II

The Response—Plan B

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Raising Water Productivity

Water scarcity, a consequence of the sevenfold growth in the world economy over the last half-century, will be a defining condition of life for many in this new century. The simultaneous emergence of fast-growing water shortages in so many countries requires a wholly new approach to water policy, a shift from expanding supply to managing demand. Managing water scarcity will affect what we eat, how we dispose of waste, and even where we live.[1]

Historically, the common response to water scarcity was to expand supply: to build more dams or drill more wells. Now this potential is either limited or nonexistent in most countries. Where rivers are drained dry and water tables are falling, the only option is reducing the growth in demand by raising water productivity and stabilizing population. With most of the 3 billion people projected to be added by 2050 due to be born in countries where wells are already going dry, achieving an acceptable balance between people and water may depend more on slowing population growth than any other single action.[2]

After World War II, as the world looked ahead to the end of the century, it saw a projected doubling of world population and frontiers of agricultural settlement that had largely disappeared. The response was to launch a major effort to raise land productivity, one that nearly tripled it between 1950 and 2000. Now it is time to see what we can do with water.[3]

Adopting Realistic Prices

Water pricing policies today are remnants of another age, a time when water was abundant, when there was more water than we could possibly use. During the first six decades of the last century, growth in irrigation came from surface water projects, consisting of dams and large networks of gravity-fed canals. Irrigation water from these large, publicly funded projects was often heavily subsidized, provided as a basic service. Because water was so cheap, there was no incentive to use it efficiently.

In some situations, such as in parts of East and Southeast Asia, water is abundant and there is no need to charge for it. But for most of humanity, that age of water abundance is now history. As the world moves into an era of scarcity, the challenge for governments is to take the politically unpopular step of adopting prices for water that reflect its value. Charging for water encourages greater efficiency by all users, including the adoption of more-efficient irrigation practices, the use of more water-efficient industrial processes, and the purchase of more water-efficient household appliances.

Pricing water to encourage efficiency can also be a threat to low-income users, however. In response to this, South Africa introduced lifeline rates, whereby each household receives a fixed amount of water for basic needs at a low price. When water use exceeds this level, the price escalates. This helps ensure that basic needs are met while discouraging the wasteful use of water.[4]

Some countries saw the value of raising water prices early on. The government of Morocco, with 30 million people living in a semiarid environment, made a huge

investment in harvesting its limited rainfall, building 88 large dams, raising storage capacity from 2.3 billion cubic meters of water in 1967 to 14 billion in 1997. But even with this sixfold expansion, Morocco was still facing water shortages, so in 1980 it doubled the price of water nationwide, encouraging efficiency. The effect of price rises on water use varies widely, but as a general matter a 10-percent rise in the price of irrigation water reduces water use by 1–2 percent. For residential and industrial use, the drop is usually higher—ranging from 3 to 7 percent.[5]

China has moved in a similar direction in recent years. With 500 of its 700 largest cities facing water shortages, with water tables falling almost everywhere, and with rivers running dry, China decided in 2001 to raise the price of water. The goal was to have water prices more accurately reflect value. Raising water prices in a country with a history of free water was politically difficult, much like raising gasoline prices in the United States.[6]

Some countries facing acute water scarcity are metering groundwater use. Jordan, a country with only 285 cubic meters of water per person per year—one of the lowest in the world—has installed meters on both new and existing irrigation wells. When the amount of water pumped exceeds that specified in the well permit, owners pay a stiff penalty. Although compliance is not automatic and is often met with resistance, it is widely recognized within the community that the failure to comply will deplete aquifers and undermine local farm economies.[7]

Australia inherited water institutions designed by Europeans, institutions that were more suitable for water-rich countries than for arid Australia. These were replaced by a system of riparian rights with licensing systems that specified how much water could be withdrawn, introduced meters to measure withdrawals, and charged for the amount of water used.[8]

Unfortunately, India moved in the opposite direction in 1997, when the government of Punjab decreed that the state utility should provide free electricity to farmers for irrigation. This populist move in India's breadbasket state lasted three years. *Washington Post* reporter John Lancaster wrote, "With no incentive to curb power use, farmers expanded the acreage devoted to water-intensive crops, especially rice, and ran their pumps indiscriminantly, seriously depleting groundwater reserves." In late 2000, when the state electricity utility was on the brink of bankruptcy, it was instructed to start billing farmers for electricity, a move that should raise Punjab's water productivity and slow the fall of water tables.[9]

Other governments in South Asia, while not so flagrant as the government of Punjab, have nonetheless subsidized the use of both electricity and diesel fuel to irrigators. This, coupled with cheap credit for financing the purchase of pumps and motors, has encouraged the overpumping and wasteful use of water, creating a false sense of food security.[10]

Because surface water is usually available only through large government projects, it is easier to charge for it than for groundwater. But the basic principles for managing the two water sources responsibly are essentially the same: provide economic incentives to use water efficiently and involve local water users' associations in the allocation of the water. Surface water typically belongs to the state and groundwater to the person who owns the land under which it is located. Even though individual farmers drill wells on their land, the pumps can be metered and farmers can be charged for the water. Local acceptance of this approach depends on convincing farmers to work together to stabilize the aquifer for everyone's long-term benefit.

Some countries have introduced tradable water rights so that individuals who have rights to surface water or who own wells can sell their water. This practice, common in the western United States, enables water to move freely to higher value uses, which essentially means the sale of water rights by farmers or local irrigation associations to cities. In India and Pakistan, small landholders often make the large investment needed for an irrigation well and then sell water to neighboring farmers.[11]

Raising Irrigation Water Productivity

Historically, farm productivity was measured in yield per hectare, since land was the constraining resource. But as the twenty-first century begins, policymakers are beginning to look at water as the limiting factor for food production. The common measure that is emerging to measure water productivity is kilograms of grain produced per ton of water.

Since 1950, world irrigated area has nearly tripled. With this growth and with grain yields on irrigated land roughly double those on rainfed land, irrigated land now accounts for easily 40 percent of the world grain harvest. For China and India it is even higher. Four fifths of China's grain harvest and close to three fifths of India's comes from irrigated land. In the United States, one fifth of the grain harvest comes from irrigated land.[12]

The relative contributions of surface water and groundwater irrigation vary widely among countries. Of China's 51 million hectares of irrigated land, 42 million depend on surface water and 9 million on underground water. For India, the breakdown is 44 million hectares and 42 million hectares, respectively, making groundwater even more important to India.[13]

Although China has only 9 million hectares of land irrigated with groundwater, this land is disproportionately productive simply because groundwater is available precisely when the farmer needs it. By contrast, surface water is usually delivered by canal to farmers in local groups, usually on a rotational basis. This timing may or may not coincide with a farmer's needs.

Although there are many ways of raising irrigation water productivity, a few stand out. For those using surface water irrigation, reducing seepage from the canals used to carry water from large reservoirs to farms cuts water use. It is not unusual, particularly where distances are long, for water seepage losses to reach 20–30 percent. This water can be saved if canals are lined with plastic sheeting or concrete—a more costly but more long-term solution.[14]

A second approach is to use a more efficient technology, such as overhead sprinkler systems. Commonly used with center-pivot irrigation systems, their weakness is that some water is lost to evaporation even before it hits the ground, especially in hot, arid settings. Low-pressure sprinklers, which release water at a lower level, close to the soil surface, lose less water through evaporation and drift. These are now widely used in the Texas panhandle of the United States, where aquifer depletion is encouraging farmers to use water much more efficiently.[15]

The gold standard for efficiency is drip irrigation, a method that supplies water directly to the root zone of plants. In addition to cutting water use by up to half, drip irrigation also raises yields because it offers a constant, carefully controlled supply of water. Israel, where water shortages are acute, is the world leader in developing drip technology. It is also now widely used in other countries, including Jordan and Tunisia.[16]

In Jordan, for example, drip irrigation reduced water use an average of 35 percent. Crops such as tomatoes and cucumbers typically yielded 15 percent more. The combination of reduced water use and higher yields raised water productivity by more than half. Tunisia, where drip-irrigated area expanded from 2,000 hectares in 1987

to 36,000 hectares in 1999, has realized similar gains.[17]

India in 1998 was irrigating 225,000 hectares with drip irrigation. Thirteen experiments at Indian research institutes on several different crops showed gains in water productivity ranging from a low of 46 percent to a high of 280 percent. (See Table 7–1.) On average, water productivity was raised by 152 percent, more than doubling.[18]

Drip irrigation may be permanent—that is, with water delivered through pipes installed underground, as is often done for orchards, for example—or flexible, con-

Table 7–1. *Water Productivity Gains When Shifting from Conventional Surface Irrigation to Drip Irrigation in India*

Crop	Changes in Yield[1]	Changes in Water Use	Water Productivity Gain[2]
		(percent)	
Bananas	52	–45	173
Cabbage	2	–60	150
Cotton	27	–53	169
Cotton	25	–60	212
Grapes	23	–48	134
Potato	46	0	46
Sugarcane	6	–60	163
Sugarcane	20	–30	70
Sugarcane	29	–47	143
Sugarcane	33	–65	280
Sweet potato	39	–60	243
Tomato	5	–27	44
Tomato	50	–39	145

[1]Results from various Indian research institutes. [2]Measured as crop yield per unit of water supplied.
Sources: See endnote 18.

sisting of rubber hose or plastic tubing. The latter typically is moved by hand every hour or so across the field and is thus a labor-intensive system of irrigation.

The traditionally high costs of both materials and labor used for drip irrigation are now dropping as new techniques and more flexible materials, including plastic tubing or pipe, become available. With these recent advances, the cost of drip irrigation systems has dropped from $1,200–2,500 per hectare to $425–625. Where water is costly, this is a financially attractive investment. And for countries where unemployment is high and water is scarce, the technology is ideal when it substitutes abundant labor for scarce water.[19]

In recent years, the tiniest small-scale drip-irrigation systems—the size of a bucket—have been developed to irrigate a small vegetable garden with roughly 100 plants (25 square meters). Somewhat larger drum systems irrigate 125 square meters. In both cases, the containers are elevated slightly, so that gravity distributes the water. Small drip systems using plastic lines that can easily be moved are also becoming popular. These simple systems can pay for themselves in one year. By simultaneously reducing water costs and increasing yields, they can dramatically raise incomes of smallholders.[20]

Sandra Postel believes that the combination of these drip technologies at various scales has the potential to profitably irrigate 10 million hectares of India's cropland, or nearly one tenth of the total. She sees a similar potential for China, which is now also expanding its drip irrigation area to save scarce water.[21]

Another technique for raising water use efficiency in both flood- and furrow-irrigated fields is laser leveling of the land, a precise leveling that can reduce water use by 20 percent and increase crop yields by up to 30 percent, boosting water efficiency by half. This practice is widely used for field crops in the United States and for rice production in a number of countries.[22]

Raising crop yields is an often overlooked way of raising water productivity. In Zhanghe Reservoir in the Yangtze River basin, where water was becoming scarce, farmers had to share with urban and industrial users. As a result, they simultaneously reduced water use by using more-efficient irrigation practices and raised rice yields from 4 tons per hectare a year on average in 1966–78 to 7.8 tons per hectare in 1989–98. The combination of lower water use and higher crop yields almost quadrupled water productivity, raising it from 0.65 kilograms of rice per ton of water to 2.4 kilograms.[23]

A comparison of wheat yields between countries also shows how higher crop yields boost water productivity. In California, where irrigated wheat produces some 6 tons per hectare, farmers produce 1.3 kilograms of wheat per ton of water used. But in Pakistan's Punjab, irrigated wheat yields averaged only 2 tons per hectare or 0.5 kilograms per ton of water—less than 40 percent the water productivity in California.[24]

Yet another way of raising water productivity is to shift to more water-efficient grains, such as from rice to wheat. The municipal government of Beijing, concerned about acute water shortages, has decreed that production of rice, a water-thirsty crop, should be phased out in the region surrounding the city. Instead of planting the current 23,300 hectares of rice, farmers will shift to other, less water-demanding crops by 2007. Egypt, facing an essentially fixed water supply, also restricts rice production.[25]

The economic efficiency of water use can also be raised by shifting to higher-value crops, a move that is often market-driven. As water tables fall and pumping becomes more costly, farmers in northern China are switching from wheat to higher-value crops simply because it is the only way they can survive economically.[26]

Institutional shifts, specifically moving the responsibility for managing irrigation systems from government agencies to local water users' associations, can facilitate the more efficient use of water. Farmers in many countries are organizing locally so they can assume this responsibility. Since local people have an economic stake in good water management, they typically do a better job than a distant government agency. In some countries, membership includes representatives of municipal governments and other users in addition to farmers.[27]

Mexico is a leader in this movement. As of 2002, more than 80 percent of Mexico's publicly irrigated land was managed by farmers' associations. One advantage of this shift for the government is that the cost of maintaining the irrigation system is assumed locally, reducing the drain on the treasury. This also means that associations need to charge more for irrigation water. Even so, for farmers the advantages of managing their water supply more than outweigh this additional expenditure.[28]

In Tunisia, where water users' associations manage both irrigation and residential water, the number of associations increased from 340 in 1987 to 2,575 in 1999. Many other countries now have such bodies managing their water resources. Although the early groups were organized to deal with large publicly developed irrigation systems, some recent ones have been formed to manage local groundwater irrigation as well. They assume responsibility for stabilizing the water table, thus avoiding aquifer depletion and the economic disruption that it brings to the community.[29]

Rainwater Harvesting

For many countries, particularly those with monsoonal climates and long dry seasons, water shortages result not

from a lack of rainfall but from a seasonally uneven supply. When annual rainfall is concentrated in a few months, storage is difficult. To illustrate, India has 2.1 trillion cubic meters of fresh water available each year, and the United States has 2.5 trillion cubic meters. While rain falls in the United States throughout the year, in India—which is geographically only one third as large—most of the rainfall comes between mid-June and mid-September. As a result, most of this deluge runs off and is quickly carried back to the sea by the country's rivers. Although there are thousands of dams in India, they can collectively store only a fraction of the rainfall.[30]

The focus on building large dams to capture and store surface water before it runs off dominated most of the last century. But because sites were becoming scarce and because the construction of large dams often inundates large areas, displacing local populations and irreversibly altering local ecosystems, this era has now largely run its course. More and more countries are turning to local water harvesting to ensure adequate supply.

In India, Rajendhra Singh is a leader of this movement. Some 20 years ago, when he was visiting semiarid Rajasthan province, he realized that water shortages were constraining development, preventing people from escaping poverty. As he surveyed the area and talked with villagers, he saw that local earthen dams to collect and store rainwater would help satisfy the need for water, both for residential use and for irrigation.[31]

Singh began working with the villagers, helping them design local water storage facilities. Once villagers helped select a site, they would organize to build an earthen dam. All the materials, the stone and the earth, were local. So, too, was the labor—sweat equity provided by the villagers. Singh would help with the engineering and design. He told villagers that in addition to meeting their daily needs for water, the seepage from the small reservoir would gradually raise the water table, restoring wells that had been abandoned. He also told them this would take time. It worked exactly as he said it would.[32]

Singh's initial success led him to create a local nongovernmental organization with 45 full-time employees and 230 part-timers. Funded by the Ford Foundation and other groups, it has not only helped build 4,500 local water storage structures in Rajasthan, it has also raised villagers' incomes and improved their lives.[33]

When the local topography is favorable for building successful small water storage structures, this can be a boon for local communities. This approach works not only in monsoonal climates, but also in arid regions where low rainfall is retained for local use. With a modest amount of engineering guidance, hundreds of thousands of communities worldwide can build water storage works.

Another technique to retain rainfall is the construction of ridge terraces on hillsides to trap rainfall near where it falls, letting it soak into the soil rather than run off. Using a plow to establish the ridges, local farmers can build these terraces on their own, but they are more successful if they are guided by a surveyor who helps establish the ridgelines and determines how far apart the ridges or terraces should be on the hill. Once the terraces are established, the moisture that accumulates behind them can help support vegetation, including trees that can both stabilize the ridges and produce fruit and nuts or fuelwood. The terraces, which are particularly well adapted to the hilly agricultural regions of semiarid Africa, can markedly raise land productivity because they conserve both water and soil.

The water storage capacity of aquifers can also be exploited. In some ways, they are preferable to dams because water underground does not evaporate. As indicated, percolation from locally constructed water storage facilities often helps recharge aquifers. Similarly, land that is covered with vegetation retains rainfall, reducing runoff and enabling water to percolate downward and recharge aquifers. Without vegetative cover, rainfall runs off immediately, simultaneously causing flooding and reducing aquifer recharge, thus contributing to water shortages. In effect, floods and water shortages are often opposite sides of the same coin. Reforestation, particularly in the upper reaches of a watershed, not only helps recharge aquifers but also conserves soil that if washed away might end up behind dams downstream, reducing the storage capacity of reservoirs.

In summary, water harvesting and local water storage behind dams and in aquifers expands the supply and strengthens the local economy. These same initiatives also help conserve soil, since any action that reduces runoff reduces soil erosion. The net effect is conservation of both water and soil: a classic win-win situation.

Raising Nonfarm Water Productivity

Nonfarm water use is dominated by the use of water simply to wash away waste from factories and households or to dissipate heat from thermal power plants. The use of water to disperse wastes is an outmoded practice that is getting the world into trouble. Toxic industrial wastes discharged into rivers and lakes or into wells also permeate aquifers, making water—both surface and underground—unsafe for drinking. And they are destroying marine ecosystems, including local fisheries. The time has come to manage waste without discharging it into the local environment, allowing water to be recycled indefinitely and dramatically reducing both urban and industrial demand.

The current engineering concept for dealing with human waste is to use vast quantities of water to wash it away in small amounts, preferably into a sewer system where it will be treated before being discharged into the local river. There are four problems inherent in this "flush and forget" system: it is water-intensive; it disrupts the nutrient cycle; most of humanity cannot afford it; and it is a major source of disease in developing countries.

As water scarcity spreads, the viability of water-based sewage systems will diminish. Water-borne sewage systems take nutrients from the land and dump them into rivers, lakes, or the sea. Not only are the nutrients lost from agriculture, but the nutrient overload has led to the death of many rivers, including nearly all of those in India and China. Water-based sewage also contributes to dead zones in coastal oceans. Sewer systems that dump untreated sewage into rivers and streams, as so many do, are a major source of disease and death.[34]

Sunita Narain of the Centre for Science and Environment in India argues convincingly that a water-based disposal system with sewage treatment facilities is neither environmentally nor economically viable for India. She notes that an Indian family of five, producing 250 liters of excrement in a year and using a water toilet, requires 150,000 liters of water to wash away the wastes.[35]

As currently designed, India's sewer system is actually a pathogen-dispersal system. It takes a small quantity of contaminated material and uses it to make vast quantities of water unfit for human use, often simply discharging it into nearby rivers or streams. Narain says both "our rivers and our children are dying." India's government, like that of many other developing countries, is hopelessly chasing the goal of universal water-based sewage systems and sewage treatment facilities—unable to close the huge gap between services needed and provided, but unwilling to admit that it is not an economically viable

option. Narain concludes that the "flush and forget" approach is not working.[36]

This dispersal of pathogens is a huge public health challenge. Worldwide, poor sanitation and personal hygiene claim 2.7 million lives per year, second only to the 5.9 million claimed by hunger and malnutrition.[37]

Fortunately there is an alternative to the use of water to wash away human waste: the composting toilet. This is a simple, waterless toilet linked to a small compost facility. Table waste can also be incorporated in the composter. The dry composting converts human fecal material into a soil-like humus, which is essentially odorless and is scarcely 10 percent of the original volume. These compost facilities need to be emptied every year or so, depending on their design and size. Vendors periodically collect the humus and market it for use as a soil supplement, returning the nutrients and organic matter to the soil and reducing the need for fertilizer.[38]

This technology reduces residential water use, thus cutting the water bill and lowering the energy needed to pump and purify water. As a bonus, it also reduces garbage flow if table waste is incorporated, eliminates the sewage water disposal problem, and restores the nutrient cycle. The U.S. Environmental Protection Agency now lists several brands of dry toilets for use. Pioneered in Sweden, these toilets are used in widely varying conditions, including Swedish apartment buildings, U.S. private residences, and Chinese villages.[39]

At the household level, water can be saved by using appliances that are more water-efficient, including showerheads, flush toilets, dishwashers, and clothes washers. Some countries are adopting water efficiency standards and labeling for appliances, much as has been done for energy efficiency. As water costs rise, as they inevitably will, investments in composting toilets and more water-efficient household appliances will become increasingly attractive to individual homeowners.

For cities, the most effective single step to raise water productivity is to adopt a comprehensive water treatment/recycling system, reusing the same water continuously. With this system, a small percentage of water is lost to evaporation each time it cycles through. Given the technologies that are available today, it is quite possible to comprehensively recycle urban water supplies, largely removing cities as a claimant on water resources.

At the industrial level, one of the largest users of water is the energy sector, which uses water to cool thermal power plants. As fossil fuels are phased out and the world turns to wind, solar, and geothermal energy, the need for cooling water in thermal power plants will diminish. In the United States, for example, thermal cooling of power plants accounts for 39 percent of all water withdrawals. With each coal-fired power plant that is closed as a new wind farm comes online, water use for thermal cooling drops, freeing up water for food production.[40]

Many of the industrial processes now used belong to a time when water was an abundant resource. Within the steel industry, for example, water use efficiency may vary among countries by a factor of three. Much of the water used in industry just washes away waste. If this is stopped, and more and more companies move into zero-emissions industrial parks, water use in industry could drop dramatically.[41]

The new reality is that the existing water-based waste disposal economy is not viable. There are too many factories, feedlots, and households to simply try and wash waste away. It is ecologically mindless and outdated—an approach that belongs to an age when there were many fewer people and far less economic activity.

A Global Full-Court Press

As fast-unfolding water shortages translate into food shortages, they will signal that we can no longer rely on incremental business-as-usual change. Three factors—the simultaneous drop in water tables, the exponential nature of that fall, and the globalization of water scarcity—ensure that such a response will not be sufficient. As water shocks become food shocks and as falling water tables translate into higher food prices, we will realize that the world has changed fundamentally. As Asit K. Biswas, Director of the Third World Centre for Water Management, notes, "The world is heading for a water crisis that is unprecedented in human history. Water development and management will change more in the next 20 years than in the last 2,000 years."[42]

Supply-side technological fixes, such as the massive desalting of seawater, do not hold much hope for food production in the foreseeable future. Although the cost of desalting seawater is falling, it is still expensive and thus not yet a viable prospect for irrigation. At present, it costs between $1 and $2 per cubic meter to desalt seawater. Even at the lower cost, producing wheat with desalted seawater would raise its price from $120 to $1,120 per ton.[43]

Some countries are still focusing on supply expansion when it might be less costly to focus on demand management. To get water to the cities in its industrial northern half, including Beijing and Tianjin, China has devised a plan to move water along three routes from the Yangtze River basin to the Yellow River basin, since the latter has only one tenth the flow of the former. These three routes, designated the East, Central, and West, will cost an estimated $59 billion. Construction on the East route began in December 2002. For China, it might be more economical to invest this $59 billion in urban water recycling and irrigation efficiency in the north rather than trying to transport water from the south.[44]

With water shortages now threatening so many countries at the same time, we need a global full-court press, to borrow an expression from basketball, to raise water productivity. This begins with improved irrigation practices and technologies, as described in this chapter. It also includes boosting crop yields on both irrigated and nonirrigated land. The former will raise the productivity of irrigation water and the latter will get more mileage out of existing rainfall. Shifting to more water-efficient crops also helps raise farm water productivity. The shift from rice to wheat, already under way in some countries, can continue wherever it is practical. With feedgrain, shifting from corn to sorghum may make sense in countries where there is not enough water for irrigation.

At the dietary level, shifting to more grain-efficient forms of animal protein can raise the efficiency of grain use, and thus the efficiency of water use. This means moving from feedlot beef and pork to more poultry and herbivorous species of farmed fish, such as carp, tilapia, and catfish. For the world's affluent, moving down the food chain also saves water.

At the consumer level, switching to more water-efficient household appliances raises water productivity. For cities and industry, recycling of water becomes the key to achieving large gains in water productivity. Finally, and perhaps most important, for water-scarce countries facing large projected increases in population, accelerating the shift to smaller families reduces the chance of being trapped in hydrological poverty.