Water scarcity can be physical, economic or institutional, and—like water itself—it can fluctuate over time and space

Beyond scarcity, water security is also about risk and vulnerability—themes taken up in the second part of this chapter. From the earliest civilizations to the globalizing world of today, the success—or failure—of societies in harnessing the productive potential of water while limiting its destructive potential has determined human progress. The predictability and reliability of access to water, and protection against water-related risks, are crucial to human well-being. As the images of suffering from floods in Mozambique and New Orleans and from droughts in northern Kenya powerfully demonstrate, too little or too much of a good thing like water can be a force for destruction. Progress is shaped partly by how and where nature delivers water, but more decisively by the institutions and infrastructure through which people and societies secure access to predictable flows of water and resilience against shocks.

Some shocks are more predictable than others. This chapter concludes by looking at the implication of one impending shock that, managed badly, could roll back the human development gains built up over generations for a large section of humanity. Climate change poses a profound, and profoundly predictable, threat to water security for many of the world's poorest countries and millions of its poorest households. Of course, the threat is not limited to poor countries. Rich countries will feel the impact of changing rainfall patterns, extreme weather events and rising sea levels. But poor countries—and poor people in those countries—lack the financial resources available to rich states to reduce risk on the scale required. International action to limit carbon emissions is important because it will limit the future damage caused by climate change. However, dangerous climate change will happen because current atmospheric concentrations bind us to future global warming. For millions of poor people across the world, who have played a minimal role in generating current emissions, the priority is to improve capacity to adapt. Unfortunately, strategies for adaptation are far less developed nationally and internationally than strategies for mitigation.

Rethinking scarcity in a water-stressed world

Just how scarce is the world's water? There is no simple answer. Water scarcity can be physical, economic or institutional, and—like water itself—it can fluctuate over time and space. Scarcity is ultimately a function of supply and demand. But both sides of the supply-demand equation are shaped by political choices and public policies.

Understanding scarcity

"Water, water everywhere, nor any drop to drink," laments the sailor in Samuel Coleridge's *Rime of the Ancient Mariner*. The observation remains a useful first approximation for understanding the world's supply of fresh water.

Earth may be the water planet, but 97% of its water is in oceans.[5] Most of the remainder is locked in Antarctic icecaps or deep underground, leaving less than 1% available for human use in easily accessible freshwater lakes and rivers. Unlike oil or coal, water is an infinitely renewable resource. In a natural cycle rainwater falls from the clouds, returns to the salty sea through freshwater rivers, and evaporates back to the clouds. The cycle explains why we cannot run out of water, but supply is finite. Planet Earth's hydrological system pumps and transfers about 44,000 cubic kilometres of water to the land each year, equivalent to 6,900 cubic metres for everyone on the planet. A large part of this flow is accounted for by uncontrollable floodwaters, or water too remote for effective human use. Even so, the world has far more water than the 1,700 cubic metres per person minimum threshold that hydrologists by (admittedly arbitrary) convention treat as the amount needed to grow food, support industries and maintain the environment.[6]

Unfortunately, the international average is a largely irrelevant number. At one level the world's water is like the world's wealth. Globally, there is more than enough to go round: the problem is that some countries get a lot more than others. Almost a quarter of the world's supply of fresh water is in Lake Baikal in sparsely populated Siberia.[7] Differences in availability across and within regions further highlight the distribution problem. With 31% of global freshwater resources, Latin America has 12 times more water per person than South Asia. Some places, such as Brazil and Canada, get far more water than they can use; others, such as countries in the Middle East, get much less than they need. Water-stressed Yemen (198 cubic metres per person) is not helped by Canada's overabundance of fresh water (90,000 cubic metres per person). And water-stressed regions in China and India are not relieved by Iceland's water availability of more than 300 times the 1,700 cubic metre threshold.

Within regions too there is often a large mismatch between water resources and population. As a region Sub-Saharan Africa is reasonably well endowed with water. Factoring in distribution changes the picture. The Democratic Republic of Congo has more than a quarter of the region's water with 20,000 cubic metres or more for each of its citizens, while countries like Kenya, Malawi and South Africa are already below the water-stress threshold.

Because water, unlike food or oil, is not readily transferable in bulk quantities, there is limited scope for trade to even out imbalances. What matters is local availability and access between populations through water infrastructure. This applies within countries as well. Northern China, for example, has less than a quarter of the per capita water availability of the south.[8] National data for Brazil put the country near the top of the world league for water availability. However, millions of people living in the huge "drought polygon", a semi-arid area spanning nine states and 940,000 square kilometres in the northeast, regularly experience chronic water shortages. Ethiopia, with several major lakes and rivers, abundant groundwater and a large volume of rainfall, almost crosses the water-stress threshold. Unfortunately, rainfall is both highly seasonal and exceptionally variable over time and space. Combined with a limited infrastructure for storage and poorly protected watersheds, that variability exposes millions to the threat of drought and floods.

Time is another important part of the water availability equation. For countries that depend on monsoons or short rainy seasons, national averages provide a distorted view of real availability. Much of Asia receives almost 90% of its annual rainfall in less than 100 hours, generating risks of short, intensive flooding during some parts of the year and prolonged drought during the rest.[9] Real availability over the course of a year therefore depends not only on rainfall, but also on capacity for storage and the degree to which river flows and groundwaters are replenished.

Increasing stress and scarcity

Hydrologists typically assess scarcity by looking at the population-water equation. As noted, the convention is to treat 1,700 cubic metres per person as the national threshold for meeting water requirements for agriculture, industry, energy and the environment. Availability below 1,000 cubic metres is held to represent a state of "water scarcity"—and below 500 cubic metres, "absolute scarcity".[10]

Today, about 700 million people in 43 countries live below the water-stress threshold. With average annual availability of about 1,200 cubic metres per person the Middle East is the world's most water-stressed region; only Iraq, Iran, Lebanon and Turkey are above the threshold. Palestinians, especially in Gaza, experience some of the world's most acute water scarcity—about 320 cubic metres per person. Sub-Saharan Africa has the largest number of water-stressed countries of any region. Almost a quarter of Sub-Saharan Africa's population

Globally, there is more than enough water to go round: the problem is that some countries get a lot more than others

By 2025 more than 3 billion people could be living in water-stressed countries—and 14 countries will slip from water stress to water scarcity

lives in a water-stressed country today—and that share is rising.

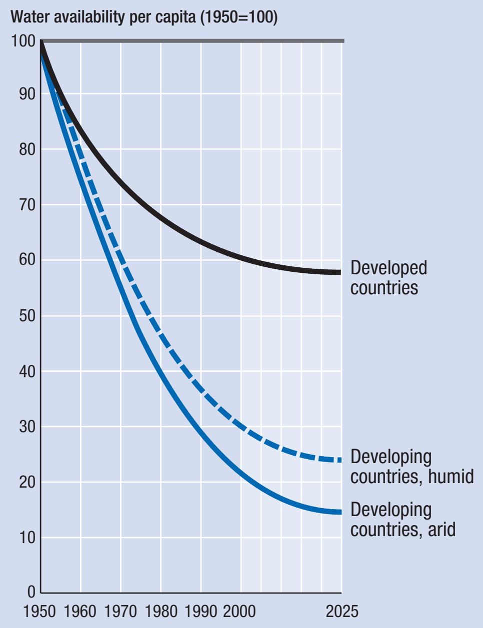
With many of the most water-stressed countries experiencing very high population growth rates, per capita availability is shrinking fast. With 1950 as a benchmark, the distribution of global population growth has dramatically reshaped the per capita availability of water. While availability stabilized in rich countries in the 1970s, the decline continued in developing countries, especially in arid developing countries (figure 4.1).

Just how rapid the decline has been becomes apparent when current trends are projected into the future. By 2025 more than 3 billion people could be living in water-stressed countries—and 14 countries will slip from water stress to water scarcity (figures 4.2 and 4.3). Developments to 2025 will include:

- Intensifying stress across Sub-Saharan Africa, with the share of the region's population in water-stressed countries rising from just above 30% to 85% by 2025.
- Deepening problems in the Middle East and North Africa, with average water availability falling by more than a quarter. By 2025 average water availability is projected to be just over 500 cubic metres per person, and more than 90% of the region's people will be living in water-scarce countries by 2025.
- High-population countries such as China and India entering the global water-stress league.

As gloomy as this projection is, it understates the problem. Consider the case of India.

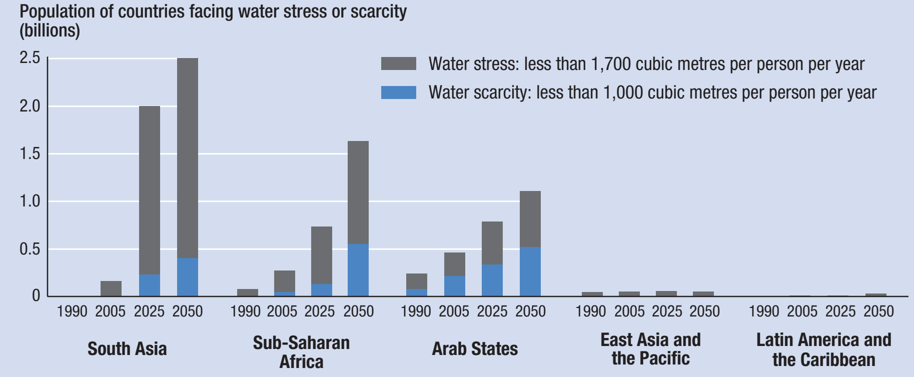
Figure **4.1** **Water availability in decline**



Source: Pitman 2002.

The country may be heading for water stress, but 224 million people already live in river basins with renewable water resources below the 1,000 cubic metres per person water-scarcity threshold. The reason: more than two-thirds of the country's renewable water is in areas that serve a third of the population. In China national per capita levels are already low, about a third of the global average. But unequal distribution within the country makes the situation far more serious: 42% of China's population—538 million people—in the northern region have access to only 14% of the country's water. If northern

Figure **4.2** **Water stress is projected to accelerate in intensity in several regions**



Source: Calculated on the basis of FAO 2006.

China were a country, its water availability—757 cubic metres a person[11]—would be comparable to that in parts of North Africa: it is lower than in Morocco, for example.

There are many problems associated with thresholds for water stress. As demonstrated above, national averages can mask real availability. Beyond questions of distribution, countries vary widely in the amount of water they need to produce a given volume of output, maintain their environment and meet human needs. Only the rainfall that runs off into rivers and recharges groundwater is counted as renewable water in national accounts. This "blue water" represents only 40% of total rainfall. The remainder—the "green water"—never reaches rivers but nourishes the soil, evaporates or is transpired by plants.[12] This is the resource that maintains rainfed agriculture, the livelihood for a large share of the world's poor. However, for all of these problems and omissions national water availability levels do capture some important dimensions of availability.

Growing water demand outstrips population growth

In the history of water use some things change but others remain the same. Today, as in the past, humans use water mainly for irrigation. Some of the greatest civilizations—Egyptian, Mesopotamian, Indic and Chinese—were based on control of river water for agriculture. Now, as then, irrigation and agriculture remain the dominant users of water. However, since the early 20th century, water use for industry and municipalities has been increasing. So, too, has the gap between population growth and demand for water: as the world has become richer and more industrialized, each person in it has been using more water.[13] These trends have lent a superficial credence to Malthusian concerns over future water shortages.

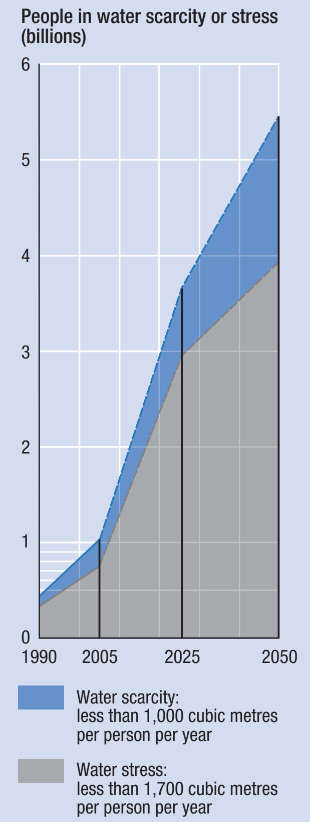
Water use has been growing much faster than population for at least a century—and that trend is continuing. Over the past hundred years population quadrupled, while water use grew by a factor of seven. As the world got wealthier, it also became thirstier (figure 4.4). Water use patterns have also changed. In 1900 industry used an estimated 6% of the world's water. It now uses four times that share. Over the same period municipalities' share of water tripled, to 9%.[14]

However, while industrial and municipal demand for water grew spectacularly in the 20th century, agriculture still takes the lion's share. In developing countries agriculture still accounts for more than 80% of water consumption (figures 4.5 and 4.6).

It is not difficult to see why. Sometimes it is assumed that water scarcity is about not having enough water to meet domestic needs or the demands of cities. While some cities face problems of water stress, it is agriculture that will face the real challenge. Basic arithmetic explains the problem. People have a minimum basic water requirement of 20–50 litres each day. Compare this with the 3,500 litres to produce enough food for a daily minimum of 3,000 calories (producing food for a family of four takes the amount of water in an Olympic-size swimming pool). In other words, it takes roughly 70 times more water to produce food than people use for domestic purposes.[15] Growing a single kilo of rice takes 2,000–5,000 litres of water.[16] But some foods are thirstier than others. It takes eight times more water to grow a tonne of sugar than a tonne of wheat, for example. Producing a single hamburger takes about 11,000 litres—roughly the daily amount available to 500 people living in an urban slum without a household water connection. These facts help to explain why rising incomes and changing diets—as people get richer they consume more meat and sugar—keep the growth of water use above that of population.

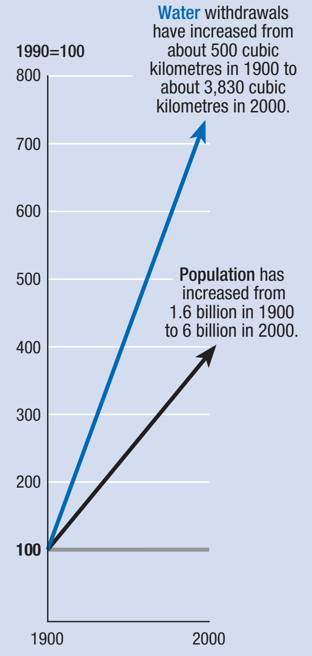
Looking to the future, it is clear that the pattern of demand for water will continue to change. As urbanization and the growth of manufacturing continue to gather pace, demand for water from industry and municipalities will continue to grow (see figure 4.6).[17] At the same time population and income growth will boost demand for irrigation water to meet food production requirements. By 2025 there will be almost 8 billion people in the world, with the

Figure **4.3** **Global water stress intensifying**



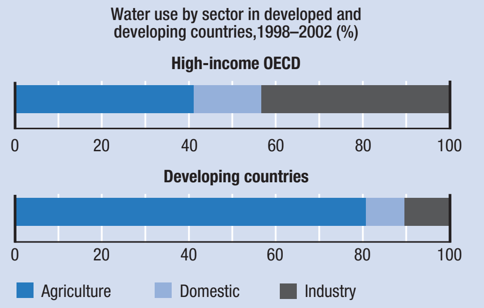
Source: Calculated on the basis of FAO 2006.

Figure **4.4** **Our wealthier, thirstier world**



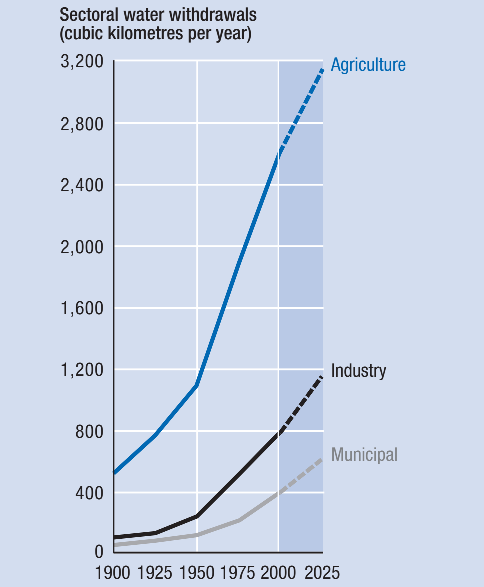
Source: SIWI and others 2006.

Figure **4.5** **How the world uses its water**



Source: FAO 2006.

Figure **4.6** **Agriculture is still the largest user of water**



Source: IWMI Forthcoming.

developing world's share rising from 79% to 82%. By 2050 the world's agricultural systems will have to feed another 2.4 billion people.

Two important consequences flow from these broad trends. First, water withdrawals in developing countries will increase: projected withdrawals are 27% higher for developing countries in 2025 than in the mid-1990s. This is the reverse of the trend in rich countries. In the United States water use is lower today than it was three decades ago, even though population has increased by some 40 million.[18] Second, there will be a redistribution of water from agriculture to industry and municipalities. Projections point to a steady decline in the share of irrigated agriculture in global water use, to about 75% of the total by 2025.[19] But this global figure understates the scale of the adjustment. In some parts of South Asia the share of non-agricultural users in water use will rise from less than 5% today to more than 25% by 2050 (table 4.1).

Behind these statistics are some questions with profound implications for human development. Most obviously, how will the world feed another 2.4 billion people by 2050 from a water resource base that is already under acute stress? In a world with about 800 million malnourished people, that question merits serious consideration. So, too, does a less prominent concern in international debate. As the distribution of water between sectors changes, there will be important implications for the distribution of water among people. An obvious danger is that people whose livelihoods depend on agriculture but who lack established rights, economic power and a political voice will lose out—an issue to which we return in chapter 5.

Breaching the limits of sustainable use—problems, policies and responses

Throughout history human societies have been largely river based. Historically, people had to locate near water supplies that could provide drinking water, carry off waste, supply irrigation and power industries. Over the past hundred years, industrial development came with an increased capacity to move and control water—along with a parallel increase in capacity to use more, waste more and pollute more. In many parts of the world humanity has been operating beyond the borders of ecological sustainability, creating threats to human development today and costs for generations tomorrow.

Beyond the limits of sustainability

What happens when the limits to the sustainable use of water are breached? Hydrologists address that question by reference to complex models designed to capture the functioning of river basin ecosystems. The simplified answer is that the integrity of the ecosystems that sustain flows of water—and ultimately human life—are ruptured.

Table 4.1 **Projected water use and diversions to nonagricultural sectors by region, 2000 and 2050**

Region	2000 Volume (cubic kilometres)	2000 Share of total (%)	2050 Volume (cubic kilometres)	2050 Share of total (%)
Sub-Saharan Africa	10	6	60	38
East Asia	101	6	511	35
South Asia	34	3	207	25
Central Asia and Eastern Europe	156	29	301	49
Latin America	53	15	270	53
Middle East and North Africa	24	6	93	28
OECD	518	93	774	72
World	897	18	2,216	41

Source: IWMI forthcoming.

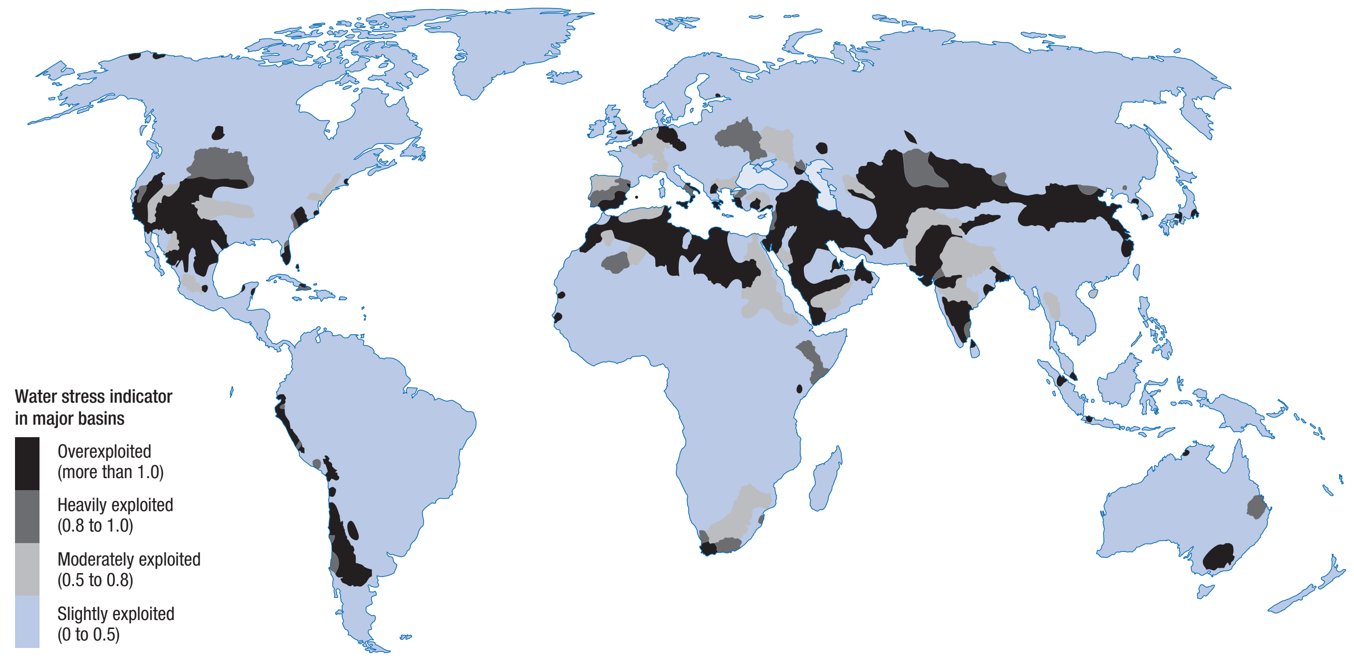
Perceptions about water have changed slowly over time. In 1908 Winston Churchill stood near the northern shores of Lake Victoria watching the world's second largest lake flow over Owen Falls into the Nile. He later recorded his thoughts: "So much power running to waste… such a lever to control the natural forces of Africa ungripped."[20] Two decades later, Joseph Stalin famously lamented the water going to waste through the Volga, the Don and other rivers, ushering in an era of huge irrigation schemes and giant dams that shrank the Caspian Sea. By the mid-1970s the Soviet Union used eight times as much water as in 1913, most of it for irrigation.

What Churchill and Stalin had in common, along with most other political leaders in the first nine decades of the 20th century, was the idea that water was there to be exploited without reference to environmental sustainability. That approach has thrown deep roots in water governance models. For much of recent history policy-makers have focussed their attention on three great users of water: industry, agriculture and households. Lacking a vocal political constituency, the fourth great user, the environment, has been ignored. Today, we are learning the hard way that the water resources developed for agriculture and industry through infrastructure investments had not previously been "wasted". Inland water systems such as wetlands, lakes and floodplains all provide vital ecological services that depend on water.

Natural flows of water provided through rivers, or stored in lakes and aquifers, define the parameters of water availability. When those parameters are broken, water assets are depleted. An analogy with finance explains what this means. People and countries can increase consumption beyond their current income flows by borrowing and running up debt against future earnings. If incomes rise enough over time to cover repayments, the debt will remain sustainable. But water is not like income in one crucial respect. Because future flows of water (unlike income) are more or less fixed, overconsumption leads to asset depletion and an unsustainable hydrological debt.[21] In effect, we are dealing today with a hydrological debt crisis built up over several decades. That crisis is growing in scale and severity.

Hydrological debt, by its nature, is difficult to measure, but it has highly visible consequences in many regions. The International Water Management Institute uses a four-part scale to classify countries on the sustainability of water use, taking into account the water requirements of ecosystems. These requirements are not a matter of theoretical environmental accounting. If ecological requirements are not respected, the environment that sustains livelihoods is eroded, to the long-term detriment of human development. Ecological stress shows up where human water use exceeds the level required to maintain the ecological integrity of river basins (map 4.1). These are the flashpoints for the hydrological debt crisis.

Map 4.1 **Water overuse is damaging the environment in many major basins**



Note: The boundaries and names shown and the designations used on this map do not imply official endorsement or acceptance by the United Nations.

Source: Smakhtin, Revenga and Döll 2004.

High overuse tends to occur in regions heavily dependent on irrigated agriculture—such as the Indo-Gangetic Plain in South Asia, the North China Plain and the High Plains in North America—and in areas undergoing rapid urbanization and industrial development. An estimated 1.4 billion people now live in river basin areas that are “closed”, in that water use exceeds minimum recharge levels, or near closure.[22] Such basins cover more than 15% of the world’s land surface. Among the more prominent examples:

- In northern China an estimated quarter of the flow of the Yellow River is needed to maintain the environment. Human withdrawal currently leaves less than 10%. During the 1990s the river ran dry at its lower reaches every year and for a record 226 days in 1997, when it was dry for 600 kilometres inland.[23] The drying up of the river caused a drop in agricultural production averaging 2.7–8.5 million tonnes a year, with losses estimated at $1.7 billion for 1997.
- In Australia’s Murray-Darling Basin irrigated agriculture uses almost 80% of available water flows. With estimated environmental requirements of about 30%, the result is extensive environmental destruction, including salinity, nutrient pollution and the loss of floodplains and wetlands. The basin contains two-thirds of the country’s irrigated lands. Its production of rice, cotton, wheat and cattle accounts for about 40% of the country’s agricultural output—but at a high and unsustainable environmental price. In recent years virtually no Murray River water has made it to the sea.[24]
- The Orange River in southern Africa is the site of growing environmental stress. The upstream reaches of the basin have been so modified and regulated that the combined reservoir storage in the basin exceeds annual flows.[25]

As millions of people in water-stressed areas are discovering, the environment is foreclosing on unsustainable water debts on an extensive scale. For example, farmers near Sana’a in Yemen have deepened their wells by 50 metres over the past 12 years, while the amount of water they can extract has dropped by two-thirds.[26] Some people in water-stressed areas have the economic resources, skills and opportunities to leave their water problem behind. Many millions—small farmers, agricultural labourers and pastoralists in poor countries—do not.

Does a high level of ecological stress in water systems support the Malthusian thesis that the world is running out of water? Only on the most superficial reading. Take the case of the Murray-Darling Basin. Evidence of water stress is unequivocal. That stress is the product of past public policies that have decided it is worth sacrificing an entire ecosystem to grow rice, cotton and sugar—three of the thirstiest agricultural products—for export. Within the basin the country's largest reservoir—Cubbie Station—holds more water than Sydney Harbour, and loses 40% of it to evaporation.[27] Until recently, water users have been paying negligible fees for using and wasting a precious asset—and Australian taxpayers have been footing the bill for multimillion dollar engineering programmes to intercept salty drainage water. The problem in the Murray-Darling Basin is not that there is too little water. It is that there is too much cotton and rice and too many cattle.

Governments in water-stressed regions have started to acknowledge the need to tackle unsustained hydrological debt. In China demand management plays a growing role in water governance. Since 2000 the Yellow River Commission has imposed restrictions on water withdrawals by upstream provinces, increasing flows in the lower reaches of the river. Provisions have also been made along the Hei River Basin for the environment as a water user, though more stringent action will be needed in the future. The Murray-Darling Commission in Australia provides a far reaching institutional framework for rebalancing the needs of human users and the environment. That framework sets annual extraction rates at a ratio determined by the pattern of water use in 1993, even though some commentators argue that this still exceeds ecological limits. Governments in South Africa and elsewhere have enacted legislation that requires taking into account environmental needs before issuing permits for human uses (see box 4.7 later in the chapter). Each of these examples demonstrate how governments are now being forced to respond to the consequences of past public policy mistakes. But far more radical approaches will be needed in the future.

Wider symptoms of stress

The physical symptoms of water overuse vary. Among the least visible but most pervasive problems are declining water tables, the result of using groundwater faster than the hydrological cycle replenishes it.[28] In Yemen, parts of India and northern China water tables are falling at more than 1 metre a year. In Mexico extraction rates in about a quarter of the country's 459 aquifers exceed long-term recharge by more than 20%, with most of the overdraft building up in arid parts of the country.[29]

River desiccation is another symptom of water stress. According to the UN Millennium Ecological Assessment, water-based ecosystems are now the world's most degraded natural resource—an outcome that can be traced to the breaching of ecological boundaries.[30] In China the Yangtze and Yellow Rivers are dry in their lower reaches for much of the year. The list of river systems registering major overabstraction and reduced flows includes the Colorado, the Ganges, the Jordan, the Nile and the Tigris-Euphrates.

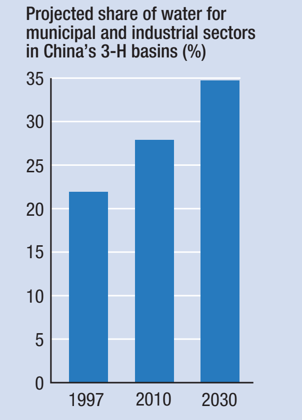
Lakes and inland water provide another indicator for asset depletion. In 1960 the Aral Sea was the size of Belgium, sustaining a vibrant local economy. Today, it is a virtually lifeless hypersaline lake a quarter of its previous size. The reason: an earlier era of Soviet state planners determined that the great rivers of Central Asia—the Syr Darya and the Amu Darya—should be put to the service of creating a vast irrigated cotton belt. This cavalier approach to water management sealed the fate of an entire ecological system, with devastating consequences for human well-being (see chapter 6). Overexploitation has contributed to the shrinking of many of Africa's greatest lakes, including Lakes Chad, Nakivale and Nakaru. Lake Chad has shrunk to 10% of its former volume, partly as a result of climate change and partly because of overextraction.

Among the least visible but most pervasive problems are declining water tables, the result of using groundwater faster than the hydrological cycle replenishes it

Box **4.1**

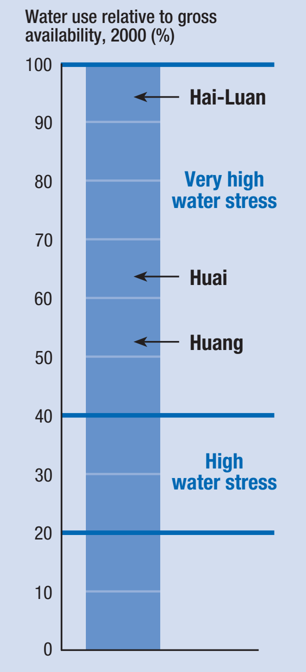
China—managing a water crisis in a high growth economy

Figure **1** **Agriculture is losing out to other users**



Source: Cai 2006.

Figure **2** **China's 3-H basins are under very high water stress**



Source: Shalizi 2006.

Since 1979 China has been the world's fastest growing economy. Poverty has fallen sharply, albeit with rising inequality, and education and health have improved at an impressive rate. But rapid growth has strained China's water resources. Economic success has been maintained partly through a mounting ecological overdraft, with northern China now facing a mounting crisis in water management.

Northern China is at the epicentre of that crisis. The Huai, Hai and Huang (Yellow) River Basins (3-H river basins) supply just under half the country's population, 40% of agricultural land, a large share of major grain production and a third of GDP. About half the country's rural poor live in the basin area. Yet the area accounts for less than 8% of national water resources. Thus each basin falls below 500 cubic metres of water per capita, making them areas of acute scarcity.

Rapid growth has increased demand for water. Since 1980 annual withdrawal rates in the 3-H basins have increased by 42 billion cubic metres, the total average run-off in the Hai River. There has also been a shift in demand, with agriculture losing out to industry and municipal users (figure 1). The share of industry in water use has doubled since 1980 to 21%, and the urban share has tripled.

Current projections indicate that demand will rise a further 20% by 2030. The resulting pressure threatens to exacerbate serious quality-related stress:

- *Surface water pollution.* More than 80% of the Hai and Huai basins are highly polluted. Agriculture and rural industry account for about half the pollution. High-growth industries such as textiles, chemicals and pharmaceuticals account for a quarter, and untreated human sewage the remainder. According to the State Environment Protection Administration, more than 70% of the water in the 3-H system is too polluted for human use.
- *Reduced run-off.* Flows to the ocean from the 3-H rivers have fallen by 60% since 1956–79. Water use across the three river systems now exceeds sustainability levels by very large margins. One assessment of scarcity suggests that withdrawals of more than 20% of available flow represent a threat to sustainable use, with 40% withdrawals an indicator for extreme stress (figure 2). In the 3-H system withdrawals range from more than 50% for the Huang (Yellow) River, to 65% for the Huai River and more than 90% for Hai-Luan River Basin. This is well beyond the bounds of sustainability. The transformation that has taken place over the past few decades is captured by the flow of the Huang River, once referred to as China's sorrow because high waters caused so much flooding. Today, the lower streams of the river have been reduced to a trickle that barely reaches the sea. Low-flow periods increased from 40 days in the early 1990s to more than 200 at the end of the decade.
- *Groundwater mining.* Water inputs for agriculture have been sustained by tapping groundwater, but aquifers are being depleted faster than they are being replenished. In the Hai basin sustainable groundwater supply is about 17.3 billion cubic metres a year, while withdrawals exceed 26 billion cubic metres. Water tables today are 50–90 metres lower than they were four decades ago, contributing to saline intrusion and ground subsidence of several metres in cities such as Beijing, Shanghai and Tianjin—and increasing the cost of pumping water.

These are classic symptoms of water stress. To them can be added the growing strains on water in cities across the north. The problems of Beijing are well known, but there are seven other cities in the northern region with populations over 2 million—and all of them face water shortages.

Is this a water shortage crisis? In one sense, not entirely. Current stress levels reflect past incentives for unsustainable water use patterns. Until fairly recently, water was not priced. One result has been the absence of incentives to conserve water. Low-value water-intensive cereals have dominated agricultural production. In industry Chinese companies use 4–10 times more water than their counterparts in industrial countries, partly reflecting technology but also pointing to the weakness of price incentives for reducing water use.

China has responded to the water crisis with supply- and demand-side policies. On the supply side is the South-North water transfer to divert more than 40 billion cubic metres of water—more than the total flow of the Colorado River—to industrial and urban regions in the Hai basin, a distance of more than 1,000 kilometres.

On the demand side the focus is on realigning water use with ecological capacity. Since 2000 the Yellow River Conservation Commission has been authorized to make transfers to environmental systems—a move prompted by recurrent droughts. Efficiency measures have been introduced to increase the productivity

Box 4.1 **China—managing a water crisis in a high growth economy** (continued)

of water in agriculture, including advanced irrigation technologies and incentives for producing higher value crops. In industry water prices are rising, and new regulatory measures are in place.

Efforts to realign supply and demand through administrative reallocation under conditions of water stress present major governance challenges:

- *Social equity*. Government support for expansion of advanced irrigation systems means higher costs for water. Poor farmers may be unable to afford access because of low income and the high costs of inputs. This could force them to use less water, give up higher value crops or leave agriculture. Working through water user associations to provide support and protect vulnerable groups could address this.
- *Fragmentation and power politics*. Current water transfer policies follow the priorities of local governments, often driven by short-sighted economic concerns in order to meet national objectives. Pollution monitoring and enforcement programmes are applied selectively. To keep industries profitable, local officials often sidestep legislation and regulations to curb pollution.
- *Weak rights and entitlements*. Farmers are losing their entitlements to water, often without compensation. Water user associations, commonly supported by local government, mark an attempt to establish water rights and claims linked to transfers. But reallocation patterns reflect decisions by often fragmented water bureaucracies that come under pressure from powerful groups in industry and municipalities. An additional problem is that existing river basin commissions operate under the Ministry of Water Resources and lack authority to impose on other ministries and provinces.
- *Managing ecological claims*. For local governments the imperatives of economic growth continue to take priority over ecological considerations, perpetuating serious environmental stress.

Several provinces and municipalities are promoting reforms to merge the functions of different water management units into a single Water Affairs Bureau. These bodies could delineate secure and consistent water rights by working through water user associations to create a transfer system consistent with a commitment to social equity and ecological sustainability.

Source: World Bank 2001; Shen and Liang 2003; CAS 2005; Cai 2006; Shalizi 2006.

Water quantity is not the only benchmark indicator for scarcity. Quality also has a bearing on the volume available for use—and in many of the most stressed water basins quality has been compromised by pollution. All of India's 14 major river systems are badly polluted. In Delhi, to take one example, 200 million litres of raw sewage and 20 million litres of waste are dumped into the Yamuna River every day. In Malaysia and Thailand water pollution is so severe that rivers often contain 30–100 times the pathogen load permitted by health standards. The Tiete River flowing through São Paulo, Brazil, is chronically polluted with untreated effluent and high concentrations of lead, cadmium and other heavy metals.[31] Why does all this matter for scarcity? Because water pollution adversely affects the environment, threatens public health and reduces the flow of water available for human use.

The physical symptoms of stress and the competition between users do not operate in isolation. Northern China demonstrates starkly how different forms of stress can create a vicious cycle—the lethal interaction of dwindling river flows, falling water tables, rising demands from urban and industrial users and increasing pollution has generated a major water crisis.[32] That crisis not only threatens to undermine future economic growth. It also poses a major threat to food security, poverty reduction and future ecological sustainability. Reversing that cycle is now a central concern of policy-makers in China (box 4.1).

Sinking aquifers—who pays the price?

Intensive development and the unsustainable depletion of water resources create winners and losers. The environment is a loser every time—while the balance sheet between human users is mixed. In some cases short-term increases in income are being generated in ways that compromise long-term livelihoods. Elsewhere, the depletion of water resources is generating profit for some while exacerbating poverty and marginalization for others. The deepening problem in groundwater highlights the difficulties.

Groundwater exploitation has done much for human development. It has given smallholder farmers—16 million of them in India alone—access to a reliable flow of water for production. In the words of one commentator groundwater has been "a great democratising force" in agricultural production.[33] One study

Box 4.2 Yemen under stress

Water and poverty are closely linked in Yemen, which has one of the world's lowest freshwater availability levels—198 cubic metres a person—and one of the highest rates of water use for agriculture. Worsening the scarcity are spatial and temporal variations. And with a population projected to double by 2025, water availability per capita will fall by one-third.

The physical and social symptoms of acute water stress are already apparent. Groundwater extraction started to exceed recharge 20 years ago. Around the city of Sana'a aquifer extraction rates are 2.5 times the recharge rates. Growing urban demand is coming up against the barrier of agricultural use. Unregulated extraction in rural areas (of the 13,000 wells in operation, only 70 are state-owned) and the development of private markets for transferring water to urban users now pose acute threats to smallholder agriculture—heightened by uncertain customary water rights. In other cities such as Ta'iz urban tensions over water use and groundwater exploitation have led to violent confrontation.

Efforts to recharge the aquifers are being undermined by uncontrolled extraction, notably by private tanker companies delivering water to the city. About two-thirds of water in the city comes from private sources. At the current rate of depletion water stress will reduce the viability of rural livelihoods on a large scale.

Source: Molle and Berkoff 2006; Grey and Sadoff 2006; SIWI, Tropp and Jägerskog 2006.

suggests that it contributes $25–$30 billion a year to Asian agricultural economies.[34] But what happens when groundwater exploitation goes too far? Water tables sink, the costs of pumping rise and environmental problems such as soil salinization become widespread. In Pakistan groundwater depletion has gone hand in hand with soil salinity, compromising rural livelihoods by reducing productivity.[35]

The costs and benefits of unsustainable groundwater mining are not distributed equally. In some countries the depletion of groundwater is associated with processes that are marginalizing agriculture (box 4.2). Within the agricultural sector the overexploitation of groundwater can reinforce wider inequalities. As water tables fall the energy costs of pumping water rise, along with the costs of digging wells. Because wealthier farmers can dig deeper and pump more, they have developed monopolies in water markets in some areas.

The Indian state of Gujarat demonstrates the problem. In the north of the state falling water tables pose a direct threat to the smallholder dairy industry, compromising the livelihoods of hundreds of thousands of vulnerable people. In some areas large landowners with access to capital markets have financed the construction of deep wells, depriving neighbouring villages of water. "Waterlords" now dominate an extensive market for both irrigation and drinking water—often selling water back to the same villages and neighbours whose wells they have effectively emptied. Thousands of villages have become waterless, left dependent on deliveries by water tankers.[36]

Groundwater mining highlights how the practices of private users can generate wider public costs. Water provides a vehicle for transferring environmental costs, or "externalities", distorting market signals. Individuals might be less likely to overuse or pollute water if they bore the full costs of the consequences. In Java, Indonesia, textile factories have polluted water supplies to the point where rice yields have fallen and the availability of fish in downstream ponds has been compromised.[37] The farmers, not the factories, bear the costs. Similarly, in India the Bhavani and Noyyal Rivers in Tamil Nadu are virtually unusable to downstream users in agriculture because of labour-intensive dyeing and bleaching industries in upstream Tiruppur.[38]

Policy-induced scarcity

Symptoms of scarcity appear to confirm some of the worst Malthusian fears about the interaction between people and water. The combined effects of rising population growth and increasing demand on a fixed water resource base produce water stress on an unprecedented scale. Often overlooked is the role of policy in inducing stress, through acts of commission and omission.

Acts of commission take many forms. Perverse incentives for overuse are among the most damaging. Once again, groundwater provides a good example. Groundwater extraction costs depend on the capital cost of pumps and the recurrent cost of electricity. Once a pump is installed, the only constraint on pumping is the price of electricity. In many cases electricity for agricultural users has been free or subsidized, removing incentives to conserve water. In India agriculture accounts for about a third of the sales of electricity boards but only 3% of revenue. According to the World Bank the electricity subsidies accounted for about a third of India's fiscal deficit in 2001.[39] These subsidies have created disincentives for water conservation and incentives for inappropriate cropping patterns. For instance, it is unlikely that a water-intensive crop like sugarcane would be grown on its current scale across much of Gujarat if water were sensibly priced and regulated.[40] Because electricity subsidies tend to rise with the size of holding and depth of wells, they are highly regressive: the wealthier the producer, the bigger the support (box 4.3).

Perverse subsidies are visible in many water-stressed environments. An extreme example is the past practice in Saudi Arabia of using oil revenues to pump irrigation water from a nonrenewable fossil aquifer to grow water-intensive wheat and alfalfa in the desert. In the 1980s the country embarked on a program of rapid irrigation development using a fossil aquifer. With price supports, input subsidies and state underwriting of investments in infrastructure, Saudi Arabia first attained self-sufficiency in wheat and then became an important exporter. Almost a third of arable land is still devoted to irrigated wheat production. Production costs are estimated at four to six times the world price, discounting the costs of subsidies and groundwater depletion. Every tonne of wheat is produced with about 3,000 cubic metres of water—three times the global norm. In 2004 a new water conservation strategy was launched to reduce water use and conserve the aquifer.[41]

Pricing policies often underpin perverse subsidy systems. Producer subsidies for water-intensive produce such as oilseeds, sugar, wheat and beef create incentives for investment, patterns that lead to overexploitation. Meanwhile, the underpricing of irrigation water creates disincentives for conservation. Even in the Middle East and North Africa, where the scarcity value of water is much in evidence, the cost of water is set well below cost-recovery levels. In Algeria current tariffs are estimated at only 1%–7% of the marginal cost of providing water.[42] Such pricing policies discourage efficient use and threaten sustainability. For the Middle East and North Africa as a region, it is estimated that only 30% of the flood water used in irrigation ever reaches the crop.[43]

Would the use of pricing policies to promote efficiency and environmental sustainability damage equity by excluding poor farmers from water markets? The answer depends on the wider policy environment and a range of distributional factors. Research in Egypt suggests that a fee covering operations and maintenance costs would be equivalent to 3% of average farm revenues (double if capital costs are included). While not an insignificant amount, it is also one that commercial farms could afford. By linking charges to farm size, location and revenue, it would be possible to limit the impact on poor rural households. Governments often justify current subsidies for water on equity grounds. However, the skewed distribution of land in some countries calls that justification into question because water use rises with landholding size. In Tunisia, for example, 53% of landowners occupy only 9% of the land, suggesting that most water subsidies are captured by large producers.

Perverse subsidies are not restricted to developing countries. The United States and Europe provide generous subsidies for water mining. Farmers in the Central Valley Project in California—a centre for the production of major water-intensive export crops such as rice and wheat—use about a fifth of the state's water. They pay prices estimated at less than half the cost of water, with a total subsidy of $416 million a year. Here, too, transfers are highly regressive: the largest 10% of farms receive two-thirds of total subsidies.[44] In southern European countries such as Spain the production of water-intensive crops is a source of water stress. That production is made possible in part by subsidies under the Common Agricultural Policy.

Rich country water subsidies have implications beyond the border, especially in crops for which the European Union and the United States are major exporters. When the United States exports water-intensive crops such as rice—it is the world's third largest exporter—it is also exporting very large virtual water subsidies. Producers in other exporting countries (such as Thailand and Viet Nam) and importing

Producer subsidies for water-intensive produce such as oilseeds, sugar, wheat and beef create incentives for investment, patterns that lead to overexploitation

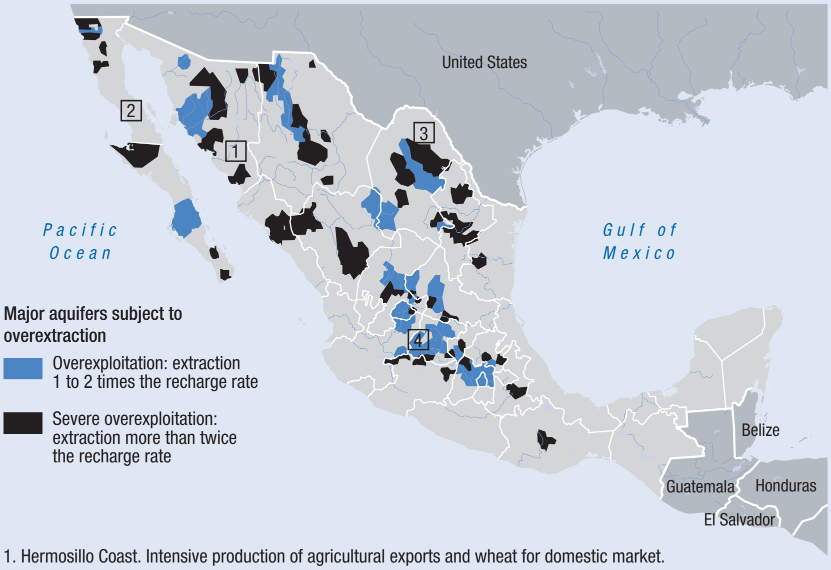
Box 4.3 Groundwater mining subsidies in Mexico

Aquifers store water beneath the earth's surface. This groundwater maintains wetlands and provides water for drinking and irrigation. But in many countries the rate of use far exceeds the rate of renewal, with implications for human development prospects. That overuse has been systematically encouraged by perverse incentives.

Mexico has a good history of water management in many areas. But in the northern and central parts of the country demand for water for irrigation and industry is outstripping supply (see map). Groundwater mining has covered the gap.

Agriculture accounts for 80% of water use in Mexico. Irrigated production accounts for more than half of total agriculture production and about three-quarters of exports, dominated by such water-intensive products as fruit, vegetables and livestock. Groundwater now represents an estimated 40% of total water use in agriculture, but more than 100 of the country's 653 aquifers are overexploited, causing extensive environmental damage and undermining smallholder agriculture.

Mexico's sinking aquifers



1. Hermosillo Coast. Intensive production of agricultural exports and wheat for domestic market.
2. Baja California. Large-scale commercial production of fruit and vegetables by companies linked to US market.
3. Coahuila. One of Mexico's fastest sinking aquifers and major site for production of alfafa to supply feed to livestock sector.
4. El Bajio. Source of 90% of Mexico's frozen fruit and vegetable export. Production dominated by large-scale commercial farms and agro-industrial processing plants supplying US market.

Note: The boundaries and names shown and the designations used on this map do not imply official endorsement or acceptance by the United Nations.
Source: Guevara-Sanginés 2006.

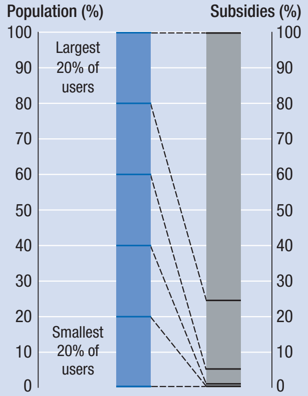
Overextraction, encouraged by electricity subsidies, threatens long-run agricultural productivity. In the state of Sonora the coastal aquifer of Hermosillo provided water at a depth of about 11 metres in the 1960s. Today, pumps extract water from a depth of 135 metres—uneconomical without electricity subsidies. Overpumping has led to saline intrusion and losses of agricultural land. Agribusiness export firms are moving inland from the worst affected coastal areas, tapping new sources.

The annual cost of electricity subsidies is $700 million a year. Because electricity use is linked to farm size, the transfers are highly regressive (see figure). What this means is that many of the largest users receive an average of $1,800 a year, while the smallest receive $94 on average. The Gini coefficient, a measure of inequality, is 0.91 (1 is perfect inequality) for subsidy distribution compared with a national Gini coefficient of 0.54.

By subsidizing consumption, electricity subsidies maintain artificially high demand for water. Econometric analysis suggests that withdrawing the subsidy would result in three-quarters of irrigators adopting more efficient practices, such as sprinkler systems. It would also give an incentive for farmers to produce crops less intensive in water use. The overall water savings would represent about one-fifth of current use—a volume equal to total urban consumption.

Source: CNA 2004; Ezcurra 1998; Guevara-Sanginés 2006; Ponce 2005; Texas Center for Policy Studies 2002; Tuinhof and Heederik 2002.

Large farmers capture most irrigation subsidies



Source: Guevara-Sanginés 2006.

countries (such as Ghana and Honduras) have to compete in markets distorted by these subsidies.

Damaging as the acts of commission of perverse subsidies can be, acts of omission are perhaps more serious. Water may be available in finite quantities—but it has been treated as an environmental resource with no scarcity value. Water-based ecosystems create the conditions and maintain the processes that sustain human life, including the provision of water for production. Yet these services are seldom traded in markets, have no price and thus are not properly valued—despite the very real contribution to wealth of water-based ecosystems (box 4.4).

National accounting conventions reinforce the market blind spot for water. There is obvious asymmetry in the way that governments measure, and therefore think about, the value of financial capital and natural resource capital, such as water. The deterioration or depletion of water does not show up in the accounts as a loss, or depreciation, in natural resource assets. Perversely, in fact, the mining of groundwater, the draining of lakes and the polluting of rivers can show up in national accounts as income growth. Adjusting GDP accounts for losses of water capital would markedly change economic performance indicators for a large number of countries, while at the same time signalling a threat to future generations.[45]

At the core of the idea of sustainability in resource use is the proposition that production systems should be managed so that we live off our resources today, without eroding the asset base to be inherited by future generations. This is vital for human development. Implicit in this idea is the principle of cross-generation distributional equity—the belief that we have an obligation to future generations.[46] Governments today are widely violating that principle by running down national water assets.

The core challenge in water governance is to realign water use with demand at levels that maintain the integrity of the environment. While policies will vary across countries, five broad elements are needed:

- *Developing a national strategy.* A core aim of integrated water resources management is to adjust water use patterns to water availability, taking into account the needs of the environment. Achieving this goal requires a high level of information about water resources. It also requires a capacity on the part of national and local governments to implement pricing and allocation policies that constrain demand within the bounds of sustainability. Effective national planning has to make provisions for the environment as a water user.

Box **4.4** The real value of water-based ecosystems

What is water worth? Markets provide only a very limited answer because ecosystem services are not widely traded—and because they provide public goods that are hard to price.

Ecosystems are a source of great wealth. They provide ecological services—such as water filtration—and sustain environments vital to the production of food and other products. One estimate of the economic value of wetlands in the Zambezi Basin by the World Conservation Union values their ecological services at $63 million, more than half of it in water purification and treatment services. In the Hadejia Nguru wetlands of Nigeria the traditional use of floodplains yields $12 per cubic metre of water in rice production, compared with $0.04 per cubic metre on irrigated schemes.

Wetlands are also crucial in the livelihoods of the poor. In Mali wetland areas in the Niger Delta support 550,000 people, including fisher folk, pastoralists and the producers who grow half of Mali's rice.

New York City provides one of the clearest examples of an ecoservice in operation. It derives most of its water from reservoirs in the Catskill Mountains. As this region developed, pollution threatened the city's drinking water. Faced with a choice between a $6–$8 billion filtration plant or $1.5 billion in environmental restoration, city authorities chose restoration. Using proceeds from an environmental bond issue, the city bought up land in and around the watershed and provided incentives for sustainable resource management.

As the city's environmental commissioner remarked: "All filtration does is solve a problem. Preventing the problem, through the watershed protection, is faster, cheaper and has lots of other benefits."

Source: Bos and Bergkamp 2001; Postel and Richter 2003; WRI 2005.

- *Cutting perverse subsidies and rethinking water pricing.* Eliminating state-sponsored water mining by reducing or removing electricity subsidies for irrigation would relieve some pressure on water resources. More broadly, governments can no longer treat water as a free good. Raising prices while implementing policies to protect the interests of poor farmers has the potential to advance both efficiency and environmental sustainability goals.
- *Make polluters pay.* Ensuring that industries pay for cleaning up the pollution that they cause would reduce pressure on water resources. This is partly about government regulation. By enshrining the polluter pays principle in tax provisions and enforcing strong environmental laws, government policies can enhance the water resource base. Effective regulation can also create incentives for new technologies and patterns of intervention. In India, for example, private companies have introduced

Box 4.5

Increasing supply by reducing pollution—markets and technology

Pricing water at levels that bear no relation to scarcity, or to ecological protection, can create a hidden incentive for wasteful use and pollution. Creating the right incentives can dramatically increase water availability. India demonstrates both the problem and potential solutions.

Legislation in 2003 introducing charges to control pollution has been ineffective. The charges represent only a tiny fraction of costs for the most polluting industries. For thermal power, paper, and iron and steel the range is 0.1%–0.5% of operating costs. Tariffs have been similarly ineffective. Many industries self-provide through groundwater pumping. Even where tariffs are applied, they are usually based on average rather than marginal-cost pricing. And they ignore environmental externalities.

Water scarcity has started to generate innovative technological solutions. The operating costs of such technology have become more competitive with the higher cost of buying water in water-scarce areas. For example, the cost of treating municipal sewage water by reverse osmosis in Chennai is 25–50 rupees per cubic metre, similar to charges by the Madras Water Supply and Sewerage Board for fresh water.

Some of the best water use practices in India have emerged in water-scarce regions, exemplified by Chennai, one of the country's most water-stressed cities. Several industries there have invested in reverse osmosis water treatment and recycling technologies, effectively filtering wastewater. With an initial investment of just under $3 million, Madras Fertilisers recycles more than 80% of its daily use of 15.12 million litres of water to the plant's cooling towers. The company also supplies 3 million litres per day of fresh water to Chennai City.

Improved water efficiency has been taken up in other areas. One of the most water-efficient pulp and paper companies in the country, J K Papers, is located in the water-scarce Rayagada District of Orissa, and the most water-efficient sugar industry, Natural Sugar and Allied Industry, is in the water-scarce district of Latur in Maharastra. The first "zero-discharge" textile mill in the country, Arvind Mills, is in Santej in Gujarat, where water shortages are a recurring problem.

These success stories highlight how incentives and technology can shift the parameters of water scarcity. Most of the innovation has been driven by the private sector. Looking to the future, there is scope for tax and other incentives to encourage the spread of water-efficient technologies in the wider public interest.

Source: Bhushan 2004.

technologies that reduce water pollution and increase availability to downstream users (box 4.5).

- *Valuing ecological services.* Going beyond the polluter pays to the pollution prevention pays principle offers further benefits. As the value of water as a productive resource has increased, awareness of economic benefits linked to ecosystem trading has developed through payments for watershed services. In Costa Rica the town of Heredia uses an environmentally adjusted water tariff to finance watershed conservation upstream, paying farmers $30–$50 per hectare for good land management.[47] This is an approach that could be more widely applied.
- *Regulating groundwater extraction.* Groundwater is a strategic ecological resource. Managing that resource to meet human and environmental needs is one of the great water security challenges of the early 21st century. Countries like Jordan have embarked on a regulatory offensive in groundwater. It carried out detailed groundwater basin studies as a precursor to a range of supply-side (regulation through the use of permits) and demand-side (installation of meters and increased prices) measures. These themes could be more widely followed, combining strategies that monitor local groundwater levels and set flexible extraction limits accordingly.

Augmenting supply—options and constraints

From time immemorial governments have responded to tensions between supply and human demand for water as a productive resource by changing the supply side of the equation. The large engineering works of the 20th century bear testimony to that approach. So does supply augmentation offer a way out of 21st century water constraints?

Diverting rivers

Some governments still see the diversion of rivers, one of the great hydrological interventions of the 20th century, as a partial solution to water stress. The south to north river diversion scheme in China is one of the world's greatest planned infrastructure programmes. With a price tag of $40–$60 billion it dwarfs even the expenditure on the Three Gorges Dam. The aim is to divert more than 40 billion cubic metres of water a year—roughly the volume of another Yellow River—from the Yangtze to the water-stressed North China plain and the megacities of the north. The Chinese plan is not an isolated case. In India the River Interlinking Project is a breathtakingly ambitious framework for redrawing the country's hydrological map, harnessing the great perennial monsoon rivers of the north, such as the Brahmaputra and the Ganges, to the perennially dry and shrinking rivers of the south, such as the Kavery and the Krishn, which have been diminished by excessive withdrawals for agriculture, industry and urban centres.

Measured in a purely quantitative sense, river diversion offers a short-term ameliorative for a long-term problem. It does not provide a panacea for overuse. Moreover, any river transfer faces the risk of creating large social and ecological costs and of running up against new environmental barriers. In Spain a scheme to divert the Ebro River from the north to commercial agricultural areas in the south has been shelved, partly because of a political reassessment of the costs and partly because the project failed to meet EU Water Directive guidelines for environmental sustainability. In China the most ambitious part of the south to north scheme envisages taking water from the glacial headwaters of the Yangtze in Tibet to the Yellow River. Yet global warming raises serious questions over the future volume and timing of glacial flows.

Desalinization

"If we could ever competitively, at a cheap rate, get fresh water from saltwater, this would be in the long-range interests of humanity [and] really dwarf any other scientific accomplishment", observed US President John F. Kennedy. Practiced since biblical times, the creation of fresh water by extracting salt from sea water is not a recent human endeavour. But does it offer a solution to problems of water stress and scarcity?

The major constraint on commercial desalinization has been energy costs. With the development of new reverse osmosis technologies, production costs have fallen sharply and output is rising. Israel, one of the world leaders, can desalinate water at costs per cubic metre comparable to those of conventional water utility plants. However, the sensitivity of production costs to energy prices, allied to the high costs of pumping water over long distances, creates restrictive conditions. For oil-rich countries and relatively wealthy cities close to the sea, desalinization holds out promise as a source of water for domestic consumption. The potential for addressing the problems of poor cities in low-income countries is more limited—and desalinization is unlikely to resolve the fundamental mismatch between supply and demand in water. It currently contributes only 0.2% to global water withdrawals and holds limited potential for agriculture or industry (box 4.6).[48]

Virtual water

Virtual water imports are another supply-side option for alleviating water stress. When countries import cereals and other agricultural products, they are also importing the water embedded in the produce. Virtual water trade generates water savings for importing countries and global water savings because of the differential in water productivity between exporters and importers.

Trade in virtual water has been rising exponentially with trade in food. Globally, the trade in 2000 was estimated at about 1,340 billion cubic metres, or three times the level in 1960. To put this figure in context, it represents about a quarter of the water required to grow food worldwide. Some analysts see virtual water trade as a way for water-scarce countries to save water by importing it from countries that face lower opportunity costs in water use and higher productivity. From this perspective virtual water trade is seen as an exercise in comparative advantage that overcomes the constraints on trading water itself.[49]

River diversion offers a short-term ameliorative for a long-term problem. It does not provide a panacea for overuse

Box 4.6 Desalinization—and its limits

Desalinization is a technical option for creating fresh water from sea water. Distilling sea water by boiling it and collecting the vapour is an age-old activity—an activity transformed over the past 20 years through new technologies. But there are limits to its scope.

In 2002 the global market for desalinization stood at $35 billion. There are now more than 12,500 plants operating in 120 countries. Traditionally, desalinization has taken place through thermal heating, using oil and energy as the source. The most modern plants have replaced this technology with reverse osmosis—forcing water through a membrane and capturing salt molecules. The costs of producing water from this source have fallen sharply, from more than $1 per cubic metre a decade ago to less than half that today. The energy to drive the conversion is a significant part of the cost.

Israel provides the gold standard in water desalinization. Following implementation of a planning strategy launched in 2000—the Desalinization Master Plan—the country now generates about a quarter of its domestic fresh water through desalinization. The $250 million Ashkelon Plant, which began operation in 2005, is the world's largest and most advanced reverse osmosis facility, producing fresh water at a cost of $0.52 per cubic metre. It supplies about 15% of Israel's fresh water used for domestic consumption. Current plans envisage an increase in production from desalinization plants from 400 million cubic metres today to 750 million cubic metres by 2020.

Current desalinization capacity is heavily concentrated. The Gulf states account for the bulk of capacity, with Saudi Arabia accounting for one-tenth of total output. Elsewhere, Tampa Bay in Florida and Santa Cruz in California have adopted reverse osmosis plants, and China has announced plans for a plant in Tianjin, its third largest city. In Spain the new government abandoned plans to pump water across the country from the wet north to the arid south in favour of 20 reverse osmosis plants (enough to meet 1% of needs), though the costs of desalinized water may not entice farmers from their current groundwater irrigation sources. In the United Kingdom the water utility serving London has a reverse osmosis plant that will come into operation in 2007.

This pattern of distribution highlights both the potential and the limits of desalinization. While costs are falling, the capital costs of new plants are considerable and operating costs are highly sensitive to energy prices. Recent projects in Israel and other countries demonstrate this, with tenders for water supply rising to $0.80–$1.00 per cubic metre. The cost of pumping water rises sharply with distance as well, so that inland cities would face higher cost structures. These factors help to explain why oil-rich states and coastal cities in water-stressed areas will probably remain the main users.

Overall use patterns are likely to change slowly. In some countries desalinization can be expected to account for an increased share of domestic and industrial water use. Municipalities currently account for two-thirds of use and industry for a quarter. The potential in agriculture is limited by cost. That is especially so for producers of low value-added staple crops that require large volumes of water.

Source: Rosegrant and Cline 2003; Schenkeveld and others 2004; Rijsberman 2004a; BESA 2000; Water-Technology.net 2006.

Does agricultural trade offer a route out of water stress? For some countries, especially in the Middle East and North Africa, virtual water trade is already an integral element in national food security strategies.[50] Were Egypt to grow a volume of cereals equivalent to national imports, it would require one-sixth of the water in Lake Nasser, the Aswan Dam's main reservoir. For developing countries as a group virtual water imports in 2025 will represent a projected 12% of irrigation consumption. However, the case for reducing water stress by expanding virtual water trade has been overstated, not least from a human development perspective.

Consider first the argument that virtual water trade represents an exercise in comparative advantage. Rich countries account for more than 60% of agricultural exports worldwide. Considering that these countries provided more than $280 billion in agricultural support in 2005, it follows that virtual water markets suffer from the same distortions as the markets for the products that facilitate water exchange.[51] As for the opportunity costs associated with water use, it is not clear that major exporters of water-intensive products such as cotton and rice—Australia and the United States, for example—factor in environmental damage (or virtual water subsidies) to their export prices.

The complex interaction between food imports and food security is another concern. Serious food security problems can arise when food imports are the result of slow growth and declining agricultural productivity, as in much of Sub-Saharan Africa. For example, Sub-Saharan African cereal imports are projected to more than triple by 2025, to 35 million tonnes.[52] It is unlikely that the region will be in a position to finance these imports on a predictable and sustainable basis, suggesting a growing dependence on food aid. Moreover, when countries import virtual water they are also importing virtual and actual subsidies against which their own farmers will have to compete in local markets. These subsidies can lower prices and reduce market shares with damaging implications for rural poverty reduction efforts.

Recycling wastewater

Some simple water management policies allied to appropriate technology can help to alleviate the mismatch between water supply and demand. One example is the reuse of wastewater by treating sewage so that it can be safely restored to rivers, used for irrigation or deployed for industry.

Recycling wastewater for peri-urban agriculture already happens on a large-scale. Wastewater is estimated to directly or indirectly irrigate about 20 million hectares of land globally—almost 7% of total irrigated area.[53] In the Mezquital Valley in Mexico about half a million rural households are supported by irrigation systems maintained through untreated wastewater. In Ghana farmers around Kumasi use wastewater on 12,000 hectares, more than twice the area covered by formal irrigation systems across the whole country. It is estimated that dry season irrigation with wastewater raises average agricultural incomes in Kumasi by 40%–50%, with the predictability of supply and the high nutrient content of the wastewater enabling farmers to enter higher value-added vegetable markets.[54]

Expanding capacity for wastewater recycling, by increasing the supply and productivity of water, could generate multiple benefits for poor and vulnerable agricultural producers. Wastewater can also be used to replenish aquifers, alleviating problems of groundwater depletion. With urban and industrial water use projected to double by 2050, wastewater could become an expanding and dependable supply: what goes into cities has to come back out again in some form. However, using wastewater sources without adequate safeguards can expose agricultural producers and peri-urban areas to acute health risks. One study in Haroonabad, Pakistan, found rates of diarrhoea and hookworm infection among wastewater farmers twice as high as those among irrigation canal farmers.[55]

The regulated use of treated water could significantly alleviate the adjustment pressures now facing water management in agriculture. Israel demonstrates the potential. Over two-thirds of the wastewater produced in the country every year is now treated and used for irrigation in agriculture. Most comes through the national water company, which also sets stringent rules for treatment levels: lower quality wastewater is allocated to tolerant crops such as cotton, with higher treatment standards applied to water for irrigating vegetables or replenishing groundwater.[56] Thus Tel Aviv's wastewater supports agricultural irrigation in the arid southern region. Other countries are following Israel's lead. Cities in water-scarce parts of California are investing heavily in plants that treat all domestic and industrial waste to a high standard, reusing the water for agriculture and industrial cooling. The Mexican city of San Luis Potosi recycles 60% of the city's wastewater for distribution to farmers through a modern sewerage plant.

Many developing countries start from a position of considerable disadvantage in developing wastewater resources. Most cities in low-income developing countries have either minimal or zero wastewater treatment capacity. In contrast to Israel or California they also lack the technological and wider capacity to segment wastewater into different treatment and allocation regimes. So does this rule out a substantive supply-side impetus from wastewater?

Even with severe resource constraints far more could be done. The underdevelopment of wastewater capacity in some countries is itself a product of fragmented and piecemeal planning. Many governments have seen investment in treatment plants as an unaffordable luxury, but factoring in the potentially high economic and social returns to an increased supply of water for irrigation would change the cost-benefit equation. If water and sanitation departments spoke to irrigation departments, there would almost certainly be more investment in this area. While

The regulated use of treated water could significantly alleviate the adjustment pressures now facing water management in agriculture

People and governments across the world are discovering the value of water and the costs of having ignored the real value of water in the past

few developing countries are in a position to duplicate Israel's wastewater allocation system, simple rules can make a difference. Mexico uses the expedient of banning wastewater for fruits and vegetables. Jordan and Tunisia have developed highly innovative public education campaigns among rural producers to communicate strategies for reducing health risks associated with the use of wastewater.

Regulating demand for a scarce resource

"When the wells dry", observed Benjamin Franklin, one of the architects of the US Declaration of Independence, "we know the value of water." Today, people and governments across the world are discovering the value of water and the costs of having ignored the real value of water in the past. Public policies today are picking up the bill for the past practice of treating water as a resource to be exploited without limit.

As awareness of the value of water has increased, there has been a growing concern for raising water productivity. What does this mean in practice? There are two broad approaches to water productivity that figure in debates on water use, though they are often confused. One approach stresses the importance of increasing physical productivity by increasing the "crop per drop" ratio. Running parallel to this approach is a focus on raising productivity as measured by value added in production: water is a scarce capital resource that should be deployed where it generates the greatest wealth.

Increasing crop per drop

What do these shifts in perspective imply for human development? The case for raising water productivity in terms of crop per drop is overwhelming. Meeting the water requirements of a growing population while protecting the natural ecosystems on which life itself depends is a critical condition for sustained human development. Addressing this challenge will involve making water management in irrigation leaner and smarter—substituting technology and knowledge for water.

Increased productivity is one route to reduced water stress—and there is great scope for generating more crop per drop. The good news is that the increase in water productivity recorded over recent decades has been spectacular. The amount of water needed to produce cereals for one person has halved since 1960. The bad news is that in many of the world's most stressed water basins productivity remains very low. Comparisons across countries amply demonstrate the scope for raising water productivity as measured on a simple crop per drop scale. In California 1 tonne of water yields 1.3 kilograms of wheat. In Pakistan it produces less than half as much.[57] Producing a tonne of maize in France takes less than half as much water as in China. Variations between irrigation systems in developing countries are equally large: China produces twice as much rice as India with the same volume of water, for example.

The benchmark for water efficiency in agriculture is drip irrigation, a method that supplies water directly to the root zone of plants.[58] In Jordan drip irrigation has reduced water use by about a third. However, Jordan is the exception. Drip technology has been adopted on less than 1% of irrigated lands worldwide—and 90% of capacity is in developed countries.[59] Global partnerships for technology transfer supported through international aid could make a difference.

From a human development perspective the problem with drip irrigation and wider technologies is distributional. New technologies have the potential to realign supply and demand at reduced water use levels. However, the technologies are seldom distribution neutral. At a global level technologies for conserving water are concentrated in rich countries partly because of the capital costs involved. Within countries, access to water-thrifty innovations requires access to capital, knowledge and wider infrastructure. Poor farmers in marginal areas are the least likely to have access to these assets, especially female farmers. The danger is that by raising productivity and reducing water use, new water technologies will help resolve one aspect of the water crisis while exacerbating wider social and economic inequalities. But that outcome is not inevitable: as we show in chapter 5, affordable drip technologies are increasingly available.

Diverting water to higher value-added uses

Diverting water use into higher value-added areas raises some analogous problems. This is one of the core recommendations of advocates for “soft-path” solutions to water stress. Rather than getting more crop per drop, the aim—crudely summarized—is to get more money per cubic metre. The underlying assumption is that water, as an increasingly scarce resource, has to be deployed where it generates high returns.[60]

At face value that assumption appears entirely reasonable. Applied to California, where water used in, say, the production of microchips, produces more income and employment than water used in heavily subsidized, capital-intensive rice and cotton farming, the policy options appear clear-cut.

In practice, though, advocates of soft-path solutions tend to overstate their case—and to suffer from an equity blind spot. The case is overstated on two counts. First, it is difficult to separate the value of water from other inputs in the production of high value-added manufactured goods. Second, and more important, there is surprisingly little evidence that the development of higher value-added industries has been held back because of competition with agriculture for water. In most cases agriculture has lost out in any competition (see chapter 5).

The equity blind spot concerns the failure to consider the range of distributional consequences that can flow from water transfer. That there are large variations in value added by water use in agricultural production is not in doubt. One cross-country study of irrigation systems covering 40 countries found a tenfold difference in the gross value of output per unit of water consumed.[61] Other things being equal, an equivalent amount of water might be expected to generate larger revenue flows when applied to the production of high value-added fruits and vegetables or beef and dairy products than to staple foods such as rice.[62] The same is true for high value-added industry.

However, in countries where the vast majority of the population depend on agriculture for their livelihoods, and where the production of food staples represents a large share of income and employment for poor households, losses of water can translate into a major human development threat. The obvious danger is that water diversion will generate more wealth while destroying the livelihoods of some of the most vulnerable people.

Integrated water management

These distributional problems are taken up in chapter 5. The backdrop though is a new emerging consensus on water governance. At the World Summit on Sustainable Development in 2002 governments embraced integrated water resources management as the model for the future. This approach emphasizes managing water allocations within the ecological limits of availability, with a premium on the three Es: equity, efficiency and environmental sustainability (box 4.7). In practice it is difficult to balance the competing claims of different users for a resource that goes to the heart of power relationships in society—and to questions of political voice and institutional accountability.

The deeper challenge is to develop a new ethic for water management backed by a commitment to address the deep inequalities that drive water insecurity. The central question has been powerfully expressed by Sandra Postel and Brian Richter:[63]

> *It would make us stop asking how we can further manipulate rivers, lakes, and streams to meet our insatiable demands, and instead ask how we can best satisfy human needs while accommodating the ecological requirements of healthy water systems. And it would inevitably lead us to deeper questions of human values—in particular, how to narrow the unacceptably wide gap between the haves and the have nots.*

The deeper challenge is to develop a new ethic for water management backed by a commitment to address the deep inequalities that drive water insecurity