from Lester R. Brown, *Outgrowing the Earth: The Food Security Challenge in an Age of Falling Water Tables and Rising Temperatures* (NY: W.W. Norton & Co., 2005).

6

Stabilizing Water Tables

Although public attention has recently focused on the depletion of oil resources, the depletion of underground water resources poses a far greater threat to our future. While there are substitutes for oil, there are none for water. Indeed, we lived for millions of years without oil, but we would live for only a matter of days without water.

Not only are there no substitutes for water, but we need vast amounts of it to produce food. At the personal level, we drink roughly four liters of water a day (nearly four quarts), either directly or indirectly in various beverages. But it takes 2,000 liters of water—500 times as much—to produce the food we consume each day.[1]

Since food is such an extraordinarily water-intensive product, it comes as no surprise that 70 percent of world water use is for irrigation. Although it is now widely accepted that the world is facing water shortages, most people have not yet connected the dots to see that a future of water shortages will also be a future of food shortages.[2]

Falling Water Tables

Over much of the earth, the demand for water exceeds the sustainable yield of aquifers and rivers. The gap between the continuously growing use of water and the sustainable supply is widening each year, making it more and more difficult to support rapid growth in food production.[3]

With river water in key farming regions rather fully exploited, the world has turned to underground water sources in recent decades to keep expanding the irrigated area. As a result, the climbing demand for water has now exceeded the natural recharge of many aquifers. Now water tables are falling in scores of countries that contain more than half the world's people. (See Table 6–1.) These include China, India, and the United States, which together account for nearly half of the global grain harvest. And as the gap between steadily rising demand and the sustainable yield of aquifers grows, water tables are falling at an accelerating rate.[4]

In the United States, water tables are falling under the Great Plains and throughout the southwest. In India, they are falling in most states—including the Punjab, the nation's breadbasket. This country of more than 1 billion people depends on underground water supplies for well over half of its irrigation water, with the remainder coming from rivers. In China, water tables are falling throughout the northern half of the country, including under the North China Plain, the source of half of the nation's wheat and a third of its corn.[5]

The effects of aquifer depletion vary, depending on whether it is a replenishable or fossil aquifer. If the aquifer is replenishable, as most are, once depletion occurs the water pumped is necessarily reduced to the amount of recharge. If, for example, an aquifer is being pumped at twice the rate of recharge, depletion means the rate of pumping will be cut in half. In a fossil, or nonreplenishable aquifer, however, depletion means the end of pumping. Fossil aquifers include the Ogallala under the U.S. Great Plains, the aquifer the Saudis use to irrigate wheat, and the deeper of the two aquifers under the North China Plain.[6]

Table 6–1. *Underground Water Depletion in Key Countries*

Country	Description
Mexico	In Mexico, where a third of all water comes from underground, aquifers are being depleted throughout the northern arid and semiarid regions. In a country where irrigated land is more than three times as productive as rain-fed land, the loss of irrigation water from aquifer depletion will be costly.
United States	Overpumping is widespread, and the overpumping of the vast Ogallala or High Plains aquifer—essentially a fossil aquifer that extends from southern South Dakota through Nebraska, Kansas, eastern Colorado, Oklahoma, and Texas—is a matter of national concern. In the southern Great Plains, irrigated area has shrunk by 24 percent since 1980 as wells have gone dry.
Saudi Arabia	When the Saudis turned to their large fossil aquifer for irrigation, wheat production climbed from 140,000 tons in 1980 to 4.1 million tons in 1992. But with rapid depletion of the aquifer, production dropped to 1.6 million tons in 2004. It is only a matter of time until irrigated wheat production ends.
Iran	The overpumping of aquifers is estimated at 5 billion tons per year. When aquifers are depleted, Iran's grain harvest could drop by 5 million tons, or one third of the current harvest.
Yemen	This country of 21 million people is unique in that it has both one of the world's fastest-growing populations and the fastest-falling

Table 6–1. *continued*

	water tables. The World Bank reports that the water table is falling by 2 meters or more a year in most of Yemen.
Israel	Both the coastal aquifer and the mountain aquifer Israel shares with Palestinians are being depleted. With severe water shortages leading to a ban on irrigated wheat, the continuous tightening of water supplies is likely to further raise tensions in the region.
India	Water tables are falling in most states in India, including the Punjab and Haryana, the leading grain-surplus states. With thousands of irrigation wells going dry each year, India's farmers are finding it increasingly difficult to feed the 18 million people added each year.
China	Water tables are falling throughout northern China, including under the North China Plain. China's harvest of wheat has fallen in recent years as irrigation wells have dried up. From 2002 to 2004, China went from being essentially self-sufficient in wheat to being the world's largest importer.

Source: See endnote 4.

In some countries, falling water tables and the depletion of aquifers are already reducing the grain harvest. In Saudi Arabia, the wheat harvest peaked in 1992 at 4.1 million tons, and then declined to 1.6 million tons in 2004—a drop of 61 percent. (See Figure 6–1.) Some other smaller countries, such as Yemen, have also experienced grain harvest declines.[7]

For the first time, diminishing supplies of irrigation water are helping to shrink the grain harvest in a large grain producer—China. The wheat harvest, which peaked at 123 million tons in 1997, dropped to 90 million tons in 2004—a decline of 27 percent. The production of wheat has dropped much more than that of corn and rice because wheat is grown largely in the semiarid northern half of the country, where water is scarce.[8]

Serious though emerging water shortages are in China, the problem may be even more serious in India simply because the margin between actual food consumption and survival is so precarious. In a recent survey of India's water situation, Fred Pearce in the *New Scientist* notes that the 21 million wells drilled in this global epicenter of well-drilling are lowering water tables in most of the country. The wells, powered by heavily subsidized electricity, are dropping water tables at an accelerating rate. In North Gujarat, the water table is falling by

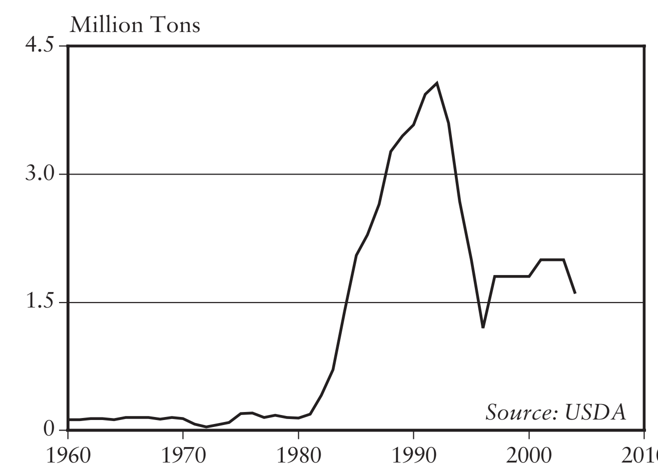

Figure 6–1. *Wheat Production in Saudi Arabia, 1960–2004*

6 meters or 20 feet per year. In some states, half of all electricity is now used to pump water.[9]

In Tamil Nadu, a state of 62 million people in southern India, falling water tables are drying up wells. Kuppannan Palanisami of Tamil Nadu Agricultural University says that falling water tables have dried up 95 percent of the wells owned by small farmers, reducing the irrigated area in the state by half over the last decade.[10]

As water tables fall, well drillers are using modified oil-drilling technology to reach water, drilling as deep as 1,000 meters in some locations. In communities where underground water sources have dried up entirely, all agriculture is rain-fed and drinking water is trucked in. Tushaar Shah, who heads the International Water Management Institute's groundwater station in Gujarat, says of India, "When the balloon bursts, untold anarchy will be the lot of rural India."[11]

In Mexico, water tables are falling throughout the more arid north. As this happens, the energy required to pump water rises. Indeed, more than 6 percent of Mexico's electricity is used to pump water.[12]

In the United States, the loss of irrigation water is making it more difficult for farmers to respond to the future import needs of other countries. In the southern Great Plains, for example, the irrigated area has shrunk by 24 percent since 1980. Leading agricultural states such as Texas, Oklahoma, and Kansas are among those most affected by falling water tables.[13]

In a rational world, falling water tables would trigger alarm, setting in motion a series of government actions to reduce demand and reestablish a stable balance with the sustainable supply. Unfortunately, not a single government appears to have done this. Official responses to falling water tables have been consistently belated and grossly inadequate.

Rivers Running Dry

While falling water tables are largely invisible, rivers that are drained dry before they reach the sea are highly visible. Two rivers where this phenomenon can be seen are the Colorado, the major river in the southwestern United States, and the Yellow, the largest river in northern China. Other large rivers that either run dry or are reduced to a mere trickle during the dry season are the Nile, the lifeline of Egypt; the Indus, which supplies most of Pakistan's irrigation water; and the Ganges in India's densely populated Gangetic basin. (See Table 6–2.)[14]

Some rivers have disappeared entirely. A few years ago, China announced plans to divert water from the Yellow River to Taiyuan, the capital of Shaanxi Province. Learning of this, I asked why they did not simply take water from the Fen, the local river that originated in northern Shaanxi and flowed southward through Taiyuan, eventually emptying into the Yellow River on the province's southern border. Fred Crook, senior China analyst at the U.S. Department of Agriculture, responded that the Fen River had dried up. It exists only on old maps. Taiyuan is now wholly dependent on underground water resources from well fields, and some of the wells are starting to go dry.[15]

The management and use of scarce water in river basins that include several countries can be difficult. The Nile, for instance, which originates largely in Ethiopia and flows through Sudan and Egypt, is reduced to a trickle by the time it reaches the Mediterranean Sea. Since it rarely rains in Egypt, the country's existence depends entirely on the Nile.[16]

Virtually all the river's water is now being used. Against this backdrop, governments could be expected to coordinate population policy with water availability, but there appears to be no effort to do so. In Egypt, the population is projected to grow from 73 million today to 127 million in 2050. Sudan's population is projected to nearly double, from 34 million today to 60 million. Ethiopia, meanwhile, is projected to go from 72 million today to 171 million by 2050.[17]

Egypt now gets the lion's share of the Nile's water partly because it developed much sooner than Ethiopia. But as Ethiopia begins to develop, it is planning to build dams on the upper (Blue) Nile that will reduce the flow in the lower reaches of the Nile river basin. It will be difficult for Egypt, where incomes average $3,900 per year, to argue that Ethiopia, with incomes of only $710 per year, should not

Table 6–2. *Major Rivers Running Dry*

River	Condition
Amu Darya	The Amu Darya, which originates in the mountains of Afghanistan, is one of the two rivers that feed into the Aral Sea. Soaring demands on this river, largely to support irrigated agriculture in Uzbekistan, sometimes drain it dry before it reaches the sea. This, along with a reduced flow of the Syr Darya—the other river feeding into the sea—helps explain why the Aral Sea has shrunk by more than half over the last 40 years.
Colorado	All the water in the Colorado, the major river in the southwestern United States, is allocated. As a result, this river, fed by the rainfall and snowmelt from the mountains of Colorado, now rarely makes it to the Gulf of California.
Fen	This river, which flowed from the northern part of China's Shaanxi province and emptied into the Yellow River at the province's southern end, has literally disappeared as water withdrawals upstream in the watershed have dropped the water table, drying up springs that once fed the river.

be permitted to develop its water resources. With virtually all the water in the basin now spoken for and with the combined population of the three countries projected to grow from 179 million to 358 million by 2050, the potential for the basin's population to outgrow its water resources—setting the stage for conflict—is clear.[18]

Another major river where conflicts over water rights are arising is the Mekong. China's construction of several huge hydroelectric dams on the upper reaches of the river system is reducing the Mekong's flow, directly affecting fisheries, navigation, and irrigation prospects downstream in Cambodia, Laos, and Viet Nam.[19]

Table 6–2. *continued*

Ganges	Some 300 million people of India live in the Ganges basin. Flowing through Bangladesh en route to the Bay of Bengal, the Ganges has little water left when it reaches the bay.
Indus	The Indus, originating in the Himalayas and flowing west to the Indian Ocean, feeds Pakistan's irrigated agriculture. It now barely reaches the ocean during much of the year. Pakistan, with a population of 157 million projected to reach 349 million by 2050, is facing trouble.
Nile	In Egypt, a country where it rarely ever rains, the Nile is vitally important. Already reduced to a trickle when it reaches the Mediterranean, it may go dry further upstream in the decades ahead if, as projected, the populations of Sudan and Ethiopia double by 2050.
Yellow	The cradle of Chinese civilization, the Yellow River frequently runs dry before it reaches the sea.

Source: See endnote 14.

Yet potential flashpoint is the Amu Darya, a river that originates in Afghanistan and flows through Turkmenistan and Uzbekistan before reaching the Aral Sea. As upstream Afghanistan stabilizes politically and begins to develop, it plans to claim some of the water from the river, which will reduce the amount available to the two downstream countries.[20]

We do not know whether sharing water in the Tigris-Euphrates River basin, where irrigated agriculture began some 6,000 years ago, was a source of conflict historically in the region. But today it is a source of tension between Turkey, Syria, and Iraq. In recent years, Turkey has invested heavily in a network of dams, mostly in the upper reaches of the Tigris, that are providing power and water for a large irrigation expansion. Turkey is one of the few countries in the world with a major expansion of irrigation still under way. Again, population growth is contributing to the mounting tensions in this river basin, since the populations of both Syria and Iraq are projected to double by mid-century.[21]

There are literally dozens of other shared rivers where the demand for water is now pressing against the limits of supply, forcing countries to work out agreements on the allocation of river water. Once these agreements are reached, it is in each country's interest to use its share of the water as efficiently as possible.

Cities Versus Farms

At the international level, water conflicts among countries dominate the headlines. But within countries it is the competition for water between cities and farms that preoccupies political leaders. Neither economics nor politics favors farms. They almost always lose out to cities.

In many countries farmers are now faced with not only a shrinking water supply but also a shrinking share of

that shrinking supply. In large areas of the United States, such as the southern Great Plains and the Southwest, virtually all water is now spoken for. Meanwhile, the demand for water continues to climb in the region's fast-growing cities, including Denver, Phoenix, Las Vegas, Los Angeles, and San Diego. The growing water needs of these cities and of thousands of small towns in the region can be satisfied only by taking water from agriculture.[22]

A California monthly magazine, *The Water Strategist*, devotes several pages in each issue to a listing of water sales in the western United States during the preceding month. Scarcely a day goes by without the announcement of a new sale. Eight out of ten are by individual farmers or their irrigation districts to cities and municipalities.[23]

Colorado, with a fast-growing population, has one of the world's most active water markets. Cities and towns of all size are buying irrigation water rights from farmers and ranchers. In the Arkansas River basin, which occupies the southeastern quarter of the state, Colorado Springs and Aurora (a suburb of Denver) have already bought water rights to one third of the basin's farmland. Aurora has purchased rights to water that was once used to irrigate 9,600 hectares (23,000 acres) of cropland in the Arkansas valley.[24]

Far larger purchases are being made by cities in California, a state of 36 million people. In 2003, San Diego bought annual rights to 247 million cubic meters (1 cubic meter of water equals 1 ton) of water from farmers in nearby Imperial Valley—the largest rural/urban water transfer in U.S. history. This agreement covers the next 75 years. In 2004, the Metropolitan Water District, which supplies water to 18 million southern Californians in several cities, negotiated the purchase of 137 million cubic meters of water per year from farmers for the next 35 years. Without irrigation water, the highly productive land owned by these farmers is wasteland. The farmers who are selling their water rights would like to continue to grow crops, but city officials are offering much more for the water than the farmers could possibly earn by using it to produce crops.[25]

In many countries, farmers are not compensated for a loss of irrigation water. In 2004, for example, Chinese farmers along the Juma River downstream from Beijing discovered that the river had run dry. A diversion dam had been built near the capital to take river water for Yanshan Petrochemical, a state-owned industry. Although there were bitter protests by the farmers, it was a losing battle. For the 120,000 villagers downstream from the diversion dam, livelihoods would suffer, perhaps crippling their ability to make a living from farming. Whether it is a result of outright government expropriation, farmers being outbid by cities, or cities simply drilling deeper wells than farmers can afford, the world's farmers are losing the water war.[26]

In the competition between cities and farms, cities have the advantage simply because they can pay much more for water. In China, a thousand tons of water can be used to produce 1 ton of wheat, worth at most $200, or it can be used to expand industrial output by $14,000—70 times as much. In a country where industrial development and the jobs associated with it are an overriding national economic goal, scarce water is no longer going to farmers. Agriculture is becoming the residual claimant on the world's increasingly scarce supply of water.[27]

Scarcity Crossing National Boundaries

Historically, water shortages were local, but today scarcity is crossing national boundaries via the international grain trade. As just described, countries facing shortages divert water from irrigation to satisfy the growing demand in cities, and then import grain to offset the loss

of farm output. The reason for this is simple: since it takes a thousand tons of water to produce a ton of grain, the most efficient way to import water is as grain. In effect, countries are using grain as a currency to balance their water books. Trading in grain futures is in a sense trading in water futures.[28]

The fastest-growing grain import market in the world in recent years has been North Africa and the Middle East. The demand for grain there is growing quickly as a result of both rapid population growth and rising affluence, much of it derived from the export of oil. Virtually every country in this region is pushing against the limits of local water supplies. To meet growing water needs in cities, governments routinely divert irrigation water from agriculture.[29]

Last year the water required to produce the grain and other farm products brought into the region equaled the annual flow of the Nile River. In effect, the water deficit in the region can be thought of as another Nile flowing into North Africa and the Middle East in the form of imported grain.[30]

It has been fashionable in recent years to say that future wars in the Middle East are more likely to be fought over water than over oil. But it is not only costly to win a water war, it is difficult to secure water supplies by winning. In reality, the wars over water are taking place in world grain markets. It is the countries that are financially strongest—not those that are militarily strongest—that will prevail in this competition.

Raising Water Productivity

To avoid a water crunch that leads to a food crunch requires a worldwide effort to raise water productivity. The tightening water situation today is similar to what the world faced with land a half-century ago. After World War II, as governments assessed the food prospect for the remainder of the century, they saw both enormous projected growth in world population and little new land to bring under the plow. In response, they joined with international development institutions in a worldwide effort to raise land productivity that was replete with commodity price supports, heavy investment in agricultural research, extension services, and farm credit agencies. The result was a rise in world grainland productivity from 1.1 tons per hectare in 1950 to 2.9 tons in 2004.[31]

Today the world needs to launch a similar effort to raise water productivity. Land productivity is measured in tons of grain per hectare or bushels per acre, but there are no universally used indicators to measure and discuss water productivity. The indicator likely to emerge for irrigation water is kilograms of grain produced per ton of water. Worldwide that average is now roughly 1 kilogram of grain per ton of water used.[32]

The first challenge is to raise the efficiency of irrigation water, since this accounts for 70 percent of world water use. Some data have been compiled on water irrigation efficiency at the international level for surface water projects—that is, dams that deliver water to farmers through a network of canals. Water policy analysts Sandra Postel and Amy Vickers write about a 2000 review that found that "surface water irrigation efficiency ranges between 25 and 40 percent in India, Mexico, Pakistan, the Philippines, and Thailand; between 40 and 45 percent in Malaysia and Morocco; and between 50 and 60 percent in Israel, Japan, and Taiwan." Irrigation water efficiency is affected not only by the mode and condition of irrigation systems but also by soil type, temperature, and humidity. In arid regions with high temperatures, the evaporation of irrigation water is far higher than in humid regions with lower temperatures.[33]

In a May 2004 meeting, China's Minister of Water

Resources Wang Shucheng outlined for me in some detail plans to raise China's irrigation efficiency from 43 percent in 2000 to 51 percent in 2010 and then to 55 percent in 2030. The steps he described to boost irrigation water efficiency included raising the price of water, providing incentives for adopting more irrigation-efficient technologies, and developing the local institutions to manage this process. Reaching these goals, he said, would assure China's future food security.[34]

Crop usage of irrigation water never reaches 100 percent simply because some irrigation water evaporates from the land surface, some percolates downward, and some runs off. When attempting to raise the water efficiency of irrigation, the trend is to shift from the less efficient flood-or-furrow system to overhead sprinkler irrigation or to drip irrigation, the gold standard of irrigation water efficiency. Low-pressure sprinkler systems reduce water use by an estimated 30 percent over flood or furrow irrigation, while switching from flood or furrow to drip irrigation typically cuts water use in half.[35]

As an alternative to furrow irrigation, a drip system also raises yields because it provides a steady supply of water with minimal losses to evaporation. Since drip systems are both labor-intensive and water-efficient, they are well suited to countries with underemployment and water shortages. They allow farmers to raise their water productivity by using labor, which is often in surplus in rural communities.[36]

Recent data indicate that a few small countries—Cyprus, Israel, and Jordan—rely heavily on drip irrigation to water their crops. (See Table 6–3.) Among the big three agricultural producers—China, India, and the United States—the share of irrigated land using these more-efficient technologies ranges from less than 1 percent in India and China to 4 percent in the United States.[37]

Table 6–3. *Use of Drip and Micro-irrigation, Selected Countries, Circa 2000*

Country	Area Irrigated by Drip and Other Micro-irrigation Methods[1]	Share of Total Irrigated Area Under Drip and Micro-irrigation
	(thousand hectares)	(percent)
Cyprus	36	90
Israel	125	66
Jordan	38	55
South Africa	220	17
Spain	563	17
Brazil	176	6
United States	850	4
Chile	62	3
Egypt	104	3
Mexico	143	2
China	267	<1
India	260	<1

[1]Micro-irrigation typically includes drip (both surface and subsurface) methods and micro-sprinklers; year of reporting varies by country.
Source: See endnote 37.

Low water productivity is often the result of low water prices. Current water prices are often irrationally low, belonging to an era when water was an abundant resource. As water becomes scarce, it needs to be priced accordingly. In Beijing, public hearings were held in mid-2004 on a proposal to raise water prices. At the end of July, officials announced rate hikes for urban and industrial users of some 26 percent, effective August 1. The price went from 4.01 yuan (48¢) to 5.04 yuan (61¢) per

cubic meter. Other local governments in northern China, mostly at the provincial level, have been raising water prices in small increments to discourage waste. The advantage of higher prices is that it affects the decisions of all water users. Higher prices encourage investment in more water-efficient irrigation technologies, industrial processes, and household appliances.[38]

In many cities in water-short parts of the world, it may be time to rethink the typical urban water use model, one where water flows into the city, is used once, and then leaves the city—usually becoming polluted in the process. This flush-and-forget model that so dominates urban water systems will not be viable over the longer term in water-scarce regions. One alternative sewage system is the use of so-called dry toilets, which do not use water and which convert human waste into a rich humus, a highly valued fertilizer.

Another variation on the existing urban water use models is one that comprehensively recycles urban water supplies. Water can be used indefinitely in cities and by industry if it is recycled. Some cities are beginning to do this. Singapore, for example, which buys its water from Malaysia, is starting to recycle its water in order to reduce this vulnerable dependence.[39]

Some countries can realize large water savings by restructuring the energy sector, shifting from fossil-fuel-powered thermal plants, which require large amounts of water for cooling, to renewable energy sources, such as wind and solar. In the United States, for instance, the 48 percent of total water withdrawals that is used for thermal cooling exceeds the 34 percent withdrawn for irrigation. Most of the water used for thermal cooling is river water that returns to its source once it is used, albeit much warmer than when it was withdrawn. Although the actual water losses from evaporation in the power plant cooling towers typically amount to only 7 percent of the water that goes through the plants, the return of the hot water to the river is often ecologically damaging.[40]

What is needed now is a new mindset, a new way of thinking about water use. In addition to more-efficient irrigation technologies, for example, shifting to more water-efficient crops wherever possible also boosts water productivity. Rice production is being phased out in the region around Beijing because it is so water-intensive. Similarly, Egypt restricts rice production in favor of wheat.[41]

Anything that raises the productivity of irrigated land typically raises the productivity of irrigation water. Anything that increases the efficiency with which grain is converted into animal protein increases water productivity.

For people consuming excessive amounts of livestock products, moving down the food chain means not only a healthier diet and reduced health care costs, but also a reduction in water use. In the United States, where the consumption of grain as food and feed averages some 800 kilograms (four fifths of a ton) per person, a modest reduction in eating livestock products could easily cut grain use per person by 100 kilograms. Given that there are 297 million Americans, such a reduction would cut grain use by 30 million tons and the use of water to produce grain by 30 billion tons. At average world grain consumption levels of roughly 300 kilograms per person a year, 30 million tons of grain would feed 100 million people—more than enough to cover world population growth for one year.[42]

Reducing water use to a level that can be sustained by aquifers and rivers worldwide involves a wide range of measures not only in agriculture but also throughout the economy. Among some of the more obvious steps are shifting to more water-efficient irrigation practices and

technologies, planting more water-efficient crops, adopting more water-efficient industrial processes, and using more water-efficient household appliances. One of the less conventional steps is to shift from outdated coal-fired power plants, which require vast amounts of water for thermal cooling, to wind power—something long overdue in any case for reasons of pollution and climate disruption. Recycling urban water supplies is another obvious step to consider in countries facing acute water shortages.

The need to stabilize water tables is urgent, thanks to the sheer geographic scale of overpumping, the simultaneity of falling water tables among countries, and the accelerating drop in water level. Although falling water tables are historically a recent phenomenon, they now threaten the security of water supplies and, hence, of food supplies in countries containing 3.2 billion people. Beyond this, the shortfall—the gap between the use of water and the sustainable yield of aquifers—grows larger each year, which means the water level drop is greater than the year before. Underlying the urgency of dealing with the fast-tightening water situation is the sobering realization that not a single country has succeeded in stopping the fall in its water tables and stabilizing water levels. The fast-unfolding water crunch has not yet translated into food shortages, but if unaddressed, it may soon do so.[43]

Data for figures and additional information can be found at www.earth-policy.org/Books/Out/index.htm.