3.

Water Futures

Whether the water crisis will deepen and intensify—or whether key trends can be bent or turned towards sustainable use and development of water resources—depends on many interacting trends in a complex system

Our Vision for water in the 21st century is an expression of a desirable future, based on an exploration of alternative water futures. The alternative possible futures in this chapter form a basis for the Vision expressed in the next chapter. Following a brief explanation of the approach in the Vision exercise (scenarios and models), projected water use and stress in 2025 are explored.[1] Given the wide range of uncertainties affecting the water futures, there is also a wide range in possible uses and stress. This range presents the potential for influencing the outcome through actions focused on key issues that may prove to be turning points.

Turning points in water futures

Whether the water crisis will deepen and intensify—or whether key trends can be bent or turned towards sustainable use and development of water resources—depends on many interacting trends in a complex system. Real solutions require an integrated approach to water resource management. Crucial issues that may provide levers for very different futures include:[2]

Expanding irrigated agriculture

- **Will the rate of expansion of irrigated agriculture continue as in recent decades, or will it slow down, as appears to be indicated by reduced investments in the sector?**

Increasing water productivity

- **Can improvement rates in water use efficiency—or preferably, water productivity[3]—be increased drastically on short notice to ease the water crisis? How can technological and institutional innovation be stimulated to improve these rates?**

- **Can water productivity for rainfed agriculture be accelerated?**

- **Will policies emphasise national food self-sufficiency or global food security (involving governance and trade issues)?**

- Crucial issues
- Big questions for each
- Scenarios and models

Developing biotechnology for agriculture

- What contribution will biotechnology make to increased water productivity?
- Will genetically modified crops gain public acceptance in Europe and developing countries?

Increasing storage

- Can the recharge to aquifers used for irrigation be drastically increased to prevent a groundwater crisis—without major environmental impacts?
- Will there be increasing or decreasing public opposition to large dams in developing countries? Will the hydropower potential in Asia, Africa, and Latin America be developed at the rate of past decades to meet the rapidly increasing demand for electricity?
- How can affordable water storage be created with acceptable environmental and social impacts?

Reforming water resource management institutions

- Will governments implement policies to charge the full cost of water services? Will current trends towards decentralisation and democratisation empower communities to select their own level of water services?
- Will the trend towards transferring management of water systems to water users continue, and will these users be assigned stable water use rights?
- Can governments and the private sector form effective public-private partnerships and develop a service-oriented approach to water management, accountable to users?
- Will countries be prepared to adopt comprehensive approaches to land and water management?

Valuing ecosystem functions

- Will wetlands continue to be claimed for agriculture and urban uses at current rates? Or can this trend be stopped or even reversed? And will wetlands receive enough water of good quality to maintain their biodiversity?
- Will environmental or dry sanitation make the expected breakthrough and become adopted on a wide scale?
- Will there be increased demand for investments in wastewater collection, treatment, and disposal in rapidly developing emerging economies? Will transition economies upgrade their systems?

Increasing cooperation in international basins

- Will countries recognise the need to cooperate as scarcity in international basins increases? Will they make binding agreements on how to share the resources of rivers that cross national boundaries?

Supporting innovation

- Will the public sector increase research funds to foster innovation on public goods aspects of the water sector—such as ecosystem values and functions, food crop biotechnology, and water resource institutions? Can innovation be linked to effective capacity building, education, and awareness raising?
- Will science, with the help of information technology, develop innovative approaches to improve water resource data, real-time methods, seasonal drought forecasting, and longer-term cyclone and flood warnings?

Scenarios and models

Many sector and regional groups explored alternative water futures for the World Water Vision exercise. At the global level three primarily qualitative scenarios prompted the consultations at the sector and regional levels (Gallopin and Rijsberman 1999). These scenarios were the starting point for several model-based simulations of specific components of the water resource management system.[4] The sector and regional visions, the three global scenarios, and the results of the modelling exercises are the basis for the water futures described in this chapter.

The three global scenarios are:

- Business as usual—a continuation of current policies and extrapolation of trends.
- Technology, economics, and private sector—private sector initiatives lead research and development, and globalisation drives economic growth, but the poorest countries are left behind.
- Values and lifestyles—sustainable development, with an emphasis on research and development in the poorest countries.[5]

Between 2000 and 2025 the global average annual per capita availability of renewable water resources is projected to fall from 6,600 cubic metres to 4,800 cubic metres

These three scenarios are not the only possible water futures, and regional and sectoral Vision groups developed scenarios that are equally valid. Many groups and organisations outside the Vision exercise have also developed scenarios of possible or desirable water futures. We are not advocating any of the three global scenarios as the most desirable future. Instead, we explore dimensions of alternative futures. Chapter 4 espouses a Vision.

The approach focused on developing qualitative scenarios to allow incorporation of the many social, economic, environmental, and cultural factors that shape the water future but that cannot be modelled quantitatively. The development and discussion of qualitative scenarios provided a platform for consultation among many stakeholders with different backgrounds and perspectives. Models were then used to analyse the consistency and coherence of the qualitative scenarios, explore some of the consequences, and fill in some of the gaps. The scenarios evolved in four rounds of development, discussion, feedback, and subsequent improvement—with interactions among the scenario developers, modellers, reviewers, and groups working on visions for sectors and regions.

The main forces affecting the global water scenarios are population growth, economic growth, demographic change, technological change, social trends, and environmental quality (Gallopin and Rijsberman 1999). Environmental quality is not a driver in the same sense as the others, because it is also a direct response to them. But it is included here as an important trend to be closely monitored.

Water use is influenced by trends in the drivers, but water use and development is—or can be, when well managed—a driver in its own right, with an important impact on economic growth, social trends, and environmental quality. Recognition of this broad integrated framework is crucial to achieving optimum economic, social, and environmental security through integrated water resource management (annex table 3.1).

The scenarios describe the unfolding of a logical, coherent, and consistent storyline of related trends—but such trends cannot simply be extrapolated. The scenarios show how some trends, following the internal logic of the scenario, would bend or break and how certain actions or policies, if implemented, could influence these and other trends. The scenarios and simulations are not described in detail in this report but in the companion volume (Rijsberman 2000); some of the key results are discussed below.

Projected water use and water stress in 2025

Because of population growth, between 2000 and 2025 the global average annual per capita availability of renewable water resources is projected to fall from 6,600 cubic metres to 4,800 cubic metres.[6] Given the uneven distribution of these resources, however, it is much more informative that some 3 billion women and men will live in countries—wholly or partly arid or semiarid—that have less than 1,700 cubic metres per capita, the quantity below which one suffers from water stress (box 3.1).

WaterGAP model simulations based on the business as usual scenario indicate that by 2025 about 4 billion people—half the world population—will live in countries where more than 40% of renewable resources are withdrawn for human uses. This is another indicator of high water stress under most conditions.

Table 3.1 shows two diverging water use projections for 2025. The projections by Shiklomanov (1999) are based on the assumption that current trends can be extrapolated—that reservoirs will be constructed as in the past and that the world's irrigated area will expand by 30% from 1995 to 2025. The projections by Alcamo and others (1999), with analysis using WaterGAP 2.0 of the World Water Vision's business as usual scenario, assumes limited expansion of irrigated area, which, combined with rapidly increasing water use efficiency, leads to reduced agricultural use but a rapid increase in municipal and industrial use linked to rising income and population (annex table 3.2). The key difference between these two projections—the amount of increase in irrigated land—is the first turning point discussed in more detail later in this chapter.

Even though water use goes up significantly in both projections, neither scenario is based on satisfying the world's water and water-related basic needs, particularly for food production and household use. Alternative futures that satisfy these needs are discussed later in this chapter.

In more developed parts of the world—that is, upper-middle-income and high-income countries—economic growth to 2025 tends to increase water use. But this increase is offset by more efficient water use and the saturation of water demands in industry and households. In addition, the amount of irrigated land stabilises, and water for irrigation is used more efficiently. As a result total water withdrawals decrease.

- **Expanding irrigation?**
- **Or stable irrigation?**

Box 3.1 Assessing the stress on water

Unlike the more traditional concept of *water scarcity,* which focuses on quantity alone, *water stress* denotes reaching the limits of water quantity as well as quality. There is no universally adopted measure of water stress, but perhaps the most widely used is the Falkenmark indicator—renewable water resources per capita a year, often on a national scale. Water stress begins when there is less than 1,700 cubic metres per person a year for all major functions (domestic, industrial, agricultural, and natural ecosystems) and becomes severe when there is less than 1,000 cubic metres per capita. But the Falkenmark indicator does not account for the temporal variability in water availability or for actual use. Its advantage is that the data are widely available.

An indicator that does account for (estimated) use is the *criticality ratio* of withdrawals for human use to renewable resources. This ratio is used for the United Nations Comprehensive Freshwater Assessment and in the WaterGAP model in this Report. The value of the criticality ratio that indicates high water stress is based on expert judgment and experience. It ranges between 20% for basins with highly variable runoff and 60% for temperature zone basins. This report uses a threshold of 40% to indicate "high water stress." The advantage of the indicator is that it is easy to understand and based on water resources as well as use.

The criticality ratio's disadvantage is that withdrawals are not the best estimate of use. Some uses are nonconsumptive and allow reuse, while others consume a smaller or larger part of the water withdrawn. Nor does the ratio take into account available water infrastructure and water management capacity. For example, the ratio shows Belgium and the Netherlands as having very high water stress. This does not mean that these countries face severe water shortages for their projected human uses. Instead, it means that a very large share of their water resources are used—that is, have been developed. In such cases natural ecosystems suffer high water stress because such a large share of the resource is diverted for human use.

A more precise (but much harder to estimate) indicator is the *current basin use factor.* It relates total consumptive use to the primary water supply. When this factor is low—say, 30%—water could be saved and put to more consumptive use. When this factor is around 70% it is difficult and often undesirable to consume more water. Saving water and increasing the consumptive use factor require investment and management.

The *potential basin use factor* relates total consumptive use to the usable water supply. The distinction between the renewable resources in a basin and the primary water supply allows distinctions between physical and economic water scarcity.

- *Physical water scarcity* means that even with the highest feasible efficiency and productivity of water use, countries will not have sufficient water resources to meet their agricultural, domestic, industrial, and environmental needs in 2025. Indeed, many of these countries cannot meet even their present needs. The only options for them are to invest in expensive desalination plants—or to reduce the water used in agriculture, transfer it to other sectors, and import more food.

- *Economic water scarcity* means that countries have sufficient water resources to meet their needs but will have to increase water supplies through additional storage, conveyance, and regulation systems by 25% or more to meet their needs in 2025. These countries face severe financial and capacity problems in meeting their water needs.

Source: Alcamo and others 1999; IWMI 2000.

Table 3.1 Two diverging projections for use of renewable water resources for business as usual

Projections under the business as usual scenario show diverging increases in water use—even without making sure all demands get satisfied—with the largest uncertainty being whether we keep expanding irrigation.

Cubic kilometres

Use	1950	1995	Expanding irrigation 2025[a]	Stable irrigation 2025[b]
Agriculture				
Withdrawal	1,100	2,500	3,200	2,300
Consumption	700	1,750	2,250	1,700
Industry				
Withdrawal	200	750	1,200	900
Consumption	20	80	170	120
Municipalities				
Withdrawal	90	350	600	900
Consumption	15	50	75	100
Reservoirs (evaporation)	10	200	270	200[c]
Total				
Withdrawal	1,400	3,800	5,200	4,300
Consumption	750	2,100	2,800	2,100

Note: All numbers are rounded.
a. Shiklomanov projection.
b. World Water Vision business as usual scenario, Alcamo projections.
c. Alcamo and others do not calculate reservoir evaporation, but since the business as usual scenario developed by the World Water Vision assumes that relatively few additional reservoirs will be built, Shiklomanov's 1995 estimate is used to obtain comparable total use figures.
Source: Shiklomanov 1999; Alcamo and others 1999.

By contrast, higher incomes in developing countries lead to greater household water use per capita, multiplied by the greater number of people. Meanwhile, economic growth expands electricity demand and industrial output, leading to a large increase in water withdrawals for industry. Even though water is used more efficiently in households and industry, pressures to increase water use overwhelm these efficiency improvements.

The result is a large increase in water withdrawals in the domestic and industrial sectors of the developing world, in response to rising population and industrialisation, and higher consumption from higher incomes. In the World Water Vision business as usual scenario analysed by Alcamo and others (1999), the increase in irrigated land does not keep pace with growing food demand. This means that the amount of water

The rate of expansion of irrigated land is the most important determinant of water stress, at least the stress related to quantity

withdrawn for irrigation decreases slightly (because of efficiency improvements). Even so, agriculture remains the world's main user of freshwater, making more than half the total withdrawals. Shiklomanov's projections, assuming strong increases in irrigation, show a large increase in water for agriculture. For Shiklomanov's projections to be realised, dam construction and groundwater extraction will have to continue apace.

The sum of trends in all sectors: significant net growth in water withdrawals in developing countries between 1995 and 2025. Adding together the trends in developed and developing countries under the business as usual scenario results in an increase in global water withdrawals from 3,800 cubic kilometres in 1995 to 4,300–5,200 cubic kilometres in 2025 (see table 3.1). The difference largely depends on how much irrigated agriculture does or does not expand.

Because of the increase in water withdrawals, the pressure on water resources will grow significantly in more than 60% of the world (Alcamo and others 1999), including large areas of Africa, Asia, and Latin America. Will this lead to more frequent water crises? That depends on how much water is available relative to withdrawals—and on countries' ability to cope with increasing pressure on water resources. That is, it depends on whether countries face physical or economic water scarcity—and whether they have the resources to overcome economic water scarcity (see box 3.1).

The effect of high water stress will differ in different countries. In developed countries water is often treated before it is sent to downstream users, and industry recycles its water supply fairly intensively. For these and other reasons developed countries can intensively use their water resources (as indicated by a criticality ratio greater than 40%) without major negative consequences.

Most developing countries, by contrast, do not treat wastewater, and their industries do not intensively recycle their water supplies. So, the projected intensive use of water here will lead to the rapid degradation of water quality for downstream users—and to frequent and persistent water emergencies.

Expanding irrigated agriculture

The rate of expansion of irrigated land is the most important determinant of water stress, at least the stress related to quantity. There are two contrasting views on how the trend in irrigated agriculture expansion will continue or bend, with important groups of stakeholders weighing in on both sides.

The conventional wisdom in agriculture is that, based on the need to produce food for the growing world, irrigated agriculture will have to keep pace—and therefore expand by some 30% in harvested area by 2025. This position, supported by the Food and Agriculture Organization (FAO) and the International Commission on Irrigation and Drainage (ICID), is also reflected in Shiklomanov's (1999) projections and the International Water Management Institute's (IWMI) first projection (Seckler and others 1998). The conclusion of these analyses, under optimistic assumptions on yield and efficiency improvements, is that water use for agriculture will have to increase at least 17% from 1995.

The other perspective—supported by environmentalists and by a number of stakeholders in agriculture—holds that a slowdown in dam building and irrigation investments, combined with the consequences of falling groundwater tables, will limit the expansion in irrigated area to 5–10%. The consequences of such a scenario were analysed in the Vision's business as usual scenario (Rosegrant and Ringler 1999; Alcamo and others 1999; IWMI 2000).

Both scenarios are persuasive. The FAO's longer-term data on the increase in irrigated area do not show a clear decline other than in OECD countries. But a slowdown in agricultural investment is a clear indication that the expansion in area is likely to slow as well. According to Rosegrant and Ringler (1999), the growth in global irrigated area declined from 2.2% a year in 1967–82 to 1.5% in 1982–93.

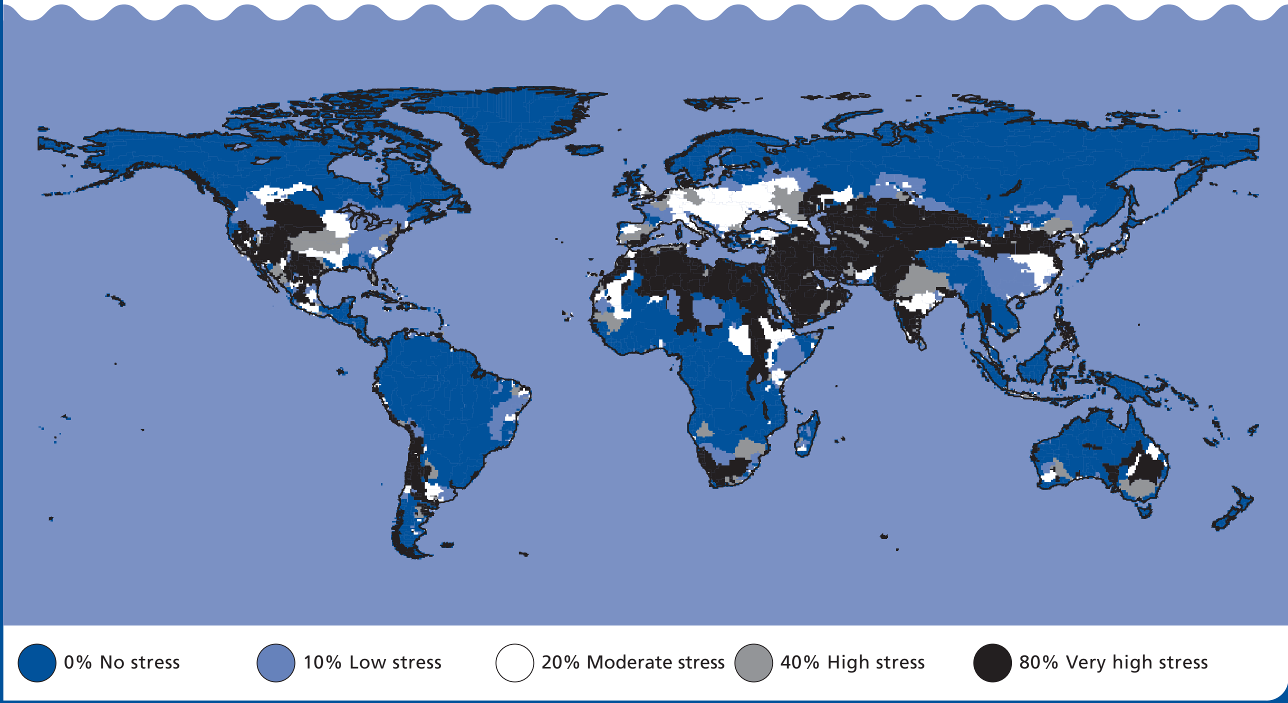
Analysis of the two alternatives shows that neither is attractive:

- *Unattractive alternative 1.* The 30% increase in irrigated area requires major investments in water infrastructure, a considerable part of which would have to be through large dams. There would also be severe water scarcities and serious risks of major damage to ecosystems (Shiklomanov 1999; Seckler and others 1998).
- *Unattractive alternative 2.* A strong reduction in irrigation expansion—under otherwise unchanged policies, or business as usual as elaborated by the Scenario Development Panel (Alcamo and others 1999; Rosegrant and Ringler

Water stress

1 Water stress in 2025 under the business as usual scenario

Under the business as usual scenario, by 2025 about 4 billion people—half the world's population—will live in countries with high water stress.



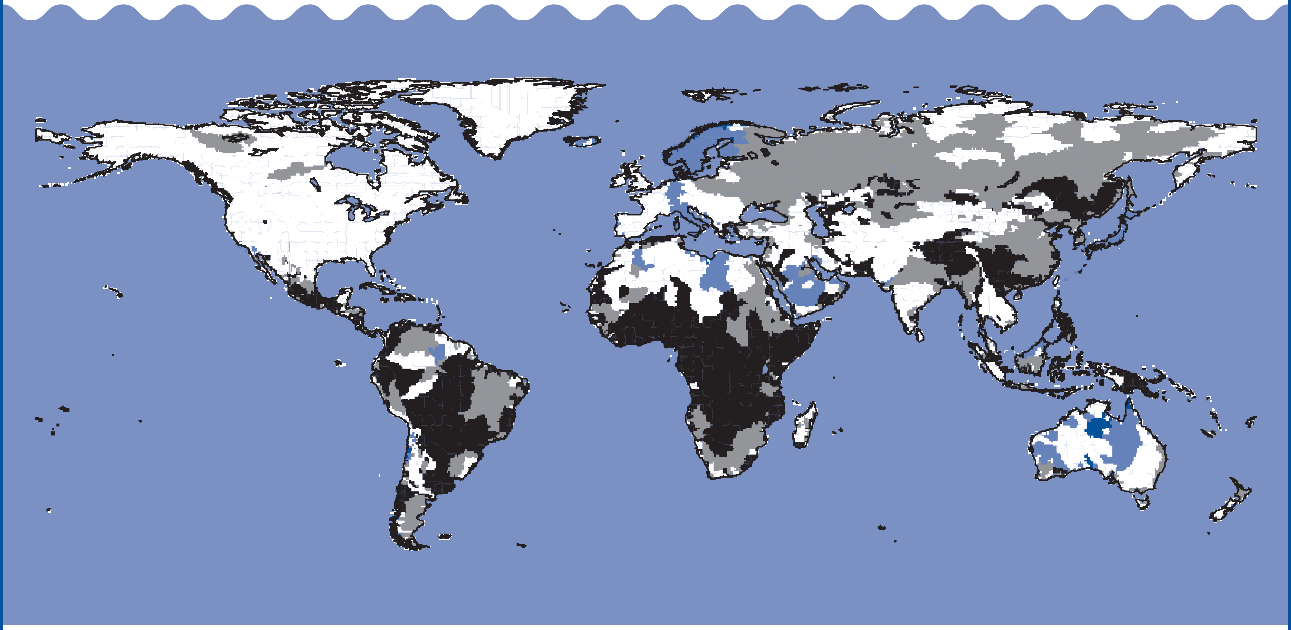
Source: WaterGAP 2 calculations (Alcamo and others 1999).

The ratio of withdrawals for human use to total renewable resources—the criticality ratio—implies that water stress depends on the variability of resources. It ranges from 20% for basins with highly variable runoff to 60% for temperate zone basins. Here we use an overall value of 40% to indicate high water stress.

Because of the increase in water withdrawals, the pressure on water resources will grow significantly in large areas of Africa, Asia, and Latin America

2 Change in water stress from 1995 to 2025 under the business as usual scenario

Many of today's developing countries will experience increasing pressure on water resources.



Source: WaterGAP 2 calculations (Alcamo and others 1999).

Withdrawals are not the best estimate of use, however. A more precise (but much harder to estimate) indicator is the ratio of consumption to the total actually available. When it is low—say, 30%—more water would be consumed. When it is high—say, 70%—it is difficult and undesirable to consume more.

Water trends

1 Sub-Saharan Africa: Another 175 million people in areas with high water stress

Under the business as usual scenario, domestic water withdrawals in Sub-Saharan Africa increase from about 10 cubic kilometres in 1995 to 42 cubic kilometres in 2025. Why? Because higher incomes lead to higher per capita water use, even though technology tends to make water use more efficient.

In West Africa in 2025 domestic water use is 34 cubic metres a person—2.1 times its 1995 value but still far below Western Europe's 105 cubic metres a person per year. Industrial water use also increases—from about 3 to 16 cubic kilometres a year between 1995 and 2025.

Because of abundant rainfall, there will likely be enough water to cover the increase in domestic and industrial water use. So, the question is whether water distribution systems can expand fast enough to fulfill the needs of growing population and industry. To cover the growth in water withdrawals, municipal water capacity must expand by 5.5% a year and industrial capacity by 7.1% a year.

Source: WaterGAP 2 calculations (Alcamo and others 1999).

2 Southeast and East Asia: Another 1.3 billion people in areas with high water stress

In South and East Asia irrigated area under the business as usual scenario grows only slightly between 1995 and 2025, while irrigation efficiency improves. The effect is a decrease in water used for irrigation from 1,359 to 1,266 cubic kilometres a year. At the same time, strong economic growth leads to more material possessions and greater water use by households, increasing water withdrawals for domestic use from 114 to 471 cubic kilometres a year. This economic growth also requires larger quantities of water for Asian industry, increasing from 153 to 263 cubic kilometres a year.

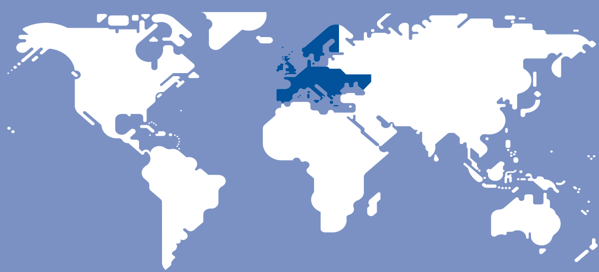
The sum of these trends is an overall increase in water withdrawals between 1995 and 2025. Thus the pressure on water resources will become even greater than was experienced in 1995, when about 6.5 million square kilometres of river basin area were under high water stress. That area increases to 7.9 million square kilometres in 2025. The number of people living in these areas also grows tremendously—from 1.1 billion to 2.4 billion.

Source: WaterGAP 2 calculations (Alcamo and others 1999).

3 Western Europe: Lower withdrawals and higher efficiency, but not much change in water stress

Water withdrawals in Western Europe are growing slowly or not at all as households, industry, and agriculture become more water efficient. The per capita use of water in households goes up slightly with the economic growth of the business as usual scenario between 1995 and 2025, but the amount of water used by industry per megawatt-hour goes down because of greater recycling and other efficiency improvements. The amount of irrigated area stabilises, and new technology increases the efficiency of irrigation systems so that there is also a decline in the amount of water used per hectare.

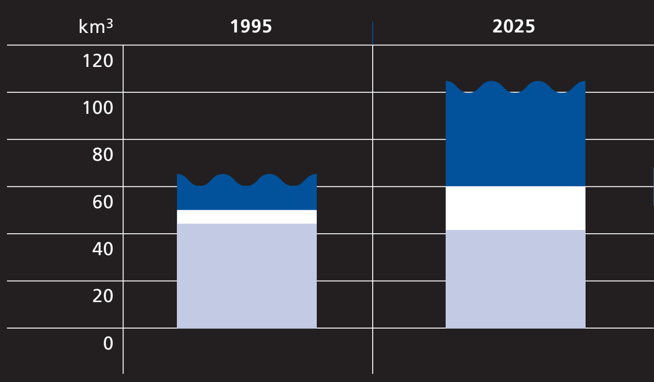
Although water withdrawals go down, the pressure on water resources continues to be high in some areas because of the density of population and industrial activity. So, some river basins remain in the high stress category with sharp competition among industrial, domestic, and some agricultural users.



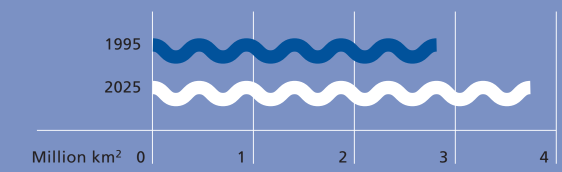
Source: WaterGAP 2 calculations (Alcamo and others 1999).

By 2025 half the world's people will live in countries with high water stress

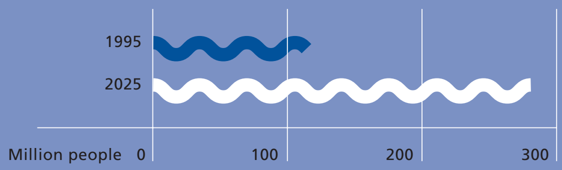
Water withdrawals, business as usual scenario



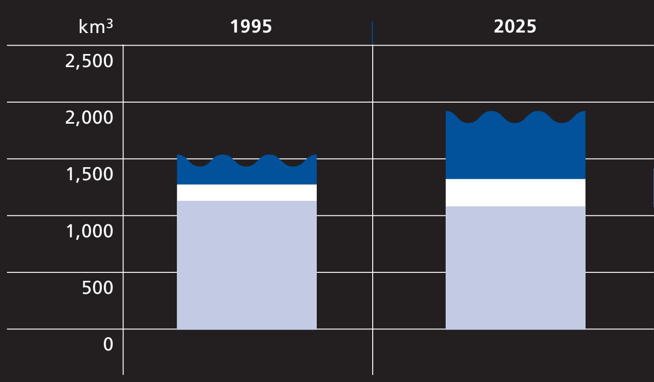
Areas with high stress on water resources



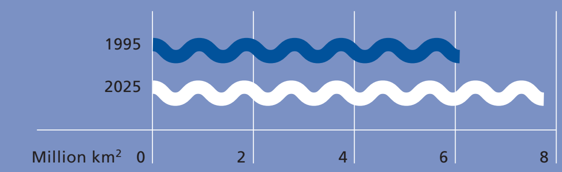
Population living in high water stress areas



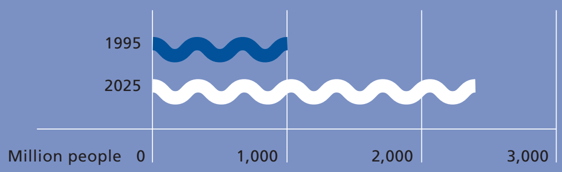
Water withdrawals, business as usual scenario



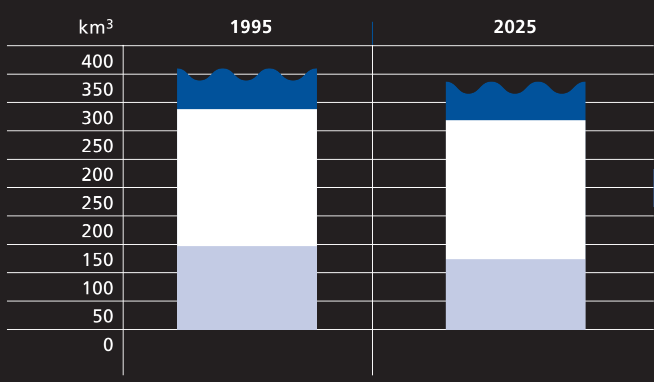
Areas with high stress on water resources



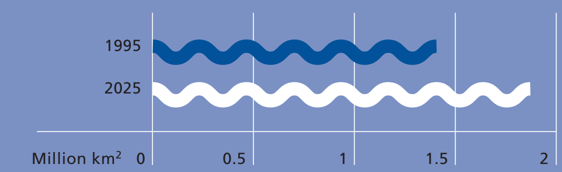
Population living in high water stress areas



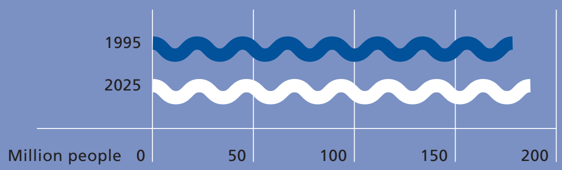
Water withdrawals, business as usual scenario



Areas with high stress on water resources



Population living in high water stress areas



Use

Agriculture Industry Domestic

• **More crop per drop**

• **More storage**

1999; IWMI 2000)—will cause considerable food shortages and rising food prices.

Both alternatives—unattractive and unsustainable—would considerably deepen today's water crisis. Thus there is every motivation to implement policies that make food production and water resource management more sustainable.

Increasing water productivity

At the heart of the question of whether a water crisis can be averted is whether water can be made more productive. The more we produce with the same amount of water, the less the need for infrastructure development, the less the competition for water, the greater the local food security, and the more water for agricultural, household, and industrial uses. And the more that remains in nature.

IWMI (2000) concludes that sustainable water management and food production is possible but requires two major improvements in water resource and irrigation technology and management:

- *Greater water productivity: more crop per drop.* The productivity of water use must be dramatically improved. The IWMI base scenario relies on meeting about half the increased demand for water in 2025 by increasing water productivity, taking many opportunities for improving the management of water. The first task is to understand where these opportunities exist. Recycling, although widely prevalent, still holds potential for saving water. Gains are also possible by providing more reliable supplies—through precision technology and through feedback systems.[7] Supplemental irrigation with low-cost precision technology offers a means for poor farmers to produce more. With competition for water on the rise, these solutions will require major changes in the institutions responsible for managing water.

- *More storage: developing additional resources.* The other half of increased demand must be met by developing additional water supplies, but at much lower economic, social, and environmental costs (IWMI 2000). The additional water storage and conveyance required by 2025 is estimated by the IWMI at some 400 cubic kilometres a year for expansion of irrigated agriculture alone. Such an expansion may be viewed as moderate by the irrigation community, but it is unlikely to be well-received by other users. Feeding the world without this expansion, however, requires a strategy that puts more emphasis on other ways to increase food production—such as intensifying rainfed production and improving management of water in existing agricultural areas. An additional 200 cubic kilometres might be required to replace the current unsustainable overconsumption of groundwater (Postel 1999). For financial, environmental, and other reasons a large part of the additional storage requirement should be met using a mix of groundwater recharging and aquifer drawdowns, developing alternative methods for storing water in wetlands, harvesting rainwater, and relying on traditional technologies such as tanks and other small-scale alternatives, rather than by building large-scale surface storage facilities alone.

Increasing the productivity of water is central to producing food, to fighting poverty, to reducing competition for water, and to ensuring that there is enough water for nature. Achieving the greater productivity needed to resolve the water crisis will not happen automatically—it will require great effort. But it is possible, especially in developing countries, where water productivity is far below potential. For cereal grains, for example, the range in water productivity—in biomass produced per cubic metre of evapotranspiration—is between 0.2 and 1.5 kilograms per cubic metre. As a rule of thumb, that value should be about 1 kilogram per cubic metre (IWMI 2000). If a country's demand for grains grows by 50% by 2025, one way to match the increase is to increase water productivity by 50%.

Meeting this challenge will require a far greater effort and significant changes in how water is managed. What needs to change? Where are improvements required? The biggest boosts to water productivity have come from better plant varieties and agronomic practices. Getting more crop per drop came from introducing shorter-duration and higher-yielding crop varieties. Adding fertilisers also pushes up yields and water productivity. This was the heart of the green revolution.

With a stable water supply through irrigation, agricultural productivity has risen dramatically in the past 50 years. But scope for improvement remains. In many areas potential productivity is not realised—largely because of poor irrigation water management. Without a stable supply of irrigation water, farmers cannot achieve their production potential.

For example, wheat yields and water productivity vary greatly in three locations with somewhat similar environments (fig-

Increasing the productivity of water is central to producing food, to fighting poverty, to reducing competition for water, and to ensuring that there is enough water for nature

ure 3.1). In a desert environment India's Bhakra irrigation system—across the border from the Pakistani Punjab—supplies a major part of India's breadbasket. The Imperial Valley in California is also in a desert environment. Within the Pakistani Punjab, yields vary greatly—with some farmers as productive as those in California, and some way below the average. Even though production depends on environmental, market, soil, and other conditions not equal across sites, there appears to be scope to manage resources for higher productivity.

In OECD countries industrial water productivity has increased rapidly in the past 20 years, in response to rising prices and stricter environmental standards for industrial wastewater. With the expected increase in the cost of providing water to industry—if users are charged the full-cost price—this trend could accelerate.

How can productivity be improved in agriculture—the largest water user? A precondition is that the same conditions are introduced as elsewhere: payment for water services, accountability of managers to users, and competition among public and private suppliers. Then there are a range of technical and management options to improve productivity. First, through better agronomic practices (IWMI 2000):

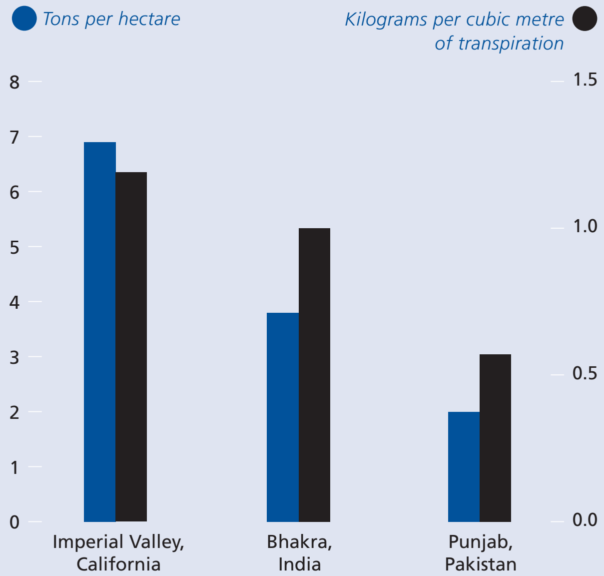
- *Crop varietal improvement.* Plant breeding plays an important role in developing varieties that yield more mass per unit of water consumed by transpiration. For example, by shortening the growth period while keeping the same yield, production per unit of evapotranspiration increases. This includes contributions from biotechnology.
- *Crop substitution.* Switching from a more to a less water-consuming crop or switching to a crop with higher economic or physical productivity per unit of transpiration.
- *Improved cultural practices.* Better soil management, fertilisation, and pest and weed control increase the productivity of land and often of water consumed.

And second, through better water management practices:

- *Better water management.* Better timing of water supplies can reduce stress at critical crop growth periods, increasing yields. When the water supply is more reliable, farmers tend to invest more in other agricultural inputs, leading to higher output per unit of water. Controlling salinity through water management at the project or field level can prevent reductions in water productivity.

Figure 3.1 Wheat yields and water productivity

Productivity is much higher in California than in India and Pakistan. In Pakistan the conditions are similar to those in India, but yields are still lower.



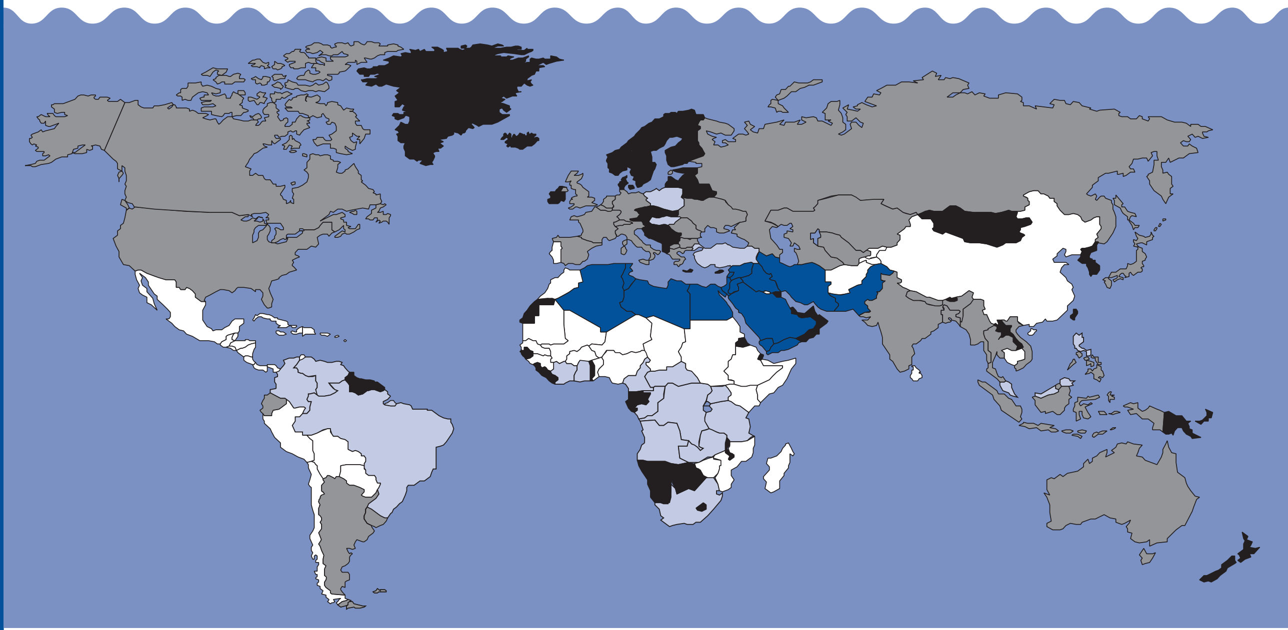
Source: IMWI 2000.

- *Deficit, supplemental, and precision irrigation.* With sufficient water control, it is possible to use more productive on-farm practices. Deficit irrigation is aimed at increasing productivity per unit of water with irrigation strategies that do not meet full evaporative requirements. Irrigation supplementing rainfall can increase the productivity of water when a limited supply is made available to crops at critical periods. Precision irrigation, including drip, sprinkler, and level basins, reduces nonbeneficial evaporation, applies water uniformly to crops, and reduces stress, and so can increase water productivity (IWMI 2000).
- *Reallocating water from lower- to higher-value uses.* Shifting from agriculture to municipal and industrial uses—or from low-value to high-value crops—can increase the economic productivity or value of water. As

Water scarcity

1 Business as usual scenario, 2025

Limited investments in new water infrastructure reduce irrigation expansion and prevent water scarcity—but food scarcity is the result.

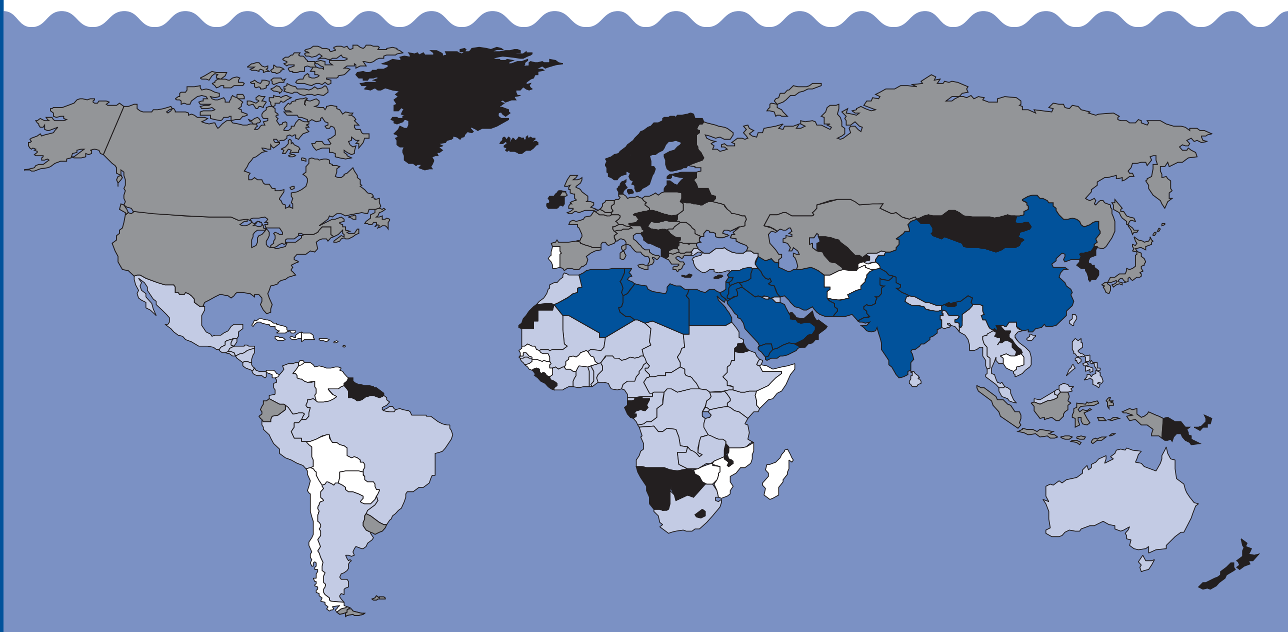


Absolute water scarcity | Economic water scarcity | Physical scarcity | No water scarcity | Not analysed

Source: PODIUM calculations (IWMI 2000). International Water Management Institute www.iwmi.org.

2 Technology, economics, and private sector scenario, 2025

Emphasis on technology and investments increases primary water supply by 24%. China and India are water short due to irrigation expansion. Many countries face economic water scarcity.



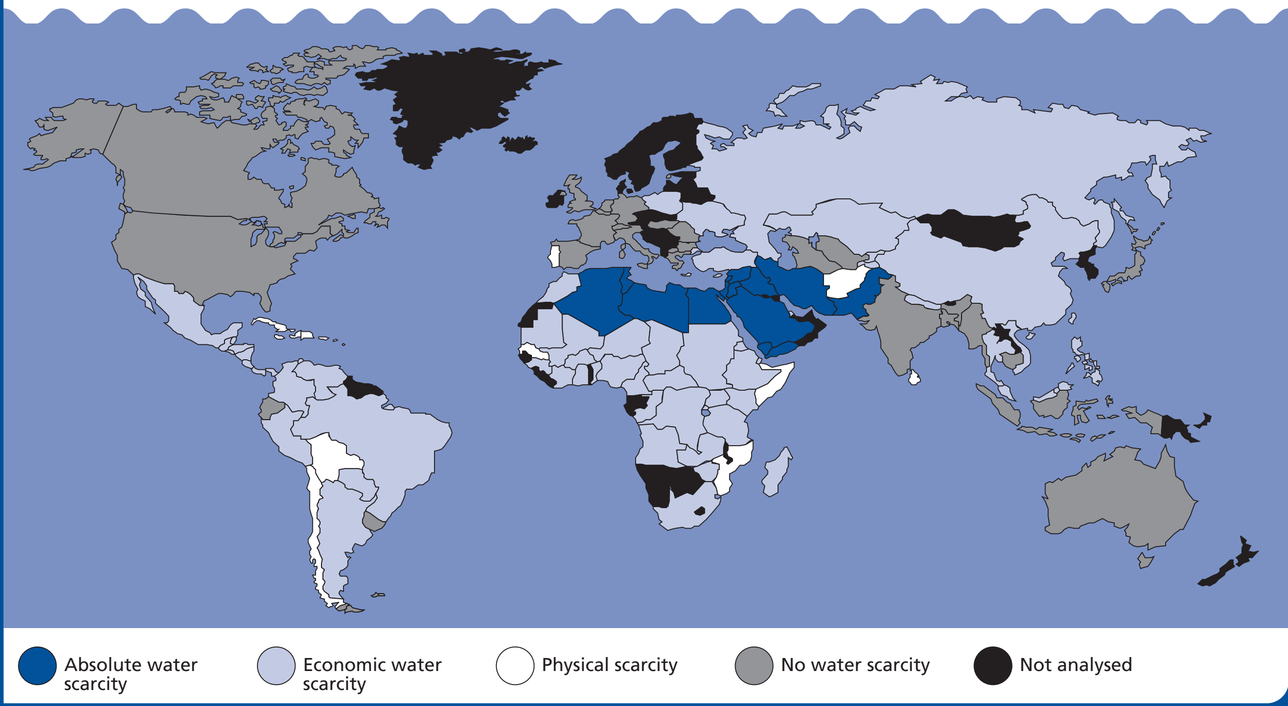
Absolute water scarcity | Economic water scarcity | Physical scarcity | No water scarcity | Not analysed

Source: PODIUM calculations (IWMI 2000). International Water Management Institute www.iwmi.org.

A country's ability to cope with increasing pressure on its water resources depends on whether it faces physical or economic water scarcity

3 Values and lifestyles scenario, 2025

Development focuses on low-income countries that face economic water scarcity. Water and food scarcity is limited.

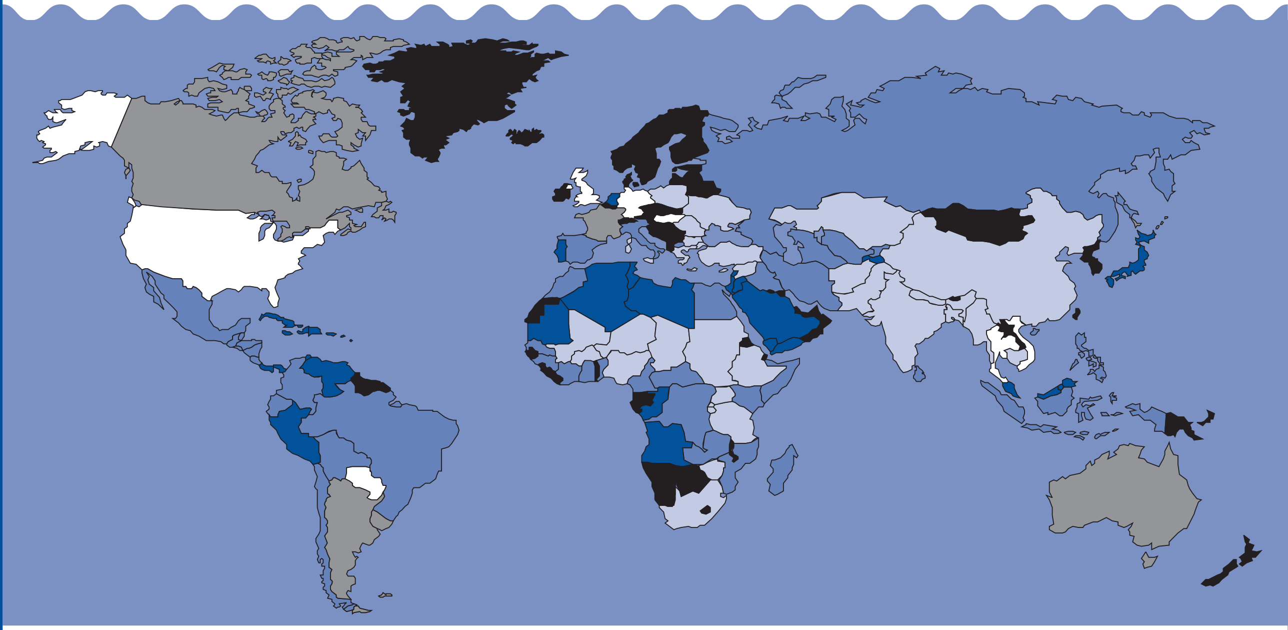


- **Business as usual—a continuation of current policies and extrapolation of trends.**
- **Technology, economics, and private sector—private sector initiatives lead research and development, and globalisation drives economic growth, but the poorest countries are left behind.**
- **Values and lifestyles—sustainable development, with an emphasis on research and development in the poorest countries.**

Cereal deficits or surpluses

1 1995

Major deficits, mostly in Africa and the Middle East.

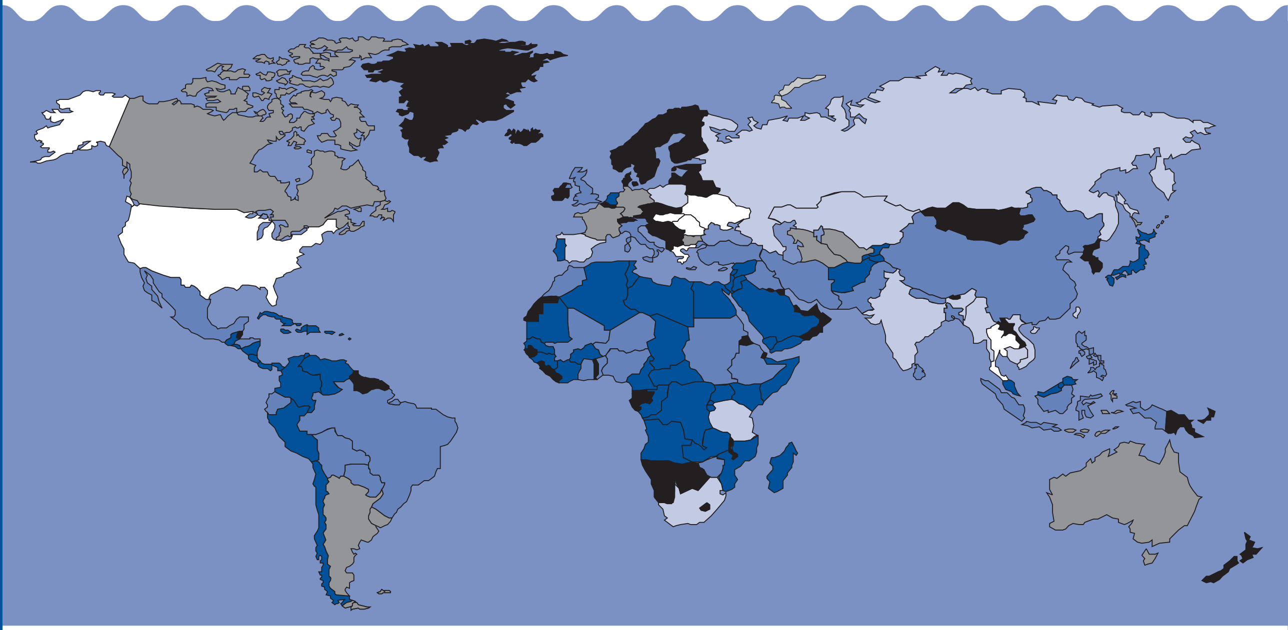


Major deficit · Minor deficit · Self-sufficient · Minor surplus · Major surplus · Not analysed

Source: PODIUM calculations (IWMI 2000). International Water Management Institute www.iwmi.org.

2 Business as usual scenario, 2025

Global deficit of 200 million tons—major deficits in many countries in Africa and the Middle East—India self-sufficient.



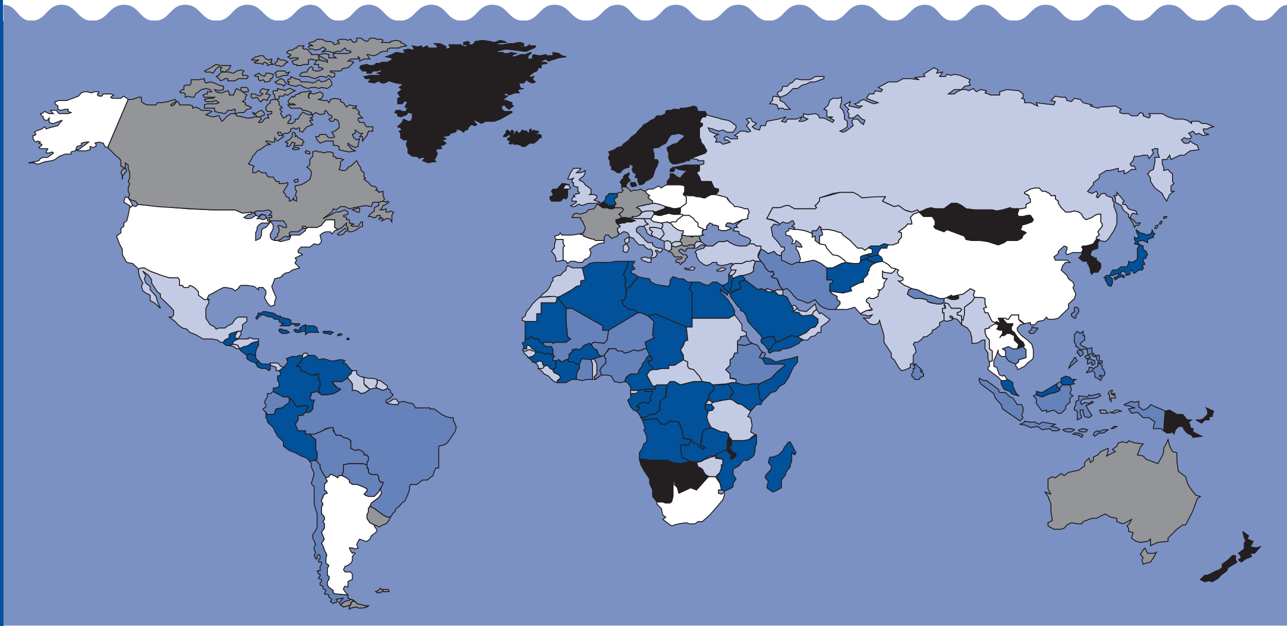
Major deficit · Minor deficit · Self-sufficient · Minor surplus · Major surplus · Not analysed

Source: PODIUM calculations (IWMI 2000). International Water Management Institute www.iwmi.org.

Under business as usual, many countries will suffer major deficits

3 Technology, economics, and private sector scenario, 2025

Global surplus of 70 million tons—surplus in OECD and high-income developing countries—growing deficit in low-income countries.

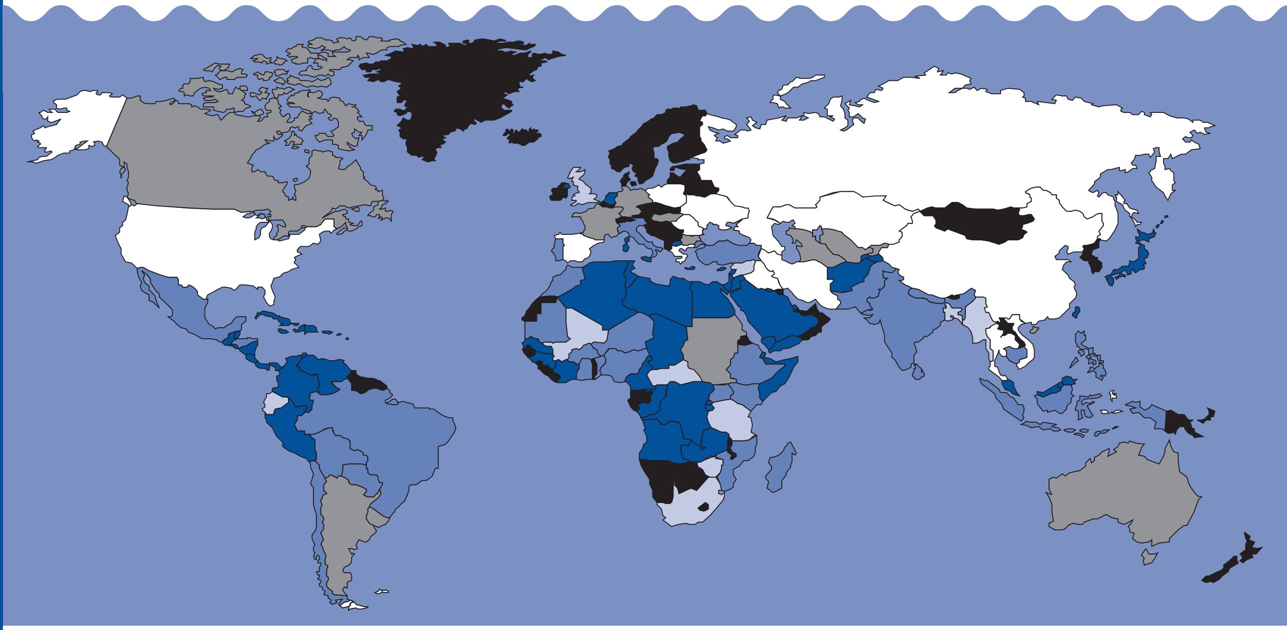


Major deficit · Minor deficit · Self-sufficient · Minor surplus · Major surplus · Not analysed

Source: PODIUM calculations (IWMI 2000). International Water Management Institute www.iwmi.org.

4 Values and lifestyles scenario, 2025

Closing yield gap, rising productivity in low-income countries, lower population growth, and more concern about the environment—deficit in low-income countries reduced.



Major deficit · Minor deficit · Self-sufficient · Minor surplus · Major surplus · Not analysed

Source: PODIUM calculations (IWMI 2000). International Water Management Institute www.iwmi.org.

- **The doubly green revolution**
- **Adding more storage**

a result of such reallocation, downstream commitments may change, with serious legal, equity, and other social considerations that must be addressed. One option here is trade in virtual water.

Trade can help alleviate water scarcity (Allan and Court 1996). Countries with plentiful water should export water-intensive crops, such as rice, to water-scarce countries. According to an earlier analysis by the International Food Policy Research Institute (IFPRI) that did not take water into account as a constraint, world trade in food will increase substantially between 1995 and 2020 (Rosegrant, Agcaoili-Sombilla, and Perez 1995). Trade in meat will triple, that in soybeans will double, and that in grains will rise by two-thirds. Developing countries will substantially increase their imports, while the exports will come mainly from the United States, Canada, Australia, and Argentina. The analysis concluded that this increase would satisfy world food demand, but not substantially reduce the number of undernourished people.

More food exports from industrial countries are not a solution for the 650 million poor and undernourished people in rural areas. Most live where agricultural potential is low and natural resources are poor (Leonard 1989). They also live in areas that suffer from periodic or chronic shortages of water. For them, access to water means local production of food that generates employment and income—and is sufficient and dependable enough to meet local needs throughout the year, including years unfavourable for agriculture (Conway 1999a).

A recent IFPRI analysis of the three World Water Vision scenarios also concluded that international trade in food will rise rapidly—for different reasons (Rosegrant and Ringler 1999). If agriculture does not expand rapidly, then the increased trade will largely come from water-constrained limits on food production. Under the other two scenarios—which explore a range of measures to increase food production in projected deficit areas—the increased trade can only be caused by faster economic growth in the developing world, which will lead to additional food demand, outstripping even the local increases in production.

David Seckler has pointed out that the increase in trade will likely be constrained by the need for foreign exchange to pay for the imports (IWMI 2000). Because of strong competition, it is unrealistic to expect all countries to move their scarce resources into the production of higher-value crops. Thus the IWMI scenario assumes that trade will remain at the current percentage of food consumption—that is, a maximum 30–40% increase in volumes traded (IWMI 2000).

Developing biotechnology for agriculture

According to Conway (1999a), the application of advances in biotechnology—including genetic engineering, tissue culture, and marker-aided selection (which uses DNA technology to detect the transmission of a desired gene to a seedling arising from a cross; box 3.2)—will be essential for:

- Raising yield ceilings.
- Reducing excessive pesticide use.
- Increasing the nutrient value of basic foods.
- Providing farmers on less favoured lands with varieties better able to tolerate drought, salinity, and lack of soil nutrients.

Indeed, biotechnology should be seen as an element of what Conway (1999b) has dubbed the "the doubly green revolution". That revolution consists of ecological approaches to sustainable agriculture, greater participation by farmers in analysis, design, and research, and the application of modern biotechnology to the needs of the poor in developing countries, particularly those in drought-prone areas.

The experts disagree on the potential of biotechnology to increase food production. Seckler, for instance, does not expect biotechnology to add more than 5–10% to the world's food production over the next 25 years (IWMI 2000). Conway (1999a), however, believes that over the next 10 years we are likely to see much greater progress in multiple gene introductions that focus on output traits or on hard to achieve input characteristics, and that a high priority will be to engineer crops for drought tolerance.

He concludes that while the potential benefits of biotechnology are considerable, they are unlikely to be realised without taking some crucial steps. Poor rural farmers in drought-prone regions are unlikely to adopt these crops unless the seeds are provided for free or at nominal cost. This will require heavy public investment, by governments and donors, in the research and distribution of seeds and technical advice. And these efforts will need to focus on crops—cassava, upland rice, African maize, sorghum, millet—that are food staples for

Retaining flood waters until the moment needed for human use remains an essential element of water resource management in all areas—especially South Asia

Box 3.2 Tissue culture and marker-aided selection techniques

Most new varieties are the result of tissue culture and marker-aided selection techniques. A rice variety from tissue culture—called La Fen Rockefeller by the Chinese breeder who developed it—is increasing yields by 15–25% for farmers in the Shanghai region. Scientists at the West Africa Rice Development Association have used another culture to cross high-yielding Asian rice with traditional African rice. The result: a new plant type that looks like African rice in its early stages of growth (it grows in dry conditions and can shade out weeds) but becomes more like Asian rice as it reaches maturity, resulting in higher yields with few inputs.

In another breakthrough, scientists announced recently that they have increased the amount of vitamin A in a new variety referred to as "golden rice"—important for reducing vitamin A deficiency, which is a major cause of blindness.

Marker-aided selection is being used in rice to pyramid two or more genes for resistance to the same pathogen, increasing the durability of resistance, and to accumulate several genes, contributing to drought tolerance. For some time to come, this is likely to be the most productive use of biotechnology for cereals.

Source: Conway 1999a.

people in drought-prone regions, who need increased yield stability as much as increased yield.

The growth of transgenic crops, likely to be extremely variable in different parts of the world, has different effects on different continents. In North America transgenic crops already dominate among some crops. In Europe a lack of public acceptance may reduce food imports, causing higher food prices and demand for water to produce food domestically, creating trade conflicts between Europe and North America. In developing countries the adoption of transgenic crops is likely to be highly variable, opening conflicts between governments and private companies with patents for numerous new varieties. The developing world needs to have access to these technologies and to make its own choices (box 3.3).

Increasing storage

Increasing water storage, retaining flood waters until the moment needed for human use, remains an essential element of water resource management in all areas—especially South Asia, where a huge percentage of annual flows are contained in a limited number of floods. The optimum strategy appears to be a combination of storage in aquifers, in tanks and other traditional microstructures, and behind small and large dams.

Box 3.3 The developing world cannot afford to forgo agricultural biotechnology

"Too little attention is paid to the effect of new agricultural technologies on the world's poor and hungry", says Per Pinstrup-Andersen, director general of the International Food Policy Research Institute, in an article summarised here. Most of these people live in developing countries, and they stand to benefit more than anyone from biotechnology. While "Frankenfood" and "terminator seeds" are buzzwords in European media and increasingly in the United States, small farmers in Asia, Africa, and Latin America must wonder what the fuss is about. For them, the heated debate over agricultural biotechnology risks closing off a huge opportunity to improve their lives.

Agricultural biotechnology can help farmers in developing countries produce more—say, by developing new crop varieties that are tolerant of drought, resistant to insects and weeds, and able to capture nitrogen from the air. Biotechnology can also make the foods farmers produce more nutritious by increasing the vitamin A, iron, and other nutrients in the edible part of the plant.

A few private corporations that focus on agriculture in industrial countries, where they expect the highest return on their investment, do most of the biotechnology research. Governments must invest in biotechnology research to help poor farmers, and the public and private sectors must work as partners. The potential of new agricultural technology is enormous, particularly for the poor in developing countries. Condemning biotechnology for its potential risks without considering the alternative risks of prolonging the human misery caused by hunger, malnutrition, and child death is as unwise and unethical as blindly pursuing this technology without the necessary biosafeguards.

Source: International Herald Tribune, 28 October 1999.

Building dams

Many large dams—defined by the International Commission on Large Dams (ICOLD) as those higher than 15 metres—are not particularly controversial. The International Hydropower Association estimates that about 300 large dams are currently built every year, not much more than what is required to replace the world's capital stock of 39,000 large reservoirs, and down considerably from the number built in 1960–80.

New dams have become a lot less popular in OECD countries over the past 10–20 years. But about 70% of the hydropower potential in these countries has already been developed, and there is little incentive to increase agricultural areas, other then to increase food exports. Thus the need for more dams is limited. The future of dams in OECD countries is probably as much about decommissioning dams as about building them—about using dams and reservoirs for recreational and environmental purposes as well as for economic development.

- **Recharging groundwater**
- **Harvesting rainwater**
- **Pricing water services**
- **Making managers responsive to users**

New large dams have also become controversial in developing countries, as with the well-known Narmada project in India and the Three Gorges project in China, because of the impacts on the environment and the displacement of people. It is possible to mitigate such impacts, and the dam-building community has done extensive work on possible measures. But the experience with implementing these measures has not persuaded the opponents of dams. Later this year, the World Commission on Dams will produce guidelines on the conditions under which the overall impacts of dams may or may not be beneficial.

Only a small part of the economically feasible hydropower in Africa (6% of 1,000 terawatt-hours a year), Asia (20% of 3,600), and Latin America (35% of 1,600) has been developed (IHA 1999). Countries in these regions may decide that they do not want to develop their hydro potential to the same level as OECD countries (70%). But it is likely that they will decide that the social optimum for hydropower is higher than their current levels of development.

Recharging groundwater

Storing water in aquifers is a compelling solution given the overdrawing of groundwater in China, India, North Africa, the United States, and elsewhere. The threat that overdrawing poses for those who depend on water for their livelihood—and those who depend on the food produced (box 3.4)—is ominous. New techniques and institutional mechanisms are urgently needed to recharge groundwater aquifers. Such mechanisms will include limiting access and providing incentives to users to limit or stop overpumping. The two routes open are to issue permits and control use or to recognise use rights and provide rights holders with incentives to conserve the resource. The second approach is generally more effective.

To make groundwater visible, groundwater protection zones could be created, with special measures for recharge and for reductions on abstraction. All groups affected by the "groundwater rush"—and the ensuing water scarcity, land degradation, water quality loss, and poor public health—need to be enlisted in initiatives to tackle the challenges. They include water user groups, local political leaders and civil society, and politicians and diplomats negotiating with riparian neighbours to reduce abstractions from common groundwater. The media and general public, unaware that this invisible "water savings account" is seriously depleted and under threat, must also be closely involved.

Box 3.4 Groundwater for agriculture

One of the greatest technical revolutions in irrigation has been the development of the small pump. Tens of millions of small pumps are drawing water out of aquifers to irrigate crops. Because pump irrigation provides water on demand, yields from pump irrigation can be two to three times those from canal irrigation. More than half the irrigated area in India is now supplied by groundwater. And since irrigation supplies about half the food produced in India, a third or more of that production depends on these humble devices and the aquifers that feed them.

Much the same is true in other arid countries. Yet almost everywhere in the world, groundwater tables are falling at alarming rates in areas that depend on irrigation from groundwater. In many of the most pump-intensive areas of India and Pakistan, water tables are falling by 2–3 metres a year. This is not surprising: the evaporation losses of a typical crop are around 0.5 metre of water table depth, and the yield of water in an aquifer is about 0.1 metre per metre of depth. Without recharge, groundwater tables would fall by about 5 metres a crop. Most of these areas receive enough rainfall to recharge the aquifers, but most of the rainfall goes to runoff—not to recharge. We desperately need to change that relationship.

It is no exaggeration to say that the food security of China, India, Pakistan, and many other countries in 2025 will largely depend on how they manage groundwater. Reducing pump irrigation is no answer, for that simply reduces the most productive agriculture. The answer has to be in groundwater recharge, not an easy solution. Indeed, no one has devised a cost-effective way to do it on the scale required. About the only plausible idea is to encourage, through subsidies if necessary, flooded paddy (rice) cultivation in lands above the most threatened aquifers in the wet season. Paddy irrigation, with high percolation losses, is inefficient from a traditional point of view. But from the point of view of groundwater recharge, it makes sense. As it turns out, India has been doing precisely this on 180,000 hectares for the past 10 years.

Source: IWMI 2000.

Harvesting rainwater

Rainwater harvesting, generally a socially attractive alternative to large construction, provides opportunities for decentralised, community-based management of water resources. But rainwater harvested upstream reduces the runoff otherwise available to others, or the environment, downstream (unless it would have run to a sink). Nor is harvesting rainwater any more free of environmental costs than taking water from streams for irrigation (box 3.5).

New reservoirs may produce cheap water, but they are expensive in environmental terms. Groundwater provides excellent on-demand storage, but if left unregulated it can easily be overconsumed, affecting other users. Thus, for every alternative, a complete balance of benefits and disadvantages needs to be drawn up. In most cases the best solution will be a combination of surface and groundwater use, with a range of storage options.

Rainwater harvesting provides opportunities for decentralised, community-based management of water resources

Box 3.5 Rainwater harvesting

Rainwater harvesting has considerable potential for meeting drinking water and irrigation needs in the poor regions of the developing world and for recharging depleted groundwater aquifers. The total rainfall endowment of an area of one hectare in an arid environment with just 100 millimetres annual rainfall is as much as 1 million litres per year.

People on the Indian subcontinent have an ancient tradition of rainwater harvesting. They depend on the monsoon, which brings large quantities of rain in highly concentrated events. Over the years, with community participation in water management taking a backseat, this tradition went into decline. But it is showing signs of revival in areas suffering from acute deforestation and poor land management. These environmental changes have upset the hydrological cycle so much that these areas have become intensely drought-prone.

- In the 1970s two highly ecologically degraded and economically destitute villages—Ralegan Siddhi in Maharashtra (where annual rainfall ranges from 450 to 650 millimetres) and Sukhomajri in Haryana (with annual rainfall around 1,100 millimetres)—took to rainwater harvesting, the first for groundwater recharge, the second for surface storage. With more water available, these villages slowly improved and stabilised their agricultural and animal husbandry outputs and are today food exporters rather than food importers.

- In the mid-1980s Tarun Bharat Sangh, a nongovernmental organisation working in the Alwar district of Rajasthan, encouraged the drought-prone village of Gopalpura to revive its water harvesting tradition of capturing surface runoff. By 1998 the success of Gopalpura had encouraged 650 other villages in the drought-prone district to undertake similar efforts, leading to higher groundwater levels, increased and more stable agricultural incomes, and reduced distress migration.

- With 70 villages building 238 water harvesting structures in one watershed, the 45-kilometre Arvari River—which previously flowed for just a few months during the monsoon season—now flows year round. And the increased groundwater recharge is making life easier for innumerable women living along the river. Village communities along the Arvari River have even formed a River Parliament to regulate use of the river and the groundwater resources of the watershed.

- Impressed by the outstanding achievement of Ralegan Siddhi, Digvijay Singh, chief minister of the state of Madhya Pradesh, replicated the effort in 7,827 villages. Between 1995 and 1998 the project covered nearly 3.4 million hectares of land through a highly participatory watershed developmen and rainwater harvesting programme. Village watershed committees were created to undertake the programme and turn water management into a people's movement.

- Rainwater harvesting is not just for poor villages. It is being promoted in the Sumida ward of Tokyo to reduce urban floods and in the Indian city of Chennai (formerly Madras) to recharge groundwater aquifers that became saline because of overextraction and seawater. And the latest terminal of Frankfurt Airport—built in 1993—captures 16,000 cubic metres of rainfall from its vast roof for such low-grade water needs as cleaning, gardening, and flushing toilets.

Source: Agarwal 1999.

Reforming water resource management institutions

The biggest challenge in water resource management remains institutional. Political will must change decisionmaking to include all stakeholders, especially women, so that stakeholders have the power to manage their own resources. Public and private management of water can only be improved through greater accountability, transparency, and rule of law.

Pricing water services

As described elsewhere in this report, making water available at low cost, or for free, does not provide the right incentive to users. Water services need to be priced at full cost for all users, which means all costs related to operation and maintenance and investment costs for at least domestic and industrial users. The basic water requirement needs to be affordable to all, but this can be done more effectively than by making all water available to all users at way below cost. Pricing water will provide an incentive for the private sector, large and small, domestic and international, to get involved. It has the potential to provide the dynamics—the funds for research and development, for instance—that the sector lacks.

Making managers responsive to users

Service-oriented management focuses on making managers responsive to user needs. This requires the development of a mutual dependency—such as service for payment—that can take various forms, including service agreements. These provide a detailed description of services to be provided, payments in return for services, verification of service provision, consequences of failing to comply with agreements for both parties, and rules for arbitration of conflict.

The service needs and expectations of users will be influenced by the price they have to pay for those services, especially if they have to pay the full cost. Recognising that services can be provided in different ways using different levels of technology at different levels of cost, service-oriented management thus requires a mechanism to ensure that the services needed by users are provided at the lowest possible cost. Consultation processes, clear service relationships, transparent administration, and accountability mechanisms are among other conditions that have to be put in place for effective service-oriented management.

- **Empowering communities**
- **Restructuring irrigation system management**
- **Valuing ecosystem functions**
- **Increasing cooperation in international basins**

Empowering communities, women, and men

The essence of Vision 21—the sector Vision on water for people—is to put people's initiative and capacity for self-reliance at the centre of planning and action. Water and sanitation are basic human needs—and hygiene is a prerequisite. Recognising these points can lead to systems that encourage genuine participation by empowered men and women, improving living conditions for all, particularly women and children.

Vision 21, in its approach to people-centred development, takes the household as the prime catalyst for change, the first level in planning and management of environmental services. Change in the household or neighbourhood leads to ripples of cooperation and action involving communities and local authorities—and then to actions by district, state, national, and global authorities.

A new alliance of local people, nongovernmental organisations (NGOs), and water agencies can contribute much to achieving the World Water Vision. Community-level action programs could include:

- Watershed action programs in which local people work with NGOs and research organisations to promote conservation and local empowerment.
- Local councils that tackle local problems in water rehabilitation and pollution.
- Basin-level organisations for integrated water management.
- Construction of groundwater recharge wells to improve village water supplies and aquifer management.
- Disaster preparedness linked with community action.
- Drought relief efforts that mobilise work and food supplies.
- Community action in controlling waterborne disease.
- Local action for monitoring water quality, crop selection, and quality control of produce irrigated with effluent water.

Restructuring irrigation system management

Restructuring irrigation systems to provide more benefits to the poor involves a mix of technical and institutional reforms. Bringing the poor into the dialogue on system priorities can yield new ideas that benefit all stakeholders. New approaches that show potential include:

- *Improving design and operations.* Participatory consultations can reveal inequities in water distribution and possible steps to improve performance. Such consultations can be especially useful during water-scarce periods, when poor and female irrigators may have a particularly hard time obtaining water. For example, flexible cultivation rights can reallocate irrigated land during seasonal water scarcity.
- *Extending new water availability to the poor.* When rehabilitation improves the water supply, new water rights can be given to the poor or those without irrigation. Nepal and Peru offer examples.
- *Linking irrigation management transfer to service improvements.* Irrigation management transfer programmes offer new opportunities for representation for small farmers and women. This participation can result in new water rotations that increase equity between the head and tail ends of an irrigation system and that recognise domestic water needs as a legitimate objective of an irrigation system.
- *Reforming land and water rights.* Some countries have undertaken large-scale redistribution of land and water rights, breaking up large holdings for small farmers and labourers. But the economic and political rationales for such reform are a thing of the past. What is needed is a policy that helps the poor, particularly indigenous groups and ethnic minorities, defend their rights in the context of the water rights consolidation and sectoral transfers emerging from today's economic policies. Where water rights are (re-)distributed, they should be awarded to all users, women and men, landowners and landless farmers.

Valuing ecosystem functions

Water is essential to life, development, and the environment—and the three must be managed together, not sequentially. Because communities rarely understand this interrelationship, awareness raising is the first step. After that, research on the local watershed, public education, and community-led watershed and river basin management can

Many practices adopted to improve the management of water for human needs will also benefit ecosystems

Box 3.6 Estimating the benefits of floodplain use in northern Nigeria

Recent estimates indicate that traditional practices provide greater benefits than irrigation crops on the Hadejia-Jama'are floodplain in northern Nigeria. Firewood, recession agriculture, fishing, and pastoralism generate $32 per thousand cubic metres, compared with $0.15 for irrigation. This evaluation is important because more than half the region's wetlands have already been lost to drought and upstream dams. Thus a proposed increase in water diversion for large-scale irrigated agriculture is inadvisable.

Even without accounting for such services as wildlife habitat, the wetland is more valuable in its current state than after conversion to large-scale irrigated agriculture. The lesson? When cost-benefit analysis includes the value of the goods and services provided by an ecosystem, large-scale development schemes are less profitable than improving the management of the unaltered ecosystem.

Source: Barbier and Thompson 1998.

make sustainability possible. As part of the water planning process, each water community should consider how much water to allocate to the natural environment. National legislation should require this, as it does in Australia and South Africa. Decision support models are available, and experience with them should be observed carefully, with a view to applying lessons from elsewhere—taking into account indigenous knowledge and local water management approaches.

Much more research is needed to improve our understanding of ecosystem functioning and to value the services that these systems provide. Recent global assessments of the services provided by freshwater ecosystems (watersheds, aquifers, and wetlands) for flood control, irrigation, industry, recreation, waterway transportation, and the like come up with estimates amounting to several trillion dollars annually (Costanza 1997; Postel and Carpenter 1997). Such knowledge will allow careful assessments of the impacts of water resource use and development on ecosystems, particularly tropical ecosystems (box 3.6). Integration needs to emphasize the river basin as the appropriate scale of management, from the forests in the upper watersheds to the coastal zones affected by the inflows of rivers into wetlands, lagoons, and mangrove ecosystems. The interactions between water resources and coastal zone management are many, but are often ignored or misunderstood (Rijsberman and Westmacott 1997). In the meantime, actions for better-integrated management include:

- Leaving the amount of water in ecosystems required to maintain proper functioning.
- Protecting wetlands and floodplains to enable the benefits from seasonal flooding and provide storage for extreme flood flows.
- Protecting and planting forests in upper catchments, especially in mountainous areas.
- Requiring full effluent treatment by industries and municipalities and applying the "polluter pays" principle.
- Protecting water resources from agricultural runoff.
- Creating groundwater protection zones.
- Rehabilitating degraded areas to recover lost ecosystem functions (through reforestation, wetland restoration, fish population restoration, and so on).

Many practices adopted to manage water for human needs—rules on extracting and sharing water, changes in cultivation and irrigation to save water for other purposes, returns to ancient and community-based water harvesting and storage—will also benefit ecosystems. Other measures include reducing nutrients through farm-based manure storage, controlling silt by reducing erosion upstream, planning for joint hydropower generation and dry season irrigation, and reducing pollutants from agriculture and industry. Above all, ecosystems will be protected by integrated land and water resource management basin by basin—along with full cost pricing for water services and management reforms for water delivery and wastewater disposal.

Increasing cooperation in international basins

Close to half the world is situated in close to 300 international river basins—rivers that cross national boundaries and whose resources are therefore shared. There are countless examples in history of peoples and countries that have made agreements on how to share such international water resources. There are also ample cases, particularly in times of droughts or rising scarcity, of conflicts over water. In fact, people have been forecasting an increase in wars over water as the ultimate result of such conflicts.

Experience shows, however, that shared water resources *can* be made into a source of cooperation rather than conflict.

- **Stages of successful cooperation**
- **Supporting innovation**

Certainly for a World Water Vision to be realised, the need for cooperation in international basins is paramount. This is not easy, as shown by the 30 years of negotiation needed to reach agreement on the United Nations Convention on the Law of the Non-navigational Uses of International Watercourses. Sadly enough, even after all that time it now seems unlikely that this convention will be ratified by enough countries to enter into force.

It appears that the best we can do is to emphasise how countries get to a better understanding and eventually to deeper cooperation over international waters. There is a series of stages through which most successful cooperation appears to evolve:

- *Confidence building.* Countries that share international rivers usually start with low-level technical cooperation that focuses on exchange of data, or jointly gathered data. International river commissions, with regular meetings of national representatives and a small technical secretariat, often serve this purpose.

- *Cooperation.* As mutual trust and confidence increase, and as issues appear that concern all parties and can be more effectively addressed through collective action, the level of cooperation gradually grows to a point where countries are willing to undertake joint action or allocate more significant resources.

- *International agreements.* After years of successful cooperation, lengthy negotiations are usually required to reach bilateral or regional agreements. Such agreements seldom address the (theoretically desired) comprehensive integrated management of water resources, but focus on specific issues of hydropower, navigation, or environment. Where the interests of upstream and downstream countries diverge sharply over specific issues, it is not unusual that agreement is reached in a wider framework involving cross-border trade or involving other issues that allow agreements in every party's interest.

- *International law and alternative dispute resolution.* Once international agreements have been established, conflicts can be addressed through formal (judiciary, international law) or alternative dispute resolution mechanisms (mediation, arbitration).

Supporting innovation

Because we have a finite amount of water resources and a growing number of people and growing demand, the sustainable use of water ultimately depends on our ability to increase its productivity at least as fast as demand grows. Increasing productivity will depend largely on innovation throughout the sector, through both fundamental research and the widespread dissemination and adoption of its results.

A key part of the necessary innovation will be increased awareness of water issues throughout the population and education and training of people capable of bringing about the necessary changes—that is, capacity building in the water sector. A crucial factor to mobilise resources for capacity building and research will be to give water its proper value. This requires pricing it. Once water is appropriately valued, users and producers will have incentives to conserve it and to invest in innovation. While pricing water is expected to be the primary motivation to bring in the private sector, a host of public goods aspects of water resources will continue to require public funding. These range from researching staple food crops in developing countries to finding cures for tropical diseases—important to populations that do not make up sufficient markets for privately funded research to be attractive.

Notes

1. The background for the work outlined here, the scenarios and modeling done in support of the World Water Vision exercise, is published in a companion volume, *World Water Scenarios: Analysis* (Rijsberman 2000).

2. For fuller treatment of these issues, see the scenarios and models referred to in note 1 and the three main sector Visions, on which much of the following discussion is based: "A Vision of Water for Food and Rural Development" (Hofwegen and Svendsen 1999), "Vision 21: A Shared Vision for Water Supply, Sanitation and Hygiene and a Framework for Future Action" (WSCC 1999), and *Vision for Water and Nature: Freshwater and Related Ecosystems—The Source of Life and the Responsibility of All* (IUCN 1999).

3. Productivity is a better indicator than efficiency. Increasing efficiency at the field or farm level may not have any benefits. And efficiency at the basin level should not necessarily be maximised, because it reduces the amount left

Increasing productivity will depend largely on innovation through both fundamental research and the widespread dissemination and adoption of its results

over for downstream uses and the environment. Water productivity can be increased by obtaining more production with the same amount of water or by reallocating water from lower- to higher-value crops or from one use to another where the marginal value of water is higher. Indeed, the greatest increases in water productivity in irrigation have not been from better irrigation technology or management, but from increased crop yields due to better seeds and fertilisers (IWMI 2000).

4. Three models were used extensively for the Vision simulations: WaterGAP, developed at the University of Kassel, Germany (Alcamo and others 1999); IMPACT, developed by the International Food Policy Research Institute, Washington, D.C. (Rosegrant and Ringler 1999); and PODIUM, developed by the International Water Management Institute, Colombo, Sri Lanka (IWMI 2000). In addition, the Polestar scenario tool of the Stockholm Environment Institute was used to disaggregate global scenario assumptions to 18 regions.

5. Data for 1995 renewable water resources and use at the country level are from Shiklomanov (1999).

6. The United Nations Medium Scenario, 1998 Revision, is the base for the business as usual scenario (UN 1999). In 2025 more than 80% of the world population—6.6 billion people—will live in developing countries. In addition, the world population will be older and more urban. About 84% of the people in developed countries and 56% in developing countries will live in urban areas, many in megacities (defined as cities with more than 10 million people). The technology, economics, and private sector scenario uses the United Nations Medium Scenario minus 2%. The values and lifestyles scenario uses the United Nations Low scenario.

7. Feedback irrigation systems provide more or less water to fields in response to signals received from farmers concerning their demands, while standard irrigation systems are scheduled to provide water to fields at predetermined times and amounts.

Annex

Annex table 3.1 Drivers for the three World Water Vision scenarios for 1995–2025

Driver	Business as usual	Technology, economics, and private sector (relative to business as usual)	Values and lifestyles (relative to business as usual)
Demographic			
Population	7.8 billion (6.6 billion in developing countries)	About the same	7.3 billion (6.2 billion in developing countries)
Population growth	1.2% (1.4% in developing countries)	Same or slightly lower (because of higher mortality)	1.05% (1.1% in developing countries)
Urbanisation	61% urbanised (56% in developing countries)	About the same	About the same
Pressures for migration from developing to developed countries	High	Higher (and stronger barriers)	Low
Technological			
Information technology	Widely available and used to increase water management efficiency	Same	Widely available and used to increase water management efficiency and effectiveness
Biotechnology	Widely available and used for new crop varieties	Widely available and used for new crop varieties with high water use efficiency	Widely available and used for new sustainable crop systems and water purification
Water use efficiency	Higher, particularly in arid areas	Dramatically higher	Higher than in business as usual but lower than in technology economics, and private sector
Water pollution	Lower pollution per unit	Lower, mostly in developed and emerging economies	Lower still
New drought-, pest-, and salt-resistant crops	Moderate and controversial	Massive development and dissemination of new varieties, largely solving the agricultural water problem	Same, but combined with ecotechnology and integrated in new agricultural systems
Sanitation	Investment in developing countries grows slower than population	Same	Investment in developing countries grows faster than overall economy; ecotechnology used
Desalinisation	Widely available	Even cheaper	Same
Economic			
Volume of production	$80 trillion ($40 trillion in developing countries)	30% higher, but mostly in developed and emerging economies	$90 trillion ($60 trillion in developing countries)
Structure of production	Gradual dematerialisation; agriculture grows in absolute terms	Little dematerialisation in developing countries; agriculture grows in absolute and relative terms in developing countries	Rapid increase of the nonmaterial economy
Water infrastructure (availability and condition)	Growing at same rate as the economy	Privatised and growing faster than the economy	Growing faster than the economy
Trade	Universal	Some countries or regions excluded from global markets	Universal and strategically regulated
Social			
Lifestyles and cultural preferences	Converge to today's levels in developed countries	Same preferences, but real lifestyles diverge in developed and developing countries	Convergence in developing and developed countries to less material-intensive lifestyles than in today's developed countries
Poverty	Absolute poverty remains constant; relative poverty decreases	Absolute poverty decreases, inequality increases	Absolute poverty eradicated
Economic inequality	High and increasing	Very high and increasing	Gradually reduced
Environmental			
Committed future climate change	Increased variability, agroecologic shifting	Slightly less	Less because of strong emission controls
Water-related disease	Gradually increasing	Gradually decreasing	Only in small pockets
Salinisation	Gradually increasing	Dramatically decreasing	Stopped
Exhaustion and pollution of surface and groundwater	Gradually increasing	Stopped; water withdrawals reduced to sustainable levels	Stopped; water withdrawals reduced to sustainable levels
Integrity and health of aquatic ecosystems	Gradually decreasing	Recovering somewhat	Recovering rapidly
Governance			
Institutions	Insufficient to resolve conflict; severely stressed	Lack of global leadership	Strong and adequate institutions created; shared goals; wide participation
Market dominance	Universal	Same	Universal but regulated
Power structure (international, national)	Asymmetrical but slowly becoming more pluralistic	Increasingly asymmetrical	Much more pluralistic
Conflicts	Ubiquitous and increasing	Same	Practically absent
Globalisation	Accelerating	Accelerating but unequal	Same

Source: Rijsberman 2000.

Annex table 3.2 Assumptions for the three World Water Vision scenarios

Variable	Country group/region	Business as usual	Technology, economics, and private sector	Values and lifestyles
Population, 2025	OECD	UN Medium Scenario	UN Medium Scenario	UN Low Scenario
	Medium income	UN Medium Scenario	UN Medium Scenario less 2%	UN Low Scenario
	Least developed	UN Medium Scenario	UN Medium Scenario less 2%	UN Low Scenario
Consumptive water use factor, 2025[a]	All	Can be above 70%	Less than 70%	Less than 70%
Degree of water resource development, 2025[b]	All	Not limited	Not limited	Less than 60%
		Annual total	***Annual total***	***Annual total***
GDP growth, 1995–2000	Western Europe	2.10%	3.32%	1.53%
	Eastern Europe	1.89%	1.42%	4.37%
	CIS	2.15%	2.13%	5.13%
	Aral Sea	2.17%	2.34%	4.50%
	North America	2.10%	3.32%	0.98%
	Central America	1.77%	1.12%	5.18%
	South America	1.95%	1.80%	4.07%
	North Africa	2.06%	4.07%	6.73%
	Southern Africa	1.69%	3.54%	5.20%
	East Africa	1.83%	3.77%	5.92%
	West Africa	1.96%	3.92%	6.11%
	Central Africa	1.92%	3.74%	5.18%
	Middle East	1.40%	1.31%	3.89%
	China	4.20%	4.02%	7.69%
	South Asia	3.49%	3.81%	6.65%
	Southeast Asia	2.98%	3.35%	6.01%
	Japan	0.96%	2.17%	0.12%
	Australia	2.05%	3.27%	1.21%
Growth in irrigated area, 1995–2025	Global	1.5% (0.22% in Brazil, India, and Turkey)	25% IWMI base adjusted	5% IWMI base adjusted
Growth in cereal area, 1995–2025	Global	0.36%	0.31%	0.16%
Growth in irrigated grain yield, 1995–2025	OECD	0.88%	1.50%	1.50%
	Medium income	1.00%	1.80%	2.30%
	Least developed	0.79%	1.00%	2.30%
Growth in rainfed grain yield, 1995–2025	OECD	0.30%	0.60%	0.40%
	Medium income	0.30%	0.45%	0.80%
	Least developed	0.30%	0.30%	1.00%
Growth in irrigation efficiency	OECD	10%	20%	30%
	Medium income	10%	20%	30%
	Least developed	10%	10%	30%

a. Ratio of evaporated water to primary water supply.
b. Ratio of primary water supply to usable water resources.
Source: Rijsberman 2000.