and is therefore politically more feasible (Rosegrant and Binswanger 1994).

Devolution of water rights from centralized bureaucratic agencies to farmers and other water users has a number of advantages. The first is empowerment of the water user, by requiring user consent to any reallocation of water and compensating the user for any water transferred. The second is security of water rights tenure provided to the water user. If well-defined rights are established, the water user can benefit from investing in water-saving technology. Third, a system of marketable rights to water induces water users to consider the full opportunity cost of water, including its value in alternative uses, thus providing incentives to economize on the use of water and gain additional income through the sale of saved water. Fourth, a properly managed system of tradable water rights provides incentives for water users to internalize (or take account of) the external costs imposed by their water use, reducing the pressure to degrade resources.

Establishment of markets in tradable property rights does not imply free markets in water. Rather, the system would be one of managed trade, with institutions in place to protect against third-party effects and negative environmental effects that are not eliminated by the change in incentives. The law establishing tradable water rights should be simple but comprehensive. It should clearly define the characteristics of water rights and the conditions and regulations governing the trade of water rights; establish and implement water rights registers; delineate the roles of the government, institutions, and individuals involved in water allocation and the ways of solving conflicts between them; and provide cost-effective protection against negative third-party and environmental effects that can arise from water trades.

The Chilean law creating a system of tradable water rights has been successful in dealing with most of these issues. Chile adopted a comprehensive, market-oriented water policy nearly 20 years ago and has had important achievements in improving water use efficiency. Tradable water rights in Chile have fostered efficient agricultural use of water, which has in turn increased agricultural productivity, generating more production per unit of water. The market valuation of water at its scarcity value has caused farmers to invest in on-farm irrigation technology that has saved water to irrigate more area or to sell to other uses, has induced a shift to high-value crops that use less water per unit value of output, and has given farmers greater flexibility to shift cropping patterns according to market demand through the purchase, rent, and lease of water. Because of the topography in Chile, reuse of drainage water is minimal in most river basins, so gains in water use efficiency in agriculture have represented real water savings (Gazmuri Schleyer and Rosegrant 1996).

Demand Management for Groundwater. The problem of overdrafting of groundwater often occurs because individual pump irrigators have no incentive to optimize long-run extraction rates, since water left in the ground can be captured by other irrigators or potential future irrigators. To encourage rational exploitation of groundwater, the same types of policy instruments employed for surface water can be used. The three broad types of institutional arrangements for managing aquifers are quantity-based controls, prices and charges, and tradable water rights (or exchangeable permits) in stocks and flows of groundwater.

Quantity-based controls. Quantity-based control mechanisms include well and pump permits that grant the right to install and operate a well of a particular capacity, and pumping quotas that specify a fixed annual rate of extraction for each water user. Pumping permits for new wells may also impose size and spacing specifications to attempt to optimize extraction rates. Pumping quotas are intended to be more precise and are usually assigned in proportion to water extraction in a base period or based on the proportion of land that is owned overlying the aquifer.

Prices and charges. Charging pumpers for water can also help control pumping rates. In theory, water prices can be set to include both the direct value of marginal product of the water and the externality cost imposed on other pumpers, thereby inducing each individual pumper to internalize the pumping externalities. Energy prices (for electricity, gasoline, diesel) also influence the profitability and rate of pumping. Subsidies for energy that encourage overuse of groundwater (such as those in India) should clearly be removed, but use of selective energy taxes to further reduce pumping rates are likely to cause inefficiencies in energy markets.

Transferable groundwater rights. Well-defined tradable property rights in stocks and flows of groundwater would also promote efficiency, because users would have an incentive to compare the opportunity costs of different types of water use and current versus future uses of water. The holder of a title to a stock of water could still face increasing extraction costs imposed by the usage rates of other pumpers, but these effects could be reduced with unitization, a contractual arrangement that evolved in oil recovery to mitigate common-pool problems. With unitization, all pumpers contract to use agreed-upon methods of extraction and delivery and to share the costs. Each pumper's share of the lift costs would be based on his or her usage rate, so unitization may entail higher delivery costs, but it would also provide incentives for increased water conservation and thus lower lift costs (Rosegrant and Binswanger 1994).

Managing groundwater in the real world. Government intervention to manage groundwater in the developing world has proven difficult to implement, subject to corruption, and in many cases very costly. The most successful tubewell development has been through small-scale private investment, which is widely dispersed and difficult to monitor. Only when private tubewell imports and markets were deregulated did the small-scale tubewell revolution take off in Bangladesh. An attempt at re-regulation through restrictions on well siting slowed growth in tubewell adoption during 1985–1987 (Rogers et al. 1994). Other Asian countries have also been ineffective in managing groundwater. Indonesia and the Philippines have systems of licensing wells, but these have proved difficult to apply in rural areas. India has been ineffective at implementing licensing laws at the state level, where ownership of all water resources resides. Pakistan has no legal system for licensing groundwater withdrawals, and limited attempts to give ownership of underlying aquifers to municipalities have been challenged in the courts. Even China, which applies a strict licensing system, has been unable to avoid massive overdrafting on the North China Plain (Frederiksen, Berkoff, and Barber 1993).

Are there approaches that can effectively manage groundwater resources in developing countries and reduce the negative effects of overdrafting without imposing unnecessary explicit or implicit taxes on groundwater and stifling the appropriate use of valuable groundwater resources? A big part of the answer to this question comes from an unlikely source, Southern California, where pragmatic, diverse, decentralized, and to a large extent successful approaches to groundwater management have evolved over time as water users and local governments have responded to depletion of groundwater resources and degradation of the environment. Groundwater management programs have eliminated overdrafts, impounded surface and imported water for aquifer replenishment, and stopped saltwater intrusion (Blomquist 1995).

The law governing California groundwater resources does not seem promising for efficient exploitation of the water, because of the potentially contradictory principles embedded in the law. Four principles govern groundwater rights:

1. Overlying landowners have rights to the reasonable use of groundwater on their land.
2. Relative to each other, overlying landowners have correlative rights to water and share proportionately in water supply reductions in the event of shortages.
3. Appropriators (those pumping water who do not own overlying land) have a seniority system with respect to one another, with reductions in water use imposed first on junior rights holders.
4. Overlying owners have first rights to the amount of water that constitutes reasonable use; appropriators have a right to the surplus remaining, if any (Blomquist 1992).

These principles allow substantial room for interpretation, but California water law also calls for adjudication of groundwater rights among all users in a basin or aquifer when disputes over these rights occur. Adjudication generally is initiated when one or more rights holders believe their rights are being impaired by a lowering of the water table or contamination of the water.

The adjudication process has resulted in a governance structure for the water basin that establishes water rights, monitoring processes, means for sanctioning violations, representative associations of water users, financing mechanisms for the governance system, and procedures for adapting to changing conditions (Blomquist 1992). Central to the governance structure is a water management program that has employed a variety of the instruments described (and combinations of instruments) in different basins to influence water demand, including pumping quotas (usually based on some notion of historical use), pumping charges, and transferable rights to groundwater.

The features that have made this governance structure for groundwater management efficient in many of the basins in Southern California also make it highly appropriate for developing-country conditions. Key elements for the success of this governance structure are that it is agreed upon and managed by the water users; it is responsive to local conditions; it operates with available information and databases, rather than requiring theoretically better but unavailable information; and it adapts to the evolving environment.

The proper role for government is also suggested by a characteristic that is both a strength and a weakness of groundwater management procedures in California. Changes in groundwater management are not imposed, or even considered, unless a management problem exists, thus preventing interventions that can derail the efficient use of groundwater. The negative side is that the move toward solutions often does not begin until significant damage to the groundwater resource has been done, in large part because of the difficulty of obtaining information about the state of the aquifer. Government can therefore play an important role in monitoring the groundwater resource to identify emerging problems and in facilitating an institutional environment that is conducive to decentralized solutions.

Privatization and User Participation in Irrigation. The importance of user participation in and management of irrigation has already been mentioned repeatedly. Involvement of farmers in the development and management of even large-scale irrigation systems is desirable from the project planning and design stage. Financial participation by future water beneficiaries in investment in new infrastructure would also be helpful. User participation in the approval and financing of infrastructure corrects inappropriate investment incentives in the public sector, which often lead to construction of unprofitable infrastructure and continuing large capital and operating subsidies financed through tax revenues.

In many developing countries, devolution of irrigation infrastructure and management to water user associations would be beneficial. In the past, turnover of the infrastructure and management of systems has often failed because of flaws in internal structural features or external factors that affect the viability and sustainability of water user associations in managing irrigation systems. A recent review has identified some of the characteristics that appear to be associated with successful water user associations (Meinzen-Dick et al. 1994). Water user associations tend to be stronger if they build upon existing social capital or patterns of cooperation. Groups are likely to be stronger if they are homogeneous in background and assets (though heterogeneity can be managed). Such associations must demonstrably improve water control and farm profitability to ensure that the benefits to farmers outweigh the costs of participation. Particularly crucial to success is a supportive policy and legal environment that includes establishment and adjudication of secure water rights, monitoring and regulation of externalities and third-party effects of irrigation, and provision of technical and organizational training and support.

Reforming Urban Water Systems. Urban areas can be important sources of water savings. More than 20 percent of the world's population lives in urban areas along coastlines. Almost all of the water used in these cities drains directly into the ocean salt sink without any reuse, so both reduced initial consumption and reduced wastage in the distribution system will be translated directly into real physical water savings (Seckler 1996). In most noncoastal cities in developing countries, reuse of drainage water is also minimal because of the absence or poor quality of treatment facilities, and what water is reused poses serious health hazards. Under these conditions, reduced consumption and transmission losses will also represent real gains in water availability.

The amount of water wasted and lost in urban distribution systems, homes, commercial establishments, and public facilities is often huge. Nonagricultural water demand requirements in Manila were estimated at 1,285 million cubic meters in 1995, 204 million cubic meters more than is available from secure groundwater yields and dependable surface water flows, leading to serious overdrafting of aquifers. Only 42 percent of water supplied, however, was actually sold to users. Thus, fully 58 percent of supply was unaccounted-for water, consumed by "illegal" users and lost during distribution (Ebarvia 1995). The average level of unaccounted-for water in World Bank–assisted urban water projects is about 36 percent. Barranquilla, Cairo, Jakarta, Lima, and Mexico City have unaccounted-for water levels as high as 60 percent, compared with 10–15 percent in well-managed systems. Although some of this unaccounted-for water is unreported water use by public agencies or unauthorized private use, much of it is losses into the soil or salt sinks. In Jakarta, for example, water loss through leakage has been estimated at 41 percent of total supply. It has also been estimated that nearly one-half of these losses can be eliminated cost-effectively (Bhatia and Falkenmark 1993).

The poor performance of urban water systems is in significant part due to flawed policies. When incremental water can be obtained at low cost as a result of subsidies, there is little incentive to improve either physical efficiency (by, for example, investing in pipes or metering) or economic efficiency (collection of water tariffs). Considerable evidence shows that the use of incentive-based policy instruments can achieve substantial water savings and improve the delivery of services. These instruments have been used to raise efficiency and generate savings in urban water service and delivery, household water use, and industrial water use.

Urban water services. In Chile, privatization and the granting of secure water rights held by the urban water companies, together with an active water market, have encouraged the construction and operation of improved treatment plants that sell water for urban use. Efficiency in urban water and sewage services has been greatly increased with no significant impact on prices. Urban water companies are more efficient because they can no longer get free water from the state, through expropriation from farmers. When incremental water could be obtained for free, there was no need to improve either physical or economic efficiency. The coverage of potable water has risen to 99 percent of the population in urban areas and 94 percent in rural areas from 63 percent and 27 percent respectively before the reforms (Gazmuri Schleyer and Rosegrant 1996).

Privatization of urban water services has also been highly effective in Africa. Urban water services in the Côte d'Ivoire have been operated by a private company, Société de Distribution d'Eau de Côte d'Ivoire (SODECI), under a mixture of concessions and lease contracts, since 1960. SODECI was established as a subsidiary of a large, French water utility to operate the water supply system of Abidjan and is now majority-owned by Ivorian shareholders. This arrangement has performed well in many ways. In 1989, 72 percent of the urban population had access to safe water, compared with 30 percent in 1974. About 80 percent of the rural population was served by water points equipped with hand pumps, compared with 10 percent in 1974. The operating efficiency in urban areas is high, with unaccounted-for water at 12 percent and the collection rate for private consumers at 98 percent (World Bank 1993).

Household consumption. Removal of subsidies in urban water use can have dramatic effects on water use. An increase in the water tariff in Bogor, Indonesia, from US$0.15 to US$0.42 per cubic meter resulted in a 30 percent decrease in household demand for water. It is likely that this degree of price responsiveness is typical for household demand in developing countries, although evidence is limited (Bhatia and Falkenmark 1993). A considerable body of analysis for developed countries shows a central range of price elasticities of demand for household water of –0.3 to –0.7 (Frederick 1993). There have been few studies of household demand elasticities in developing countries because water tariffs have generally been low, price changes have not been significant, and metering has been absent. However, the limited available evidence is consistent with the estimated values for developed countries. In urban Brazil and Mexico, estimated price elasticities for urban water demand are –0.60 and –0.38, respectively (Gomez 1987).

Industrial water use. The experiences in Japan and the United States show that increased water prices, effluent charges, and pollution regulations have great potential to generate industrial water savings by promoting investment in water recycling and water conservation technology. Increased water tariffs induced a 50 percent reduction in water use over a six-year period by a fertilizer factory in Goa, India. In São Paulo, Brazil, three industries reduced water consumption by 40–60 percent in response to the establishment of effluent charges. In Israel, water consumption per unit value of industrial output dropped by more than two-thirds from 1962 to 1982. These dramatic improvements were achieved through the issuance of restrictive water licenses, the introduction of water-saving technologies, and subsidized financing for investment in water-saving processes (Bhatia and Falkenmark 1993).

Conservation through Appropriate Technology

If improved demand management introduces incentives for water conservation, availability of appropriate technology will be essential to generating water savings. As the value of water increases, the use of more advanced technologies, such as drip irrigation utilizing low-cost plastic pipes, sprinklers, and computerized control systems, used widely in developed countries, could have promising results for developing countries. Any evaluation of the impacts of these technologies must take account of the difference between consumptive use of water and water withdrawals or applications. All of these advanced technologies can significantly reduce the amount of water applied to a field, but, to the extent that the saved water simply reduces the amount of drainage water that is reused, the actual water savings will be lower than the apparent efficiency gains. Nevertheless, if the scarcity value of water is high enough, appropriate use of new technologies appears to offer both real water savings and real economic gains to farmers.

Field application efficiencies in flood irrigation in developing countries are typically in the range of 40–60 percent. High-pressure sprinklers save on drainage losses but may not reduce consumptive use because of the high evaporative losses. Modern low-pressure, downward-sprinkling systems, however, can reduce evaporation considerably (Seckler. 1996). Surge irrigation can reduce water applications significantly. Instead of releasing water continuously down field channels, surge irrigation alternates between rows at specific intervals. The initial wetting of the channel partially seals the soil and allows water to be distributed more uniformly, reducing percolation, runoff, and evaporation. Drip irrigation offers perhaps the greatest potential benefits in real water savings. By directing water applications directly to the root zones, drip irrigation can significantly reduce field evaporation losses. Drip irrigation can also increase the productivity of water in areas already affected by salinity. Used in conjunction with tubewells, these systems can lower water tables and leach salts below the root zone of plants.

Technological opportunities also exist at the irrigation system level. In Malaysia's Muda irrigation system, real-time management of water releases from the dam, keyed to telemetric monitoring of weather and streamflow conditions, has significantly improved water use efficiency and reduced drainage to the ocean. In North Africa, modern irrigation systems using hydraulically operated diversion and measuring devices were developed as early as the late 1940s and were employed in irrigation schemes constructed in the 1950s. Modern schemes in this region deliver water on demand to individual farmers, allowing water users to be charged according to the volume of water delivered, encouraging conservation and efficient use of water. Some of these irrigation techniques have been transferred to the Middle East and in pilot projects to other developing countries (World Bank 1993). Continued increases in the value of water could make these capital-intensive irrigation distribution systems more widely feasible in other regions of the world.

Environmental Demands for Water

Many aspects of environmental protection and improvement of water quality have already been discussed. Demand management instruments such as development of appropriate legal and institutional frameworks, regulatory policy, and incentive policies can promote environmental sustainability and water quality through recycling, reduction of excess water application in saline areas, and elimination of groundwater overdraft. In many of the critically important aspects of water resource strategy, the goals of water use efficiency and conservation, economic efficiency, and environmental sustainability are fully complementary.

In other ways, however, as countries grow and incomes increase, environmental demands for water may increasingly compete with the use of water for directly productive purposes in agriculture, household, and industrial sectors. California shows the potential for competition among different uses. Instream flows and runoff are legally mandated for a variety of environmental purposes, including preservation of wild and scenic rivers, protection of endangered fish and wildlife species, and prevention of saltwater intrusion. Between 1960 and 1990, urban water use in California rose from 2.5 cubic kilometers to 7.4 cubic kilometers and water use in irrigated agriculture also increased, from 24.7 cubic kilometers to 29.6 cubic kilometers, while legally mandated natural runoff for environmental purposes increased from 1.2 cubic kilometers to 29.6 cubic kilometers, or 28 percent of total water supply.

As incomes grow in developing countries, there will be significant increases in the demand for environmental "goods," including demand for direct allocation of water for environmental purposes. In addition to dealing with the environmental concerns arising from urban and industrial use of water, direct environmental demand for water will need to be accommodated, together with urban and agricultural water demand. The evidence shows that effective environmental protection policies can be designed, but in the final instance, in any society, how much environmental protection will be provided will be a matter of political choice and commitment.

International Water: Conflict or Cooperation?

Water policy reform must also transcend national boundaries. In many regions, long-term solutions to domestic water shortages will require international cooperation among countries sharing scarce water resources. Intergovernmental activities to settle conflicts over shared bodies of water have had mixed success but in general seem to indicate that progress can be made in solving international water disputes, albeit in fits and starts. Perhaps the most effective solution was the 1960 agreement dividing the waters of the Indus basin between India and Pakistan. This agreement was mediated by the World Bank and greatly facilitated by the bank's assistance in mobilizing financial resources to increase the supply of water to both countries. More typical are the disputes over the Tigris-Euphrates, the Jordan River, and the Ganges. In these cases, slow progress has been punctuated by sharp setbacks, followed by additional progress.

The Tigris-Euphrates Basin

The Tigris and Euphrates Rivers rise in Turkey and flow through or along Syrian territory before entering Iraq. The three riparians to the river coexisted with varying degrees of tension through the 1960s. Beginning at that time, Turkey built the Keban Dam (1965–73) and Syria constructed the Tabqa Dam (1968–73) on the Euphrates, leading to reductions in streamflow to Iraq as the dams filled in 1973. Protests by Iraq led in 1975 to troop movements by Iraq and Syria to their mutual border, before mediation by Saudi Arabia culminated in an agreement on water releases to Iraq (Wolf 1996).

Tensions have again escalated with the construction by Turkey of the US$21 billion Greater Anatolia Project (GAP) on the Euphrates in southeast Anatolia. GAP will include 21 dams irrigating 1.65 million hectares and 19 hydroelectric plants with installed capacity of 7,500 megawatts (Wolf 1996). It has been estimated that when completed in the late 1990s, the project could cause Syria to lose up to 40 percent of its water from the Euphrates and Iraq as much as 90 percent. The centerpiece of the project is the Ataturk Dam, the world's ninth largest, which was completed in 1990. In order to begin filling the reservoir behind the dam, Turkey stopped the flow of the Euphrates entirely for one month, from mid-January to mid-February of 1990, rekindling tensions with Iraq and Syria (McCaffrey 1993).

In negotiations since then, Turkey and Syria have apparently agreed upon a flow of 500 cubic meters per second across the border with Syria, but Iraq has also demanded at various times 500 cubic meters per second and 700 cubic meters per second, neither of which would be possible, given Syrian withdrawals from their own share of 500 cubic meters. To date, the issue of Iraq's share of the Euphrates has not been resolved (Wolf 1996; McCaffrey 1993).

The Jordan Basin

The Jordan basin, consisting of the Jordan and Yarmuk Rivers and major groundwater aquifers underlying the region, has been viewed as a vital resource and source of contention among the states of the region since the early part of the century, and tensions over water issues increased following World War II and partition. Despite vigorous international attempts to obtain an agreement for the sharing of the basin's waters among Israel, Jordan, and Syria in the 1950s, these countries began unilateral development of the basin.

In 1964, Israel began withdrawing 320 million cubic meters per year of Jordan River water and Jordan completed a major phase of its East Ghor Canal to divert water from the Yarmuk. In 1965, the Arab states began construction of their Headwater Diversion Plan to prevent the Jordan headwaters from reaching Israel. The plan would have diverted up to 125 million cubic meters per year, cut by 35 percent the installed capacity of the Israeli carrier, and drastically increased the salinity of the Sea of Galilee. In March, May, and August of 1965, Israel attacked the diversion works in Syria (Wolf 1996).

Following the war of 1967, Israel gained control over nearly all of the headwaters of the Jordan and an overlook over much of the Yarmuk, eliminating the possibility of the headwater diversion. Closer integration of the West

Bank and Gaza into Israel's economic and water networks together with population pressure from Jewish settlements increased pressure on groundwater supplies and heightened tensions between Palestinians and Israelis. However, it was not until peace talks began in 1992 that significant progress was made on allocation of water among the riparians. Following a series of tense meetings and numerous fits and starts, agreement was reached in 1994 among Israel, Jordan, and the Palestinians on sharing of the Jordan and Yarmuk Rivers and the major groundwater aquifers. However, the lack of participation of Lebanon and Syria in any of the multilateral water talks has made it difficult to reach full settlement on the use of water from these rivers (Wolf 1996).

The Ganges

The Ganges originates in the Himalayas and flows through India to Bangladesh, where it joins the Brahmaputra to form the Padma, which empties into the Bay of Bengal through a vast delta. In 1975 India completed construction of a barrage on the Ganges at Farakka, 18 kilometers upstream from the border with Bangladesh, that diverts water through a canal into the Hooghly River, a distributary of the Ganges that flows to Calcutta. The increased flows from the diversion prevent siltation of that river and of Calcutta harbor and the disruption of shipping. The diversion deprived Bangladesh of Ganges water, which is especially crucial for irrigation in the dry season, to prevent siltation of the Bangladesh portion of the Ganges, and to prevent saltwater intrusion from the Bay of Bengal (McCaffrey 1993). Following negotiations begun in 1968 (during construction of the barrage), an agreement was reached in 1977 between India and Bangladesh allocating 63 percent of the dry season flow of the Ganges at the India-Bangladesh border to Bangladesh. At the time of the agreement, India accepted the principle that "each riparian State was entitled to a reasonable and equitable share of the waters of the international river." However, in 1988 the agreement was not renewed, and the Farakka barrage again became a serious source of dispute between the two countries.

After the lapse of the 1977 pact, Bangladesh received only about one-fourth of the Ganges River flows that it had previously received. The cutback in river flows dried out some irrigated areas, reduced food production, and threatened important coastal mangrove habitats by allowing saltwater intrusion from the Bay of Bengal.

The two countries finally reopened negotiations in 1995, and in December 1996 they reached a new water-sharing agreement. Under the new agreement, Bangladesh will get slightly more water than under the lapsed 1977 agreement. In the crucial dry season it will receive more than one-half of the average flow of the Ganges at Farakka between 1949 and 1988. India's turnaround on the sharing of the Ganges appears to have been motivated by its new "good neighbor" policy, together with the desire to set a favorable precedent for future negotiations with Bangladesh on other contentious issues, including transit, immigration, and hydroelectric power (Cooper 1996).

Toward Cooperation on International Waters

In each of these disputes over international waters, the process of negotiation shows ups and downs, including bitter conflict, but a general forward momentum. An important contributor to this forward movement is a set of shared principles informing international water disputes.

Although there is no agreed-upon international legal framework to govern the use and development of international rivers by riparian countries, many countries have largely accepted the following set of principles: (1) prior consultation, (2) avoidance of significant injury, (3) equitable apportionment of water, (4) nondiscrimination and nonexclusion, and (5) provision for settlement of disputes. These principles have helped sustain negotiations and provided apparent maneuvering room for increasing water supplies and reducing water demand in even the most arid regions. The principles are embedded in the Helsinki Rules formulated by the International Law Association in 1966 (Rogers 1992). Although the Helsinki Rules are not binding, they have provided a useful framework for settling water disputes.

Within this negotiating framework, the steps to a cooperative resolution of disputes in international watersheds may be remarkably similar to the steps required to reform domestic water policy to meet growing national water scarcity. Wolf and Lonergan (1995) describe the following process for resolution of water conflicts in the context of the Middle East: division of existing water resources; investment in greater water use efficiency and water conservation; alleviation of short-term needs through water imports; and development of long-term, large-scale desalination projects. Essential to this process is ongoing communication between the concerned nations, particularly at the technical level (McCaffrey 1993). As shown in the Bangladesh case, even inconsistent measurement of streamflows at a given point can exacerbate a conflict. Technical exchanges to develop a factual consensus on hydrological, meteorological, and other essential data can greatly assist the process of negotiation.

Conclusions

Addressing the challenges of water scarcity will require both selective development and exploitation of new water supplies and comprehensive policy reform that encourages more efficient use of existing water supplies. The most appropriate mix of supply augmentation and demand management, and the most feasible institutional arrangements and policy instruments, will vary depending on a region's level of development, agroclimatic zone, relative water scarcity, level of agricultural intensification, and degree of competition for water.

Highly selective, economically efficient development of new water can involve impoundment of surface water and sustainable exploitation of groundwater resources, as well as expanded development of nontraditional sources of water. To get past the proposal stage, future large and small irrigation and water supply projects will need to be 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 costs and full benefits, including not only irrigation benefits, but health, household water use, and catchment improvement benefits. Of utmost importance, compensation programs for those who are displaced or negatively affected by water projects must be better designed and implemented.

Comprehensive reform of water demand management will be even more important in meeting new water demand by saving water in existing uses and in improving the quality of water and soils. The most significant reforms will involve changing the institutional and legal environment in which water is supplied and used to one that empowers water users to make their own decisions regarding use of the resource, while at the same time providing a structure that reveals the real scarcity value of water, including environmental externalities. Key elements of these reforms include establishment of secure water rights of users; decentralization and privatization of water management functions; and the use of incentives including markets in tradable property rights, pricing reform and reduction in subsidies, and effluent or pollution charges. Nonmarket instruments such as licensing and regulation, and direct interventions such as conservation programs can also play an important role.

Finally, cooperation between countries sharing the same water basin will become increasingly important as water becomes more scarce. Domestic and international water policy are closely intertwined. One key to defusing potential international conflicts over water is national water policy reform to ensure the most efficient use of available water supplies. Thus, countries must begin the painful process of reforming national water policies and treating water as a scarce resource.

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