OECD Environmental Outlook to 2050

Chapter 5

Water

by

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Around the world, cities, farmers, industries, energy suppliers, and ecosystems are increasingly competing for their daily water needs. Without proper water management, the costs of this situation can be high – not just financially, but also in terms of lost opportunities, compromised health and environmental damage. Without major policy changes and considerable improvements in water management, by 2050 the situation is likely to deteriorate, increasing uncertainty about water availability. This chapter summarises the key pressures on water, as well as the main policy responses. It starts by looking at current water challenges and trends and how they could affect the water outlook in 2050. It considers competing demands for water (from agriculture/irrigation, industry, electricity, domestic/urban supply, environment flows) and over-exploitation (both surface and groundwater), water stress, water-related disasters (e.g. floods), water pollution (in particular nutrient effluents – nitrogen and phosphorus – from agriculture and wastewater) and discharge into the seas, and lack of access to water supply and sanitation (as defined by the Millennium Development Goals or MDGs). It reviews the existing policy tools to manage water (such as water rights, water pricing), and explores how the water outlook could be improved by more ambitious policies. The chapter discusses emerging issues in water policy; it pays particular attention to water as a driver of green growth, the water-energy-food nexus, allocating water for healthy ecosystems, and alternative sources of water (reuse). For all these, governance, the use of economic instruments, investment and infrastructure development are important dimensions. They all contribute to and facilitate water policy reforms in OECD countries and globally.

KEY MESSAGES

Access to clean water is fundamental to human well-being. Managing water to meet that need is a major – and growing – challenge in many parts of the world. Many people are suffering from inadequate quantity and quality of water, as well as stress from floods and droughts. This has implications for health, the environment and economic development. **Without major policy changes and considerable improvements in water management processes and techniques, by 2050 the situation is likely to deteriorate, and will be compounded by increasing competition for water and increasing uncertainty about water availability.**

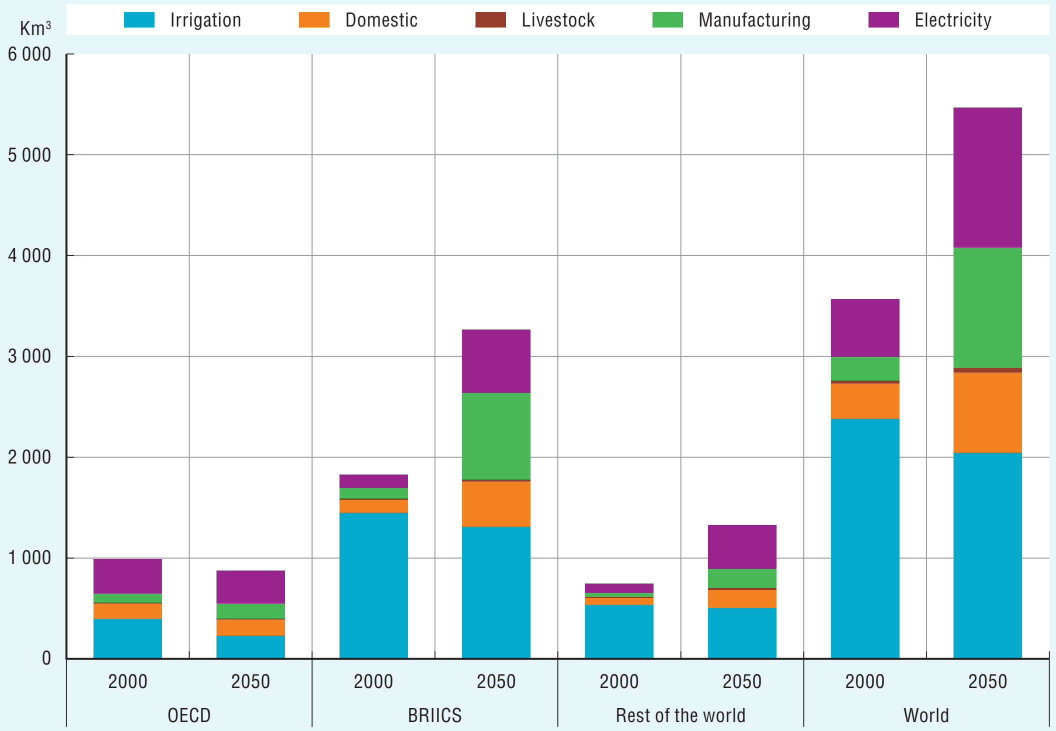
Trends and projections

Water quantity

The *Outlook Baseline* scenario projects that by 2050, 3.9 billion people, over 40% of the world's population, are likely to be living in river basins under **severe water stress**.

Water demand is projected to increase by 55% globally between 2000 and 2050. The increase in demand will come mainly from manufacturing (+400%), electricity (+140%) and domestic use (+130%). In the face of these competing demands, there will be little scope for increasing water for irrigation.

Global water demand: *Baseline* scenario, 2000 and 2050



Notes: This graph only measures "blue water" demand (see Box 5.1) and does not consider rainfed agriculture. The country groupings BRIICS and RoW are explained in Table 1.3 in Chapter 1.

Source: *Environmental Outlook Baseline*; output from IMAGE.

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In many regions of the world, **groundwater** is being exploited faster than it can be replenished and is also becoming increasingly polluted. The rate of groundwater depletion more than doubled between 1960 and 2000, reaching over 280 km^3 per year.

Water quality

Continued efficiency improvements in agriculture and investments in wastewater treatment in developed countries are expected to stabilise and restore **surface water and groundwater quality in most OECD** countries by 2050.

The **quality of surface water outside the OECD** is expected to deteriorate in the coming decades, through nutrient flows from agriculture and poor wastewater treatment. The consequences will be increased eutrophication, biodiversity loss and disease. For example, the number of lakes at risk of harmful algal blooms will increase by 20% in the first half of this century.

Micro-pollutants (medicines, cosmetics, cleaning agents, and biocide residues) are an emerging concern in many countries.

Water supply and sanitation

The number of people with **access to an improved water source** increased by 1.8 billion between 1990 and 2008, mostly in the BRIICS group (Brazil, Russia, India, Indonesia, China and South Africa), and especially in China.

More than 240 million people (most of them in rural areas) are expected to be without **access to an improved water source** by 2050. The Millennium Development Goal for improved water supply is unlikely to be met in Sub-Saharan Africa. Globally, more city dwellers did not have access to an improved water source in 2008 than in 1990, as urbanisation is currently outpacing connections to water infrastructure. The situation is even more daunting given that access to an *improved* water source does not always mean access to *safe* water.

Almost 1.4 billion people are projected to still be without **access to basic sanitation** in 2050, mostly in developing countries. The Millennium Development Goal on sanitation will not be met.

Water-related disasters

Today, 100-200 million people per year are **victims of floods, droughts and other water-related disasters** (affected or killed); almost two-thirds are attributed to floods. The number of people **at risk from floods** is projected to rise from 1.2 billion today to around 1.6 billion in 2050 (nearly 20% of the world's population). The economic value of assets at risk is expected to be around USD 45 trillion by 2050, a growth of over 340% from 2010.

Policy options and needs

Create incentives for water efficiency

- **Improve water pricing** to signal scarcity and to create incentives for efficient water use in all sectors (*e.g.* agriculture, industry, domestic); address social consequences through well-designed tariff structures or targeted measures. Combine multiple policy instruments to curb water demand and make alternative water sources (such as reusing treated wastewater) competitive.
- **Implement flexible water allocation mechanisms** (*e.g.* by combining water rights reform and pricing policies).

Improve water quality

- **Better co-ordinate the expansion of wastewater collection (sewerage systems) with wastewater treatment** to avoid wastewater being discharged untreated. Innovative techniques and business models will be needed; the private sector is an important player.
- Improve and increase the use of appropriate wastewater treatment equipment and techniques, and the efficient management of nutrients and agricultural run-off. Encourage further R&D to **speed up and disseminate innovation** in developed and developing countries. Build capacity in target economies (essentially farmers), through training and education.

Invest in green infrastructure

- **Invest in innovative water storage capacities** which do not conflict with other environmental policy objectives (*e.g.* preservation of ecosystem services, forests or biodiversity).
- **Reduce the impact and occurrence of water–related disasters** by restoring the ecosystem functions of floodplains and wetlands, paying attention to hydromorphology and removing incentives which encourage people to settle or invest in risk-prone areas.
- **Accelerate the deployment of water supply and sanitation infrastructure** in developing countries. Explore innovative options which consume less water, energy or capital. This can be funded partially by OECD member states, *e.g.* by increasing the portion of official aid to these areas, and the private sector can also play an essential role.

Ensure policy coherence

- **Improve water governance** to ensure coherence with other policy areas such as energy, agriculture and urban planning. Engage all relevant stakeholders (different levels of government, water user groups, private companies). Ensure appropriate governance to prevent tensions over transboundary waters.
- **Assess and reform subsidies that encourage unsustainable water use**, and ensure coherence between water policy objectives and initiatives in other sectors (including energy and agriculture).

Fill in information gaps

- **Invest in better water-related information** (*e.g.* on consumption, irrigation, and the impact of climate change on water resources).

1. Introduction

Around the world, individuals, farmers, industries, and ecosystems are increasingly competing for their daily water needs. Without proper management, the costs of this situation can be high – not just financially, but also in terms of lost opportunities, compromised health and environmental damage.

This chapter summarises the key pressures on water, as well as the main policy responses. The chapter starts by looking at current water challenges and trends – how competing demands and over-exploitation, water-related disasters, poor water quality and lack of access to water supply and sanitation services could affect the water outlook in 2050. It then reviews the existing policy toolbox, and presents a few more ambitious policy scenarios[1] building on OECD data (where available) and models to explore how the water outlook could be improved. This leads to a discussion of the actions that need to be taken now by national governments, the international community and the private sector.

Key drivers of water health

What processes are affecting the quantity and quality of our water systems? This section briefly outlines the main drivers, followed by summarising the key policy responses (developed more fully in Section 4). The state of water systems is affected by both human activities and environmental change. Today the key human drivers include population, income growth and economic activities (see Chapter 2, on socio-economic developments). To date, economic growth and population dynamics have affected water more than climate. However, after 2050, climate change is expected to become a major driver (see Box 5.3 for an illustration, and Annex 5.A).[2]

Population growth and lifestyle changes drive household water demand and the release of pollutants into water bodies. Projections discussed in Chapter 2 anticipate that global population will continue to grow until 2050, albeit at a slower pace, mainly in developing countries and particularly in West Africa.

Growth in gross domestic product (GDP) drives agricultural and industrial water demand and water pollution discharges, as well as water demand for electricity generation. Agriculture deserves particular attention: production will need to increase significantly by 2050 to meet the growing demand for food. Agriculture has an impact on both water availability (by altering run-off and competing with other uses for surface and groundwater) and quality (through the release of nutrients and micro-pollutants into surface water and groundwater). Different types of energy sources also affect the quality and quantity of water available for other uses. Increasing energy demand and shifting energy mixes have to be factored into water management.

Urbanisation drives water supply and sanitation needs. On the one hand, urbanisation lowers the per-capita costs of connection to water infrastructure. On the other hand, as city dwellers become more numerous, they require more investment to connect to water and wastewater infrastructure. The situation is particularly complex in slums. Urbanisation also drives the need for flood control infrastructure: sealed surfaces alter run-offs from rain and storm water, impair the recharge of underground aquifers and increase flood risks.

Policy responses: A summary

Governments and the private sector must co-ordinate and act urgently to address the water-related challenges we are already facing. Additional action will be needed to address future water stress and the emerging challenges described in the next sections.

The *Environmental Outlook* models show that incremental improvements in water use efficiency will not be enough (see Section 3 Policy: current and future scenarios). Even radical changes in the efficiency of current uses may not be enough to avoid a more fundamental appraisal of the allocation of water. Rapidly growing water demands for electricity production, industry and urban supply are likely to come into increasingly acute competition with agriculture for available water in the coming decades. As described below, OECD governments are gaining experience with innovative approaches to water allocation (such as tradable water rights, smart metering), water reuse, or sustainable water pricing (which includes abstraction charges or licences that reflect scarcity). More needs to be done to properly assess and scale up the use of some of these instruments, to secure environmental values while meeting social and economic needs.

Some of the required policy responses will make claims on public spending. But in the current context of fiscal consolidation, the extent of such claims need to be backed by robust valuation of benefits, the exploration of alternative financing schemes, and a search for low-cost options.

Innovation has a major role to play in promoting sustainable water resource management. This includes (but is not limited to) technologies. Examples include efficient irrigation systems and ecological farming techniques to reduce fertiliser run-off, crop research, water treatment technologies such as membranes and filtration techniques, and advanced wastewater treatment. Technologies need to be supported by innovative business models and corresponding regulatory regimes to improve water management, and to integrate water priorities into other policy areas such as energy, food, and spatial planning. Developing an inventory and improving the valuation of hydrological ecosystems services can pave the way to greater use of innovative, ecologically-based and low-cost approaches to address some of the challenges identified here. Water purification, flow regulation, erosion and sedimentation control, and restoration of hydromorphology all have a role to play, together with new techniques being developed to improve the collection, processing and presentation of data that support both policy-making and water operations.

In the search for innovative technologies and business models, the private sector has a pivotal role to play. This includes the water industry, the financial sector (which may realise water-related investment opportunities) and water users in the fields of energy production, industry, farming and their suppliers (which will develop and diffuse water efficient practices).

Water governance is also key, as water policies intersect with a wide array of sectors at different geographical scales, from local to transboundary levels. Analysis of water governance arrangements in OECD countries has highlighted that a lack of finance for water resource management is a primary concern for most countries, followed by the fragmentation of roles and responsibilities at central and sub-national levels, and the lack of capacity (infrastructure and knowledge) at the territorial level (OECD, 2011g). In the case of transboundary rivers, lakes or aquifers, governance is essential to prevent diplomatic and social tensions. Generic instruments, such as the UNECE Convention on the Protection and Use of Transboundary Watercourses and International Lakes (Water Convention) and specific ones (such as the International Fund for Saving the Aral Sea, IFAS) have a role to play.

2. Key trends and projections

This section reviews trends and long-term projections for water demand, exploitation and availability (including groundwater and water stress), water-related disasters, water quality and access to water supply and sanitation services. It also provides definitions of the terms used (Box 5.1). More detail on the assumptions made and analysis underpinning this section can be found in Chapter 1 (Introduction) and in Annex 5.A at the end of this chapter.

Box 5.1. **Key definitions**

The chapter refers to several concepts which need to be carefully defined.

Water demand: the demand for water by different water users. Water demand can be met from freshwater withdrawn from the environment (a river, lake or aquifer) or from other sources of water (*e.g.* recycled water).

Water abstraction (or withdrawal) is water physically withdrawn from the environment. Part of that water may return to the environment. Typically, a number of industries abstract water for cooling purposes – then return the water to the environment in a suitable condition for use by other purposes. However, a significant part of the water abstracted from the environment is lost. For instance, in some cities, up to 40% of the water treated for domestic uses leaks from pipes.

Water consumption: water use that reduces either the quantity or quality of water that is returned to the environment. Consumed water is not necessarily abstracted from the environment (it can be generated from other sources, *e.g.* recycled water). A variety of water uses do not consume water (*e.g.* shipping, swimming, the environment). These uses should however be taken into account in water resource management (*e.g.* through environmental flow and quality requirements for environmental purposes). In the case of agriculture, water consumption occurs through evapotranspiration and harvesting of crops. In the case of hydropower, water consumption includes the additional evaporation that results from the increased surface of the water body impounded by the dam. The impacts of domestic and industry uses on water quality depend on treatment before discharge into the environment.

Groundwater depletion: when groundwater is abstracted at a greater rate than natural recharge.

Blue water: freshwater in aquifers, rivers, lakes, that can be withdrawn to serve people, for example as water for irrigation, manufacturing, human consumption, livestock, generation of electricity.

Green water: precipitation that naturally infiltrates into the soil and leaves the drainage basin through evapotranspiration into the atmosphere.

Box 5.1. **Key definitions** *(cont.)*

Water stress: a measure of the total, annual average water demand of "blue water" (see above) in a river basin (or sub-basin) compared with the annual average water available (precipitation minus evapotranspiration) in that basin. The green water flow is thus taken into account in the volume of available water. Often the resulting ratios are grouped into four categories: less than 10% = no stress; 10-20% = low stress; 20-40% = medium stress; and more than 40% = severe stress. Given seasonal and inter-annual variability of demand and supply, and the wish to maintain an environmental flow level, high ratios imply a high risk that water supply will be inadequate.

Sources: Adapted from FAO publications, including FAO (1996), *Land Quality Indicators and Their Use in Sustainable Agriculture and Rural Development*, Rome; see in particular the section on indicators for sustainable water resources development (*www.fao.org/docrep/W4745E/w4745e0d.htm*); FAO (2010), *Disambiguation of Water Use Statistics*, FAO, Rome.

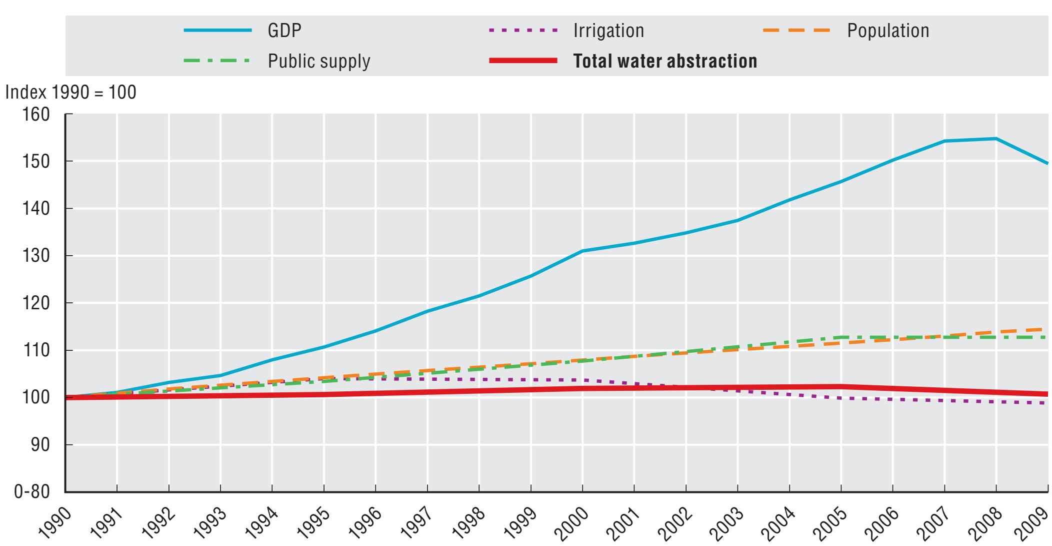
Freshwater demand and exploitation

Recent trends in OECD countries

Globally, it is estimated that water demand rose twice as fast as population growth in the last century. Agriculture was the largest user of water, accounting for about 70% of total global freshwater demand (OECD, 2008c). The largest global water demand after irrigated agriculture in 2000 was for electricity generation, primarily for cooling of thermal (steam cycle-based) power generation.

In the OECD area, total surface water abstraction has not changed since the 1980s (Figure 5.1). This is despite increases in abstractions for public water supply and, to a lesser extent, irrigation. This stability can be explained by more efficient irrigation techniques; the decline of water intensive industries (*e.g.* mining, steel); more efficient use of water for

Figure 5.1. **OECD freshwater abstraction by major use and GDP, 1990-2009**



Note: Data exclude Chile, Estonia, Israel and Slovenia.

Source: OECD Environment Directorate.

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thermoelectric power generation; the increased use of cleaner production technologies; and reduced leaks from piped networks. More recently, this stabilisation also partly reflects droughts, *i.e.* that water was physically not available for abstraction in some regions.

OECD agricultural water use rose by 2% between 1990 and 2003, but has declined since then. Irrigation accounted for 43% of total OECD water use in 2006. Much of the growth in OECD agricultural water use occurred in Australia, Greece, Portugal and Turkey – countries where farming is a major water user (more than 60% of total freshwater abstractions) and/or irrigation plays a key role in the agricultural sector (on more than 20% of cultivated land).

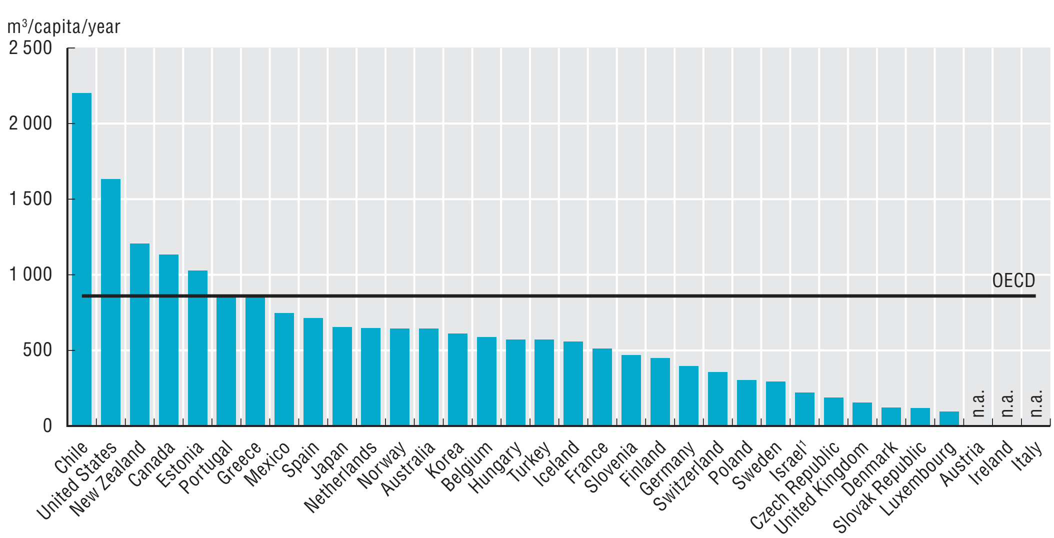
Although at the national level, most OECD-country water use is sustainable overall, most still face at least seasonal or local water shortages and several have extensive arid or semi-arid regions where lack of water constrains sustainable development and agriculture.

Figures 5.2 and 5.3 display the intensity of use of freshwater resources (both surface and groundwater) expressed as gross abstractions per capita and as a percentage of renewable resources. Indicators of water-use intensity show large variations among individual OECD countries. European countries tend to be less water intensive in per-capita terms. Water use is more sustainable in some countries than in others. For example, Canadians withdrew roughly 1.2% of the country's total average water yield in 2005, while Korea abstracted more than 40%, putting its water balance at risk. The situation is also a concern in some OECD European countries such as Belgium and Spain, where abstraction as a share of renewable water resources is higher than 20% (Figure 5.3).

However, the situation is more complex than is implied by aggregate indicators. National indicators may conceal unsustainable use in some regions and periods, and high dependence on water from neighbouring countries (in the case of transboundary basins). In arid regions, freshwater resources may at times be so limited that demand, so far, is only met by exploiting it unsustainably.

Figure 5.2. **Annual freshwater abstraction per capita, OECD countries**

2009 or latest year available

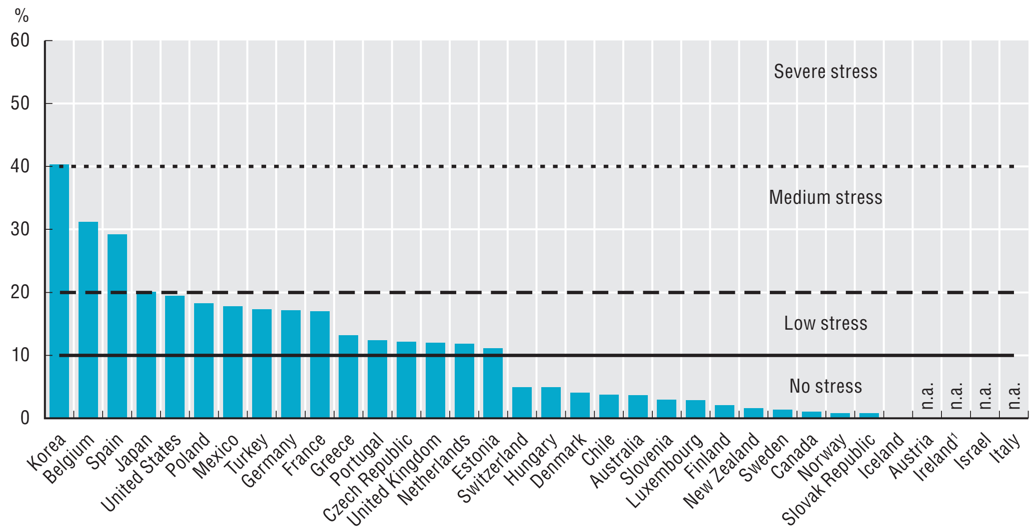


1. The statistical data for Israel are supplied by and under the responsibility of the relevant Israeli authorities. The use of such data by the OECD is without prejudice to the status of the Golan Heights, East Jerusalem and Israeli settlements in the West Bank under the terms of international law.

Source: OECD Environment Directorate. StatLink http://dx.doi.org/10.1787/888932571133

Figure 5.3. **Water stress, OECD countries**

2009 or latest year available; water abstractions as a % of renewable resource



1. The statistical data for Israel are supplied by and under the responsibility of the relevant Israeli authorities. The use of such data by the OECD is without prejudice to the status of the Golan Heights, East Jerusalem and Israeli settlements in the West Bank under the terms of international law.

Source: OECD Environment Directorate.

StatLink http://dx.doi.org/10.1787/888932571152

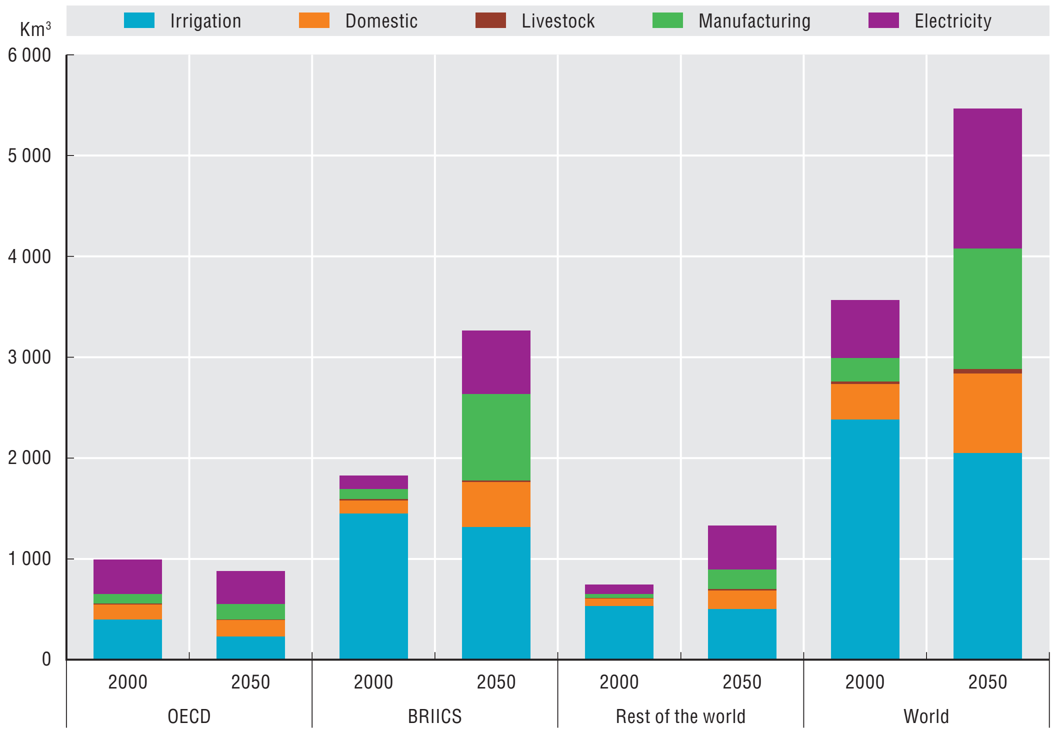
In OECD countries, principal concerns are the inefficient use of water (including waste, for instance through leaks from urban supply systems) and its environmental and socio-economic consequences: low river flows, water shortages, salinisation of freshwater bodies in coastal areas, human health problems, loss of wetlands and biodiversity, desertification and reduced food production.

Global water demand by 2050

The *Environmental Outlook Baseline* scenario projects future global water demand to increase significantly – from about 3 500 km^3 in 2000 to nearly 5 500 m^3 in 2050 (Figure 5.4), or a 55% increase. This increase is primarily due to growing demand from manufacturing (+400%, about 1 000 km^3), electricity (+140%, about 600 km^3) and domestic use (+130%, about 300 km^3). However, demand does not automatically translate into consumption, as a significant share of water is discharged back into water bodies after use, remaining available for use downstream, depending on water quality.

Without new policies, the relative importance of uses which drive water demand is also projected to shift significantly by 2050. Sharp rises in water demand are expected in South Asia and China as well as other emerging economies of the BRIICS (Brazil, Russia, India, Indonesia, China and South Africa), with much higher shares for manufacturing, electricity and domestic supply in 2050. Developing countries (rest of the world or the RoW) are also projected to see significant water demand for electricity generation. In all parts of the world, the growing demand for these uses will compete with demand for irrigation water. As a result, the share of water available for irrigation is expected to decline (Box 5.2). If the model projections were to factor in the additional water needed to ensure enough flows to maintain ecosystem health, the competition among different water users would intensify even further.

Figure 5.4. **Global water demand: *Baseline*, 2000 and 2050**



Notes: This graph only measures "blue water" demand (see Box 5.1) and does not consider rainfed agriculture.
Source: *OECD Environmental Outlook Baseline*; output from IMAGE.

StatLink http://dx.doi.org/10.1787/888932571171

Box 5.2. **Uncertainties about agricultural water demand**

The projections for irrigation water use in this *Environmental Outlook* assume that the area of irrigated land will stay constant to 2050 for several reasons:

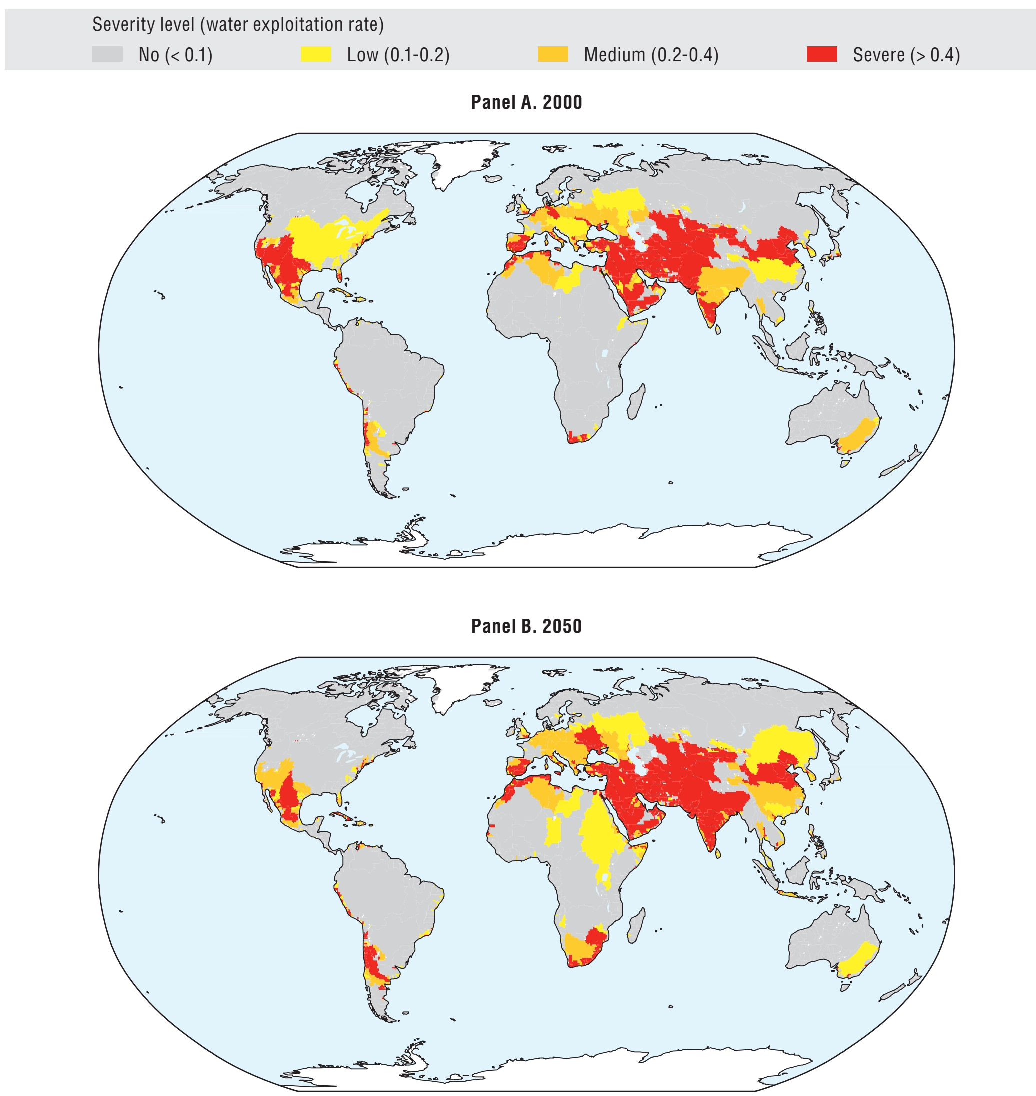
- Most analysts observe that massive extension of irrigation will not be possible in the coming decades because available land for irrigation is scarce in most regions; where it is available, the land is unlikely to be irrigated soon because of lack of infrastructure and limited public budgets.
- Irrigation is expected to compete increasingly with other water uses, and experience indicates that domestic uses usually receive priority over irrigation in water allocation.
- There is significant uncertainty about the current extent and future extension of irrigated land and irrigation water use. A review of scenario projections in the literature with similar assumptions to the OECD's *Outlook Baseline* indicates that projections range from the current uncertain level to plus 10%-20% until the middle of the century (see Annex 5.A).

Given the uncertainty regarding this issue and the limited potential for expansion, this *Outlook* takes a conservative approach and assumes no expansion of irrigated land. This may underestimate future water stress in some regions. Further discussion of the methods used to estimate water demands for the *Environmental Outlook* is provided in Annex 5.A.

Water stress: A growing problem

Increased water demand will exacerbate water stress (see Box 5.1 for definition) in many river basins, in particular in densely populated areas in rapidly developing economies. More river basins are projected to come under severe water stress by 2050 under the *Baseline* scenario, mainly as a result of growing water demands (Figure 5.5). The number of people living in these stressed river basins is expected to increase sharply, from 1.6 billion in 2000 to 3.9 billion by 2050, or more than 40% of the world's population. By then, around three-quarters of all people facing severe water stress will live in the BRIICS. Almost the entire population of South Asia and the Middle East, and large shares of China and North Africa's population, will be located in river basins under severe water stress. The consequences for daily life are uncertain, depending greatly on the adequacy of water management strategies put in place. On the other hand, water stress is projected to be

Figure 5.5. **Water stress by river basin: *Baseline*, 2000 and 2050**



Source: *OECD Environmental Outlook Baseline*; output from IMAGE.

somewhat reduced in some OECD countries, *e.g.* the United States. This results from a projected decrease in demand (driven by efficiency gains, and a structural shift towards service sectors that are less water intensive) and higher precipitation caused by climate change (Box 5.3).

Box 5.3. **The impact of climate change on freshwater: An example from Chile**

Climate change will affect freshwater resources through shifts in the hydrological cycle. The Intergovernmental Panel on Climate Change (IPCC) projects that the impact of climate change on freshwater systems and their management will be felt primarily through temperature increases, sea-level rise and precipitation variability. There will be shifts in the quantity, variability, timing, form, and intensity of precipitation and annual average run-off; the frequency and intensity of extreme events such as floods and droughts will increase; water temperature and the rate of evapotranspiration will increase; and water quality will deteriorate (Bates *et al.*, 2008). The nature and magnitude of these projected impacts are highly context specific, with some regions projected to have too much or too little water and many regions suffering unsustainable levels of water pollution driven by higher variability in precipitation and river discharge. These problems will become more severe in the second half of the century (IPCC, 2008).

To date, economic growth and population dynamics have affected water more than climate. A more immediate consequence of climate change is a call for resilience and flexibility in water allocation mechanisms and water infrastructures (including hydropower, structural flood defences, drainage and irrigation systems, wastewater treatment), as future water regimes are less certain.

For example, in recent years, various national studies conducted in Chile have allowed for the preliminary quantification of the impacts of climate change on water resources. In particular, studies have analysed the impact of the changes in temperature, evapotranspiration and precipitation on hydrologic resources in eight river basins located along the central valley of Chile.

The analysis projects water flow to decrease on average in all river basins by 35% between 2041 and 2070. The most northern and southern regions analysed (the Limarí and Cautín basins) will be more severely affected in the short term. The results also show variations in the timing of increased flow levels produced by melting snow in some river basins, which in some cases would shift from spring and summer to winter months. Practically all of the river basins analysed show a major increase in the number of months with hydrological deficits. This will greatly affect the availability of water resources for different productive sectors in Chile. At the same time, the predicted rise in temperatures is expected to produce an upward shift in the altitude of the snow line and lead to an increase in hydrologic flows generated during the winter in the Andes Mountains.

Sources: See for instance Vicuña, S., R.D. Garreaud, J. McPhee (2010), "Climate Change Impacts on the Hydrology of a Snowmelt Driven Basin in Semiarid Chile", *Climate Change*, doi: *10.1007/s10584-010-9888-4*; Bates, B.C., Z.W. Kundzewicz, S. Wu and J.P. Palutikof (eds.) (2008), *Climate Change and Water,* Technical Paper of the Intergovernmental Panel on Climate Change, IPCC Secretariat, Geneva.

Groundwater depletion

Groundwater is by far the largest freshwater resource on Earth (not counting water stored as ice). It represents over 90% of the world's readily available freshwater resource (UNEP, 2008; Boswinkel, 2000). The total amount is difficult to assess, but one estimate suggests that, worldwide, groundwater resources amount to some 10.5 million km^3 (Shiklomanov and Rodda, 2003). Especially in areas with limited surface water supply, such as parts of Africa, and where there is no other alternative, it is a relatively clean, reliable and cost-effective resource. Groundwater also plays a significant role in maintaining surface water systems through flows into lakes and rivers.

However, the rate of groundwater exploitation is becoming unsustainable in a number of regions. The role of groundwater as a water source is becoming increasingly prominent as modern extraction technologies become commonplace and more accessible surface water resources are gradually over-exploited. The fraction of global freshwater use currently drawn from groundwater is estimated globally at 50% of domestic water supply, 40% of water withdrawals for self-supplied industry and 20% of irrigation water supply (Zektser and Everett, 2004). In the European Union, the fraction of groundwater supply for domestic water use is approximately 70%; in France, groundwater accounts for 63% of withdrawals for domestic uses, 41% for industry, and 20% for irrigation.

In the last half of the 20^{th} century, the boom in agricultural groundwater use has improved livelihoods and food security for billions of farmers and consumers. But groundwater depletion may be the single largest threat to irrigated agriculture, exceeding even the build-up of salts in soils. Rapid groundwater depletion is a consequence of the explosive spread of small pump irrigation throughout the developing world. The volume of groundwater used by irrigators is substantially above recharge rates in some regions of Australia, Greece, Italy, Mexico and the United States, undermining the economic viability of farming. In countries with significant semi-arid areas such as Australia, India, Mexico and the United States, more than one-third of irrigation water is pumped from the ground (Zektser and Everett, 2004). Over-exploited aquifers, especially in semi-arid and arid regions, lead to environmental problems (poor water quality, reduced stream flows, drying up of wetlands), higher pumping costs and the loss of a resource for future generations (Shah *et al.*, 2007).

Although we use only a relatively small fraction of the Earth's known groundwater reserves, the rate at which global groundwater stocks are shrinking ("groundwater depletion" – see Box 5.1) has more than doubled between 1960 and 2000, from 130 (± 30) to 280 (± 40) km^3 of water per year (Wada *et al.*, 2010). During the past 50 years, groundwater depletion has spread from isolated pockets to large areas in many countries. One assessment shows that the highest rates of depletion are in some of the world's major agricultural centres, including northwest India, northeast China, northeast Pakistan, California's central valley, and the Midwest of the United States (Wada *et al.*, 2010). It found, furthermore, that the rate of depletion increased almost linearly from the 1960s to the early 1990s, linked to rapid economic growth and population increase, mainly in India and China.

The depletion of even a small portion of the total volume of groundwater (in some cases only a few percent) has a substantial effect on water resources. For example, it can cause land subsidence, which permanently reduces aquifer storage capacity and increases susceptibility to flood damage. And where groundwater discharges to streams and lakes, even a small amount of groundwater depletion reduces stream flow and lowers lake water levels, reducing the amount of surface water available for use by humans or riparian and aquatic ecosystems. These external effects can in turn become limiting factors to the further development of the groundwater resource (Alley, 2007).

Although it is essential to balance exploitation of groundwater resources with supplementation, many dry countries subsidise groundwater exploitation either directly or indirectly (for instance, some policies relieve farmers of the need to pay the price of energy for pumping water from aquifers), and do not have policies to replenish the exploited groundwater. Energy subsidies to agriculture have significantly lowered the costs of extracting groundwater in a number of OECD countries and India.

Water-related disasters

Many people already have to use water that is inadequate in both quantity and quality. The stress from droughts and floods threatens their security even further. Flood, storm and drought disasters have implications for health, the environment and economic development. For example, in 1983, drought in Ethiopia and Sudan led to over 400 000 deaths through famine. Drought in India, and floods and storms in China affected 450 million people in 2002. In the United States in 2005, Hurricane Katrina and the flooding it caused led to damage valued at USD 140 billion.

Recent trends

The number of weather-related disasters has increased worldwide over the last three decades, particularly floods, droughts and storms (Figure 5.6). Trends in water and weather-related disasters between 1980 and 2009 have been analysed using information from the Emergency Events database (EM-DAT), maintained by the Centre for Research on the Epidemiology of Disasters (CRED).[3] The database compiles information on the human and economic impacts of water-related disasters and indicators monitor direct economic losses and the number of victims (people affected or killed). Disasters are categorised according to their causes (floods, droughts and storms).

Figures 5.6 shows historic trends in the number of weather-related "severe" disasters (Panel A), in terms of number of victims (Panel B) and economic losses (Panel C). The main drivers of this increase are a growing world population, increasing wealth and expansion of built-up areas. Although there is a tight relation between extremes in climate variables and weather-related disasters (IPCC, 2011), there is not enough data to confirm a link between frequencies of disasters and climate change. Studies where economic losses have been corrected for population growth and economic growth generally show stabilised or even decreasing trends in losses due to severe water events (Neumayer and Barthel, 2011; Bouwer, 2011; and see Annex 5.A).

Floods made up well over 40% of all weather-related disasters between 1980 and 2009, storms nearly 45% and droughts 15%. The number of victims ranges between about 100 million and 200 million per year, with peaks of 300 million or more. Almost two-thirds of the victims can be attributed to floods. Droughts and other temperature extremes account for 25% and storms the remaining 10%.

Economic losses are estimated to range between USD 50-100 billion per year between 1980 and 2009. A peak of USD 220 billion reflects the Katrina disaster in the United States in 2005. Storms account for half of all losses, floods one-third and droughts almost 15%.

The number of disasters has been spread quite equally over the regions: almost 40% in the OECD, 30% in the BRIICS and 30% in the RoW. But there is a striking difference in impacts between these three groups of countries. Well over 80% of victims (people affected

Figure 5.6. **Global weather-related disasters, 1980-2009**

Note: Losses are in USD 2010, for comparison purposes.

Source: Visser, H., A.A. Bouwman, P. Cleij, W. Ligtvoet and A.C. Petersen (forthcoming), *Trends in Weather-related Disaster Burden: A global and regional study*, PBL Netherlands Environmental Assessment Agency, The Hague/Bilthoven.

StatLink http://dx.doi.org/10.1787/888932571190

or killed) were in the BRIICS countries, nearly 15% in the RoW and only about 5% in OECD countries. OECD countries suffered almost two-thirds of the economic losses, BRIICS one quarter and RoW over 10%. These figures reflect differences in adaptive capacity and the economic value of real estate and other property in the three groups of countries.

Floods: The picture to 2050

The *Environmental Outlook Baseline* projects the world's population to increase by one-third to over 9 billion in 2050 (Chapter 2). In flood plains and deltas – those areas most affected by floods – the population is projected to increase even more rapidly, by nearly 40% over the same period. Changes in exposure of people and economic assets, and in some cases changes in vulnerability, have been the major drivers of the observed increase in disaster losses in the past (IPCC, 2011). This trend may continue in the coming decades. Leaving aside climate change as a likely key driver of floods by 2050, the number of people and value of assets at risk will still be significantly higher than today: more than 1.6 billion people (or nearly 20% of the world's population) and economic assets worth some USD 45 trillion (340% more than in 2010). By region, the increase in economic value at risk is almost 130% for the OECD, over 640% for the BRIICS and nearly 440% for developing countries (see Annex 5.A for more detail on these calculations).

Vulnerability to floods is not evenly distributed within countries and often the poorest suffer disproportionally. For example, Dhaka, Kolkata, Shanghai, Mumbai, Jakarta, Bangkok, and Ho Chi Minh City represent the cities with most people at risk to flooding and all are also situated in countries with low national GDPs per capita in both 2010 and 2050 (see Annex 5.A). This list of cities agrees with an earlier OECD study on coastal cities referred to in Chapter 3 on climate change (Nicholls *et al.*, 2008).

Water quality

Good quality water is essential for human well-being, to support healthy aquatic ecosystems and for use in primary industries such as agriculture and aquaculture. Eutrophication (discussed below), acidification, toxic contamination and micro-pollutants all place pressures on human health, the cost of treating drinking water, irrigation and the maintenance of aquatic ecosystems. Water quality that is too poor for use exacerbates the problem of water scarcity.

Recent trends in OECD countries

Despite significant progress in OECD countries in reducing pollution loads from municipal and industrial point sources by installing wastewater treatment plants and reducing chemical use, improvements in freshwater quality are not always easy to discern,[4] except for organic pollution. Pollution loads from diffuse agricultural and urban sources (fertilisers and pesticides, run-off from sealed surfaces and roads, and pharmaceuticals in animal and human waste) are continuing challenges in many countries.

The share of nutrient water pollution from farming has risen as absolute levels of industrial and urban pollution have decreased more rapidly than those from agriculture. The pressure from agriculture on water quality in rivers, lakes, groundwater and coastal waters in most OECD countries eased between 1990 and the mid-2000s due to a decline in nutrient surpluses and pesticide use. Despite this improvement, absolute levels of nutrient and pesticide pollution remain significant in many OECD countries and regions. In nearly half of OECD countries, nutrient and pesticide concentrations in surface and groundwater in agricultural areas exceed national recommended limits for drinking water standards. Another concern is agricultural pollution of deep aquifers, where natural recovery from pollution can take several decades. In some cases, a reduction of agricultural pollution has not helped to improve water quality due to legacy pollution from slow-moving older groundwater.

The economic costs of treating water to remove nutrients and pesticides to meet drinking water standards are significant in some OECD countries. Eutrophication of marine waters also imposes high economic costs on commercial fisheries for some countries (*e.g.* Korea and the United States). Persistent micro-pollutants in water bodies also add to the costs of treating water for potable use (Box 5.4).

Box 5.4. **Addressing the risks from micro-pollutants**

A growing source of concern is micro-pollutants and their effects on aquatic ecosystems and human health. Micro-pollutants include medicines, cosmetics, cleaning agents, or biocide residues (herbicides, fungicides). They enter water bodies from urban drainage, agriculture, rainwater runoff from transport routes and sealed surfaces. They can have negative effects on organisms, including humans, typically by interfering with endocrine (hormone) systems leading to cancers, birth defects, and other developmental disorders (see Chapter 6, Section 4 on chemicals). The risks are compounded by the combination of multiple pollutants in water bodies, which can together create additional pressures on organisms. Moreover, micro-pollutants tend to be persistent: they are not adequately removed by regular treatment technologies. This allows them to accumulate in water bodies and sediments, leading to higher concentrations. The expected increase in the frequency and intensity of extreme weather events and high flow rates caused by climate change may cause re-suspension of pollutants stored in sediments.

Addressing this issue requires complementary approaches: reducing contamination at source; retrofitting of existing wastewater treatment plants with additional treatment facilities such as ozonation, and powdered active carbon;* setting up decentralised treatment plants for places where large volumes of micro-pollutants are likely to be generated (*e.g.* hospitals, nursing homes); and developing and disseminating new treatment technologies such as sensors, nanotechnologies, and hybrid treatments.

* The Swiss authorities plan to retrofit 100 out of 700 operating wastewater treatment plants.

Eutrophication of surface water and coastal zones

Eutrophication occurs when water bodies receive excess nutrients that stimulate too much plant growth, leading to oxygen depletion and harmful algal blooms. It is a serious concern, causing aquatic biodiversity loss in rivers, lakes and wetlands, hampering human use of the water (*e.g.* drinking water, recreation, fishing, swimming) and it can also affect human health (see below and Chapter 4 on biodiversity). Eutrophicating pollution originates from point sources (urban wastewater systems) and diffuse sources (mainly run-off from agricultural land). Each issue is discussed below.

Under the *Baseline* scenario, eutrophication is expected to increase globally in the coming two decades, then stabilise in some regions (the OECD, Russia and Ukraine). In Japan and Korea nutrient surpluses per hectare of agricultural land have already reached high levels. In China, India, Indonesia and developing countries, eutrophication is projected to increase after 2030; in

China, this is driven by nutrients from wastewater – surpluses in agriculture are projected to stabilise. In Brazil, eutrophication is expected to increase, driven by growing phosphorus surpluses from agriculture, while phosphorus from wastewater effluents and nitrogen is projected to stabilise or decrease after 2030.

Nutrient effluents from wastewater

In the *Baseline,* nutrient effluents from wastewater are projected to increase rapidly. Nitrogen (N) effluents are projected to grow by 180% (from about 6 to 17 million tonnes per year between 2000 and 2050 globally); and phosphorus (P) effluents by over 150% (from 1.3 to 3.3 million tonnes per year in the same period) (Figure 5.7). This is primarily due to population growth, rapid urbanisation, an increasing number of households with improved sanitation and connections to sewage systems, and lagging nutrient removal in wastewater treatment systems. The nutrient removal in wastewater treatment systems is also expected to improve rapidly, but not fast enough to counterbalance the large projected increase in nutrient inflows.

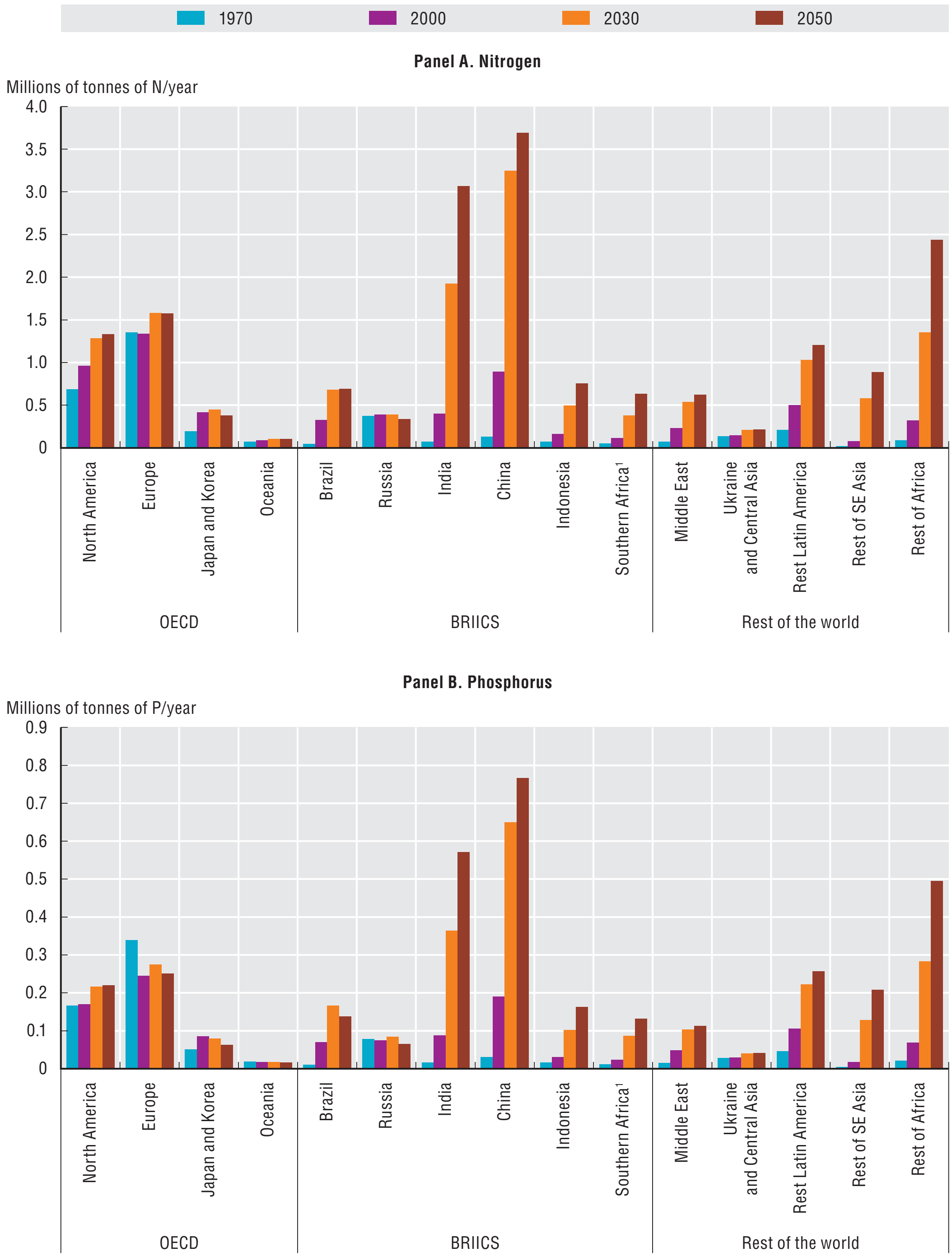
Nutrient effluents from agriculture

Nutrient surpluses in agriculture occur if more nutrients are added to the soil than are withdrawn. If there is a surplus of nitrogen, it is likely to be leached into the groundwater, run off the fields into watercourses, or be lost to the atmosphere through conversion to ammonia (volatilisation). Nitrogen enters the soil through biological fixation, atmospheric deposition, application of synthetic nitrogen fertiliser and animal manure. Nitrogen is withdrawn from the soil through crop harvesting and livestock grazing. Phosphorus comes from animal manure and fertiliser. It follows the same routes as nitrogen, except that it accumulates in the soil and is not leached to the groundwater or lost to the atmosphere (see Annex 5.A for more detail).

Surpluses of nitrogen in agriculture are projected to decrease in the *Baseline* in most OECD countries by 2050 (Figure 5.8, Pannel A). This is because the efficiency of fertiliser use is likely to improve more rapidly than increases in productivity. In China, India and most developing countries, the trend goes in the opposite direction: nitrogen surplus per hectare is likely to increase as production grows more rapidly than efficiency. In China and India, crop production is expected to grow by more than 50% between 2000 and 2030 and 10% to 20% between 2030 and 2050. In Brazil, crop production is expected to grow by 65% between 2000 and 2030 and another 10% by 2050. The production of soybeans and other pulses in Brazil is projected to grow by over 75% between 2000 and 2030, stabilising by 2050. The efficiency of nitrogen fertiliser use in Brazil is projected to be high and nearly stable by 2030, because soybeans fix atmospheric nitrogen and require little nitrogen fertiliser input.[5]

The growth in fertiliser surpluses in Africa (excepting Southern Africa) is dominated by North Africa, which is projected to contribute 20% of Africa's total nitrogen surplus and 40% of its phosphorus surplus by 2050. Surpluses in Sub-Saharan Africa are smaller than in many other developing countries. As soils are often deficient in phosphorus, increased fertilisers are needed to restore and improve soil fertility and sustain crop production. Overall, total crop production in Africa is projected to increase in the *Baseline* scenario between 2000 and 2050 (North Africa by 150%; West Africa, 375%; East Africa, 265%). This is assumed to be achieved through a considerable expansion in agricultural land and increased yields. If this production increase is to be sustained without expanding agricultural land any further, restoration and improvement of soil fertility, technological improvements and higher fertiliser application rates – especially phosphorus – are likely to be needed. More ecological farming techniques will be needed as well.

Figure 5.7. **Nutrient effluents from wastewater: *Baseline*, 1970-2050**

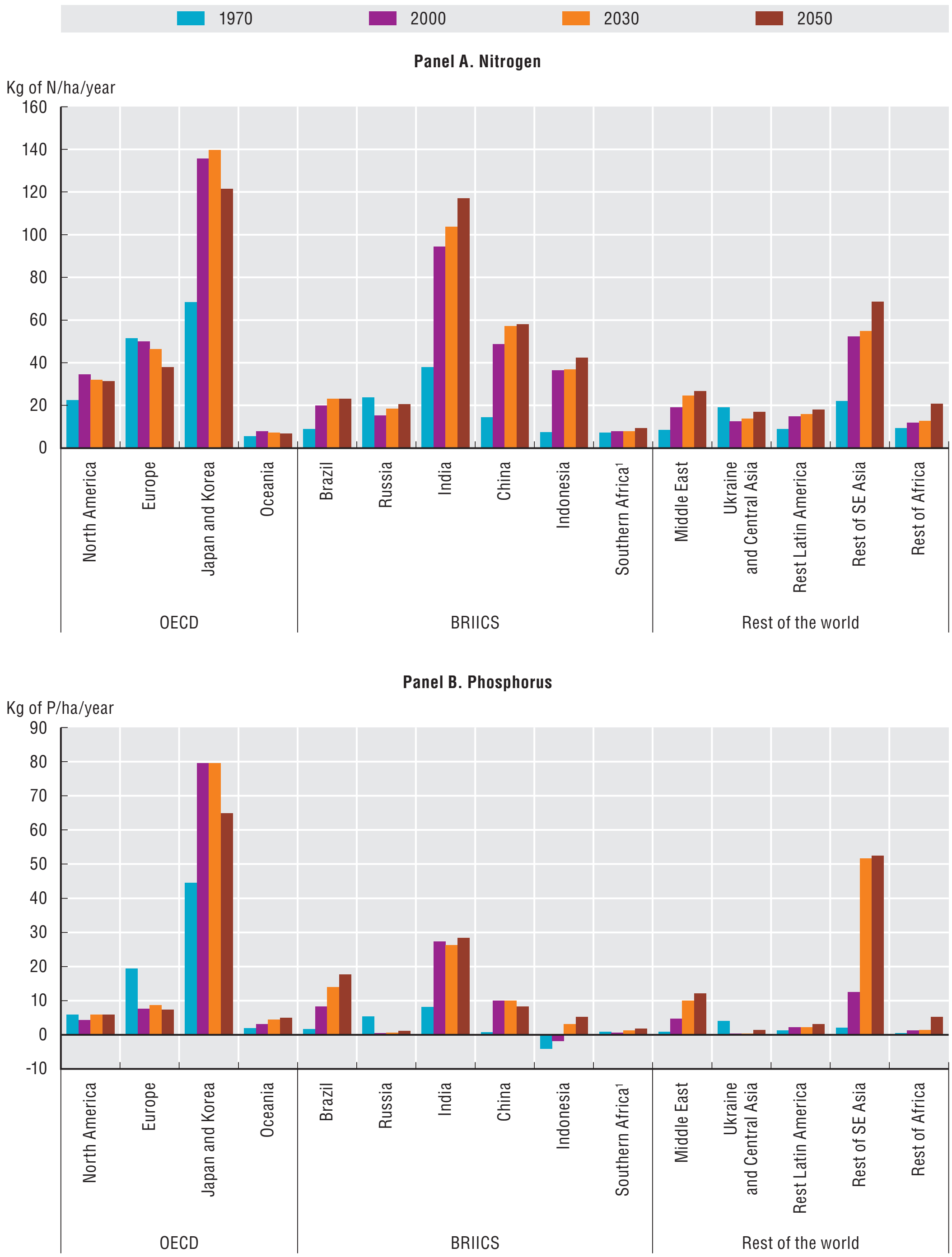


1. In the IMAGE model the *Southern Africa* region includes ten other countries in this geographical area including the Republic of South Africa, when dealing with land use, biodiversity, water and health. For energy-related modelling the region has been split into the Republic of South Africa and "Rest of Southern Africa".

Source: OECD Environmental Outlook Baseline; output from IMAGE.

StatLink http://dx.doi.org/10.1787/888932571209

Figure 5.8. **Nutrient surpluses per hectare from agriculture: *Baseline*, 1970-2050**



1. In the IMAGE model the *Southern Africa* region includes ten other countries in this geographical area including the Republic of South Africa, when dealing with land use, biodiversity, water and health. For energy-related modelling the region has been split into the Republic of South Africa and "Rest of Southern Africa".

Source: *OECD Environmental Outlook Baseline*; output from IMAGE.

StatLink http://dx.doi.org/10.1787/888932571247

In most OECD countries, phosphorus surpluses per hectare are projected to increase slightly in the coming two decades, but to decrease thereafter (Figure 5.8, Pannel B). In China and India, phosphorus surpluses are also expected to decrease or stabilise, while in most developing countries and Brazil, they are projected to increase. Phosphorus is fixed in the soil and builds up until the soil is saturated. It is necessary to add a surplus of phosphorus to compensate for this fixation and leave enough phosphorus for the crop. These surpluses cause extra run-off. If the soil is saturated, fixation stops, and fertiliser inputs can approximately equal crop withdrawal to produce crops. In that situation surpluses may tend to be zero. This is the case in many agricultural regions in Europe, for example. China and India's soils are rapidly becoming saturated –hence surpluses are projected to stabilise or slightly decrease.

Brazil currently has a much lower fertiliser use per unit of production than most OECD countries – this is projected to change slowly until it reaches similar levels to OECD countries, allowing for a large increase in crop production. Another important factor is that soybeans and other pulses require large amounts of phosphorus. These two factors explain the increase in phosphorus surpluses in Brazil.

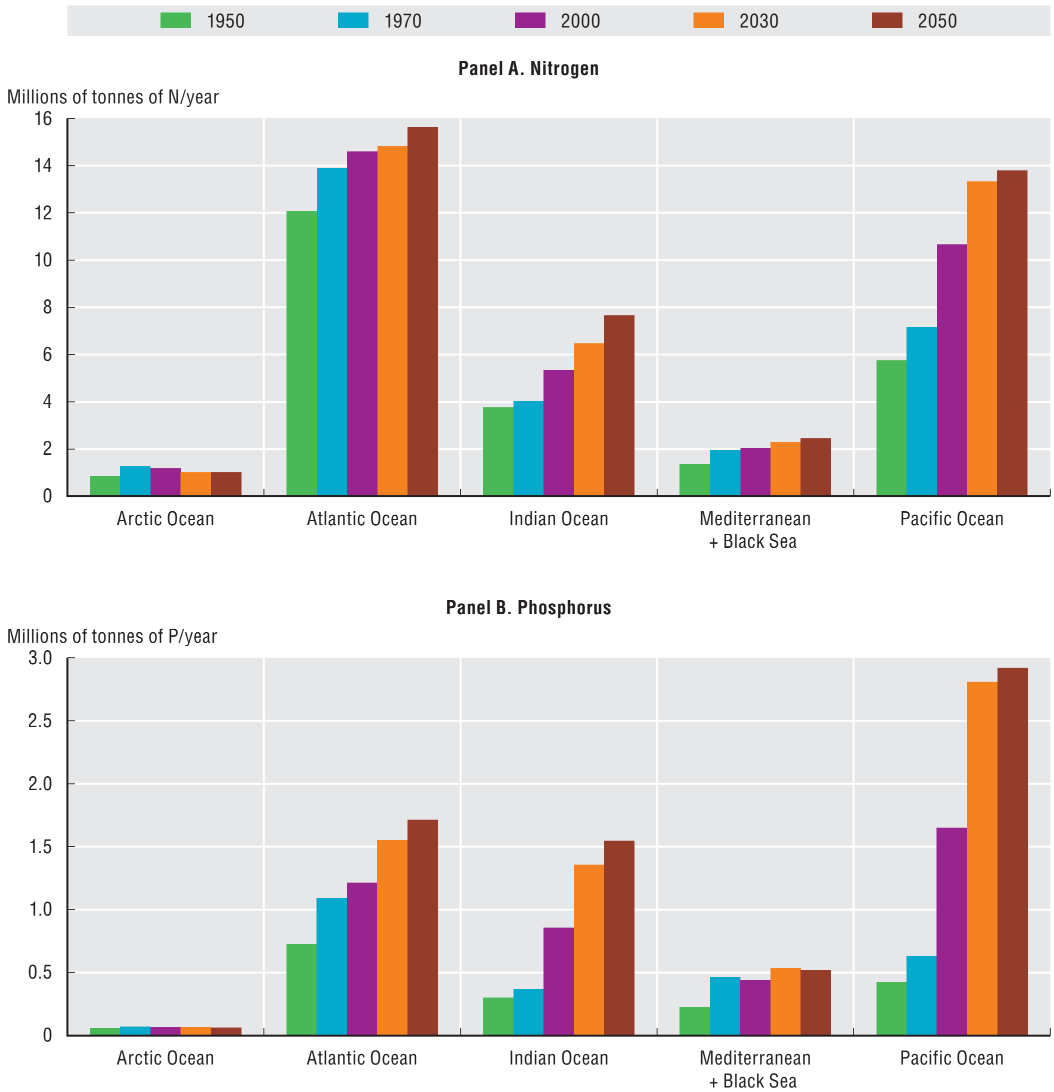
Environmental consequences

The deterioration in water quality is estimated to have already reduced biodiversity in rivers, lakes and wetlands by about one-third globally, with the largest losses in China, Europe, Japan, South Asia and Southern Africa (model calculations, see Chapter 4 on biodiversity). In the *Baseline* scenario, a further decrease in aquatic biodiversity is expected in the BRIICS and developing countries up until 2030, followed by stabilisation (see Chapter 4 on biodiversity for further discussion). However, this modelled decrease is an underestimation because the effects of future river dams, wetland reclamation and climate change have not been included. Over-exploitation of some water resources and changes in the hydromorphology of water systems have also damaged aquatic ecosystems. Setting and enforcing minimum ecological water flow rates in rivers and restoration of morphology of river channels and banks and flow regimes to a more natural state are increasingly a part of environmental planning in some OECD countries, stimulated in the European Union by the European Water Framework Directive (Box 5.9).

As a result of the increasing nutrient loads in surface water, the number of lakes with harmful algal blooms is projected to increase globally under the *Baseline* by some 20% in 2050 compared to 2000, mostly in Asia, Africa and Brazil. It is expected that these effects will be aggravated by climate change and increased water temperatures (Mooij *et al.*, 2005; Jeppesen *et al.*, 2009).

The occurrence, frequency, duration and extent of oxygen depletion and harmful algal blooms in coastal zones are projected to increase under the *Baseline* to 2050, as rivers discharge rapidly growing amounts of nutrients into the sea, especially the Pacific (Figure 5.9). Phosphorus discharges are projected to increase more rapidly than those of nitrogen and silicon (Figure 5.9, Panel B), leading to deterioration in the natural balance of coastal marine ecosystems. Another driver exacerbating this trend is the rapid growth in the number of dams worldwide. Dams cause sediment with silicon to settle down in the reservoir and lower the sediment loading in rivers downstream, thereby reducing the level of silicon. This imbalance increases the risk of harmful algal blooms.

Figure 5.9. **River discharges of nutrients into the sea: *Baseline*, 1950-2050**



Source: OECD Environmental Outlook Baseline; output from IMAGE.

StatLink http://dx.doi.org/10.1787/888932571285

Besides wastewater and agriculture, aquaculture is a growing source of nutrient discharges. As these are not included in the model calculations, the projected nutrient discharges to rivers and the sea may be underestimated.

Access to water supply and sanitation services

Current trends

The Millennium Development Goal (MDG) Target 7C is "to halve, by 2015, the proportion of people without sustainable access to safe drinking water and basic sanitation". This section measures the number of people without access to *improved water sources* and to basic sanitation, as reported by the Joint Monitoring Programme. However, access to an improved water source does not guarantee access to *safe water*.

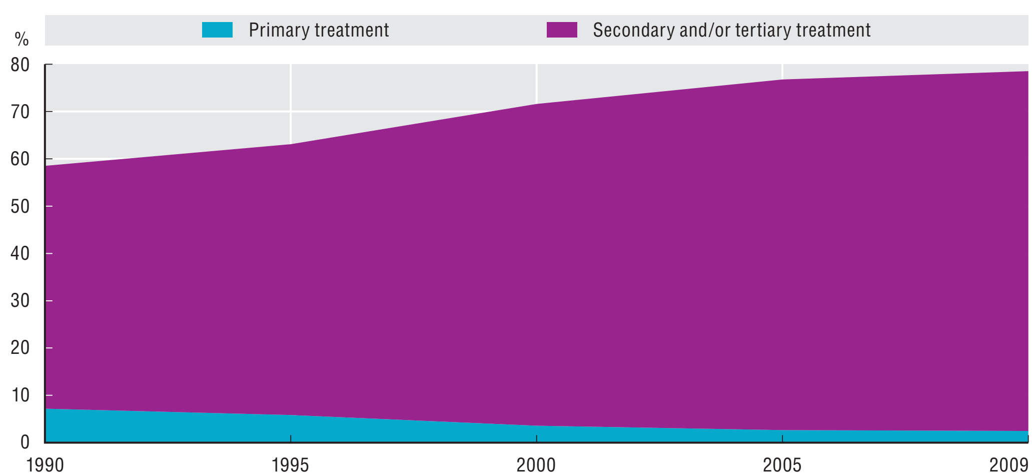
The official monitoring of the MDG Target 7C shows that worldwide between 1990 and 2008, the number of people with access to an improved drinking water source grew by an estimated 1.1 billion people in urban areas and 723 million people in rural areas (UN, 2011). Most of them live in the BRIICS. Nevertheless, in 2008, 141 million city dwellers and 743 million rural dwellers still relied on unimproved sources of drinking water (UN, 2011). The number of city dwellers without access to an improved water source actually increased between 1990 and 2008, as urbanisation outpaced connection (Figure 5.12).

The official monitoring also indicates that in 2008, 2.6 billion people still did not have access to basic sanitation. According to the Global Annual Assessment of Sanitation and Drinking-Water (GLAAS; WHO, 2010),[6] the greatest numbers of people without improved drinking water supplies and basic sanitation are in South Asia, East Asia and Sub-Saharan Africa. To date, efforts to increase connection rates have benefitted the better-off more than the poor (UN, 2011). This poses enormous health risks, especially to the poorest, who are the most vulnerable.

In OECD countries, the share of the population connected to a municipal wastewater treatment plant rose from nearly 50% in the early 1980s to about 70% today (Figures 5.10 and 5.11). For the OECD as a whole, almost half of public pollution abatement and control expenditure relates to water (sewerage and wastewater treatment). When expenditures from the private sector are factored in, this domain represents up to 1% of GDP in some countries.

Figure 5.10. **OECD population connected to wastewater treatment plants, 1990-2009**

% of total population



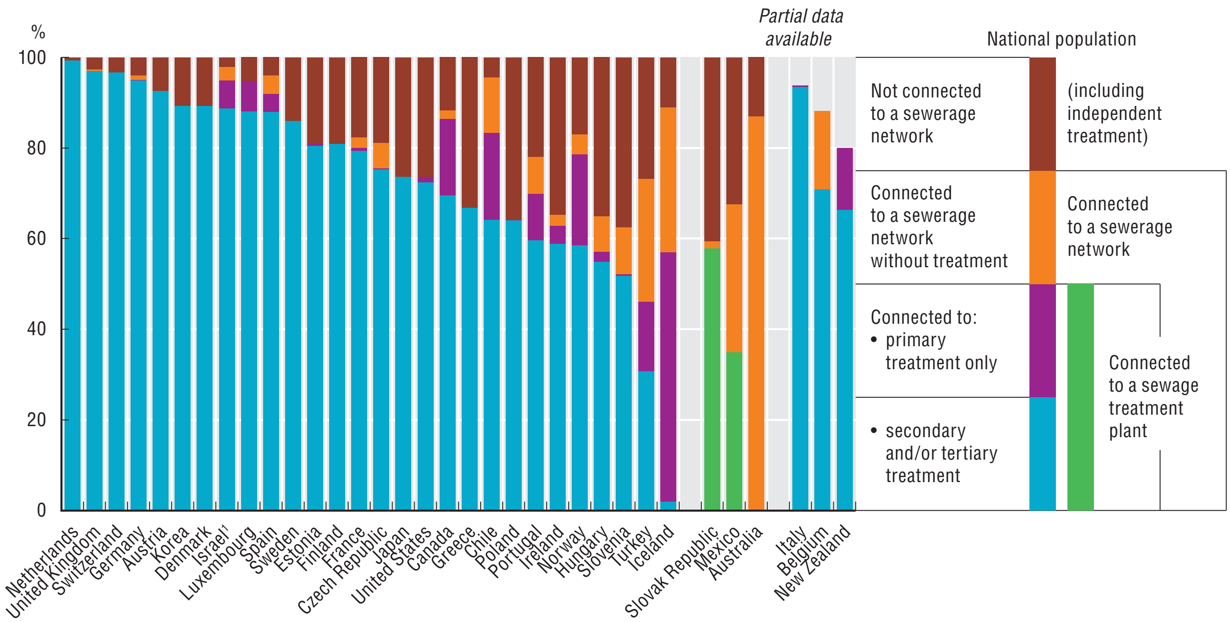
Note: This indicator shows the percentage of national population connected to public wastewater treatment plants, and the degree of treatment (primary treatment only, secondary treatment and tertiary treatment – defined below). "Connected" here means actually connected to a wastewater treatment plant through a public sewage network. Non-public treatment plants, *i.e.* industrial wastewater plants, or individual private treatment facilities such as septic tanks are not covered. The optimal connection rate is not necessarily 100%; it may vary among countries and depends on geographical features and on the spatial distribution of habitats. Primary treatment refers to treatment of (urban) wastewater by a physical and/or chemical process involving settlement of suspended solids, or other processes in which the biological oxygen demand (BOD) of the incoming wastewater is reduced by at least 20% before discharge and the total suspended solids of the incoming wastewater are reduced by at least 50%. Secondary treatment refers to treatment of (urban) wastewater by a process generally involving biological treatment with a secondary settlement or other process, resulting in a BOD removal of at least 70% and a chemical oxygen demand (COD) removal of at least 75%. Tertiary treatment refers to treatment (additional to secondary treatment) of nitrogen and/or phosphorous and/or any other pollutant affecting the quality or a specific use of water: microbiological pollution, colour, etc. The different possible treatment efficiencies cannot be added and are exclusive.

Data exclude: Australia, Chile, Mexico, Slovak Republic and Slovenia.

Source: OECD Environment Directorate. StatLink http://dx.doi.org/10.1787/888932571323

Figure 5.11. **OECD population connected to public wastewater treatment plants by country**

2009 or latest year available, in % of total population



Note: See note for the previous figure.

1. The statistical data for Israel are supplied by and under the responsibility of the relevant Israeli authorities. The use of such data by the OECD is without prejudice to the status of the Golan Heights, East Jerusalem and Israeli settlements in the West Bank under the terms of international law.

Source: OECD Environment Directorate.

StatLink http://dx.doi.org/10.1787/888932571342

The share of population connected to wastewater treatment plants and the level of treatment vary significantly among OECD countries (Figure 5.11): secondary and tertiary treatment has progressed in some, while others are still completing sewerage networks or the installation of first generation treatment plants. In the future, additional treatments will be required to eliminate micro-pollutants (Box 5.4). Additional points of concern are the management of and pollution in storm water and surface water run-off. Some countries have reached the economic limit in terms of sewerage connection, and use other, non-collective ways of treating wastewater, mainly from small, isolated settlements (Box 5.5).

Box 5.5. **The Iberoamerican Water Programme**

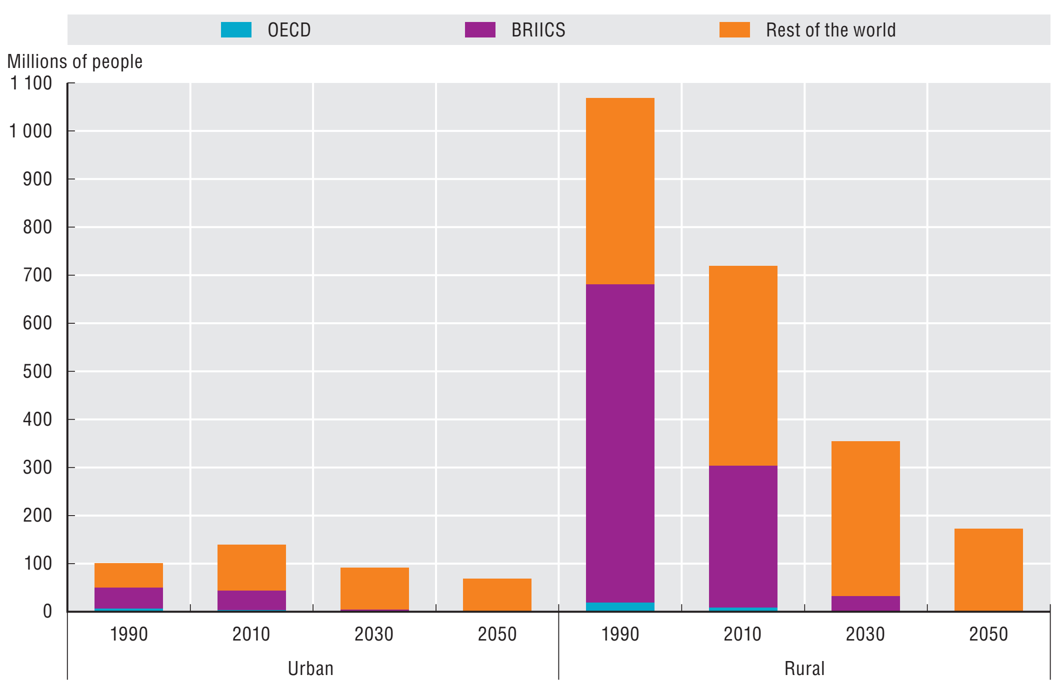
Spain is promoting the Iberoamerican Water Programme, endorsed by the Iberoamerican Summit of Heads of State in 2007. This programme is devoted to achieving the MDGs on water supply and sanitation in Latin America and involves four activities: capacity building, technical transfer, institutional strengthening and supporting the Ibero-American Water Director's Conference (CODIA). One notable development is the establishment of a Research and Testing Centre for non-conventional water treatment technologies in Uruguay, fostering technological research and transfer through dialogue among stakeholders and countries. This sort of technology park tests new unconventional sanitation techniques for small and isolated communities and identifies the best option according to climatic conditions and the specific pollutants involved.

Future trends

Under the *Baseline* scenario, access to improved water supply in the BRIICS is projected to be universal before 2050 (Figure 5.12).[7] Connection rates are likely to improve because of higher income levels and continuing urbanisation, which makes water supply and sanitation (WSS) coverage easier to achieve. However, far slower progress is expected in developing countries (RoW). The United Nations estimates that by 2015, 89% of the population in developing regions are likely to have access to improved sources of drinking water, compared with 70% in 1990 (UN, 2011). The MDG of halving by 2015 the 1990 level of population without improved water supply is expected to be met in most regions, but not in Sub-Saharan Africa.

However, this apparent success can be misleading. This is so for three reasons. Firstly, progress has been rapid in rural areas – a trend which is projected to continue under the *Environmental Outlook Baseline* – but the absolute number of people in rural areas without access is still a concern (Figure 5.12). Secondly, as noted above, the number of city dwellers without access to improved water supply worldwide has actually increased between 1990 and 2008, as service extension fails to keep pace with city growth. Thirdly, the MDG target indicator – the "proportion of population using an improved drinking water source" – does not necessarily reflect access to *safe* water, which was defined as a fundamental human right by the UN in 2010 (see Section 3 for more on this). OECD work has shown ample evidence of this, in particular in Eastern Europe, the Caucasus and Central Asia (EECCA; see OECD, 2011d).

Figure 5.12. **Population lacking access to an improved water source: *Baseline*, 1990-2050**



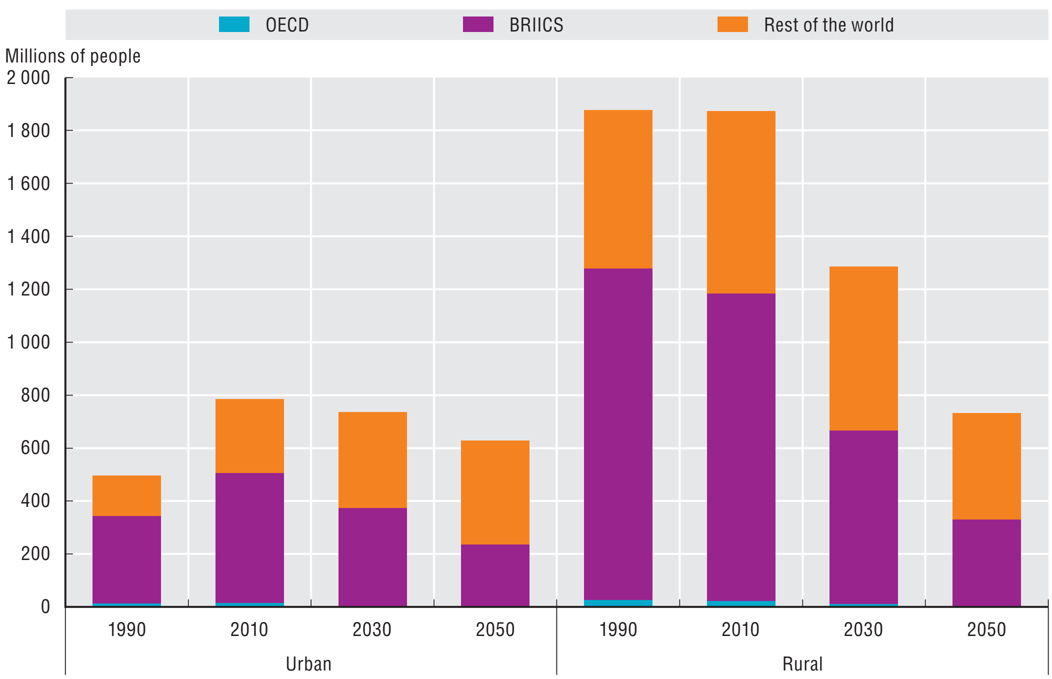
Source: *OECD Environmental Outlook Baseline*; output from IMAGE.

StatLink http://dx.doi.org/10.1787/888932571361

Under the *Baseline*, the number of people without access to basic sanitation is expected to remain at 2.5 billion in 2015 and to be almost 1.4 billion in 2050, with 60% of them living outside the OECD and the BRIICS (Figure 5.13). This means that Sub-Saharan Africa and a number of Asian countries are unlikely to meet the MDG target for sanitation.

As can be seen in Figures 5.12 and 5.13, the vast majority of those without access to water supply and sanitation today live in rural areas. This trend is projected to continue to 2050, when the number of people in rural areas who lack access to sanitation is likely to become comparable with urban areas.

Figure 5.13. **Population lacking access to basic sanitation facilities: *Baseline*, 1990-2050**



Source: *OECD Environmental Outlook Baseline*; output from IMAGE.

StatLink http://dx.doi.org/10.1787/888932571380

These figures are daunting, and the serious consequences of failing to speed up progress cannot be overemphasised. The health consequences are well documented. Worldwide every year unsafe water, inadequate sanitation and poor hygiene claim the lives of an estimated 2.2 million children under the age of 5. Of these deaths, 1.5 million are due to diarrhoea, the second leading contributor to the global burden of disease. The death (mortality) impact of diarrhoeal disease in children under 15 is greater than the combined impact of HIV and AIDS, malaria, and tuberculosis (see Chapter 6 on health and the environment).

The implications for water quality of the failure to meet the sanitation target are also severe. With progress in wastewater treatment lagging behind that of wastewater collection, new sources of nutrients and pathogens are being deposited untreated into the environment. The environmental consequences of this situation have been discussed in the section on water quality above.

3. Policy: Current and future scenarios

This section first reviews the policy instruments currently available to manage water resources and develop water and sanitation services, illustrated by examples of recent progress in OECD countries in applying these policy approaches. It then explores three model-based policy simulations to discuss alternative futures for water use efficiency, nutrient reduction and improved access to safe water and sanitation.

An inventory of water policy instruments

OECD countries have adopted a range of policy approaches to address the water challenges they face, including regulatory approaches, economic instruments, information-based and other policy tools (Table 5.1).

Table 5.1. **Selected policy instruments for water resource management**

Regulatory (command-and-control) approaches	Economic instruments	Information and other instruments
Norms and standards for water quality (*e.g.* drinking water quality, ambient water quality for recreational water bodies, industrial discharges).	Charges (*e.g.* abstraction, pollution). User tariffs (*e.g.* for water services). Payment for watershed services (*e.g.* for protection of catchment upstream).	Metering of water usage. Eco-labelling and certification (*e.g.* for agriculture, water-saving household appliances).
Performance-based standards.	Reform of environmentally harmful subsidies (*e.g.* production-linked agricultural support; energy subsidies for pumping water).	Voluntary agreements between businesses and government for water efficiency.
Restrictions or bans on activities which have an impact on water resources (*e.g.* polluting activities in catchment areas; ban on phosphorus detergents).	Subsidies (*e.g.* public investment in infrastructure, social pricing of water).	Promotion of, awareness raising and training in ecological farming practices or improved irrigation technologies.
Abstraction and discharge permits Water rights.	Tradable water rights and quotas.	Stakeholder initiatives and co-operative arrangements seeking to improve water systems, *e.g.* between farmers and water utilities.
Land use regulation and zoning (*e.g.* buffer zone requirements for pesticides application).	Insurance schemes.	Planning tools (*e.g.* integrated river basin management plans). Cost-benefit analysis of water management policies.

Regulatory approaches

To protect human health, most countries set ambient water quality standards for different uses, such as drinking water supplies, recreation use or bathing. Quality standards are regulated for discharges from municipal sewage systems and wastewater treatment plants, industries and power generation facilities.

For example, Australia has non-mandatory national guidance (The National Water Quality Management Strategy) that may be taken up in state or territory legislation and regulated at that level. The levels of phosphorus and nitrates in the EU's freshwater have declined in recent years (1992-2008) according to long-term data from monitoring stations (Eionet), primarily due to improved wastewater treatment and bans on phosphorous detergents.

Water rights[8]

Modern water rights specify the volume of water that may be abstracted by right owners from a water body. The volume can be a fixed amount, or a proportion of available water. In most countries, when explicitly defined, water rights are attached to land ownership. Countries are gaining experience with unbundling water rights from land ownership and managing them separately. This opens opportunities for flexible reallocation of water rights. Indeed, water rights are potentially an effective policy instrument to re-allocate water to higher-value uses (be it valuable crops, or selected industrial uses).

Water rights come with a range of conditions, including the payment of water fees or charges. In practice, however, right holders may consider high water prices as depriving them of their entitlement. In a number of jurisdictions, water rights may be traded. Water rights tend to have a limited duration. This generates trade-offs between the security of right holders and the flexibility of water allocation.

In most cases, before water rights can be used as a policy tool, they need to be reformed to place water under state ownership and control. This can generate opposition from right holders and rent seekers. Appropriate processes and compensation measures need to be considered.

Recent developments illustrate important policy issues related to water rights. Firstly, fast-growing economies that need to secure food supplies are increasingly making land-lease deals with poorer nations that have fertile land with water availability (WEF, 2011); unbundling water rights from land ownership in these countries would ensure that water benefits domestic needs, but this may generate tensions with the new owners of the land. Secondly, there is a risk that some water rights may be purchased for speculative purposes. To mitigate this risk, several states in Australia prohibit or cap the ownership of water rights by people not owning or occupying land, or restrict the proportion of entitlements in a given catchment that can be held by non-farm users. As a result, water markets are often inaccessible to urban users (Ekins and Salmons, 2010). Thirdly, potential negative impacts of water re-allocation on third parties should be minimised. In particular, the needs of the environment have to be factored in, for instance through ensuring minimum ecological reserves.

A variant of tradable water rights is tradable nutrient rights to mitigate nutrient pollution. The case of Lake Taupo in New Zealand is an interesting example of a tradable rights mechanism that reduces nutrient run-offs to lakes and helps restore water quality (see Box 5.6).

Water pricing

Putting the right price on water and water-related services encourages people to waste less, pollute less, invest more in water infrastructure and value watershed services. Pricing water can help serve four objectives:

- Along with tax incentives and transfers, tariffs on water-related services generate finance to cover investment and operation and maintenance costs.
- It helps to allocate water among competing uses.
- It can manage demand and discourage depletion of water resources.
- Appropriate tariffs ensure adequate and equitable access to affordable water and water-related services.

Box 5.6. **Tradable nutrient rights to mitigate nutrient flows: The case of Lake Taupo, New Zealand**

Lake Taupo is the largest freshwater lake in New Zealand, and supports an important fishery. The regional government has decided to reduce nutrient inputs to Lake Taupo in order to maintain or improve water quality. This is to be done through a "cap-and-trade" scheme, which involves the following steps:

1. Define the "cap" – the nutrient load that maintains lake water quality.
2. Define the players in the market – those who release the most nutrients into the lake's catchment.
3. Allocate nutrient polluting allowances to the key players.
4. Trade allowances – this involves having a market place and setting a price.
5. Monitor compliance.

This system ensures that any increases in nitrogen leaching are offset by corresponding and equivalent reductions in nitrogen leaching within the Lake Taupo catchment. The target is to reduce the nitrogen load by 20%. Farms contribute more than 90% of the manageable nitrogen input to the lake, so farmers are key parties to the scheme. Another party is the Lake Taupo Protection Trust, which administers a fund to protect lake water quality, and will be able to purchase nitrogen discharge allowances (NDA) and/or farmland.

The initial allowances are being allocated based on documented stocking rates, meat and wool production, fertiliser use, and other parameters, during a five-year window and using Overseer® (a computer model that calculates and estimates the nutrient flows in a productive farming system) to predict nitrogen exports. When this process is completed, each farmer will have a consent which details their NDA – a fixed amount expressed as tonnes of nitrogen per year.

From year to year, farmers can alter how they farm, provided their nitrogen export (as predicted by Overseer®) does not exceed their NDA. If a farmer wants to increase production, they must purchase NDA from another farmer who wants to decrease production. Once a trade has been agreed between two farmers, each of their consents is adjusted to increase or decrease their NDA.

Source: Adapted from Rutherford K., T. Cox (2009), "Nutrient Trading to Improve and Preserve Water Quality", *Water and Atmosphere*, 17(1).

Efforts are being made in OECD countries to better account for the costs and externalities of water use by households and industrial users (OECD, 2010a). This is reflected in the level of prices (which have increased, at times substantially, over the last decade) and in the structure of tariffs (which better reflect consumption and treatment costs).

OECD countries are also gaining experience with abstraction, pollution/effluent charges and other economic instruments – such as tradable water rights or payment for watershed services – to achieve more economically efficient, socially equitable and environmentally sustainable abstraction and allocation among competing uses:

- Abstraction charges are often designed to provide funding for water resources management or for watershed protection activities. However, they seldom reflect water scarcity and tend to be relatively low. Abstraction taxes imposed on groundwater tend to be higher than on surface water. In most cases, charges are collected and retained locally.
- Pollution charges can be linked to different characteristics of the polluter, the effluents or the recipient water body. In most cases, they are collected at the local level – only

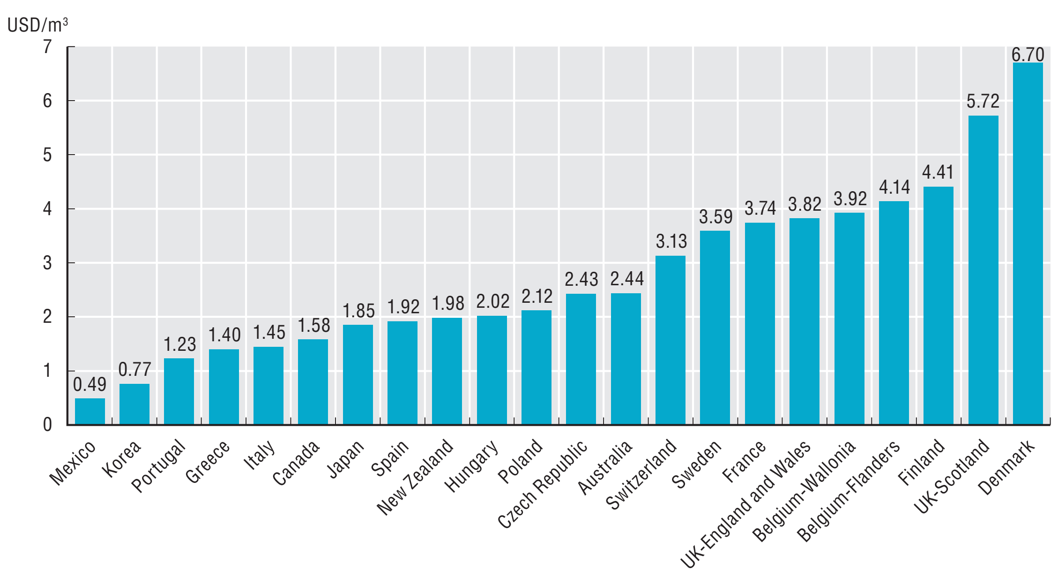
rarely at the river basin level – and earmarked to finance environmental activities. In some countries, revenues collected from downstream beneficiaries are used to compensate upstream residents for restrictions put on their land use. This is an important step towards truly integrated water and land management across a river basin.

The level of prices for water supplied to farms has risen in OECD countries. Frequently, however, farmers are only paying the operation and maintenance costs for water supplied, with little or no recovery of capital costs of irrigation infrastructure. Water scarcity and environmental costs are rarely reflected in water prices. This often results from claims that higher water prices will undercut farmers' competitiveness on global markets. However, where countries have raised water charges for farmers, the available evidence indicates no reduction in agricultural output (OECD, 2010c). Pricing policies for farmers are often combined with other (regulatory) instruments, such as abstraction thresholds and permits.

Tariff levels charged to households for water supply and sanitation services vary greatly among OECD countries (Figure 5.14), reflecting contrasted efforts to recover the costs of the services through prices. The data show that in half of the countries, wastewater services can be more expensive than drinking water supply. They also confirm that prices have risen over the last decade (although in some cases more slowly in the most recent years), primarily driven by wastewater charges, which were brought in line with the costs of investment needed for environmental compliance (*e.g.* tertiary treatment). Value added tax (VAT) and other taxes also explain part of the increase.

Tariff structures for water supply vary within and across OECD countries, reflecting the degree of decentralisation of the tariff-setting process. Several OECD surveys note that fewer countries over the years are reporting the use of flat fees and decreasing block tariff structures. An emerging trend in some OECD countries is the combination of fixed charges alongside a

Figure 5.14. **Unit price of water and wastewater services to OECD households (including taxes), 2007/08**



Source: OECD estimates based on country replies to the 2007/08 survey or on public sources validated by the countries; see OECD (2010a), *Pricing Water Resources and Water and Sanitation Services*, OECD Publishing.

StatLink http://dx.doi.org/10.1787/888932571399

component based on the volume of water used, or the progressive increase in the weight of fixed charges in the overall bill.

Increasingly, wastewater charges are being introduced to cover wastewater management costs. Most countries levy separate charges for sewerage and for wastewater treatment, although in most cases the basis for charging remains water consumption. Only the size of the volumetric rate differs.

Lessons have been learned on the social consequences of water tariff policies. Low water prices hurt the poor most, as they deprive utilities from revenues to expand coverage, forcing the poor to procure poor quality water from private vendors. Water tariffs can be structured to account for the basic needs of all segments of the population. However, social policy objectives are better attained through socially targeted measures such as income support. Targeting and keeping the transaction costs low are essential criteria in designing such measures.

The pricing of water supply and sanitation services to industry is a little different to household tariff structures. For example, more countries and regions use decreasing block water tariffs for industry, particularly for large users. The desire to keep large customers that provide substantial local and stable revenues seems to inhibit the use of tariff structures that would encourage less water use. With regard to wastewater management, there is a growing use of separate charges for wastewater collection and for wastewater treatment, with the latter increasingly based on the pollution load of industrial effluents, thus better reflecting actual treatment costs.

Policy mix: Towards a coherent policy framework

Effective water management requires a coherent mix of policy instruments combining regulatory and market-based tools, often within comprehensive management plans with specific goals and targets. The boxes below (5.7-5.9) give examples from OECD countries of various combinations of policy instruments, including economic instruments (pricing, trading) and institutional reforms:

- Australia's National Water Initiative which places a strong emphasis on water planning, pricing and trading;
- Israel's water policy which combines improved technologies with water pricing and metering; and
- the EU Water Framework Directive, which places an emphasis on River Basin Management Plans and cost-effectiveness.

Australia's National Water Initiative includes a comprehensive mix of policy instruments addressing different aspects of water management. This initiative is being assessed and adjusted periodically since its implementation in 2004.

In Israel, the intensity of freshwater use is extremely high by OECD standards. Israel already consumes more water than supplied from the environment (essentially rainfall). Water scarcity has been exacerbated in recent years by several multiyear cycles of drought and consequent over-pumping of water to meet growing water demands. Rainfall has decreased by 9% since 1993, on average, and could drop by a further 10% between 2015 and 2035, according to climate change models. Israel's water outlook to 2050 (Figure 5.15) anticipates that increasing population and agricultural growth will place additional pressures on the country's limited water resources, in terms of both quantity and quality (OECD, 2011c). In this context, the water policy mix in Israel has emphasised targets to reduce freshwater use, and the diffusion of economic instruments to manage demand and to allocate water.

Box 5.7. **Australia's National Water Initiative**

The Intergovernmental Agreement on a National Water Initiative (NWI) was established in Australia in 2004. It is Australia's blueprint for water reform. The overall objective of the NWI is to achieve a nationwide market, regulatory and planning based system for managing surface and groundwater resources for rural and urban use that optimises economic, social and environmental outcomes at the national level. The NWI agreement includes objectives, outcomes and commitments across eight inter-related elements of water management: water access entitlements and planning, water markets and trading, best practice water pricing, integrated management of water for the environment, water resource accounting, urban water reform, knowledge and capacity building, community partnerships and adjustment.

The Australian government publishes biennial assessment reports on the implementation of the NWI. These national assessments cover all groundwater and surface water systems across the states and territories, rural and urban. The 2011 assessment noted that progress has been made since the initiation of the NWI in 2004, particularly in improving planning frameworks, water markets and trading. The major criticisms tended to be over the pace of reform, which was considered too slow and unequal across jurisdictions.

To address these and other issues, the Australian government has passed Commonwealth legislation: *the Water Act 2007, the Water Amendment Act* 2008 and relevant water regulations. This regulatory framework established the Murray-Darling Basin Authority and required it to prepare a strategic plan for the integrated and sustainable management of water resources in the basin. The *Water Act 2007* also established a Commonwealth Environmental Water Holder to manage the Commonwealth's environmental water to protect and restore the environmental assets of the Murray-Darling Basin (Australia's most important agriculture region, producing one third of Australia's food supply), and outside the basin where the Commonwealth owns water.

The Australian government is also funding the Water for the Future initiative (Box 5.13). This is a long-term initiative to secure the water supply of all Australians (AUD 12.9 billion investment over 10 years); it builds on the NWI and the Water Act 2007.

Sources: National Water Commission website *www.nwc.gov.au/www/html/117-national-water-initiative.asp*; Australian National Water Commission (2011), *The National Water Initiative – Securing Australia's Water Future: 2011 Assessment*, NWC, Canberra.

The European Water Framework Directive (WFD) was adopted in 2000. It takes a holistic approach to water policy for the European Union. Its overarching objective is to restore the status of European water bodies (surface waters, transitional waters, coastal waters and ground waters) to good ecological and chemical condition by 2015. It is a flexible policy framework for the EU member states to implement according to national legislation, but sets a number of principles and ambitious targets and makes the case for the use of economic instruments.

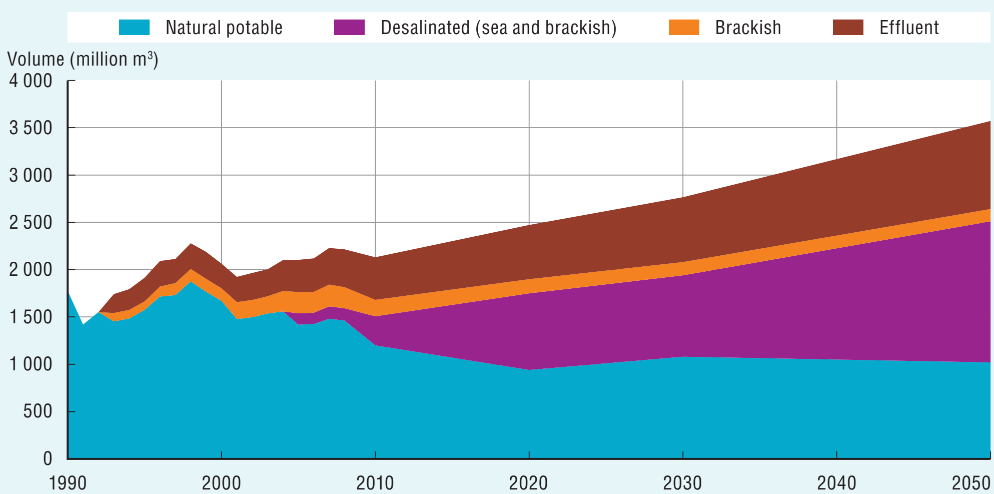
Box 5.8. **Policy response to water stress in Israel**

Israel's national goal is to supply water to all consumers sustainably, based on approved requirements for quality, quantity, efficiency, and economic feasibility. To this end, Israel has set specific targets to gradually reduce its reliance on natural potable water by 2050. The key policy initiatives aim to reduce demand by *i)* requiring by law that all water supplies are metered; *ii)* monitoring water reuse and the use of brackish water in agriculture; and *iii)* promoting drip irrigation and reuse of treated domestic wastewater in agriculture. The government also aims to increase potable water supply by constructing large-scale desalination facilities.

Efforts are also being made to use economic instruments. Significant increases in water tariffs have taken place or are planned in all sectors, and lower prices for effluent and brackish water encourage their use for irrigation. A quota of potable water is allocated to the agricultural sector each year; farmers who opt to exchange part of this quota for alternative sources can secure the volume of wastewater they will procure at a fixed price.

Figure 5.15. **Israel's water consumption outlook to 2050**

Per type of water



Note: The statistical data for Israel are supplied by and under the responsibility of the relevant Israeli authorities. The use of such data by the OECD is without prejudice to the status of the Golan Heights, East Jerusalem and Israeli settlements in the West Bank under the terms of international law.

Source: Water Authority, quoted in OECD (2011c), *OECD Environmental Performance Review: Israel 2011*, OECD, Publishing.

StatLink http://dx.doi.org/10.1787/888932571418

The case of agricultural water

For the world to feed its growing population, world agricultural production would need to increase by some 70% between 2005 and 2050 (FAO, 2006; Bruinsma, 2009). According to the *Environmental Outlook Baseline*, this will probably have to be achieved with less water, mainly because of pressure from growing urbanisation, industrialisation and possibly climate change.

This implies an urgent need to adopt water-efficient irrigation technologies, such as drip emitters, and better maintenance of irrigation infrastructure. OECD work on the transfer of environment friendly technologies has found that the most positive environmental effects materialise when transfer mechanisms develop the absorptive capabilities of the target economy (see OECD, 2011f); education and training are therefore essential.

Box 5.9. The EU Water Framework Directive: A river basin approach

The WFD considers all pressures and impacts on the aquatic environment and integrates requirements from other pieces of EU water legislation. The directive has a number of objectives. The key ones are general protection of aquatic ecology, specific protection of unique and valuable habitats, protection of drinking water resources, and protection of bathing water. All these objectives must be integrated for each river basin.

The WFD is ambitious but flexible, as it does not prescribe one single policy package. Member states can implement it according to their own legislation, and are free to set their own targets for the share of water bodies which will be restored by 2015.

One core principle of the WFD is that the best model for water management is by river basin – the natural geographical and hydrological unit – instead of according to administrative or political boundaries. Therefore, member states are requested to develop river basin management plans (RBMPs). Economic instruments, including water pricing, play a prominent role in the WFD. The aim is to lead to the recovery of the financial and environmental costs of water services (the cost recovery principle).

The EU WFD comes with a suite of water-related directives (*e.g.* Directive 2007/60/EC on the assessment and management of flood risks entered into force on 26 November 2007), and this requires co-ordination. In the case of the Flood Directive, co-ordination is required between flood risk management plans and river basin management plans, and between public participation procedures.

The first phase of a recent assessment concluded that, although the right measures may be in place, they are sometimes difficult to enforce and vulnerable to political pressure at national level (Deloitte, IEEP, 2011). Moreover, many plans appeared to delay action until the final stages of EU law implementation. Member states have made only sluggish progress with introducing economic instruments such as water pricing, while the principle of cost recovery remains controversial (see Deloitte and IEEP, 2011).

In parts of the OECD water use has become more efficient and there are fewer leakages – overall the average water application rate per hectare irrigated declined by 9% between 1990 and 2003 (OECD, 2010c). Reductions have been most notable in Australia, and to a lesser extent in Mexico, Spain and the United States. However, in other countries – including Greece, Portugal and Turkey – water application rates are increasing (OECD, 2008b).

Steps must be taken to move towards more efficient management of water resources in agriculture, while responding to the growing global food demand and the impacts of climate change (OECD, 2010c):

- Institutions and water rights need to be strengthened.
- Water supplied to agriculture needs to be subject to tariffs which take into account the cost of supply, scarcity, social values and environmental costs and benefits. The latter are usually addressed by other policy measures, including agri-environmental payments, pollution taxes and water allocation mechanisms (Box 5.10). Some countries are using the principle of full cost recovery to guide their water policy frameworks (defined as using tariffs to recover the financial and environmental costs of water services). Trading water entitlements places a price on scarcity and can promote the highest value use of water resources. However, such a policy may interfere with food security issues, and requires a well-informed and transparent debate to be successfully implemented. Trade must be factored in, as freer trade in agricultural commodities can enhance food security and protect environmental values.

- Agriculture's resilience to climate change needs to be enhanced, using strategies to adapt agricultural production systems. These are likely to be more effective if they are embedded in longer-term strategies closely linked to agricultural policy reform and risk management policy.

Box 5.10. **Reform of agricultural support and water: The case of the European Union**

Until 2005, EU agricultural policy (the Common Agricultural Policy or CAP) was based on direct aid payments to farmers to promote production. These payments were accompanied by optional agri-environmental payments to protect and improve the environment. A common view is that this policy has traditionally promoted a large expansion in agricultural production. At the same time it has allowed farmers to use unecological ways of increasing production, such as the indiscriminate use of fertilisers and pesticides, with serious environmental consequences. A total re-focusing of the payment scheme in 2004 now puts the environment at the centre of farming policy. By linking farmers' payments to a number of strict environmental standards (among others) in the so-called cross-compliance scheme, farmers now have to face cuts in their subsidy levels if they don't meet the strict environmental requirements.

Across the European Union, there are numerous examples of crops with high water requirements that were nevertheless encouraged by the CAP. For example, maize is considered a water-demanding crop in temperate countries, but until 2003 EU maize growers were entitled to a direct subsidy of EUR 54/tonne. With the new decoupling policy, this inconsistency has been eliminated, and farmers' use of water will not be driven by subsidy differences across crops. Garrido and Varela-Ortega (2008) have reported the gradual but steady changes of irrigated land allocation that have occurred in Spain since the CAP reform. The major and most significant changes are that drier areas are being allocated to vineyards, olive trees and citrus (especially in Andalusia), while higher rainfall areas have been allocated to water-consuming crops such as maize and other reformed crops, including sugar beet, cotton and tobacco.

When EU farm subsidies become completely decoupled from production in 2012, the economics of irrigation will be more guided by the productivity of crops and their water requirements, than by the agricultural support available.

Sources: Adapted from OECD (2010c), *Sustainable Management of Water Resources in Agriculture*, OECD, Publishing; Calatrava J. and Garrido, A. (2010), *Agricultural Water Pricing: EU and Mexico*, OECD consultant report available at *www.oecd.org/water*.

"Virtual water": A limited concept for policy making

The concepts of "virtual water" and "water footprints" have gained broad appeal for raising awareness of water scarcity, global impacts of consumption and production on water resources, and allocation issues. However, these indicators have limits as policy or management tools, as they do not take into account the opportunity cost of water in production, other inputs used in production (*e.g.* labour), or distinguish between the management of water resources and water quality. They should be used in combination with other indicators to discuss broader policy goals, such as reducing poverty, stimulating economic development and ensuring high employment while preserving natural resources (Box 5.11). Moreover, they would certainly benefit from more work to refine the calculations of water footprints.

Box 5.11. **Economic analysis of the virtual water and water footprint concepts for water policies**

Virtual water: The term "virtual water" began appearing in the water resources literature in the mid-1990s. Professor Tony Allan of London University chose the term to describe the water used to produce crops traded in international markets. During the 15 years since its inception, the virtual water concept has been very helpful in gaining the attention of public officials and policy makers responsible for encouraging wise use of limited water resources.

However, the fundamental shortcoming of the virtual water concept as a valid policy prescriptive tool is the lack of an underlying conceptual framework. Some researchers have incorrectly described virtual water as analogous to, or consistent with the economic theory of comparative advantage. The virtual water concept is applied most often when discussing or comparing water-short and water-abundant countries. By focusing on the water resource endowment alone, virtual water represents an application of absolute advantage, rather than comparative advantage. For this reason, policy prescriptions that arise from virtual water discussions will not maximise the net benefits of engaging in international trade. Comparative advantage is the pertinent economic concept, and virtual water considers only absolute advantage.

A number of authors have begun describing the important role of non-water factors such as population densities, historical production trends, national food security goals, poverty reduction targets, and the availability of complementary inputs when determining whether to transfer water from one region to another, or to achieve desired outcomes alternatively by transporting or trading agricultural commodities.

Water footprints: The notion of water footprints describes the volume of water required to support production and consumption in selected regions or countries. It is used to assess whether a region or country is consuming resources in a sustainable or unsustainable fashion from a global perspective. However, estimated water footprints are somewhat one-dimensional, as they depict the use of only one resource. In addition, water footprints do not describe the implications of water use. Instead they consider only the amounts of water used in production and consumption activities. Hence, ecological water footprint analysis is not sufficient for determining optimal policy alternatives, as it does not account for the opportunity (scarcity) costs of water resources and the ways in which water is combined with other inputs in production and consumption. Water footprints enable one to compare estimated water use per person or in aggregate across countries, but they are inadequate for evaluating the incremental costs, benefits, or environmental impacts of water use.

Farmers, traders, and public officials must consider many economic and social issues when determining optimal strategies. Virtual water and water footprint concepts will be helpful in policy discussions in many settings, in combination with other environmental, economic, and social indicators. But they will not be sufficient for determining the optimal outcomes of those discussions and establishing economically efficient and environmentally effective policy alternatives.

Source: Adapted from OECD (2010c), *Sustainable Management of Water Resources in Agriculture*, OECD Publishing.

A recent analysis confirms that "virtual water transfers are highly unequal but represent a small volume of water relative to total water needs" (Seekel *et al.*, 2011). It concluded that "virtual water transfer is not sufficient to equalise water use among nations primarily because internal agricultural water use, the main contributor to inequality, dominates national water needs and cannot be completely compensated by current volumes of virtual water transfers".

What if…? Three model-based simulations of alternative water futures

So far this chapter has described the situation for water in 2050 under a "business-as-usual" policy context of the *Baseline* scenario. But could the situation be improved in the future with more ambitious policies? This section presents the *Outlook* modelling work which explores the implications of three hypothetical scenarios:

- a *Resource Efficiency* scenario;
- a *Nutrient Recycling and Reduction* scenario;
- an *Accelerated Access* scenario for water and sanitation.

Resource Efficiency scenario

The *Resource Efficiency* scenario models how the water-stress picture would change if more ambitious policies reduced water demand and enhanced water-use efficiency. This policy simulation is based on the 450 *Core* scenario explored in Chapter 3, climate change. That scenario assumes lower water demand for thermal electricity generation and a greater share of electricity produced through solar and wind generation. In addition, the *Resource Efficiency* scenario assumes further efficiency improvements of 15% for irrigation in non-OECD countries, as well as 30% improvements in domestic and manufacturing uses globally. Further details on the assumptions used for this policy simulation are given in Annex 5.A.

Under the *Resource Efficiency* scenario, the rate of increase in global water demand is expected to slow down. Total demand in 2050 would be around 4 100 km^3, 15% above the demand in 2000, but 25% below the *Baseline* scenario. In the *Resource Efficiency* scenario, water demand in OECD countries would be 35% lower in 2050 than in 2000 (compared to 10% lower in the *Baseline* scenario).

Water stress would also improve under the *Resource Efficiency* scenario in many river basins in China, the United States, Southern Europe and Eastern Europe and Russia. However, the number of people globally living under severe water stress would be reduced only slightly compared to the *Baseline*, from 3.9 to 3.7 billion (Figure 5.16), suggesting that this scenario can only tame the severity of stress in a number of regions. The number of people facing no stress would increase, but many would still face severe water stress, especially in North Africa and Middle East, the India region and Central Asia.

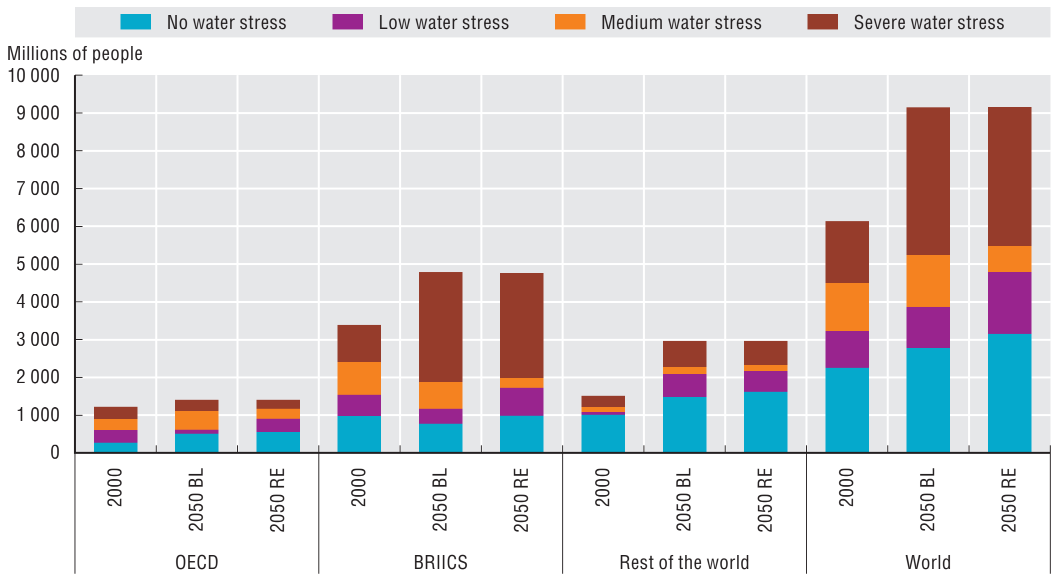
This simulation suggests that, in a number of regions, efficiency gains alone will not be sufficient to reduce water stress. More ambitious and radical approaches are needed to further reduce demand and mitigate competition across water users. Allocation of water across users (including for ecosystems) will be an important challenge.

Nutrient Recycling and Reduction scenario

This second model-based policy simulation reflects the need for aggressive policies to further reduce nutrient discharges in order to decrease eutrophication of lakes and oceans. The *Nutrient Recycling and Reduction* scenario assesses the impact of measures to reuse nutrients in agriculture and reduce both domestic and agricultural discharges of nitrogen (N) and phosphorus (P). As supplies in phosphorus rock dwindle,[9] P recovery from wastewater may help to fill the gap. The assumptions used are described in Annex 5.A.

Figure 5.16. **Number of people living in water-stressed river basins in 2000 and in 2050**

Baseline (BL) and *Resource Efficiency* scenario (RE)



Source: *OECD Environmental Outlook projections*; output from IMAGE.

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New measures that could bring about these improvements would include an increase in fertiliser use efficiency, higher nutrient efficiencies in livestock production and using animal manure instead of synthetic N and P fertilisers in countries with a fertiliser-dominated arable system. The scenario assumes investments in sewage systems that separately collect urine from other wastewater in households (see Table 5.A1 in Annex 5.A) – recycling treated wastewater back into agriculture would significantly reduce wastewater nutrient flows *and* fertiliser use.

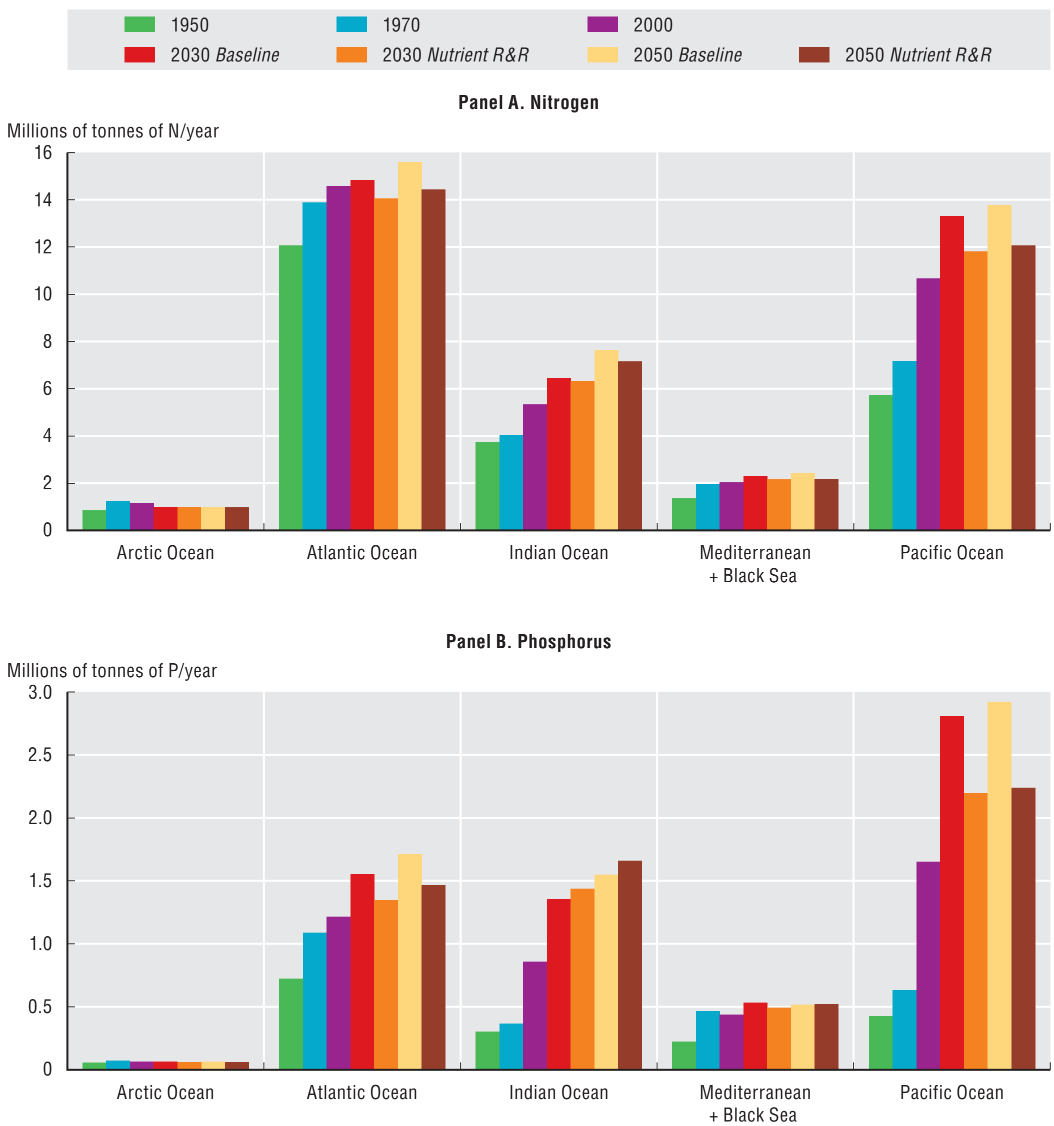
Under this scenario, by 2050 the global N and P surpluses in agriculture could be almost 20% less than in the *Baseline* scenario, and the effluent of nutrients in wastewater could fall by nearly 35%. Total nutrient loads to rivers would be reduced by nearly 40% for nitrogen and 15% for phosphorus compared to *Baseline*. Such reductions could help to prevent further biodiversity loss in rivers, lakes and wetlands in the long term, and even allow some recovery locally. As for coastal zones, the measures to reduce nutrient flows would be most effective in the Pacific Ocean. For the Atlantic and Indian Oceans, the opportunities to reduce nutrient losses from agriculture are limited due to the projected rapid growth in production (Figure 5.17). Phosphorus emissions to the Indian Ocean would even increase in the *Nutrient Recycling and Reduction* scenario. This is because of the following developments in the world regions that discharge into this ocean:

- A small fraction of the population would have a sewage connection.
- Current fertiliser use is low, and would have to increase to achieve the higher yields that are assumed in this scenario; consequently run-off of N and P would increase.
- As the use of fertilisers is low, opportunities to substitute fertiliser by manure would be limited.

- Manure that in the *Baseline* would end up outside the agricultural system (fuel or building material, especially in India), would be used in agriculture in the *Nutrient Recycling and Reduction* scenario.

However, even if N and P loadings are reduced, the risk of harmful algal blooms in coastal zones would stay high as the imbalance between nitrogen, phosphorus and silicon would persist. This is caused by different reduction rates between P and N and the growing number of dams, which decrease river loads of sediment and silicon. This suggests that an integrated approach is required, as progress on only one nutrient will have adverse effects in the long term.

Figure 5.17. **River discharges of nutrients into the sea: *Baseline* and *Nutrient Recycling and Reduction* scenario, 1950-2050**



Source: *OECD Environmental Outlook projections*; output from IMAGE.

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Accelerated Access to water and sanitation scenario

In June 2010, the United Nations General Assembly adopted a resolution recognising access to clean water and sanitation as a human right. The resolution calls on states and international organisations to provide financial resources, build capacity and transfer technology, particularly to developing countries, in scaling up efforts to provide safe, clean, accessible and affordable drinking water and sanitation for all. In May 2011, the Special Rapporteur on the human right to safe drinking water and sanitation noted that these rights should be described in terms of availability, quality, acceptability, accessibility and affordability.[10]

These depart significantly from the definitions encapsulated in the MDGs. The MDGs originally refer to "*safe* drinking water" and "*adequate* sanitation", but actually monitor access to "an *improved* water source" and "*improved* sanitation". This potentially leads to a radical re-evaluation of how many people (and what kind of people) do not have "access to *safe* drinking water and sanitation". The WHO/UNICEF Joint Monitoring Programme for Water Supply and Sanitation, the official UN mechanism tasked with monitoring progress towards the MDG on drinking water and sanitation, is considering additional criteria to better monitor some of these dimensions.

The *Environmental Outlook*'s *Accelerated Access* scenario explores the additional annual costs and health benefits of meeting more ambitious targets than the MDGs. The targets would occur in two steps as follows:

i) By 2030 the population without access to an *improved* water source and to basic sanitation is halved again from the 2005 base year, building on the progress already achieved under the current MDG.

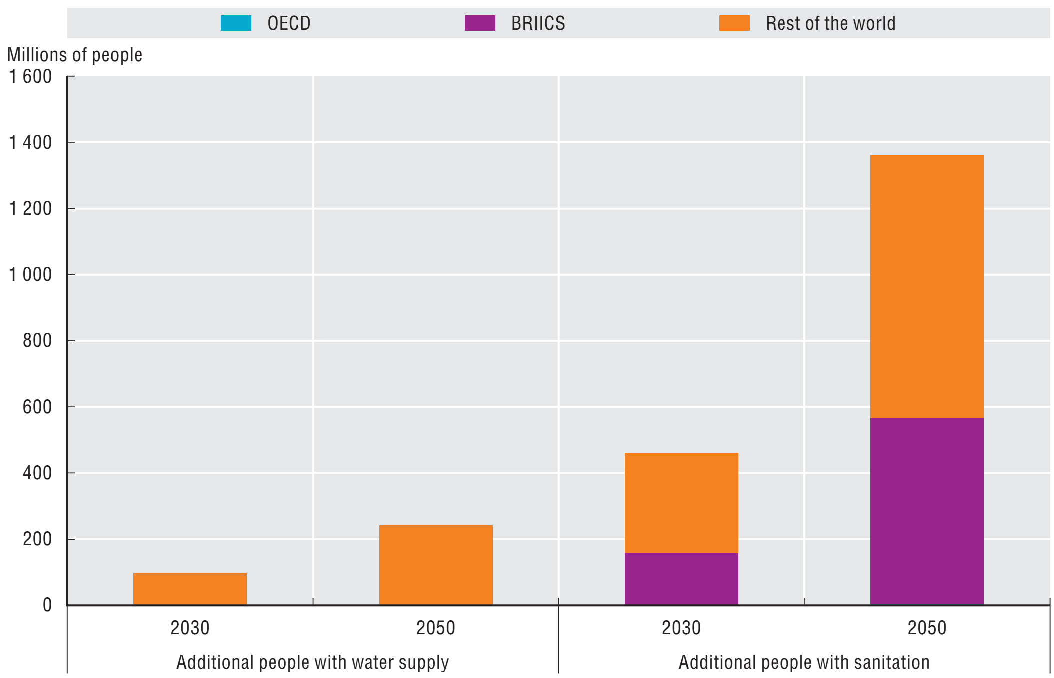
ii) Universal access to a water source and to basic sanitation is achieved by 2050.

Under this scenario, by 2030 almost 100 million additional people would have access to an improved water source and around 470 million more people would have access to basic sanitation facilities than under the *Baseline* (Figure 5.18). Almost all of these people would be living outside OECD and BRIICS countries (*i.e.* in the rest of the world – RoW). By 2050, an additional 242 million would have access to an improved water source, with the RoW accounting for most of this gain. Over 1.36 billion additional people would have access to basic sanitation facilities (nearly 800 million in the RoW, and more than 560 million in the BRIICS).

What would the benefits be from this scenario? The consequences for health are discussed in Chapter 6. The estimated number of avoided deaths per year would be about 76 000 by 2030 and 81 000 by 2050, essentially in the RoW group of countries. The benefits for the environment and certain economic sectors, such as fisheries or tourism, are substantial. Actual benefits are even greater, given that some significant positive consequences (such as pride and dignity, or amenity value) are more difficult to quantify in monetary terms.

In least developed countries in particular, the benefits are massive and far outstrip the costs. The World Health Organization estimates that benefit-to-cost ratios can be as high as 7 to 1 for basic water and sanitation services in developing countries (quoted in OECD, 2011b). According to the GLAAS report, improved access to water and sanitation produces economic benefits that range from USD 3 to USD 34 for every dollar invested, increasing a country's GDP by an estimated 2% to 7% (WHO, 2010).

Figure 5.18. **Number of additional people with access to water supply and sanitation in the *Accelerated Access* scenario, compared to the *Baseline*, 2030 and 2050**



Source: OECD Environmental Outlook projections; output from IMAGE.

StatLink http://dx.doi.org/10.1787/888932571494

The valuation of the benefits for any single country must take account of national circumstances, such as the stage of infrastructure development and GDP per capita. In addition, benefit values are highly location specific, depending, for example, on the prevalence of water-related diseases or the condition of receiving water bodies. Some benefits are likely to tail away as there tends to be diminishing returns from further investments in improving quality of water related services. Benefits are more likely to materialise if investments are appropriately sequenced, thereby lowering costs and ensuring that collected wastewater is properly treated.

OECD experience indicates that increasing access to water supply and sanitation requires large investments to retrofit poorly adapted infrastructure and to build new facilities. The *Accelerated Access* scenario indicates that globally an average of USD 1.9 billion would need to be invested each year between 2010 and 2030 to achieve the 2030 target in addition to what would be invested under the *Baseline* scenario; and an additional USD 7.6 billion beyond the *Baseline* would be needed annually between 2031 and 2050 to achieve the 2050 target. The difference between the two figures reflects the fact that the last step is more costly than the previous ones. In Sub-Saharan Africa these additional costs would make up 0.09% of the GDP in 2030 and 0.08% in 2050.

In addition, significant and stable financial flows will be needed to maintain and operate this infrastructure. This will require well-developed and realistic strategies which tap three main sources of finance: revenues from tariffs for water services, taxes channelled through public budgets, and transfers from the international community (OECD, 2010a). The private sector (the water industry and financial institutions) can also play a key role in developing and channelling innovations and enhancing efficiency. They can also harness private savings and facilitate investment when appropriate framework conditions are in place (OECD, 2009; 2010e). Increasing competition to access scarce public financial resources may be an incentive to revisit past experience with private sector finance in the water sector, which has been disappointing in developing countries (Annez, 2006). Public funds to achieve universal access are expected to increase when the UN Resolution on water as a human right is translated into action. In addition, all OECD member states are committed to raising their official development assistance to reach 0.7% of their GDP; some of this increase could help fund these much-needed developments.

4. Need for further action: Emerging issues in water policy

The previous sections have shown that more ambitious policies and new ways of looking at the water challenge are urgently needed. This final section highlights some of the most important emerging directions for water policy and its reform. These include:

- seeing water as an essential driver of green growth;
- allocating enough water for healthy ecosystems;
- fostering greater coherence among water, energy, environment and food policies;
- finding alternative sources of water (*e.g.* water reuse);
- filling information gaps;
- designing reforms that are realistic and politically acceptable.

Seeing water as an essential driver of green growth

The OECD is working to reconcile the demand for continued economic growth and development with the need to ensure that natural assets continue to provide the resources and environmental services on which all human well-being relies. This underpins the concept of "green growth", which sees sustainable water use as an essential driver, since a lack of water of appropriate quality can significantly hinder growth (OECD, 2011a). As discussed above, water management can generate huge benefits for health, agricultural and industrial production. Water management can preserve ecosystems and the watershed services they provide, thereby avoiding the enormous costs that can be imposed by flooding, drought, or the collapse of watershed services.

Similarly, UNEP (2011) confirms that investments in infrastructure and operation of water-related services can provide high returns for both the economy and the environment. It highlights the need for more private and public investment in green technologies and infrastructure to boost water (and energy) efficiency and sees such investments as critical to building the green economy of the future.

Thus, water efficiency and water demand management are essential ingredients for green growth, along with water reuse and recycling. The Four Rivers Project in Korea (Box 5.12) is an example of a green growth policy factoring in investment in water-related infrastructure.

The following specific policy approaches can more systematically harness water management for green growth:

- Invest in ecologically sensitive water storage and water distribution systems in water scarce regions. Reliable resources are essential for green growth. However, water storage

Box 5.12. **Korea's Four Rivers Restoration Project (4RR)**

The Four Rivers Project is a good illustration of an holistic approach to water resource management that also aims to drive green growth. Following the economic crisis, Korea decided to allocate 2% of its GDP every year between 2009 and 2013 (totalling USD 86 billion) to green investment to solve short-term economic problems and create jobs. Twenty per cent of this green budget (USD 17.6 billion) is to be invested in the water sector through the Four Rivers Restoration Project (4RR).

This project brings five ministries together in a holistic approach (Environment; Food, Agriculture, Forestry and Fisheries; Culture, Sports and Tourism; and Public Administration and Security; Ministry of Land, Transport and Maritime Affairs). Its aims are to secure enough water to respond to future water scarcity and severe drought due to climate change (target: water supply of 1.3 billion m^3); to take preemptive measures against floods due to climate change, as well as 200-year floods, by dredging sediment, strengthening old levees, and building small multipurpose dams (target: secure 920 million m^3 of flood control capacity); to improve water quality by expanding sewage treatment facilities and establishing green algae reduction facilities (target: BOD 3 mg/L); to restore ecological rivers, create wetlands, and readjust farmland to rehabilitate the ecosystem (223 restoration projects planned); to develop river banks to ensure space for leisure; and to develop the regions around rivers. The deadline for implementation of the plan is 2012.

The government expects the 4RR to generate USD 32.8 billion in economic benefits, and to create 340 000 jobs. Ultimately, the government expects the experiences and technologies developed in the 4RR project to make Korea one of the leading countries in the water management sector.

Source: Korea Environmental Policy Bulletin (2009), "Four Major River Restoration Project of Republic of Korea", *Korea Environmental Policy Bulletin*, Issue 3, Volume VII.

technologies and infrastructure such as large dams can disturb ecosystem balances. Soft infrastructure (*e.g.* wetlands, flood plains, groundwater recharge), small-scale dams, rainwater harvesting, or appropriately designed infrastructure are more ecologically sensitive and cost-effective.

- Put a sustainable price on water and water-related services as an effective way to signal the scarcity of the resource and to manage demand. This will require identifying the beneficiaries and implementing mechanisms to ensure beneficiaries contribute to cover the costs of the benefits they enjoy.
- Be prepared to allocate water across sectors and across water uses where it adds most value. This difficult policy challenge – diverting water to value-adding activities (including environmental services, see below) may require reallocation between water users (*e.g.* from farmers to cities). Some OECD countries are gaining experience with socially fair and politically acceptable approaches for achieving this. These include water abstraction licences which reflect scarcity; market mechanisms, *e.g.* tradable water rights; and information-based instruments (smart metering). How best to allocate water is still the subject of widespread debate. More needs to be done to properly assess and scale up the use of some of these instruments, to secure environmental values while meeting social and economic needs. Experience from OECD and non-OECD countries indicates that building a strong constituency and aligning incentives are two major requisites (see the discussion below on the political economy of water policy reforms).

- Invest in water supply and sanitation infrastructure, in particular in urban slums where unsafe water and lack of sanitation generate huge health costs and lost opportunities to the economy.
- Catalyse investment and innovation which will underpin sustained growth and give rise to new economic opportunities.

Allocating enough water for healthy ecosystems

The need to restore environmental flows and to allocate more water to watershed services is already generating interesting initiatives in several countries (Box 5.13). Well-designed regulations (on environmental flows) and market mechanisms (such as payment for watershed services) still need to disseminate more widely. They all benefit from more thorough assessments of the benefits of watershed services.

However, shifting water allocation – especially for environmental flows, but also among other users – can be challenging, as it requires difficult policy reforms that overturn expectations about "rights" to existing uses by different stakeholders. Gaining support for such reforms is a major challenge for policy makers. Experience from OECD and non-OECD countries indicates that building a strong constituency and aligning incentives are two major requisites (see the discussion below on the political economy of water policy reforms).

Fostering greater coherence among water, energy, environment and food policies

Water policies intersect with a wide array of sectors at different geographical scales, from local to international; coherent water governance is therefore pivotal. Analysis of water governance arrangements in OECD countries has highlighted that along with a lack of finance for water resource management for most countries, the fragmentation of roles and responsibilities at central and sub-national levels and the lack of capacity (infrastructure and knowledge) in local administrations are both limitations and drivers for future water policy reforms (OECD, 2011g).

The nexus among water, energy, environment and agriculture is close, complex, and challenging. Policy coherence among water policies and other sectoral policies – particularly energy and agriculture – is thus a key component of a co-ordinated approach to water resource management (OECD, forthcoming). Water is an essential element in energy production (*e.g.* for biofuels, hydropower, and cooling techniques for thermal and nuclear power plants). Energy is a critical input for transferring water and tapping alternative sources of water (*e.g.* desalinisation). In an increasing number of locations, there is competition between food and energy commodities for limited water resources. Under current trends, water for the environment and for food production will conflict in several regions (see Rosegrant *et al.*, 2002).

Tensions may arise from real or perceived trade-offs, for instance between food security (and the willingness to secure domestic production) and water productivity (and the allocation of water to activities which add more value). Inefficiencies may result from harmful subsidies (*e.g.* subsidising energy for groundwater abstraction by farmers).

Resolving such tensions requires a global perspective. For instance, freer trade in agricultural commodities and the reform of farm support policies in OECD countries can alleviate some of the tensions between food security and water productivity (Box 5.10). The linkages between the policy areas also have to be considered early on. For instance, when

Box 5.13. **Prioritising the environmental health of water courses: OECD case studies**

Australia

The Australian Commonwealth Government is funding the Water for the Future initiative – a long-term initiative to secure the water supply of all Australians. Under this programme, which involves an AUD 12.9 billion investment over 10 years, the government is acquiring tradable water entitlements with the objective of returning more water to the environment. The water is acquired through direct buybacks of water entitlements from irrigators as well as savings from infrastructure upgrades. These entitlements become part of the Commonwealth environmental water holdings and are managed so that increased flows are provided to rivers and wetlands, particularly within the Murray-Darling Basin (see also Box 5.7). Between June 2009 and July 2011, the Commonwealth government's environmental water holdings rose from 65 to 1 001 gigalitres. By 30 June 2011, over 550 gigalitres of Commonwealth environmental water had been delivered back to rivers, wetlands and floodplains of the Murray-Darling Basin. A strategic Basin Plan is also being developed in consultation with stakeholders from across the Murray-Darling to ensure the integrated and sustainable management of the basin in the longer term. A key part of the plan will be to set limits for water consumption in order to return sufficient water to the environment.

Switzerland

In December 2009, the Swiss Parliament decided that all rivers and lakes should be revitalised to restore their natural functions and to enhance the benefits they provide to society. At the same time the major negative environmental impacts of hydropower generation (surge and flow, reduced connectivity and impaired bed load regimes) are to be mitigated. This is considered a new step in the restoration of river quality in the country.

The following considerations were therefore added to the Water Code:

- River bank space for waters: the ordinance sets minimal width requirements and defines which extensive agricultural practices are allowed. The code requires that space be made available for waters and that this is integrated into a management plan in the next five years.
- Revitalisation: the ordinance defines the process which will be followed to plan the revitalisation. Highest priority will be given to revitalisations with the greatest impacts.
- Reduction of the negative impacts of hydropower generation: the ordinance sets the impacts considered as significant and defines equipments for which remediation actions will be required. It also defines the process for planning and implementing such actions. Recommendations on prioritising small hydropower station projects are being developed to assist local authorities to implement cost-covering remuneration for feeding-in to the electricity grid (Confédération Suisse, 2011).

Sources: Australian Government Commonwealth Environmental Water website: *www.environment.gov.au/ewater/about/index.html*; Confédération Suisse (2011), *Renaturation des Eaux: Modifications d'Ordonnances en Consultation*, Environment Switzerland, Bern/Neuchâtel, available at *www.news.admin.ch/message/index.html?lang=fr&msg-id=33269*.

countries set biofuel production targets, there is a need to factor in potential consequences for water withdrawal in the future.[11]

Policy co-ordination requires institutions to support discussion among different communities. This is more difficult where responsibility is fragmented among various ministries, and where decision making needs to be co-ordinated at different territorial levels (national, regional, state, municipal, river basin, etc.). Institutions' capacity needs to be strengthened through better information and data exchange, sector integration and joint planning.

More coherent policy approaches are beginning to take shape in a growing number of OECD countries. This is particularly evident around climate change, with many countries starting to co-ordinate previously separate policy domains such as energy, water, flood and drought control, and agri-environment (Box 5.14). For example, the restoration of agricultural land in floodplains by planting trees has helped to reduce flood impacts, improve water quality, restore biodiversity and sequester greenhouse gases (OECD, 2010c). While some progress has been made, there is clearly much more to be done to achieve greater policy coherence.

Box 5.14. **Combining hydropower, river restoration and private investment in Bavaria, Germany**

Within the context of the European Water Framework Directive, in 2006 the Bavarian Ministry for Environment, Health and Consumer Protection, the Bavarian Ministry of Economic Affairs, Infrastructure, Transport and Technology and major electric supply companies in Bavaria agreed on a master plan on the future of hydropower in Bavaria, which aims to combine increased use of hydropower with restoring the ecological status of the region's main water bodies.

The implementation of the measures recommended in the plan would result in an increase in climate-friendly hydropower production in Bavaria, and in private sector investments. The plan envisages an increase in the production of hydropower by almost 14% through a combination of new plants at new sites, new plants at existing weirs or steps, modernisation and retrofitting.

Once implemented, the plan will be a good example of how economic development and ecological performance can be mutually reinforcing in Bavaria.

Source: Adapted from Haselbauer, M. and C. Göhl (2010), *Evaluation of Feasible Additional Hydro Potential in Bavaria/Germany*, RMD-Consult GmbH, Berlin, *www.rmd-consult.de/fileadmin/rmd-consult/news/2010_Hydro_paper_HA.pdf*.

Developing alternative sources of water

Tapping alternative water sources – rain and storm water, used water, and desalinated sea or brackish water – or encouraging successive uses of water can help to alleviate scarcity and can be a low-cost response to the water challenge. Additional benefits can include saving energy (depending on the technologies and on contextual features) and cutting investment, operation and maintenance costs. However, there are also risks attached to these technologies (see Box 6.6 in Chapter 6 on Environment and Health for a discussion).

Countries are already accumulating experience with these approaches. For example Israel is using wastewater to recharge groundwater or for irrigation. Pollutant discharges have been reduced by 20% (total nitrogen), 40% (organic matter) and 70% (total phosphorus) since 2000, largely due to the construction of new wastewater treatment plants and increasing reuse of effluent in agriculture. Windhoek in Namibia and Singapore are paving the way in recycling wastewater for urban water supply. Rainwater harvesting is increasingly considered as a complement to piped water supply (*e.g.* it is mandatory in Calcutta).

A wide array of technologies, equipment and systems is available for different uses: wastewater reuse for groundwater recharge, irrigation, gardening, or non-potable domestic uses; rainwater harvesting to increase the yields of rain fed agriculture, or to supply water for non-potable domestic uses, etc. Markets for technologies related to water reuse are booming, contributing to green growth.

Governments and local authorities would benefit from considering installing these alternative water sources and their support infrastructure. Wastewater reuse for irrigation is being adopted in different contexts. Reuse for domestic uses is gaining traction as well, sometimes combined with small-scale, distributed systems. This combination is particularly appropriate in new urban areas where there is no existing central infrastructure; in city centres with decaying water infrastructure or with infrastructure facing diseconomies of scale or capacity constraints; in urban renewal projects; in unstable contexts, where flexibility, resilience and adaptation are valuable (*i.e.* because of climate change impacts); and in projects where property developers operate the buildings they invest in (to recoup investment costs).

The technologies involved are often simple, and future research and development will make alternative water sources (such as sea water desalination) even more competitive. To realise the full benefits of alternative water systems and to mitigate the risks they generate (such as pollution of agricultural land, or health risks), the following steps will be important:

- Involve and inform the public through effective communication and sound evidence; people are usually sceptical about reusing water.
- Provide regulations that allow for alternative options for supplying water to be explored. In particular, water quality standards need to be adjusted to specific uses and potential reuse. Typically, urban wastewater can only be reused if it is not heavily polluted. Such regulations need to factor in several dimensions, including life-cycle costs and benefits, and the risks and uncertainties attached to the various water sources and technologies.
- Ensure that water sector regulators monitor the quality of a variety of water sources.
- Ensure that the price of water reflects its scarcity in order to stimulate markets for alternative water sources.
- Plan the development of several water sources and infrastructure (*e.g.* central and distributed systems) thoroughly, as tapping alternative water sources can challenge the business model of existing operators (either public or private).

Filling information gaps

Reforms and new policies are most successful when: *i)* they rely on robust data and information (on water availability, water use, the costs and benefits of water-related services); *ii)* they are backed by realistic and enforceable action and investment plans; and *iii)* they are designed by a community of stakeholders with a clear understanding of their own needs and priorities.

There is a crucial need to develop water information systems (WIS) to support more efficient and effective delivery of sustainable water resource management and policies (OECD, 2010d). In particular, the rapid development in water policy reforms has created an information imbalance in many countries, with implementation of water policy initiatives often supported by little data and information.

There are also uncertainties when analysing the kinds of trends and model-based projections presented in this chapter because of data gaps and uncertainties surrounding future scientific developments or policy outcomes. Examples of uncertainties include the impact of climate change (patterns of precipitation and temperature change) on water resources at a disaggregated level; the development and diffusion of new technologies in the water sector (*e.g.* desalinisation, leakage control, etc.), in agriculture (*e.g.* new crop varieties, improved agricultural practices, irrigation efficiency, etc.), and in the energy sector (*e.g.* cooling towers, waterless biofuels, water efficiency in energy production operations); the impact of policy measures on economic behaviour (*e.g.* water pricing elasticity); and the responses of water ecosystems to policy and management interventions (*e.g.* as outlined in preparation of river basin management plans in Europe or in the design of "payment for environmental services" schemes).

In addition to these genuine sources of uncertainty, many international and national water information systems are maintained without sufficiently addressing the policy relevance of the data and information that is regularly being collected. Data concerning the economic and institutional aspects of water systems are much less developed than physical data and are only partially covered in the regular updates of most national and international WIS.

To address these issues, there is a need to:

- Assess existing WIS at local, regional, national and international levels to determine how current water information and data are collected (or not collected) and used (or not used) by policy makers, and the costs and benefits of collecting, analysing and communicating this information.
- Implement a System of Environmental and Economic Accounts for Water[12] (SEEAW) that is flexible enough to respond to varying water basin, country and international policy needs.
- Improve the understanding of hydrological systems to better guide WIS data collection efforts, for example improving knowledge of the connections between groundwater and surface water, and determining environmental flows in the context of climate change.
- Encourage innovations in water data collection, such as using new technologies or voluntary initiatives to collect data; or public agencies may regulate, finance or charge for data collection, maintenance and analysis.
- Strengthen economic and financial information including improving the understanding and measurement of the value of water.

Designing reforms that are realistic and politically acceptable

The OECD has gained extensive experience in water policy reforms, learning from successful reforms in member countries, and accompanying water policy reforms in countries of Eastern Europe, the Caucasus and Central Asia (EECCA). Valuable lessons have been learned from this experience in making water reform happen.

A general lesson is that reform is a process that takes time, it is continuous and planning is key. Specific recommendations include:

Build a broad constituency

- Solutions to the water challenges cannot be expected to come from water policies alone, as discussed above. Water authorities need to work with other constituencies, including the agriculture and energy sectors, while taking the environment into account; they also need to work at different levels of government (local, basin, municipal, state and federal levels).
- For river basins which cross international boundaries, international co-operation can help – not only to share information and best practices – but also to share costs and benefits. For example, there has been long-standing co-operation between Canada and the United States through the Canada-US Boundary Waters Treaty and the Canada-US Great Lakes Water Quality Agreement. The United Nations Economic Commission for Europe operates the Convention on the Protection and Use of Transboundary Watercourses and International Lakes, providing an important framework for international co-operation.

Explore a mix of policy options and build capacity

- As noted above, there is a range of policy approaches available to address water challenges (Table 5.1). An optimal policy mix combines a variety of these approaches (for example, Israel's water policy combines improved technologies with water pricing and metering; see Box 5.8).
- Institutions and capabilities have to be adjusted to ensure there is the expertise to make complex technical and non-technical choices and to undertake comprehensive options assessments (including economic, social and environmental impact assessments).

Factor in financial sustainability from the start

- The financial dimension should be factored in early in the process (to avoid designing a plan that is not financially affordable); cost reduction potentials have to be systematically considered; and financial realism needs to be brought to Water Resource Management (WRM) plans.
- There are only three ultimate sources of finance for water-related investment and services, the 3Ts: tariffs, taxes, transfers from the international community (*e.g.* EU funds, or official development assistance). All other sources of finance, which have a role to play, have to be paid back.
- Strategic financial planning can help in defining and prioritising water policies within the practical constraints of available financial resources.[13]
- Financial incentives from other sectors should be aligned with water policy objectives (*e.g.* subsidies for energy or agriculture).

Manage the political process and improve the knowledge base

- Hard facts on the economic dimension of water policies can facilitate water policy reforms, demystify taboos and advance debates. This requires information on water demand and availability, and on the economic dimension and distributional impacts of the reform of water policies.
- Sharing international experience on water policy reforms can substantiate such a process.

Notes

1. Future projections are global, with a particular emphasis on policy actions needed in OECD countries and the emerging economies of Brazil, Russia, India, Indonesia, China and South Africa (BRIICS).
2. See Alcamo *et al*., 2007 for a detailed assessment and review of existing literature on the processes driving water health.
3. More details are given by Visser *et al.* (forthcoming). The disaster database gives information on "weather-related" rather than "water-related" disasters. These terms largely overlap but are not identical. The main difference is the category "storms", which comprises both storm-induced floods, such as due to hurricane Katrina, and the direct impact of wind. The category "floods" comprises coastal, fluvial and flash floods, along with landslides and avalanches.
4. This is because of poor data and because quality may not have systematically improved despite these changes. Over time, improvements in monitoring of physico-chemical pollutants and biological indicators can partly help to address this.
5. The soy is grown in a system of crop rotation, *e.g.* with maize that uses up nitrogen that has built up in the soil; soy grown under these conditions does not leak activated nitrogen into groundwater.
6. The Global Annual Assessment of Sanitation and Drinking-Water (GLAAS) is a UN-Water initiative implemented by the World Health Organization (WHO). The objective of UN-Water GLAAS is to provide policy makers at all levels with a reliable, easily accessible, comprehensive and global analysis of the evidence to make informed decisions in sanitation and drinking water.
7. See Annex 5.A for some assumptions underlying this analysis.
8. This section is based on FAO (2007).
9. Predictions for how long the world's rock phosphorus supply will last are very uncertain. They vary from 50 to over 100 years, but depend on estimates of available resources (van Vuuren *et al*., 2010).
10. See for instance the Keynote by Catarina de Albuquerque (*www.ohchr.org/EN/NewsEvents/Pages/DisplayNews.aspx?NewsID=11017&LangID=E*).
11. van Lienden *et al.,* (2010) calculate that by 2030, water use for first generation biofuels such as sugar cane, maize and soy beans may have increased more than tenfold compared to today, enhancing the competition for freshwater resources in many countries. A breakthrough in producing second generation biofuels that do not require expansion of croplands (*e.g.* using residues from agriculture or forestry) will greatly reduce these impacts on environment and water resources. See further discussions on bioenergy in Chapters 3 and 4.
12. To support implementation of environmental-economic accounts, the System of Environmental-Economic Accounts for Water (SEEA-Water), a SEEA sub-system, provides compilers and analysts with agreed concepts, definitions, classifications, tables, and accounts for water and water-related emission accounts (see *http://unstats.un.org/unsd/envaccounting/seeaw/*).
13. See OECD (2011e) for more information on how strategic financial planning can help in practice.

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ANNEX 5.A

Modelling Background Information on Water

This annex contains further background detail for the following modelling aspects:

- a summary of the projected socio-economic developments behind the *Baseline* scenario;
- freshwater demand, especially irrigation;
- the *Resource Efficiency* scenario;
- water quality, especially nutrient effluents;
- the *Nutrient Recycling and Reduction* scenario;
- people and assets at risk from water-related disasters;
- water supply and sanitation.

More general information on the modelling context for the *Environmental Outlook* is provided in Chapter 1, and further details on the models used are in the Annex on the Modelling Framework at the end of the report.

Socio-economic developments under the *Baseline* scenario

The *Environmental Outlook Baseline* scenario makes projections of a number of socio-economic developments as outlined below (and further discussed in Chapters 1 and 2), and these in turn were used to construct the *Baseline* projections on water-related issues discussed in this chapter (except water-related disasters):

- World GDP is projected to nearly quadruple over the coming four decades, in line with the past 40 years and based on detailed projections on the main drivers of economic growth. By 2050, the OECD's share of the global economy is assumed to decline from 54% in 2010 to less than 32%, while the share of Brazil, Russia, India, Indonesia, China and South Africa (BRIICS) is assumed to grow to more than 40%.
- By 2050, the world is assumed to add over 2.2 billion people to the current 7 billion. All world regions are assumed to be facing population ageing but will be at different stages of this demographic transition.
- By 2050, nearly 70% of the world's population is assumed to be living in urban areas.
- World energy demand is assumed to be 80% higher in 2050 under current policies. The 2050 global energy mix is assumed to be fairly similar to today's, with the share of fossil energy still at about 85% (of commercial energy), renewables including biofuels (but excluding traditional biomass) just above 10%, with the balance being nuclear. Among fossil fuels, it is uncertain whether coal or gas will be the main source of increased energy supply.

- Globally, the area of agricultural land is assumed to expand in the next decade, but at a slower rate. It is assumed to peak before 2030 to match the increase in food demand from a growing population, and decline thereafter, as population growth slows down and yield improvements continue. Deforestation rates are already declining, and this trend is assumed to continue, especially after 2030 with demand for more agricultural land easing (Section 3, Chapter 2).

Water demand

Demands for irrigation are calculated by the process-based LPJmL model (Box 5.A1). LPJmL stands for "Lund – Potsdam – Jena managed Land Dynamic Global Vegetation and Water Balance Model" (Rost *et al.*, 2008). Abstractions for domestic uses are estimated using a relatively simple equation, which takes into account the number of people, their income level, climate and cultural influences and whether or not they are connected to tap water supply. Geographical distribution is modelled from downscaled population projections, corrected for urban/rural splits and income dependent connection rates to tap water systems. Industrial water for processing and cooling purposes is based on the value added of the output produced, corrected by efficiency improvements in processes and applications. A relatively small share of water, though vital at the place of consumption, is used for livestock (see below). Finally, a large and growing volume is assumed to be used in electricity production for cooling purposes. Electricity produced from thermal (steam) cycle plants is the main driver. The model takes into account the change over time in efficiency, the cooling mode and the share of new technologies with reduced cooling water demand, such as combined cycle installations.

Not all demands lead one-on-one to consumptive use. Varying shares are lost to the atmosphere or embedded in products carried off to other locations. The remainder returns to the same water basin, with some delay and changes in heat and pollution load. For water stress calculations, the total demands are compared with the renewable supply, on an average annual basis and aggregated per major water (sub-) basin.

Estimation of historical, current and future water demand is characterised by many uncertainties. Water is often freely available to users, and can be withdrawn from surface waters (rivers, natural lakes, reservoirs), but also from groundwater reservoirs and wells without any formal metering or monitoring taking place. There is very little published monitoring data on the global area equipped for irrigation, and even less for the areas actually irrigated, the water volumes applied to the fields and extracted from river systems. Existing data sources show substantial differences, even for OECD countries, which are relatively well monitored compared to other world regions.

Estimate of water demands in 2000

The global demand for irrigation water estimated with the LPJmL model is estimated at 2 400 m^3 for the year 2000, though estimating this is fraught with uncertainty (see section below). On the global scale as much as 50% of the water extracted is estimated to be lost for effective supply to crops, and does not contribute to soil moisture for plant growth. Other estimates in the literature end up around the same level: *e.g.* 51% (Fischer *et al.*, 2007) to 60% (Fraiture *et al.,* 2007).

Based on an estimate made for the previous OECD *Environmental Outlook* (OECD, 2008a), corrected for population, the estimated global domestic water use for the year 2000 is around 350 km^3, while the demand by the manufacturing sector is estimated to be around 230 km^3. For the manufacturing sector and for electricity production, OECD 2008 calculations were used as the starting point. While water use in different industrial sectors can vary significantly, an overall average relationship with total industrial value added was assumed per geographical region, according to assumed regional structure of the sector and technological level. Over time this relationship was adapted according to assumed structural sector shifts and technological progress.

Box 5.A1. **The LPJmL model: Calculating water demand, especially irrigation**

The LPJmL model describes how water flows are influenced by precipitation, evaporation from soil and water surfaces, and transpiration of plants, both natural and managed by humans. A water balance can be established for each grid cell (see Chapter 1), taking account of land-use patterns, natural vegetation, crop distribution and management, climate parameters (temperature, precipitation and CO_2 concentration), and soil parameters. This shows the resulting run-off per grid cell, *i.e.* the amount that ends up in river systems, lakes and dams, and the volumes available for downstream extraction. The demand for non-agricultural use of water is calculated at the world region level and down-scaled to grid-cell level using the spatial distribution of people and GDP as a measure of human activity. Together with demands for irrigation per grid-cell (see below), the run-off is then corrected for the total withdrawals in the cell. The resulting run-off is passed on to the next downstream cell and so on until the entire water basin is covered.

The irrigation water requirement is calculated by comparing the amount of water needed for unrestrained growth with the supply from precipitation. The gap is filled by irrigation, using surface water and groundwater available in the same or neighbouring grid cells.

Depending on the irrigation system in place and its management, the ratio can vary between the water effectively contributing to soil moisture for plant growth and the volume extracted from river systems. Open canal systems evaporate water and lose water through canal walls, cracks, etc. Piped systems do not lose water through evaporation, but by leaking through faults in joints and pipes. Another variation in efficiency is the method of application on the field, for example sprinklers lose water via evaporation, interception by leaves and drift; surface irrigation loses it to evaporation, surface run-off, non-uniform soil wetting, etc. Drip irrigation close to the roots is the most efficient. In the LPJmL model, estimates are made of the dominant systems in use in countries and regions, and their typical efficiencies (Fader *et al.*, 2010).

The largest global water demand after irrigated agriculture in 2000 was for electricity generation, primarily for cooling of thermal (steam cycle-based) power generation. Based on rough estimates, the global water use for electricity was around 540 km^3 in 2000. Differences of water use per unit of electricity produced between individual thermal power plants can be significant, according to their overall efficiency (from less than 30% to around 60%), the type of plant (steam cycle or combined gas/steam cycle) and the cooling system in place (once-through or closed-loop). Hydropower plants are assumed to return withdrawn water back to the river after use, so except for relatively small evaporative losses from reservoirs they do not contribute to the water demand.

Finally, relatively small amounts of water are needed for livestock globally, estimated at around 25 km^3 in 2000. However, this can sometimes represent a large share of water use locally. Breed varieties, diets and climate all influence water demand from this sector.

Uncertainties in calculating future irrigation demand

Future water demand for irrigation is driven by the change in irrigated area and by the change in water use per area. Future projections on irrigation demand differ widely in the literature. Irrigation is not only driven by biophysical and technical factors, but also by socio-economic and governance factors (Neumann, 2010). For instance, low political stability and low economic strength may reduce the options for irrigation, whereas a strong tradition and government support may stimulate it. These factors are hard to model. Projections published in the literature for future irrigation demand therefore range from the current (uncertain) level to plus 10%-20% until the middle of the century (Alcamo *et al.*, 2007; Bruinsma, 2003; Bruinsma, 2009; Fischer *et al.*, 2007; Fraiture *et al.,* 2007; Shen *et al.*, 2008). For example, Alcamo *et al.* (2007) computed several scenarios of future increase of irrigated land which between 1995 and 2050 ranged between 0.4% and 9.7%. The resulting changes in global irrigation water withdrawals are computed to range between –15.3% and +43.3% over the same period.

The *Environmental Outlook Baseline* projection assumes constant irrigated area and constant water efficiency outside the OECD to 2050. The first assumption will probably underestimate irrigation water demand in 2030 and 2050 and the second assumption may overestimate the demand outside the OECD.

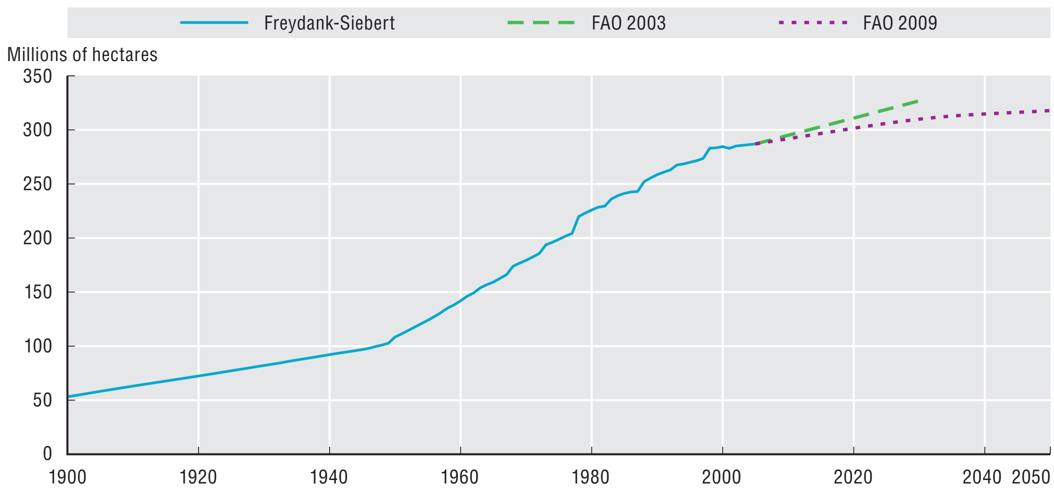
There is a practical reason why the model framework used for the *Outlook* keeps the future irrigated area at its current level. Changing the area would require the model to be able to allocate water demand for irrigation according to different crops and actual locations; this facility is currently not available. Even if the *Environmental Outlook Baseline* projection were to consider a modest expansion of irrigation,[1] the associated growth in irrigation water demands would not alter the total demands decisively. These are increasingly determined by much faster growing demands for domestic and industrial use and electricity production. Other projections of total water demands show a comparable picture (Shen, 2008).

Data from Freydank (2008; also used for FAO projections) show that the area of arable land equipped for irrigation grew between 1900 and 2008 at variable growth rates (Figure 5.A1). However, despite being equipped, the area is often not irrigated for various reasons such as lack of water, absence of farmers, land degradation, damage and organisational problems. No long-term data are available on trends of the area actually irrigated on which to base future projections.

FAO projections made in 2003 assumed an increase in the area equipped for irrigation from 287 to 328 million hectares (Mha) by 2030 (Bruinsma, 2003). A more recent FAO projection (Bruinsma, 2009) reduced the expansion expected to 2030 to 310 Mha (+ 8%), and practically no further increase through to 2050 (Figure 5.A1). All expansion is projected to take place in emerging economies and developing countries.

Methods for projecting future demand range from using a simple rule of constant area per person so the area grows with population (Shen, 2008), to more sophisticated approaches combining potential demand (the ratio of precipitation to evapotranspiration) with local availability of water resources to supply irrigation water (Fischer, 2007). Still others assume investment strategies to meet future food demands through improvements in rainfed and/or irrigated agriculture by targeting either area expansion, or yield and water productivity improvements (Fraiture *et al.,* 2007). A mixed scenario spreads investments over the various measures, resulting in fairly limited expansion of irrigated land (+16%) and water withdrawals (+13%).

Figure 5.A1. **Global area of arable land equipped for irrigation, 1900-2050**



Sources: Bruinsma, J.E. (2003), *World Agriculture: Towards 2015/2030. An FAO Perspective,* Earthscan, London; Bruinsma, J.E. (2009), "The Resource Outlook to 2050: By How Much do Land, Water and Crop Yields Need to Increase by 2050?", paper presented at the *FAO Expert Meeting on "How to Feed the World in 2050"*, 24-26 June 2009, Rome; Freydank, K. and Siebert, S. (2008), "Towards Mapping the Extent of Irrigation in the Last Century: Time Series of Irrigated Area per Country", *Frankfurt Hydrology Paper* 08, Institute of Physical Geography, University of Frankfurt, Frankfurt am Main, Germany.

All the strategies explored by Fraiture *et al.* (2007) assume significant efforts and hundreds of billion dollars of investments. Expanding irrigation is relatively expensive and less cost-effective than other investment strategies for increasing agricultural production explored. The cheapest option is enhanced trade in agricultural commodities, so that production in regions with potential for rainfed agriculture increases at the expense of irrigated agriculture. In their assessment this is the cheapest option, and would mean no change in irrigated area and only a minor change in water withdrawals compared with today.

In addition to the extent, the current and projected amount of water withdrawn per hectare of irrigated land is important for calculating total irrigation water demand. This depends on crop water consumption, the gap between water required to sustain crop growth and precipitation, and the irrigation and water transport system.

In the *Outlook* projection, efficiency improvements are assumed in OECD countries, based on observed trends under current policies. In other regions it is unclear if and to what extent similar improvements can be expected in the absence of specific policies, hence the efficiency is kept constant per region, estimated on the basis of an analysis of prevailing technology and management practices per region (LPJmL model, Fader, 2010).

Crop requirements can be influenced by climate change: a higher temperature induces more evapotranspiration, and changes in (seasonal) precipitation can either decrease or increase the irrigation demand. A related phenomenon is the water-use efficiency of plants, which increases in principle with more elevated atmospheric CO_2 concentration. The LPJ model assumes a relatively strong effect, but the strength of this mechanism is under discussion among experts.

Transporting water for irrigation can result in a range of losses, such as over-watering, leakage from canals or pipe systems, evaporation from uncovered canals and soil, spray losses, etc. Estimates of global average losses range from 40% to over 50%.

Projections in other sectors

In the *Outlook Baseline*, demand for domestic water use increases by a factor of 2.3 between 2000 and 2050. This is a faster growth rate than for the population, caused by rising per capita disposable income and a larger share of the population being connected to tap water supply systems. Industrial use grows by a factor of five over the same period, following a more than sevenfold increase in value added. Finally, water for electricity production is projected to increase by a factor of 2.5 through to 2050.

Water-specific hypotheses under the Resource Efficiency scenario

A simple "what-if" scenario approach was modelled to explore the potential to reduce the water stress observed in the *Outlook Baseline* by reducing demand (van den Berg *et al.*, 2011).

The assumptions made are as follows:

- For irrigation, all non-OECD countries are assumed to improve their efficiency by 15% more than in the *Baseline*. This is based on Fischer *et al*. (2007), who extended an FAO assumption (Bruinsma, 2003) of a 10% improvement by 2030 to reach 20% by 2080. Considering that the annual rate of improvement declines over time, this is consistent with our assumption of a 15% efficiency improvement by 2050. Further efficiencies than those assumed in the *Baseline* are considered less likely for OECD countries and therefore this remains unchanged in this scenario; it is assumed that irrigation in the OECD in the *Baseline* has reached an upper limit of efficiency as risks of salinisation and pollution problems are associated with more than 70% evapotranspiration of irrigation water (Fraiture *et al.,* 2007).
- For domestic and manufacturing uses, it is assumed that water savings can be achieved that are comparable to savings in energy consumption. Hence, compared to the *Baseline*, the water demands in each region are reduced in proportion with the energy savings rate in the *Resource Efficiency* scenario (van den Berg *et al*., 2011).
- This scenario makes the same assumptions as the *450 Core* scenario explored in the Climate Change chapter, (for details, see Chapter 3, Section 4). Larger shares for solar and wind-based power generation *versus* thermal are assumed, but until 2050 an assumed shift to (thermal) bio-energy and nuclear power plants limits the overall reduction in this sector. The assumed reduction in energy demand described in the point above translates directly into less water demand for cooling.
- No adjustment was made for the livestock sector. Demand may well be reduced from dietary and conversion efficiency improvements. But no attempt was made to quantify the effect as the *Baseline* demand is already so small that any adjustment will be negligible compared to the large uncertainties surrounding each of the much larger demand categories.

- Finally, in the (global) *Resource Efficiency* scenario, climate change is well below the *Baseline,* implying lower temperatures and atmospheric carbon dioxide levels compared to the Baseline. Given the net response of the LPJmL model, this may result in slightly higher demand for irrigation water. Differences up to 2050 are relatively limited however, and are not quantified here.

As a result, total water demands in 2050 could be reduced by some 25% under this scenario, from 5 465 km^3 in the *Baseline* to 4 140 km^3. The largest difference between the *Baseline* and this scenario is brought about by reducing water demand from electricity generation (down by 37% in 2050), followed by domestic and manufacturing demands (each down by nearly 30%).

Water quality

Baseline

Nutrient effluents from wastewater

Nutrient flows in urban wastewater were calculated using the approach presented by van Drecht *et al.* (2009). Human nitrogen (N) emission is the N emitted in wastewater by households and industries that are connected to the same sewerage system. The overall approach for calculating human N emission that is actually discharged into surface water is as follows:

$$E^{N}_{sw} = E^{N}_{hum}\, D(1 - R^{N}) \qquad (1)$$

where E^{N}_{sw} is the N emission to surface water (kg person^{-1} yr^{-1}), E^{N}_{hum} is the human N emission (kg person^{-1} yr^{-1}), D is the fraction of the total population that is connected to public sewerage systems (no dimension), and R^{N} is the overall removal of N through wastewater treatment (no dimension). The total P emission to surface water is calculated as:

$$E^{P}_{sw} = \left(E^{P}_{hum} + E^{P}_{Ldet} + \frac{E^{P}_{Ddet}}{D}\right) D(1 - R^{P}) \qquad (2)$$

where E^{P}_{sw} is the P emission to surface water (kg person^{-1} yr^{-1}), E^{P}_{hum} is the human P emission (kg person^{-1} yr^{-1}), E^{P}_{ldet} is the P emission from laundry detergents (kg person^{-1} yr^{-1}), and E^{P}_{Ddet} the P emission from dishwasher detergents (kg person^{-1} yr^{-1}), and R^{P} is the overall removal of P through wastewater treatment (no dimension). E^{P}_{Ddet} is calculated for the population connected to sewerage systems. Dividing by D results in a value that applies to the total population.

The assumptions for the population with access to improved sanitation, population with a sewage connection, detergent use and nutrient removal in wastewater treatment plants are provided in Table 5.A1.

Nutrient effluents from agriculture

Data on fertiliser use, animal manure distributions and fertiliser use efficiency were obtained from trends described in the FAO study *Agriculture Towards 2030* (Bruinsma, 2003), combined with data on crop and livestock production from the IMAGE model.

Generally, in the *Baseline*, farmers in countries with a nutrient surplus are assumed to be motivated to be increasingly efficient in their use of fertiliser. Especially for China a

Table 5.A1. **Scenario assumptions for *Baseline* and point source reduction in the *Nutrient Recycling and Reduction* scenario**

Scenario driver	*Baseline* scenario	Reduction of point sources in *Nutrient Recycling and Reduction* scenario
Population	*Baseline* data	As in *Baseline*
Per capita GDP	*Baseline* data	As in *Baseline*
Urbanisation	*Baseline* data	As in *Baseline*
Fraction of population with access to improved sanitation	2030: reduce 50% of the gap between Su(2000)[1] and 100% improved sanitation. 2050: reduce 50% of the gap between Su (2030) and 100% improved sanitation.	As in *Baseline*
Fraction of population connected to public sewerage	50% of the gap between the situation in 2000 and 100% is closed in the period 2000-2030 and constant afterwards.	As in *Baseline*; in 2030 25% of the urine from connected households is collected and recycled in agriculture; in 2050 this is 50%.
Detergent use	Laundry detergent use and fraction of P-free laundry detergents, and automatic dishwasher detergent use and fraction P-free dishwasher detergents are entirely based on GDP.	In 2030 25% of P-based detergents are replaced by P-free detergents; in 2050 this is 50%.
Removal of N and P through wastewater treatment plants	Removal of N and P through wastewater treatment plants will increase by a gradual shift to a higher technological treatment classes. The removal efficiency per class remains constant; 50% of each treatment class shifts toward the next in line in the period 2000-2030 and another 50% in 2030-2050 (50% of "no treatment" is replaced by mechanical; 50% of mechanical treatment is replaced by biological; 50% of biological is replaced by advanced treatment).	As in *Baseline*

1. Su(2000) = Percentage of urban population with improved sanitation in the year 2000.

rapid decrease in the use of P fertiliser to levels comparable to Europe and North America is assumed, thus reducing emissions to surface water. In countries with nutrient deficits, it is assumed that nutrient discharges to surface water will gradually increase due to increasing fertiliser use.

Total surpluses are calculated on the basis of all inputs. N inputs include biological N fixation (N_{fix}), atmospheric N deposition (N_{dep}), application of synthetic N fertiliser (N_{fert}) and animal manure (N_{man}). Outputs in the soil N budget include N withdrawal from the field through crop harvesting, hay and grass cutting, and grass consumed by grazing animals (N_{withdr}). The soil N budget (N_{budget}) was calculated as follows:

$$N_{budget} = N_{fix} + N_{dep} + N_{fert} + N_{man} - N_{withdr} \quad (1)$$

A positive value for the budget indicates a surplus, and a negative value indicates a deficit. For P the same approach was used, P inputs being animal manure and fertiliser. A surplus represents a potential loss to the environment; for N, this includes NH_3 volatilisation, denitrification, surface run off and leaching; for P, it refers to run off and accumulation of nutrients in the soil. Negative budgets indicate soil N or P depletion. Details on the various terms in equation (1) and the uncertainties can be found in recent peer-reviewed articles (Bouwman *et al.*, 2009; 2011).

Livestock production plays a major role in the nutrient budgets for cropland. An increase in livestock production will cause an increase of manure storage and availability for spreading in croplands, and is therefore an important driver of the increases of N and P budgets in croplands. Production of animal manure is a result of livestock production increase, intensification and productivity increase. The contribution of animal manure to total N budget of croplands is only 6%-14% in OECD countries, while it is up to 50% in some African countries. In India, animals contribute 38% to total N supply, and in China 18%. Similar to croplands, the uses of grasslands by ruminants also involves the development of surpluses. This is because losses of N by NH_3 volatilisation, denitrification and leaching are inevitable. For P, the build up of residual soil P by adsorption to soil material causes the development of surpluses.

In the FAO study (Bruinsma, 2003) assumptions of the fertiliser use efficiency were based on economic and agronomic considerations, and the soil and climatic conditions of the country considered. The use of fertiliser may change as a result of production increase and efficiency changes.

Various ways to analyse efficiency of nutrient use are available (Ladha *et al.*, 2005). This *Environmental Outlook* uses the concept of apparent fertiliser N and P use efficiency (NUE and PUE, respectively), which represents the production in kg dry matter per kg of fertiliser N or P (Dobermann and Cassman, 2004 and 2005; Bouwman *et al.*, 2009). This is the broadest measure of N and P use efficiency, also called the "partial factor productivity" of the applied fertiliser N (Dobermann and Cassman, 2004 and 2005). NUE and PUE incorporate the contributions of indigenous soil N, fertiliser uptake efficiency and the efficiency of conversion of uptake to harvested product. NUE and PUE vary among countries because of differences in the crop mix, their attainable yield potential, soil quality, amount and form of N and P application and management. For example, very high values in many African and Latin American countries reflect current low fertiliser application rates; NUE and PUE values are much lower in many industrialised countries with intensive, high-input agricultural systems. In contrast, countries in Eastern Europe and the former Soviet Union had a rapid decrease in fertiliser use after 1990, causing a strong apparent increase in the fertiliser use efficiency.

In the *Baseline* scenario, generally farmers in countries with nutrient surplus are motivated to use fertiliser increasingly efficiently. For China it is assumed that there will be a rapid decrease of the use of P fertilisers to PUE levels comparable to Europe and North America, and in both China and India further decreases up until 2050, thus reducing emissions to surface water. In countries with nutrient deficits, it is assumed that nutrient discharges to surface water will gradually increase due to increasing fertiliser use.

See Section 3 of Chapter 2 on socio-economic developments, and Box 3.2 in Chapter 3 on climate change for assumptions on developments in agriculture.

Nutrient Recycling and Reduction scenario

Nutrient effluents from wastewater

It is assumed that the urine from 25% of the population with a sewage connection in 2030 and 50% in 2050 will be collected and recycled in agriculture. A gradual replacement of P-based detergents to P-free ones between 2030 and 2050 is also assumed (Table 5.A1).

The potential for P recycling is much larger. Total P removal in wastewater treatment amounted to 0.7 million tonnes a year in 2000, which was assumed to increase to 1.7 million tonnes a year in 2030 and 3.3 million tonnes in 2050. Using this removed P to produce fertiliser could provide 15% of the projected P needed in agriculture (22 million tonnes a year in 2050). However, this would imply considerable efforts to remove heavy metals, pharmaceuticals and other chemicals from sewage sludge.

Nutrient effluents from agriculture

This scenario involves combining different strategies in the crop and livestock production system to improve both productivity and nutrient use efficiency, as follows:

- In crop production systems the yield increase is assumed to be 40% higher than in the *Baseline*. A larger production per unit area is assumed, and thus a smaller harvested area than in the *Baseline*. This could be achieved if fertiliser use as well as fertiliser use efficiencies were higher than in the *Baseline*; it is assumed that half of the yield increase originates from increased fertiliser use and half from improved crop varieties and better management practices, leading to higher efficiencies.
- Major changes are also assumed in the livestock sector. Compared to the *Baseline* the following modifications were made:
  - Production in mixed and intensive production systems is 10% larger, and thus production in pastoral systems 10% smaller.
  - Feed conversion rates (feed use in kg per kg of product) in mixed and industrial production systems are 10% lower.
  - Productivity in mixed and industrial systems is 10% higher (milk production per animal per year, and carcass weight of ruminants).
  - Off-take rates (fraction of animal stock that is slaughtered) is 10% higher.
  - The fraction of concentrates in feed rations is 18% higher (3% to 10% in industrialised countries, and up to 65% increase in developing countries where use of concentrates is currently limited).

  All these modifications have an effect on the use of different feedstuffs, including feed crops. This is accounted for in the IMAGE model. The result of this set of strategies is an improved N and P efficiency, and on top of the improvement in the *Baseline*, N and P excretion rates are assumed to be 90% of those in the *Baseline*.
- A final strategy is to better integrate animal manure in crop production, leading to a reduction in the use of fertiliser.

People and assets value at risk of water-related disasters

The *Environmental Outlook Baseline* assumes that climate change will (still) not be a dominant driver of the occurrence of flood disasters in 2050. This is based on the IPCC *Special Report Managing the Risks of Extreme Events and Disasters to Advance Climate Change Adaptation* (IPCC, 2011). Laurens Bouwer also shows that in the next 40 years, increases in population and GDP by far prevail over climate change as causes of increased risk of flood disasters (Bouwer, 2011).

For the *Outlook* analysis presented in Section 2 on water-related disasters, a static flood map has been combined with dynamic maps of the population and GDP for 2010 and 2050. The following data were used to map potential inundated areas:

- the detailed Dartmouth Flood Database (satellite images): *http://floodobservatory.colorado.edu/*;
- floodplains from the Global Lakes and Wetlands Database (Lehner and Döll, 2004);

- Spaceshuttle Radar Topographic Mission Digital Elevation Map for low coastal zones which might be inundated by the sea (coastal zones were selected at an elevation of maximum 5 metres above sea level): *www2.jpl.nasa.gov/srtm/*.

These three maps were aggregated into one map. The main uncertainty in this map is that it has no return period and no inundation depth in it. The theoretical return period is the inverse of the probability that the event will be *exceeded* in any one year. For example, a 10-year flood (return period) has a 1 in 10 = 0.1 or 10% chance of being exceeded in any one year and a 50-year flood has a 1 in 50 = 0.02 or 2% chance of being exceeded in any one year.[2]

Data on population and GDP were derived from PBL's GISMO model (see Annex 6.A in Chapter 6 on health and environment). The urban and rural population data based on GRUMP are available for 2010 and 2050. The GDP is based on the purchasing power parity (PPP) per capita on a national level. The PPP is used as an approximation of the value of goods at a certain location in order to estimate value of losses from flood risks.

In order to combine the population with the more detailed flooding data, the GISMO results were downscaled from 0.5 by 0.5 degrees to 30 by 30 arcseconds. The GRUMP[3] urban and rural extent dataset, in combination with Landscan 2007 population data, were used to allocate the urban and rural population in the downscaling process. The GDP was downscaled and regionalised using the downscaled population data and the PPP per capita. Concerning the downscaling from cells of 0.5 degrees to cells of 30 arcseconds, the greatest uncertainty is in assigning population to grid cells using GRUMP and fractions based on the Landscan population 2007. Hence, population growth is projected to be within current urban areas; expansion of urban areas is not included, and neither is the development of new cities. Using the GDP based on PPP per nation is just an approximation of the real value of buildings, infrastructure and goods at certain locations within a country.

To calculate the most vulnerable cities the results of population and value at risk were combined with a world cities map. All cells were ranked from 0 to 1 based on the absolute number of people at risk (highest risk is ranked as 1) and the absolute GDP at risk as a proxy for adaptive capacity (lowest GDP is ranked as 1). Both ranking results were summed. This resulted in a list of the cities most vulnerable to floods, *i.e.* those with a high score on both the ranking of population and value at risk.

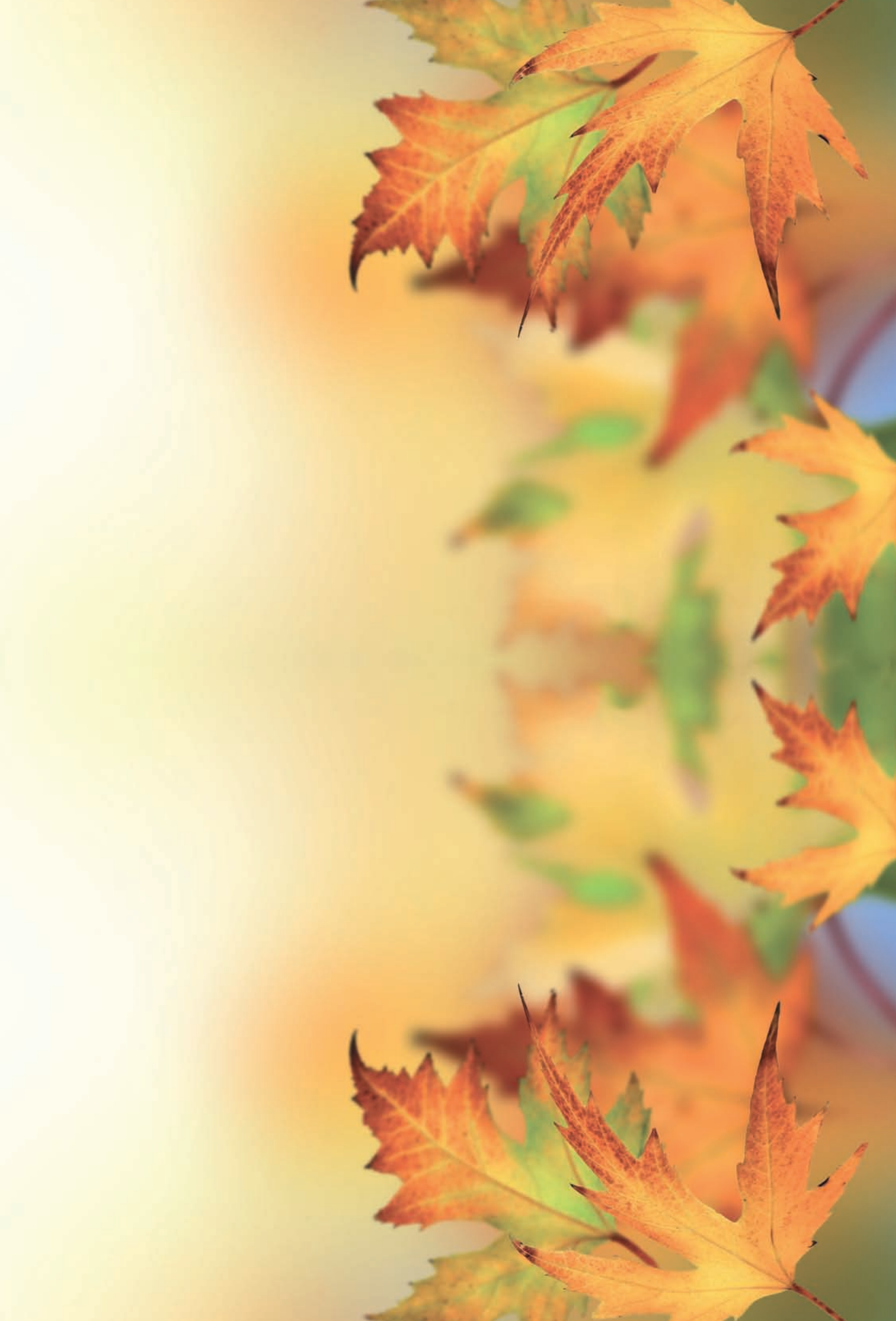
Water supply and sanitation

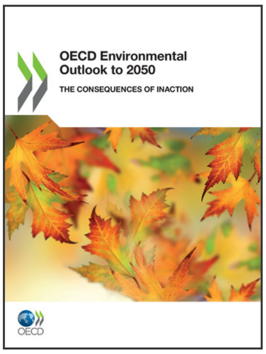
Levels of water supply and sanitation were modelled separately for urban and rural populations by applying regressions based on available data for 1990 and 2000 (WHO/UNICEF, 2008). The explanatory variables include GDP per capita, urbanisation rate and population density. Region-specific parameters are included using calibration.

The associated costs for the projected connection rates are based on Hutton and Haller (2004), who estimated annual costs for various levels of connection rates. Their annualised cost assumptions are based on investment and recurrent costs, using values from the literature. For example, the annual costs for in-house piped water are USD 10-15 per person, while other improved water supply connections range from USD 1-4 per person. It is important to note that the costs in this simulation are approximate since the categories and regions do not fully match those of Hutton and Haller. In addition, translating initial investment costs to annual costs might underestimate the costs when using them over time.

Notes

1. Applying the simple rule of a region-weighted population growth factor for irrigation (Shen, 2008) to the Outlook *Baseline* projection would end up 25% above the current level.
2. *http://en.wikipedia.org/wiki/Return_period*
3. Global Rural-Urban Mapping Project, Version 1 (GRUMPv1). Center for International Earth Science Information Network (CIESIN), Columbia University; International Food Policy Research Institute (IFPRI); The World Bank; and Centro Internacional de Agricultura Tropical (CIAT). 2004. Global Rural-Urban Mapping Project, Version 1 (GRUMPv1). Palisades, NY: Socio-economic Data and Applications Center (SEDAC), Columbia University. Available at *http://sedac.ciesin.columbia.edu/gpw*.





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