PBL Netherlands Environmental
Assessment Agency

Towards a world of cities in 2050

An outlook on water-related challenges

Background report to the UN-Habitat Global Report

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In collaboration with
ARCADIS Shelter program
UNESCO-IHE
VU University Amsterdam

Shelter
initiative by ARCADIS for UN-HABITAT

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VU UNIVERSITY AMSTERDAM

Towards a world of cities in 2050 – an outlook on water-related challenges
Background report to the UN-Habitat Global Report

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PBL Netherlands Environmental Assessment Agency is the national institute for strategic policy analyses in the fields of the environment, nature and spatial planning. We contribute to improving the quality of political and administrative decision-making, by conducting outlook studies, analyses and evaluations in which an integrated approach is considered paramount. Policy relevance is the prime concern in all our studies. We conduct solicited and unsolicited research that is both independent and always scientifically sound.

Contents

Summary

UN-Habitat will publish their fourth global report on water and sanitation in cities. At their request, PBL Netherlands Environmental Assessment Agency has conducted a study on future trends and challenges as input for this global report. Topics addressed are water supply and sanitation, nutrient emissions and water quality, and flood risks.

An increasing population and expanding cities are challenging water management

Around 50% of the world's population currently lives in an urban environment, and this percentage is expected to increase over the coming decades. Under the Baseline Scenario used in this study, major changes in socio-economic and environmental trends are projected. The world's population is expected to grow by more than 2 billion people, to 9.2 billion by 2050. Most of this growth will take place in developing countries and, more specifically, in the urban areas there. By 2050, around 70% of the world's population is expected to live in an urban environment (Figure 1).

As a result, demand for water, food and energy will increase and is expected to put pressure on the environment. Climate change, with higher average temperatures and changing precipitation patterns, combined with increasing competition for available water resources, may result in substantial increases in the number of people living under severe water stress. Without major policy changes, substantial improvements in water management and techniques as well as 'smart' spatial development, this trend is likely to affect quality of life; for example, through increasing impacts on human health.

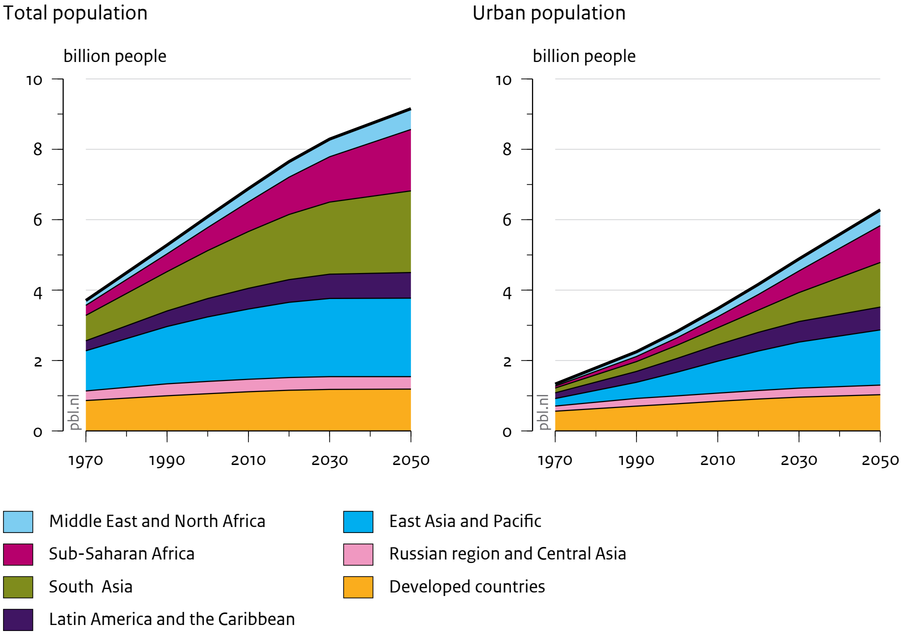
Access to clean drinking water and protection against flooding is fundamental to human well-being. The water management that is needed to meet those needs poses a major and growing challenge – especially in the fast growing cities in developing countries.

Access to water is expected to improve; sanitation to lag behind. The cost-benefit ratio of investments in water supply and sanitation will be positive, with respect to human health

In the coming years, substantial progress may be expected in the access to safe drinking water and improved sanitation. As a result of income increases (which make a higher standard of living more affordable) and increasing urbanisation (which enables more cost-efficient higher coverage rates), the Millennium Development Goals that target water supply have already been attained, globally, and further progress is projected. With respect to access to sanitation, however, current developments show that many countries still lag behind, particularly in sub-Saharan Africa, although here future progress also is projected.

Despite this progress, policy challenges remain. First of all, the Millennium Development Goals only focus on *halving* the number of people without access to improved sanitation. Secondly, the MDGs also only aim to achieve *improved* drinking water services, which even then would still be far from those ensuring a decent standard of living (i.e. in the form of household connections). Thirdly, achieving coverage still does not necessarily mean that connections are safe. For example, increasing water stress may affect water quality, causing negative health impacts.

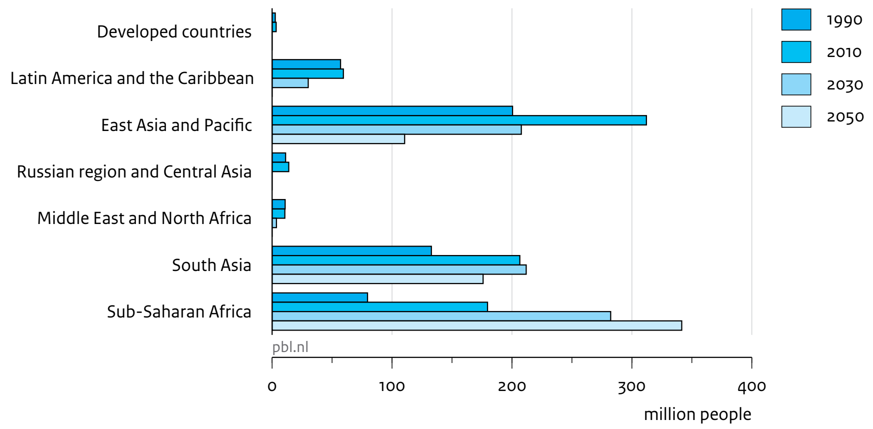
Figure 1
Population and urbanisation under the Baseline Scenario



Source: UN DESA (2009; 2010)

Baseline Scenario for population and urbanisation up to 2050, used in this study for exploring future trends and challenges with respect to water and sanitation in cities.

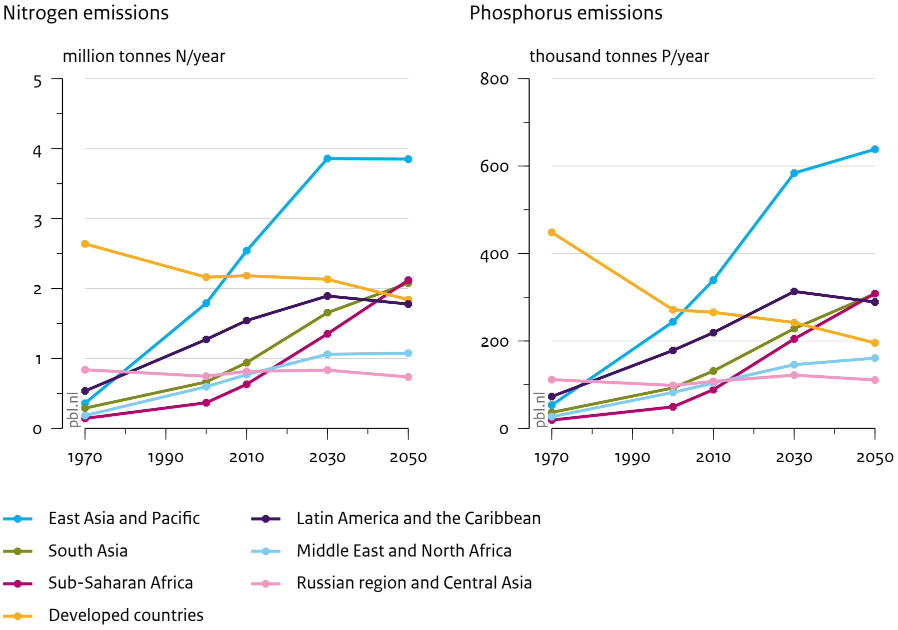
Figure 2
Urban population without improved sanitation



Source: Hilderink et al. (2008)

Population without access to improved sanitation in urban areas, 1990, 2010, 2030 and 2050

Figure 3
Household nutrient emissions to surface water



Source: OECD (2012)

Trends in household nitrogen and phosphorus emissions to surface water

Investments in water supply and sanitation are projected to have a positive cost-benefit ratio, in terms of health impacts and their valuation. Aiming for universal coverage by 2050, an annual 70,000 deaths could be avoided in sub-Saharan Africa alone.

Without action, nutrient emissions will increase. Improved sanitation requires improved waste-water treatment.

A century ago, the dominant pathway for nutrients was their reuse in agriculture; today, the dominant pathway is for them to end up in surface water. Continued investments in waste-water treatment in developed countries are expected to stabilise and restore surface water quality. The quality of surface water in other countries, however, is expected to deteriorate between 2010 and 2050. Under the Baseline Scenario, nutrient emissions in Asia and Africa are projected to double or triple over next 40 years (Figure 3). This will lead to increased eutrophication and biodiversity loss, as well as an increased threat to drinking water, fishery, aquaculture and tourism ecosystem services.

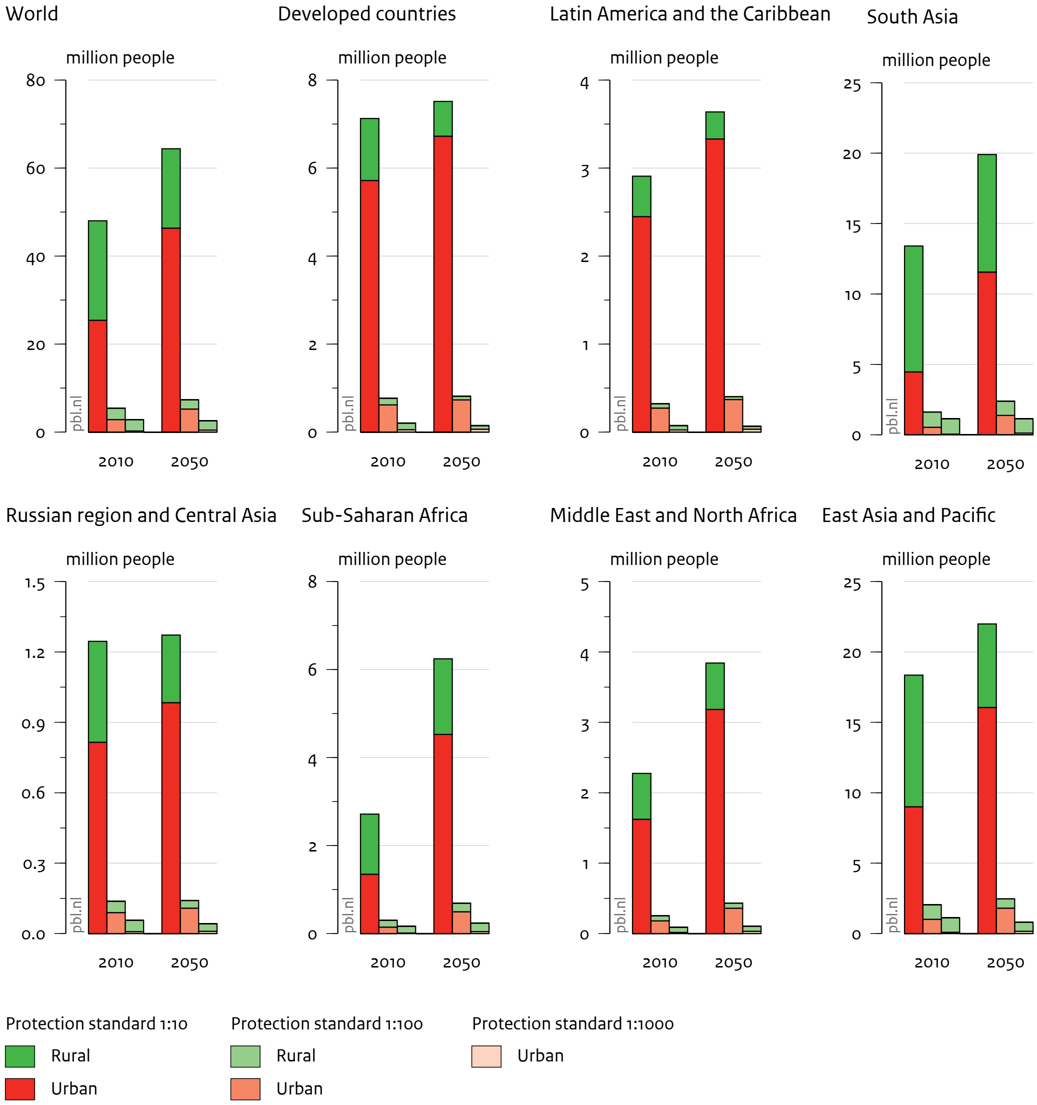
Higher sanitation coverage rates could have a direct positive effect on human health, but may also have adverse effects on the environment if these improved sanitation connections are not combined with waste-water treatment. Population growth combined with higher income levels will further increase nutrient emissions from cities. This poses an increased risk to the quality of drinking water and food production in and around cities.

It is increasingly recognised that the urban water system is best designed, planned and managed in an integrated manner. Waste-water treatment should be part of a larger system, aimed at delivering services to urban dwellers without compromising on sustainability. Options for reducing emission levels and achieving a more sustainable city include better sewage and waste-water treatment systems and the reuse of nutrients in agriculture.

There are many examples of successful large-scale developments in sanitation, sewage and waste-water treatment systems in cities. New technologies and incentives for local reuse of nutrients from sewage sludge may favour comparatively low-cost decentralised options when costs for large-scale systems are too high. For local communities in rural areas, on-site sanitation and better management of faecal sludge may be interesting options.

In transboundary catchment areas, agreements between countries are necessary to improve water quality and

Figure 4
Annual exposed population to floods



Source: PBL

Comparison of urban and rural populations' annual exposure to floods, in 2010 and in 2050 applying different protection standards. Note the difference between the y-axis scales

prevent excessive pollution of coastal waters, resulting in large-scale fish kills and algae blooms.

By 2050, 15% of the global population will live in flood-prone areas. Integrating flood risk strategies in urban development may strongly reduce the loss of lives as well as economic losses

Over the past 30 years (1980–2010), on average, close to 90 million people were affected by flood disasters, and each year around 5,000 people were killed. Average annual global losses due to floods over this period amounted to almost USD 20 billion. Floods make up over 40% of all weather-related disasters, affect the most people and are the second-largest natural cause of economic loss. No climate change signal has been detected in flood disasters in the historical trend up to 2010. Population growth and economic development were the dominant drivers of increases in the numbers of people affected and economic losses due to coastal and river floods.

Leaving aside the effects of climate change, the number of people living in flood-prone areas is estimated to be 1.3 billion by 2050, or 15% of the global population. This is an increase of 0.3 billion compared with the present situation. As urban areas expand, hundreds of trillions of dollars in infrastructure, industrial and office buildings and homes will be increasingly at risk from river and coastal flooding – particularly in Asia. Under the Baseline Scenario, by 2050, there could be 670 cities of 500,000 inhabitants or more, and 88 of which will have more than 5 million inhabitants. Of these 88 cities, 50% will rank highest with respect to vulnerability to flooding, based on the size of the population exposed and GDP per capita. The most vulnerable megacities could be Dhaka, Kolkata, Shanghai, Mumbai, Jakarta, Bangkok and Hoh Chi Minh City.

There is a wide range of measures available to reduce flood risk. Figure 4 shows both the strong increases in annual exposed population by 2050 – especially in the urban areas – and the potentially large effects of improving flood protection. Given the potentially large effect of these measures, it is important for cities and countries to pay serious attention to the development of adequate flood risk strategies. The costs of adequate flood protection measures may not necessarily be high, and high concentrations of assets and people in cities may provide an opportunity for highly cost-effective flood protection strategies, strongly reducing both loss of lives and economic losses

Flood vulnerability is unevenly distributed within cities and, often, the poorest suffer disproportionally. Within the context of environmental justice, public authorities face the challenge of improving the level of protection against flooding without increasing the inequality with respect to flood risk.

Towards integration of water-related challenges in urban development

The findings of this report show that, in the coming decades, major changes and challenges lie ahead. Despite positive developments policy challenges remain; for example, regarding the health impacts of improved water supply and sanitation. Each chapter in this report identifies potentially successful policy options that would result in an improvement regarding the issues at hand. However, there are also important interconnections between the various water issues. For example, investing in sanitation without adequate investment in waste-water treatment would, in fact, deteriorate the water quality in rivers, lakes and coastal waters. In turn, poorer water quality could impact human health. Also, despite sufficient investment in water supply, sanitation and waste-water treatment infrastructure, urban expansion – which will take place particularly in developing countries – could still be at risk if flooding is not taken into account. This calls for a more integrated approach in urban development, in which these aspects are considered in combination. A promising concept that allows for such an integrated approach is that of 'smart cities'. Applying such a concept to the water challenges of the future ('smart water') may help create cities that use water and energy more efficiently, reuse water and waste-water treatment products (such as nutrients), and achieve the smart and climate-proof design of sewage and waste-water treatment systems, urban development plans and green and blue infrastructure, preventing urban flooding and reducing flood risks.
Existing and newly developed city networks are important platforms to exchange knowledge, understand the common challenges and share best practices and innovations that can support cities in their economic, spatial and social development strategies.

Introduction

1.1 Main messages

- UN-Habitat will publish a report entitled 'Global report on water and sanitation in cities of the future' (working title). PBL Netherlands Environmental Assessment Agency (PBL) has been commissioned by UN-Habitat to produce an input report for this global report.
- This input report provides future projections of relevant issues relating to water and sanitation, making use of PBL's global modelling suite. PBL has a proven track record in producing integrated assessments with a strong modelling component. Given the limited resources available, the projections have been based on available scenario studies, such as the OECD Environmental Outlook, Roads from Rio, and studies commissioned by the Dutch Ministry of Foreign Affairs.
- Based on an inventory of PBL studies, the following topics were included: 1) water supply and sanitation, 2) nutrients in surface water and wastewater treatment, and 3) flood risks.

1.2 Context: towards a world of cities

Around 50% of the world's population currently lives in an urban environment, and this percentage is expected to increase in the coming decades. A growing urban population provides both opportunities and challenges. Opportunities, because a high concentration of people makes it easier to supply a larger part of the population with adequate health and water services, as well as improve the efficiency of energy, water and land use. Growing cities will also provide opportunities for implementing and disseminating new knowledge and technologies relating to urban planning and building design, as well as the development of traffic, energy and water service systems (Glaeser, 2011).

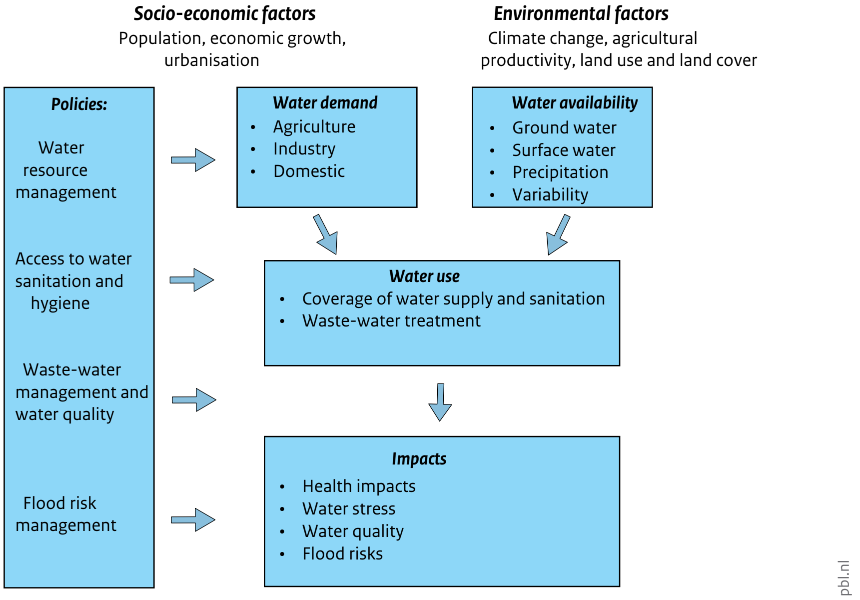
At the same time challenges arise about how to protect the environmental quality in and around these fast-growing cities. To connect more people to a sewerage system is one important step, but without proper wastewater treatment the receiving rivers and coastal zones will become polluted with excess nutrients, heavy metals and other health-threatening substances. History shows that failure to acknowledge this results in a decline in environmental quality. Consequently, poor air quality, water quality and spatial quality will strongly reduce the quality of the living environment and health of the city population. Very often, the effects of environmental pollution, poor water availability and poor health services, and the resulting losses in health and quality of living are unequally distributed among the urban population, with the poor often suffering the most (MEA, 2005). Segregation and inequality in cities is of all times and all regions (Nightingale, 2012), but in many cities – especially in developing countries – slum dwellers number more than 50% of the population and have little or no access to shelter, water and sanitation (UN-Habitat, 2005). Reducing inequality and poverty in cities on the path towards 2050 may well be one of the major challenges of the future.
Climate change forms an additional challenge for these urban areas (IPCC, 2013). Temperature rises, the increasing frequency and intensity of rainfall or drought, rising sea levels and changing river discharges need to be addressed while developing new urban areas and restructuring the old.

1.3 Fourth UN-Habitat report

UN-Habitat will publish a report entitled 'Global report on water and sanitation in cities of the future' (working title). This report will be the fourth report on this topic. Following the mandate of the 19th Governing Council, resolution 19/6, UN-Habitat has made 'Water and sanitation in the world's cities' a recurrent publication,

Figure 1.1

Conceptual framework of water-related issues



published every three years. In 2003, UN-Habitat published the first edition entitled 'Water and sanitation in the world's cities: local action for global goals'. The second report, 'Water and sanitation in the world's cities: meeting development goals in small urban centres' was published in 2006, and the third report, 'Water and sanitation in the world's cities: solid waste management in the world's cities' was published in 2010. This report focused on the management of solid waste and bio-solids in urban centres. A forward-looking perspective will be taken in the fourth report in 2014. It is with regards to such a forward-looking perspective that PBL can make a particularly useful contribution, based on recent PBL scenario studies that include the OECD Environmental Outlook, Roads from Rio, and other projects for the Dutch Ministry of Foreign Affairs. It is for this reason that UN-Habitat has asked PBL to write a background report to be used an input for the upcoming UN-Habitat report.

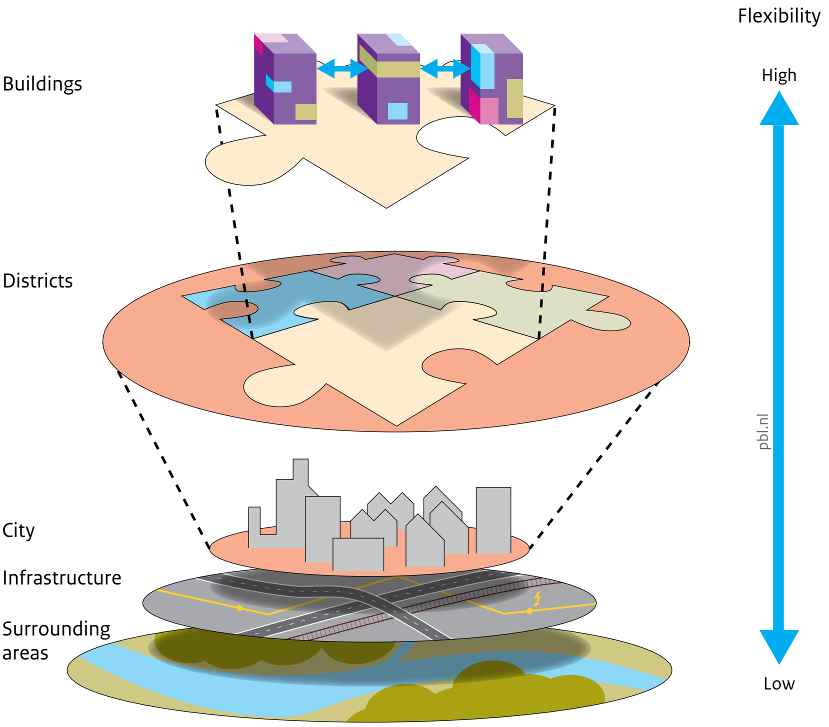
1.4 OECD Environmental Outlook-based approach

Based on an inventory of PBL studies, the following topics were identified as being of interest: 1) water supply and sanitation, 2) nutrients in surface water and wastewater treatment, and 3) flooding risks. The approach taken in this report is based on recent PBL scenario studies. One of the most relevant studies used is the OECD Environmental Outlook, which includes a thematic water chapter (OECD, 2012). The OECD Environmental Outlook covers all three topics at the global level, while also allowing differentiation by urban and rural populations or certain regions. Another relevant study is the Roads from Rio report (PBL, 2012), which focused on potential policy pathways for achieving globally agreed policy targets. Choosing an existing scenario study has the advantage that some parts of the work – including the capacity-intensive ones – have already been done. It obviously also has its disadvantages, as the selection of issues cannot be altered, the time horizon and units of analysis (i.e. regional breakdown) are already fixed, and the scenario logics, for example a baseline approach with a single incarnation of the future, are determined without having this particular application in mind. However, given the topics covered in the OECD Environmental Outlook, the relatively detailed unit of analysis of the simulation models used and the time horizon of 2050, it was considered to provide a sound basis for this study.

1.5 Conceptual framework

The following conceptual framework was used to position and analyse the water-related issues in cities. This framework (see Figure 1.1) shows the most relevant contextual socio-economic and environmental factors related to various aspects of water addressed in this report. These are demand, availability, use and impacts. The different policies that may influence these water aspects are also shown. These policies are water resource

Figure 1.2
Adaptation measures at various scales within the urban environment



Source: PBL

Various scales for water-related adaptation policies in the urban environment

management, access to water supply and sanitation, wastewater management and flood risk management.

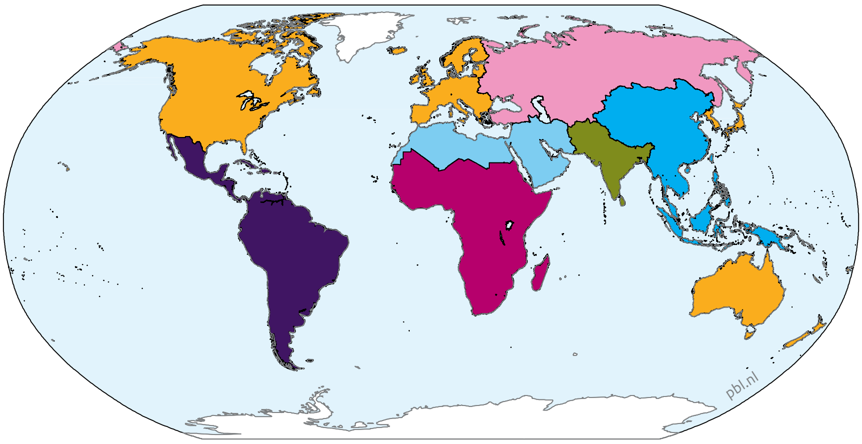
1.6 Water-related policy options

There are many ways to position water-related policies in the urban environment, at various scales, and with many actors involved in the planning and implementation. This requires close cooperation between the various social actors and a clear division of responsibilities between government, public parties, private companies and the general public. Figure 1.2 provides an overview of the relationships between the various scales and associated policy options and actors, using adaptation measures as an example. In this report, we focus on policy interventions that aim to improve water supply and sanitation and water quality, and that anticipate and lower flood-related risks.

1.7 This report

The outline of this report is as follows. The Baseline Scenario is described in Chapter 2. This includes the most important socio-economic and environmental drivers (such as population, urbanisation and climate change). Other aspects of water that are not specifically covered by other chapters, such as water demand and water stress, are also presented in Chapter 2. Drinking water and sanitation are discussed in Chapter 3, and water quality in Chapter 4. In Chapter 5, the possible impact of flooding in terms of people and assets at risk is calculated. In the final chapter, Chapter 6, the overall findings and conclusions are presented and discussed within the broader context of the concept of smart cities. The analyses in this report are mostly conducted at a grid level of 0.5 by 0.5 degrees for environmental aspects such as land use and climate change, and 30 by 30 seconds for flood risks. For socio-economic aspects such as economic growth, population and health the analyses are carried out for the 27 world regions and countries in the IMAGE modelling suite (Bouwman et al., 2006). The final results are presented at the aggregated level of the seven World Bank regions (see Figure 1.3).

Figure 1.3
World Bank Regions



World Bank region

- Developed countries
- East Asia and Pacific
- Russian region and Central Asia
- Latin America and the Caribbean
- Middle East and North Africa
- South Asia
- Sub-Saharan Africa

Source: World Bank

Regional presentation used in this report (World Bank, 2014)

Text box 1.1 Water and the Sustainable Development Goals

The definition, design and implementation of long-term sustainability goals has taken centre stage in the United Nations with the discussion on the post-2015 development agenda, as a follow-up to the Millennium Development Goals (MDGs), and the Sustainable Development Goals (SDGs) that emerged from the 2012 UN Conference on Sustainable Development (Rio+20). It was recognised at Rio+20 that 'water is at the core of sustainable development', and Member States reconfirmed previous commitments made in the Johannesburg Plan of Implementation and the Millennium Declaration, also regarding the right to safe drinking water and sanitation. Furthermore, the pervasive links between water and other priority areas were reflected in the Rio+20 outcome document.

The open consultation on water concluded that Water, Sanitation and Hygiene (WASH), Water Resources Management and Wastewater Management and Water Quality are all indispensable elements for building a water-secure world (UN-Water, 2013). This is also recognised in the many proposals for a post-2015 development agenda, many of which integrate the social, economic and environmental dimensions of the water challenge in one single goal (Griggs et al., 2013; HLP, 2013; UNGC, 2013; UNSGAB, 2013). UN-Water (2014) builds on all these reports and proposes a goal to 'secure sustainable water for all', with five underlying targets that address:

- drinking water, sanitation and hygiene;
- water resources;
- water governance;
- water-related disasters;
- wastewater pollution and water quality.

It should be noted that the very local nature of water poses challenges regarding the reconciliation of a universal agenda with the variety of national, local or basin-specific realities. This report provides insights into the magnitude of these future challenges and possible policy interventions for achieving these five targets.

TWO

Baseline Scenario

2.1 Main messages

- Under the Baseline Scenario, the world population is projected to grow by 2.2 billion between 2010 and 2050, reaching almost 9.2 billion by 2050. In the 49 least developed countries, the population is projected to double in size.
- In 2050, nearly 70% of the world's population will live in cities, which implies an urban population increase of 2.8 billion compared with today. This will have positive economic consequences, but may also lead to higher environmental pressures.
- World GDP is projected to quadruple between 2010 and 2050. Between 2010 and 2030, GDP growth will be largely driven by the increased use of physical capital.
- The world energy demand by 2050 is projected to be about 80% higher than today; the area of agricultural land is projected to peak before 2030 and decline thereafter; the area of irrigated land is assumed to remain constant up to 2050. This latter assumption may result in an underestimation of future water stress in some regions.
- By the end of the 21st century, the global average temperature is likely to be 3 °C to 6 °C higher than pre-industrial levels. Temperature rises and precipitation changes will be unequally geographically distributed.
- Global water demand is projected to increase by 55% between 2000 and 2050, with sharp rises expected in the emerging economies. Competition for water between urban claims and water for irrigation will intensify. By 2050, 3.9 billion people – over 40% of the world's population – are projected to live in river basins under severe water stress.

2.2 Introduction

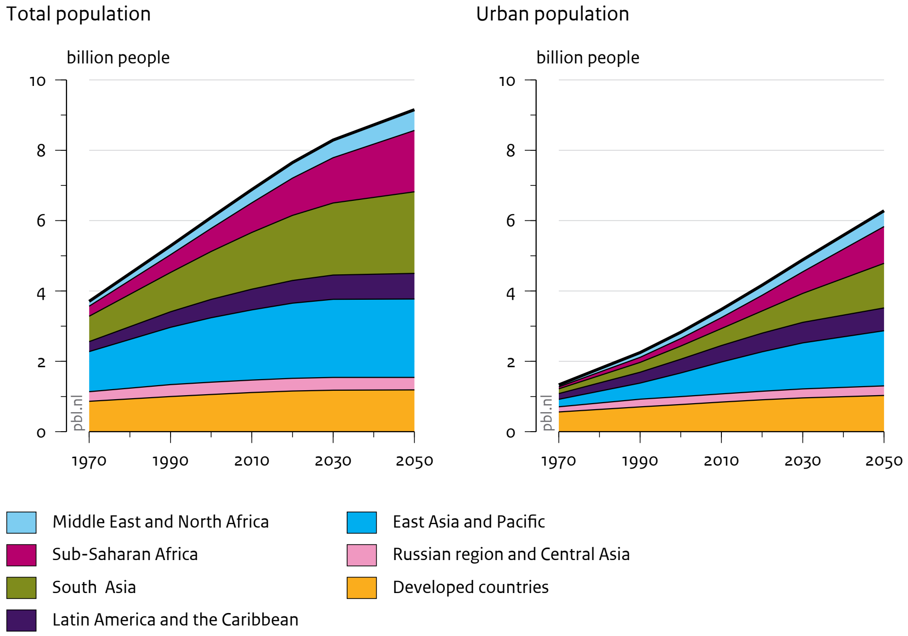
This chapter describes the Baseline Scenario used for the analysis in the following chapters. The scenario stems from the third OECD Environmental Outlook (OECD, 2012). It assumes that no new policies are introduced and provides a benchmark against which the different policy variants are assessed.

2.3 Main drivers: demography, urbanisation and economy

Demographic developments

Future population growth is based on the medium projection of the UN World Population Prospects (UN DESA, 2009). According to this projection, the world population will grow by 2.2 billion between 2010 and 2050, reaching almost 9.2 billion people. Most population growth will take place in developing countries, and in the 49 least developed countries in particular, where the population will double in size (Figure 2.1).
Between 2010 and 2050, nine countries are expected to account for half of the world's projected population increase. These are India, Pakistan, Nigeria, Ethiopia, the United States of America, the Democratic Republic of Congo, the United Republic of Tanzania, China and Bangladesh (listed according to the size of their contribution to global population growth). The population of Africa could double by the middle of the century, from around one billion in 2010 to two billion by 2050.
According to the 2012 UN World Population Prospects (UN DESA, 2013), the global population may increase up to 9.6 billion by 2050, with a margin of plus or minus 1.3 billion in the high and low variants, meaning that the projections used in the Baseline Scenario are within the lower margin of uncertainty of this newer projection. The 2012 revision projections are particularly higher for Africa, with the medium variant projecting a population of 2.4 billion by 2050.

Figure 2.1
Population and urbanisation under the Baseline Scenario



Source: UN DESA (2009; 2010)

Main socio-economic drivers – population and urbanisation

Urbanisation

Future urbanisation is based on the UN World Urbanization Prospects (UN DESA 2010). By 2050, 2.8 billion more people than today are projected to be living in urban areas, which is more than the total population growth. In 2050, nearly 70% of the world's population will live in cities (Figures 2.1 and 2.2). The urban population is projected to be unevenly distributed around the world. In OECD countries, it is projected to be 86% of the total population by 2050, and in sub-Saharan Africa it is projected to increase from 37% in 2010 to 60% by 2050, implying high growth rates. Growth rates are also high in urban agglomerations in Southeast Asia. Small urban centres of less than 0.5 million inhabitants are projected to grow more rapidly than other urban areas.

A positive consequence of urbanisation may be higher economic growth because of the higher concentration of activities leading to economies of scale. The provision of infrastructure for the delivery of energy, water and sanitation may also be easier with higher concentrations of people. On the other hand, concentrated economic activities and traffic can lead to environmental problems caused by air and water pollution (OECD, 2012). High growth rates also put pressure on the ability to keep pace with the required provision of water and sanitation facilities. Furthermore, one in every three city dwellers worldwide – about one billion people – currently lives in a slum (UN-Habitat, 2003; 2006). The total number of slum dwellers is expected to grow, especially in rapidly growing cities in developing countries. Problems with substandard housing and inadequate water, sanitation and waste management services could therefore become magnified (OECD, 2012).

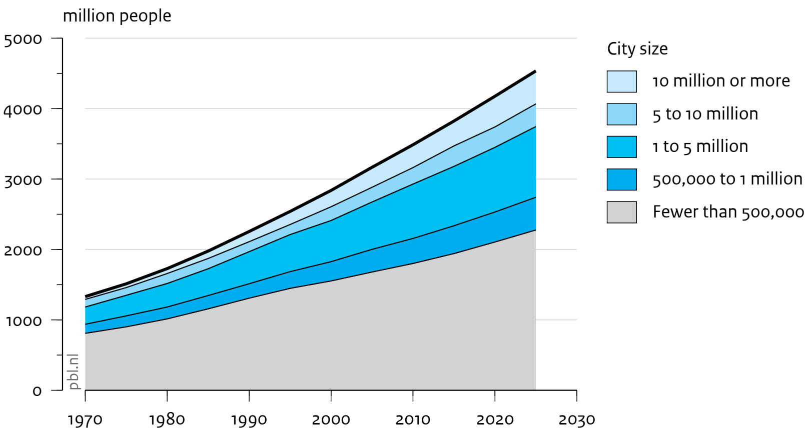
Economic developments

GDP growth under the Baseline Scenario is driven by: i) increasing the value added of production through the increased use of capital, labour and natural resources (including land), ii) increasing the productivity of these primary production factors, and iii) reallocating production factors to those activities that yield the highest value added. Between 2010 and 2030, GDP growth will be largely driven by the increased use of physical capital (such as buildings, machines and infrastructure). In the longer term, GDP growth will partially converge across economies and physical capital accumulation and human capital will contribute more equally to GDP growth.

As a result, global GDP will nearly quadruple between 2010 and 2050. The share of the developing countries Brazil, Russia, Indonesia, China and South Africa is projected to grow to more than 40%, while the share of developed countries is projected to decline from 54% in 2010 to around 30% by 2050. Africa is projected to experience high economic growth between 2030 and 2050, but will remain the poorest continent (Figure 2.3).

Figure 2.2

Global urban population, according to city size, under the Baseline Scenario

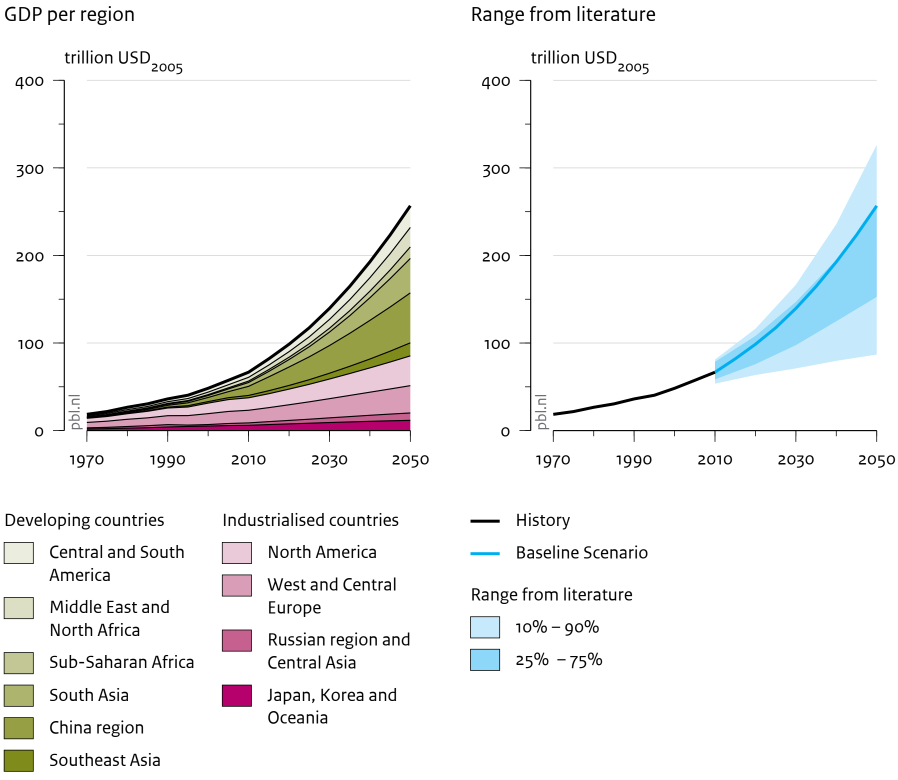


Source: UN DESA (2010)

World urban population by city size, 1970–2025

Figure 2.3

Global GDP growth under the Baseline Scenario



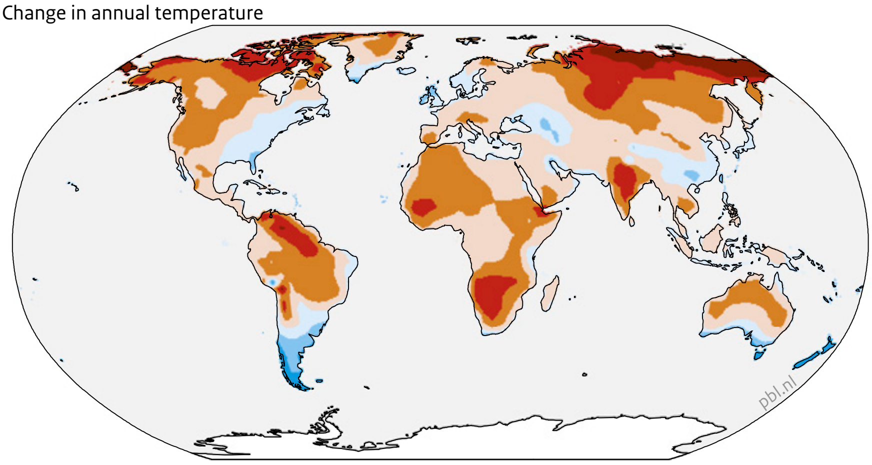
Source: World Bank (2009), OECD (2012) and literature range from Van Vuuren et al. (2012)

Global GDP trends under the Baseline Scenario

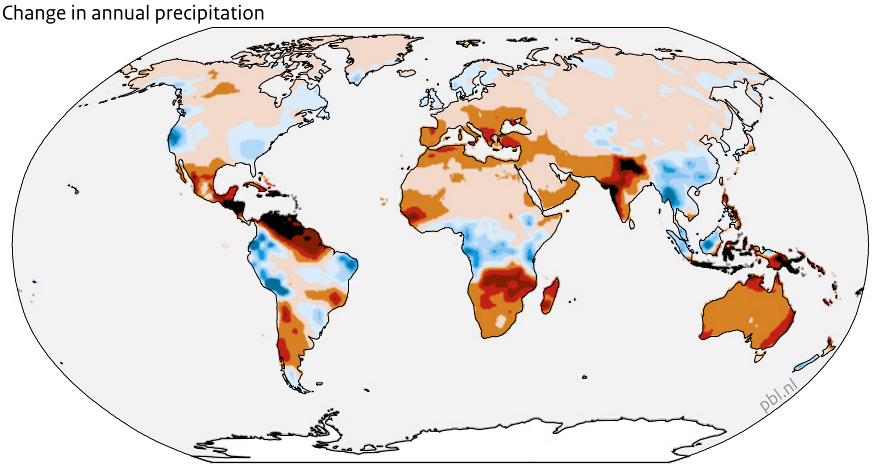
Figure 2.4

Regional climate change, temperature and precipitation, in 2050, under the Baseline Scenario

Change in annual temperature



Change in annual precipitation



Temperature change (°C)

- < 0.5
- 0.5 - 1.0
- 1.0 - 1.5
- 1.5 - 2.0
- 2.0 - 2.5
- 2.5 - 3.0
- 3.0 - 3.5
- 3.5 - 4.0
- > 4.0

Precipitation change (mm/day)

- < -0.6
- -0.6 - -0.4
- -0.4 - -0.2
- -0.2 - 0.0
- 0.0 - 0.2
- 0.2 - 0.4
- 0.4 - 0.6
- 0.6 - 0.8
- 0.8 - 1.0
- > 1.0

Source: OECD (2012)

Climate change under the Baseline Scenario

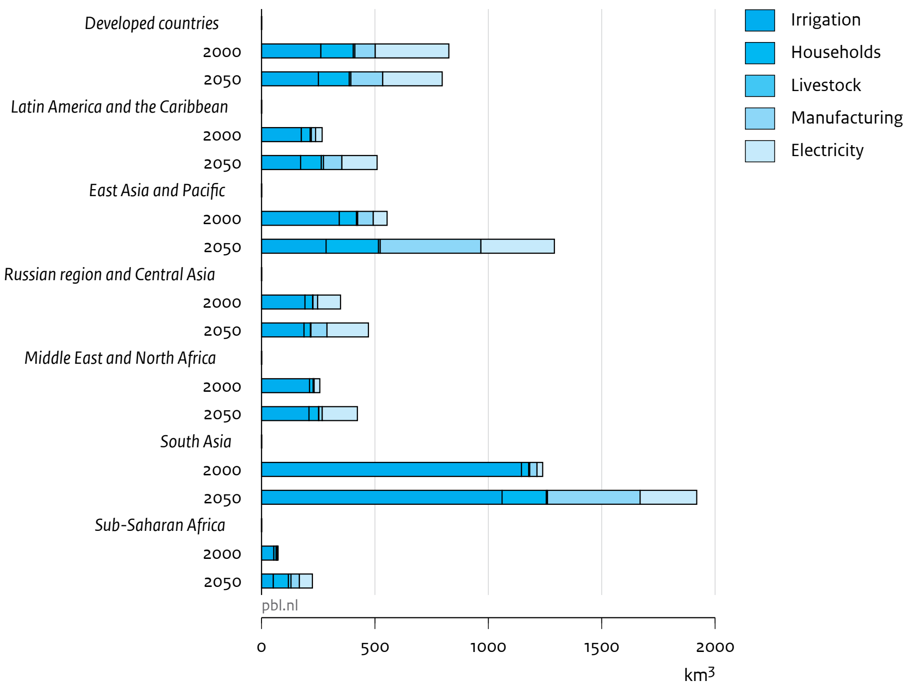
2.4 Energy, land and climate in relation to water

The trends sketched above will make demands on the Earth's natural resources. In this section, the impacts on energy use, land and climate are outlined.

Energy production

Energy use is essentially driven by economic activity and technological developments. Assuming no change in current policies, the world energy demand by 2050 is projected to be about 80% higher than it is today, with fossil fuels retaining a large market share of 85% (OECD, 2012). This growing need for energy will lead to a growing water demand for cooling in power stations (see Section 2.5). Other energy-use related impacts on the water system are higher flood peaks and lower basic

Figure 2.5
Blue-water demand under the Baseline Scenario



Source: OECD (2012)

Blue water demand: 2000 and 2050 under the Baseline Scenario

Please note: Blue water here describes fresh water in aquifers, rivers and lakes, suitable for human use; for example, for irrigation, human consumption and livestock, and in manufacturing and power generation.

river flows due to deforestation caused by the use of traditional bio-energy, water withdrawal and pollution related to the growing of irrigated bio-energy crops and the building of dams for hydropower generation. Overall land-use change and irrigation are included in the Baseline Scenario; the effects of river dams on water availability and quality are not.

Land use

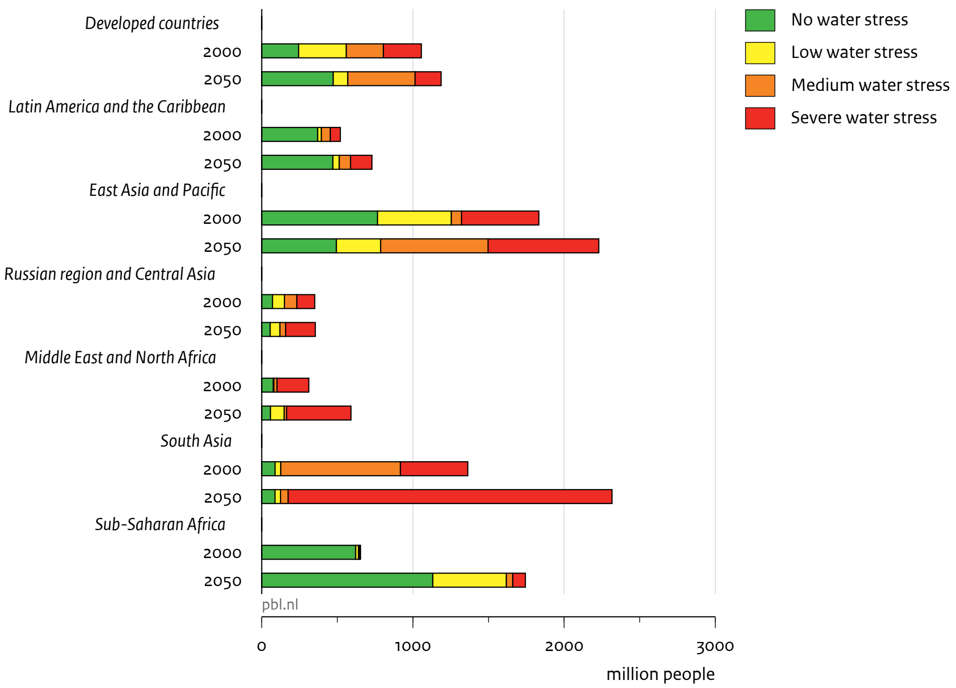
The area of agricultural land is projected to expand in the next decade to match the increase in food demand from a growing population. Agricultural land is projected to peak before 2030 and decline thereafter as population growth slows and yield improvements continue. Agricultural land area will increase most in the less developed countries, especially sub-Saharan Africa, where population and economic growth are projected to be the largest.
There is significant uncertainty about the current extent of and future increase in irrigated land and irrigation water use. Under the Baseline Scenario, the area of irrigated agricultural land is assumed to stay constant up to 2050 for several reasons. For example, available land for irrigation is scarce and where it is available it is unlikely to be irrigated soon because of lack of infrastructure and limited public funds. Furthermore, there will be increasing competition with other water demands, and water resources in highly irrigated areas are declining. The assumption that the area of irrigated agricultural land will remain constant means that the Baseline Scenario may underestimate future water stress in some regions.

Climate change

As a result of increasing energy production based on fossil fuels and increasing agricultural area expansion, the atmospheric concentrations of greenhouse gases are projected to increase to almost 685 ppm CO2 equivalents by 2050. By the end of the 21st century, the global average temperature is likely to be 3 °C to 6 °C higher than pre-industrial levels. This will continue to alter precipitation patterns, melt glaciers and ice caps, cause sea-level rise and intensify extreme weather events (OECD, 2012).
Temperature rises and changes in annual precipitation are geographically unequally distributed, thereby also differently affecting local agriculture and water systems (Figure 2.4).

Figure 2.6

Number of people living under water stress under the Baseline Scenario



Source: OECD (2012)

People experiencing water stress, under the Baseline Scenario

2.5 Water demand and water stress

This section discusses water demand and water stress under the Baseline Scenario. The Baseline Scenario's results for water supply and sanitation, water quality and flooding risks are described in Chapters 3, 4 and 5, respectively.

Water demand

Over the last century, water demand has risen twice as fast as population growth. In 2000, agriculture – primarily for irrigation – accounted for about 70% of the total global freshwater demand. Electricity generation – primarily for cooling thermal (steam cycle-based) power generation – accounted for the second largest share. Under the Baseline Scenario, global water demand is projected to increase by 55% between 2000 and 2050, mainly caused by increased demand from manufacturing (+400%), electricity production (+140%) and domestic use (+130%) (Figure 2.5). Sharp rises in water demand are expected in South Asia and China, as well as in other emerging economies. In the face of these growing demands, competition between urban claims and water for irrigation will intensify.

Water stress

Increasing demand for water will exacerbate water stress (a water exploitation rate of more than 40%) 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 demand. By 2050, 3.9 billion people – over 40% of the world's population – are projected to live under severe water stress (Figure 2.6). This holds for almost the entire population of South Asia and the Middle East, and large parts of China and North Africa's population. In many regions of the world, groundwater is being exploited faster than it can be replenished. The rate of groundwater depletion more than doubled between 1960 and 2000, reaching over 280 km3 a year in 2000. The consequences for daily life are uncertain, and depend greatly on the adequacy of water management strategies put in place.

THREE

Water supply and sanitation

3.1 Main messages

- The number of people with access to a safe water supply is projected to increase, while developments with respect to basic sanitation will lag behind, especially in sub-Saharan Africa.
- Investments in safe water supply and improved sanitation show a positive cost-benefit ratio in terms of costs, health impacts and valuation of the health impacts.
- The Millennium Development Goal relating to an 'improved source' should be advanced towards a 'safe source'.

3.2 Introduction

In 2011, almost 800 million people did not have access to an improved drinking water source, while around 2.5 billion people lacked access to an improved sanitation facility (WHO/UNICEF, 2013). Around 70% of all people without improved sanitation live in Asia, while progress has been slowest over the last decade in sub-Saharan Africa. Although almost 1.9 billion people have gained access to an improved sanitation facility since 1990, in relative terms the situation has worsened in South Asia and sub-Saharan Africa (Figure 3.1). Of these 1.9 billion people, 1.1 billion people gained access in urban areas, while the total urban population grew during the same period by 1.3 billion. An important question therefore is whether future increases in connection rates will be able to keep up with further rising urbanisation rates.

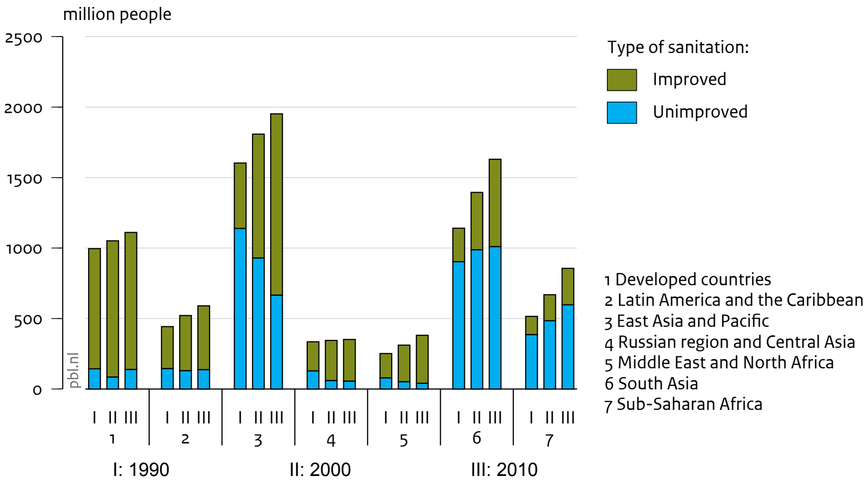
Safe drinking water and basic sanitation are important to human health. Furthermore, improvements in safe drinking water and basic sanitation can have significant economic benefits. These benefits relate to an improved health status (in relation to morbidity and mortality), time saved in water collection and increased potential for small enterprises.

In 2004, unsafe water supply and sanitation (WSS) and the associated exposure to pathogenic micro-organisms were responsible for around 1.8 million deaths and 6.3% of worldwide disability-adjusted life years (DALYs) (WHO, 2013). The DALY is a measure of disease burden that, as well as mortality, also accounts for morbidity and disability. The vast majority (around 80%) of these deaths were observed in Africa and Southeast Asia. More than 80% of all water-supply and sanitation-related deaths were in children under 5 years of age. Children have an even larger share (85%) of total DALYs related to water supply and sanitation (Prüss-Üstün et al., 2008).
Unsafe water supply and sanitation is an important determinant of diarrhoeal diseases. Approximately 88% of diarrhoeal deaths globally are caused by unsafe water, poor sanitation or poor hygiene, and 99% of these are in developing countries (WHO, 2009a). Unsafe water supply and sanitation is therefore the fourth largest cause of disease burden in low-income countries, after child underweight, high blood pressure and unsafe sex. It is important to note that the risk factors cannot be considered independently, as the effects of unsafe drinking water and sanitation can be aggravated by child underweight. In addition, climate change, through temperature increases that affect water quality, also has a negative effect on diarrhoeal diseases. It is not only in health terms that the significance of water supply and sanitation is high, but it also has a substantial impact in financial terms. In Africa alone, economic losses due to a lack of access to safe drinking water for human consumption and sanitation is estimated to total about 5% of GDP per year (UN-WWAP, 2009).

Access to clean drinking water and sanitation has economic, environmental and social benefits. Benefit-to-cost ratios have been reported to be as high as 7 to 1 in developing countries (OECD, 2011). Three quarters of these benefits stem from time gains, due to less time being spent having to walk long distances to collect water or to queue at the water source. The other benefits are largely linked to a reduction in diarrhoea.

Figure 3.1

Population grouped by type of sanitation



Source: WHO/UNICEF (2013)

Population grouped per type of sanitation, 1990, 2000 and 2010

Table 3.1

Deaths and burden of disease attributable to water, sanitation and hygiene in 2004 (WHO, 2013)

Region	Attributable deaths (thousands)		Attributable DALYs (thousands)	
	Total	Children	Total	Children
Africa	895	677	28,685	23,703
Americas	59	44	2,211	1,657
Southeast Asia	599	528	20,176	18,580
Europe	31	28	1,125	998
Eastern Mediterranean	217	179	6,993	6,281
Western Pacific	95	79	4,538	2,904
Total	**1,896**	**1,535**	**63,727**	**54,123**

Other non-health benefits must therefore be taken into consideration when adding up the full benefits of improved access to water and sanitation. These benefits mean that there is more time available for education, and a more productive labour force.

Health experts have debated whether water quantity or water quality matters most in terms of driving health benefits. Cairncross and Valdmanis (2006) estimate that most of the benefits from a water supply are attributable to improved convenience of access to water in terms of quantity. Other experts argue that water quality is a critical determinant driving health benefits. Waddington (2009) points out that while water supply interventions appear ineffective – with a negligible or insignificant impact on diarrhoea morbidity on average – water quality interventions can reduce the incidence of diarrhoea in children by about 40%. Prüss et al. (2002) state that point of use treatment solutions (such as boiling) can significantly improve the impact of water supply interventions, with an estimated 45% reduction in diarrhoea rates. Such analysts argue that treatment at the point of use is more effective than treatment at the point of source.

Large benefits were reaped in many developed countries in the late 19th and early 20th centuries when basic water and sanitation infrastructure was extended to much larger parts of the population. For instance, the introduction of water chlorination and filtration in 13 major US cities during the early 20th century led to significant reductions in mortality, with a calculated benefit to cost ratio to society of 23 to 1 and a saving of about USD 500 per person in 2003 (OECD, 2011). The benefits of wastewater treatment are not obvious to the public and are more difficult to assess in monetary terms.

Text box 3.1 Overcoming health concerns surrounding water reuse and recycling

Reused water (either reclaimed water or grey water, such as domestic wastewater used for laundry, dishwashing or bathing) is increasingly seen as a sustainable source for some water uses, in particular irrigation, groundwater recharge and possibly non-potable domestic uses. It could be an option for addressing the increasing mismatch between rising demand and available water resources in both OECD and developing countries. Reused water can be supplied from either centralised or decentralised distribution systems.

Markets for water reuse are booming. In addition, emerging economies and rural areas are gaining experience with distributed water infrastructure systems for water supply and sanitation services, although this is less the case in urban areas in OECD countries. Australia, Israel, Spain and some states in the United States are pioneering these new technologies, spurred on by serious constraints to water resources. However, health-related issues are a major driver, or constraint, in the development of such systems. First of all, these systems can generate public health risks (such as possible water contamination during domestic use, or the salinisation of irrigated soils). Secondly, the payback period of the additional investment cost for such systems (due to additional equipment, or in-house dual plumbing, for instance) depends on the standards set by the regulatory agencies (environment and/or health authorities) for reused water. These standards govern what water can be harvested, quality standards for reused water for specific applications, building standards, agricultural standards, and so on. The National Water Quality Management Strategy in Australia, for example, addresses health risks by including quality guidelines and monitoring for the safe use of recycled water, and includes an easy-to-use Decision Support Tool to help users create a draft management plan for their water recycling scheme.

For more detailed information see OECD (2009).

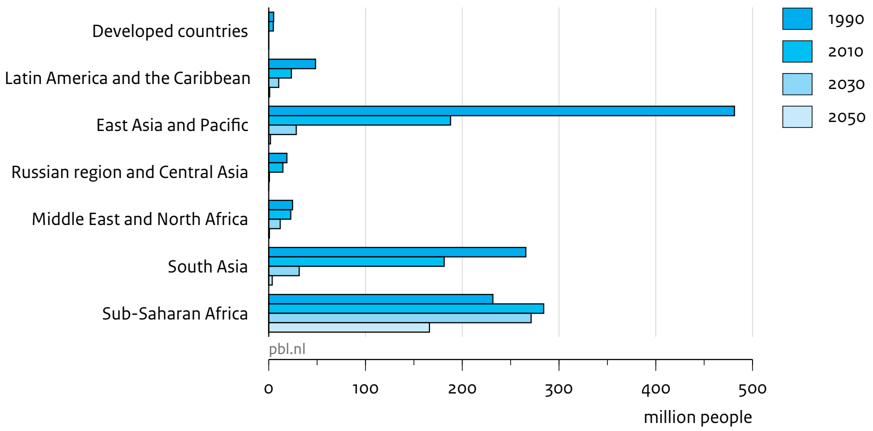
However, anecdotal evidence can be derived from case studies. For instance, the health benefits of quality improvements in recreational waters in south-west Scotland have been calculated at GBP 1.3 million per year (Hanley et al., 2003).

3.3 Modelling water supply and sanitation and associated health impacts

Water supply and sanitation can be categorised according to three levels of service: no coverage, improved services (such as public standpipes or boreholes) and household connections. Each of these levels has a particular risk potential for incidence of diarrhoea (Cairncross and Valdmanis, 2006). The proportion of the population that lacks access to safe drinking water and basic sanitation was modelled for these different service levels (note: the third service level was only modelled for drinking water). The service levels were modelled by applying linear regressions with GDP per capita, urbanisation rate and population density. Service level data were taken from the Joint Monitoring Programme (JMP) for Water Supply and Sanitation (WHO/UNICEF, 2012). Developments in water supply were assumed to be implemented ahead of sanitation and were modelled separately for urban and rural populations. It is important to emphasise the safety of the water provided, as household connections may not necessarily provide safer water than improved services. It is also important to note that the JMP measures access to specific water supply and sanitation technologies, rather than the actual quality of service to which people have access. The projections might therefore overestimate water supply and sanitation coverage rates. The costs of the projected connection rates are based on Hutton and Haller (2004), who estimated the annual cost of various levels of connection. Their annual cost assumptions are based on investment and recurrent costs, using values from the literature. For example, the annual cost of in-house piped water is USD 10 to 15 per person, while other improved water supply connections cost USD 1 to 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 applied by Hutton and Haller.

The water-supply- and sanitation-related health impacts were modelled using risk factor-attributable mortality, based on a multi-state approach, distinguishing exposure, disease and death (Cairncross and Valdmanis, 2006; WHO, 2002). Mortality rates due to specific diseases (e.g. diarrhoea) were obtained by multiplying the incidence rate with the case fatality rate. The impacts of water supply and sanitation were only calculated for children under the age of five. Given the different connection levels to water supply and sanitation facilities, relative risks were used to calculate incidence rates. These relative risks were based on the estimates of the 'realistic scenario' used in the Disease Control Priorities Project (DCPP; Cairncross and Valdmanis, 2006). The incidence rate was modified by the extent to which a child is underweight (categorised as mild, moderate or severe underweight; see Edejer et al., 2005) and climate change

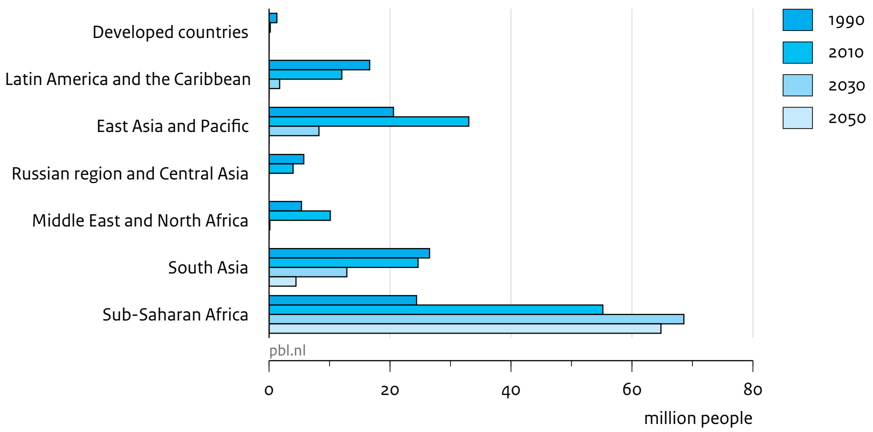
Figure 3.2
Rural population without an improved drinking water supply



Source: Hilderink et al. (2008)

Population without improved water supply in rural areas, 1990, 2010, 2030 and 2050

Figure 3.3
Urban population without an improved drinking water supply



Source: Hilderink et al. (2008)

Population without improved water supply in urban areas, 1990, 2010, 2030 and 2050

(McMichael, 2004). The case fatality rates were modified by underweight levels and the use of oral rehydration therapy (ORT). Underweight levels were derived from average food consumption levels.
The category 'improved water supply and sanitation' encompasses a broad range of possible types of connection, each of which is assumed to lead to the same health risk potential. The analysis considers only two classes of urbanisation – urban and rural. However, this may not reflect all situations within urban areas (which can include slums and more affluent areas). While increasing water and sanitation connections may be easier to achieve in urban areas, it is not always the case that increased urbanisation leads to more connections. It may instead lead to greater health risks, such as less favourable living conditions. Empirical data on the combination of water supply and sanitation categories are lacking, although the health risks are specifically related to combinations of the two. The assumption was therefore made that there is no dependency between the two, which may affect the estimation of health risks.

3.4 Trends and projection

The Millennium Development Goals (MDGs) set targets for human development, including a target for water supply and sanitation (UN, 2000). The target is to 'halve, by 2015, the proportion of people without sustainable access to safe drinking water and basic sanitation' (Target 7.C). The reference year for this target is 1990. Under the Baseline Scenario, the world as a whole would meet the MDG drinking water target by 2015, although this will mainly be due to the rapid progress made in large emerging economies such as China and India. In East Asia in particular, remarkable progress has been made in water supply coverage rates in recent decades, and with continuing economic growth universal coverage in this region will almost be achieved by 2030 (Figures 3.2 and 3.3). Other regions, such as sub-Saharan Africa, are unlikely to meet the water supply target. The number of city dwellers without access to an improved water source actually increased between 1990 and 2008, as urbanisation outpaced progress in access. By 2050, socio-economic progress in urban areas is projected in all regions. In rural areas, and especially in sub-Saharan Africa, the number of people lacking an improved water supply will increase up to 2030 and only slightly decrease afterwards. Under the Baseline Scenario, access to an improved water supply is expected to be universal in more developed countries before 2050.

Progress is slower with regard to access to sanitation. Under the Baseline Scenario, the MDG sanitation target will not be met, while by 2030 more than two billion people will still lack basic sanitation facilities (Figures 3.4 and 3.5). This number will only drop in the longer term, to 1.5 billion by 2050. In 2030, the majority of those without improved sanitation will live in developing countries, and this proportion will continue to grow towards 2050. Today, the vast majority of people without access to a water supply and sanitation live in rural areas. However, towards 2050 the number of people in rural areas without access to sanitation will drop significantly and become comparable to numbers in urban areas.

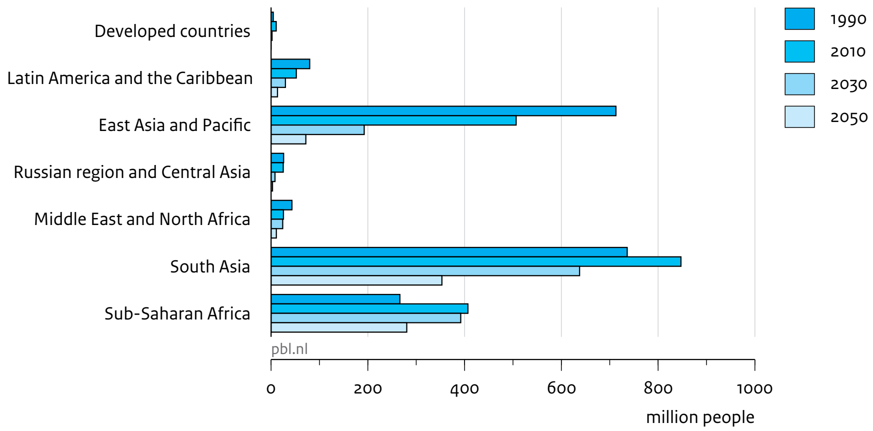
3.5 Impacts on human health

With greater access to an improved water supply and sanitation facilities, the Baseline Scenario projects that the coming decades will see a substantial reduction in child mortality from diarrhoea. At the beginning of this century, almost two million annual deaths, mostly children, could be attributed to a lack of basic water supply and sanitation facilities. Under the Baseline Scenario, this number is projected to be around 1 million by 2030 and about 0.5 million by 2050 (Figure 3.6). As a result of the coverage rate projections, most of these deaths will occur in sub-Saharan Africa, although the number will also decline steadily in this region.
These projections implicitly assume that increasing urbanisation will make it easier and cheaper to connect residents to water supplies and sanitation facilities, that greater economic growth will increase the basic standard of living (including access to medical treatment), and that the number of people most susceptible to unsafe water and sanitation (i.e. children under the age of five) will decrease due to the continuing ageing of the population in most countries, including developing countries.
Despite these assumptions, it is important to note that greater urbanisation can in some cases magnify water challenges – such as the management of waste and water in slums (see Chapter 4) – with serious consequences for human health.

3.6 Policy options

To assess the impacts of improved access to safe drinking water and improved sanitation, an Accelerated Access Scenario was constructed. This policy simulation was used to estimate the expected additional annual cost and health benefits of achieving universal access to improved water supply and sanitation by 2050. Compared with the Baseline Scenario, this simulation assumes: i) halving, by 2030, the population without access to an improved water source and basic sanitation compared with the base year 2005, and then ii) moving to universal access by 2050. The results are presented in Table 3.2.
Compared with the Baseline Scenario, almost 100 million additional people will have access to an improved source of water by 2030 under the Accelerated Access Scenario, and around 470 million more will have access to sanitation facilities. By 2050, universal access will mean that an additional 242 million people will have access to an improved water source, and an additional 1.36 billion people will have access to basic sanitation facilities.
In terms of health impacts over the next 40 years, the highest number of avoided deaths under this policy will be in sub-Saharan Africa, where every year around 70,000 deaths related to unsafe drinking water and sanitation will be avoided. It is important to note that while access to improved water sources will increase substantially, there will not be a commensurate reduction in mortality. One reason is that an improved water source still involves relatively high health risks compared with a household connection. Also, a connection does not necessarily ensure access to 'safe' water.
The policy simulation indicates that an average of USD 1.9 billion globally would need to be invested each year between 2010 and 2030 to achieve the 2030 target, and USD 7.6 billion would be needed annually between 2031 and 2050 to achieve the 2050 target.

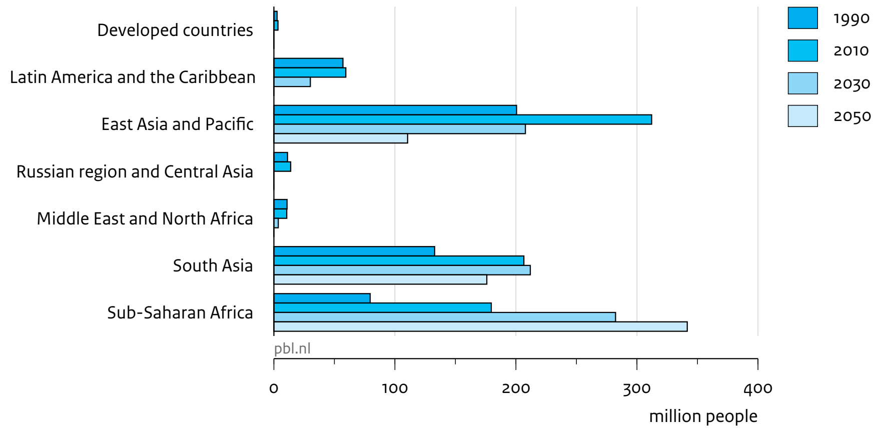
Figure 3.4
Rural population without improved sanitation



Source: Hilderink et al. (2008)

Population without improved sanitation in urban areas, 1990, 2010, 2030 and 2050

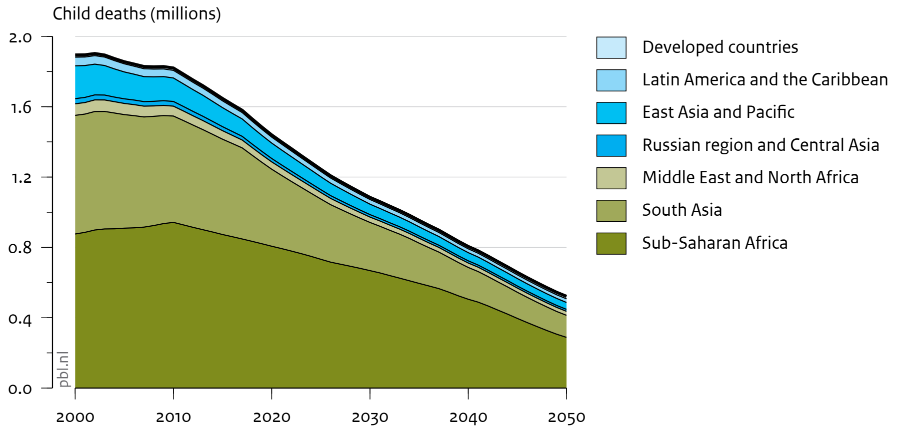
Figure 3.5
Urban population without improved sanitation



Source: Hilderink et al. (2008)

Population without improved sanitation in rural areas, 1990, 2010, 2030 and 2050

Figure 3.6
Annual child deaths due to the lack of basic water supply and sanitation



Source: Hilderink et al. (2008)

Annual child deaths due to lack of basic water supply and sanitation, 2000–2050

Table 3.2
Impacts of accelerated access to water supply and sanitation, 2030 and 2050, compared with the Baseline Scenario

	Additional water Supply	Additional sanitation	Additional cost	Avoided deaths	Additional value of statistical life (VSL)
2030	Thousands	Thousands	Million USD	Thousands	% of GDP
Developed countries	0	0	0	0	0.00
Latin America & the Caribbean	21	5,786	52	0	0.00
East Asia & Pacific	0	24,173	174	0	0.02
Russian region & Central Asia	0	357	3	0	0.01
Middle East & North Africa	277	8,556	65	0	0.01
South Asia	855	198,889	1,435	7	0.19
Sub-Saharan Africa	93,719	234,201	2,123	68	1.89
2050					
Developed countries	0	34	0	0	0.00
Latin America & the Caribbean	976	13,226	126	0	0.00
East Asia & Pacific	1,770	182,453	1,319	3	0.26
Russian region & Central Asia	0	3,044	24	0	0.00
Middle East & North Africa	694	10,883	87	0	0.01
South Asia	8,024	529,032	3,843	8	0.23
Sub-Saharan Africa	230,891	622,062	5,843	70	1.72

Water quality: nutrients in surface water

4.1 Main messages

- The most important drivers for deteriorating water quality in many developing countries are population growth and urbanisation, and in several countries the construction of sewage systems without wastewater treatment. A century ago, the dominant pathway for nutrients was reuse in agriculture; nowadays the dominant pathway ends in surface water.
- Continued investments in wastewater treatment in developed countries are expected to stabilise and restore surface water quality.
- The quality of surface water in other countries is expected to deteriorate between 2010 and 2050. This will lead to increased eutrophication, biodiversity loss and a higher risk to drinking water, fishery, aquaculture and tourism ecosystem services.
- An option for improving wastewater quality is the expansion of wastewater collection with wastewater treatment to avoid the discharge of untreated wastewater.
- Agreements between countries are necessary to improve water quality in transboundary catchment areas and prevent excessive pollution of coastal waters, resulting in large scale fish kills and algae blooms.

4.2 Introduction

Wastewater from urban areas, along with emissions of organic compounds, pathogens, nutrients, heavy metals and micro-pollutants such as pesticides, medicines and cosmetics, is a major pollutant of surface water. Sewage systems and wastewater treatment plants are built to remove and transport human waste, reduce oxygen demand and remove nutrients from the effluent. Even so, two thirds of the world's population was not connected to a sewage system in 2010, and wastewater from households with a sewage systems was sometimes discharged without treatment (6% of the total population) or with some treatment to remove organic compounds or nutrients (28%).

Wastewater treatment plants are built to improve the water quality of surface water. The first treatment plants were constructed to reduce the biological oxygen demand of the effluent, while the next generation also reduced the nutrient load to the surface water. The past 30 years have seen major changes in many countries in emissions of nitrogen and phosphorus from households to surface water. In 1950, most of the cities in developed countries had sewage systems that directly discharged wastewater effluent to surface waters, resulting in a decline in water quality.

Emissions of the nutrients nitrogen and phosphorus cause eutrophication, which is the stimulation of plant or algae production in the water column. One phenomena caused by severe eutrophication is oxygen depletion during the decomposition of this excess plant biomass. Eutrophication is currently the foremost aquatic ecosystem management problem in rivers, lakes and estuaries worldwide. Eutrophication resulting from nutrient loading first became evident in lakes and rivers suffering from an excessive growth of macrophytes and floating algal scum (Butcher, 1947). In its most serious manifestation, the eutrophication of surface waters leads to turbid waters with decreased oxygen concentrations (hypoxia), the production of toxins by algae and bacteria, and fish-kills (Diaz and Rosenberg, 2008). Algal blooms can also have a negative impact on ecosystem services such as tourism and the drinking water supply.

Wastewater treatment is necessary to improve water quality and reduce the negative effects of nutrient emissions. For example, in around 1970 the water quality in the Rhine River had decreased to such an extent that fish could no longer survive in the low oxygen levels. Since then, countries in the Rhine catchment area have improved their sewage systems by constructing wastewater treatment plants, and this has led to a substantial improvement in the quality of water in the Rhine. Wastewater treatment systems have improved from primary (mechanical) treatment to secondary

Table 4.1
The impact of the most important phases in sanitation and wastewater treatment on water quality

Sanitation	Nutrients / organic pollution	Water quality effects
No access to improved sanitation	Use in agriculture as fertilizer	Minor or local effects
Access to improved sanitation, no sewage system	Sludge dumped in land or water	Negative effects
Access to improved sanitation, sewage system, no treatment	Nutrients discharged directly to surface water	Major negative effects
Access to improved sanitation, sewage system and wastewater treatment	With more advanced treatment more nutrients are removed from the effluent; the removed nutrients are stored in sewage sludge	With increase of wastewater treatment fewer effects
Access to improved sanitation, sewage system and advanced treatment	Nearly all nutrients removed from effluent, reuse of phosphorus is possible	Hardly any effects

treatment, and many cities are now connected to tertiary treatment plants with a high nutrient removal efficiency. The next generation of wastewater treatment plants will remove more nitrogen and phosphorus from the effluent, make the reuse of phosphorus possible and have much lower energy costs. The impacts of different types of sanitation and wastewater treatment on water quality are presented in Table 4.1.
Improving public health and reducing negative impacts on the environment are a major concern in many countries. Many urban areas in developing countries do not have a public sewage system, and there are often no wastewater treatment systems. Improved sanitation with septic tanks is an alternative when sewage systems are not available, and form an improvement in terms of public health, although systems with septic tanks may cause groundwater or surface water pollution when the overflow ends up in soil or groundwater, or untreated sludge from septic tanks is dumped on land or in surface water.

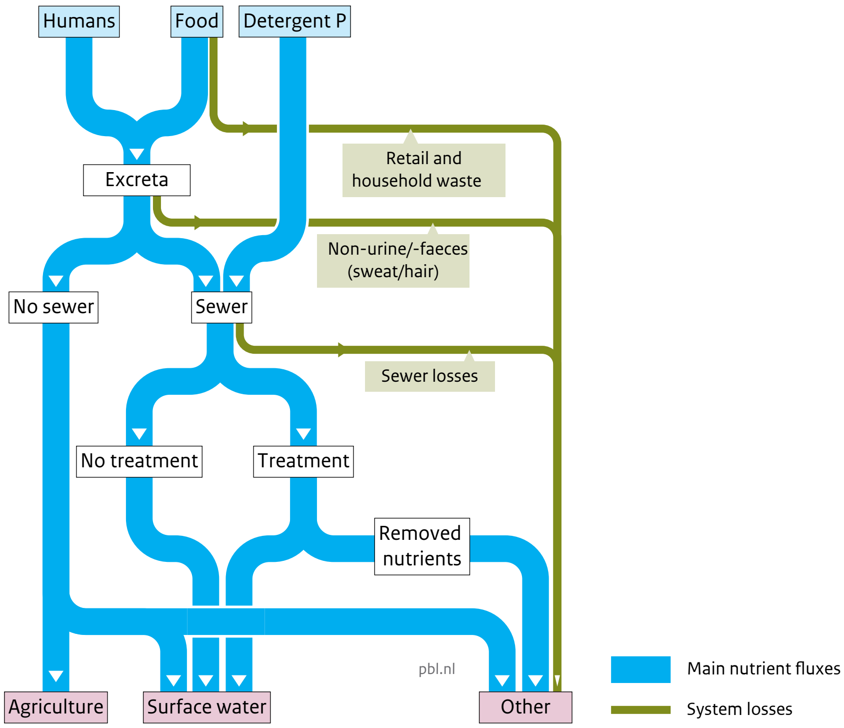
The effect of GDP growth and urbanisation is two-sided. A growth in GDP allows for investment in improved sanitation and the construction of sewage systems in urban areas, although the construction of wastewater treatment plants often lags behind the construction of sewage systems so that wastewater is discharged directly to surface water. On the other hand, consumption patterns also change as incomes grow. Generally-speaking, there is a shift towards more proteins from meat and milk in human diets, causing increased nitrogen excretion, and access to drinking water means that more households own a dishwasher and laundry machine, which often use phosphorus-based detergents.
In the following sections, we present a global country-scale modelling approach to show past and future changes in the discharge of nutrients in wastewater to surface water. These changes are illustrated using examples from different cities. Sanitation options to improve water quality are presented and finally the effects of high nutrient loads in surface water are discussed. The discussion is limited to urban wastewater. Nutrient loading caused by agriculture and other pollutants such as pathogens, heavy metals and plastics are not discussed.

4.3 Modelling emissions from urban areas to surface water

Nutrient emissions from households and industries in urban areas were calculated using a global country-scale model (Van Drecht et al., 2009; Morée et al., 2013). The model also describes nutrient emissions from urban live-stock and traction animals where relevant. Input data for the model include urban population, connection to sew-age systems and the presence and type of wastewater treatment (Figure 4.1). Human excretion of nutrients depends on food protein intake. The protein intake per capita ranges by a factor of three between the poorest and the wealthiest countries. Proteins are assumed to have a nitrogen content of 16% and a phosphorus content of 1.6%. The model also accounts for phosphorus emis-sions from the use of phosphorus-based detergents in laundry machines and dishwashers, and the extent to which phosphorus-free detergents are used (e.g. due to regulations). The removal of nitrogen and phosphorus in primary treatment plants is 10%; in secondary treatment 45% for phosphorus and 35% for nitrogen; and in tertiary treatment plants 90% and 80% respectively.
Emissions to surface water are divided into three sources (Figure 4.1):

- households in urban and rural areas that are connected to a sewage system where wastewater is discharged untreated or is treated in a wastewater treatment plant;
- households in urban areas that are not connected to a sewage system, and direct discharge of wastewater through open sewers is assumed;

Figure 4.1
Different pathways of household emissions of nitrogen and phosphorus



Source: Morée et al. (2013)

Different pathways of human emissions of nitrogen and phosphorus from households (Morée et al., 2013)

– households in rural areas that are not connected to a sewage system, and the reuse of waste in agriculture or collection of waste in septic tanks without a direct connection to surface water is assumed.

A century ago, the dominant pathway for nutrients was reuse in agriculture; nowadays the dominant pathway ends in surface water. In some developed countries, most nutrients are removed from the wastewater. Nitrogen is removed by denitrification and phosphorus is deposited in treatment sludge.
The spatial resolution of the model is one degree by one degree for the population density and urbanisation and country-based information on sewage systems and wastewater treatment. Results were aggregated to the river basin or country level.

4.4 Trends and projection

The number of households connected to a sewage system will increase in all regions (Figure 4.2; Table 4.2). In absolute numbers, the largest increase will be in East Asia, South Asia and sub-Saharan Africa. The smallest increase in sewage connection will be in the Russian region and Central Asia and in developed countries. Most wastewater in developed countries, by 2050, will be treated using tertiary treatment. In other regions, the sewage effluent will be treated using a primary or secondary treatment plant, or discharged without treatment. In sub-Saharan Africa and South Asia, population growth will be higher than the growth in sewage systems. Most cities in sub-Saharan Africa (except in South Africa) do not have a sewage system or have a small sewage system which no longer functions (Miller and Parker, 2013; Text box 4.1). Improvements to the sewage system will take place in the more well-off districts of cities, but very few wastewater treatment plants will be built. In Latin America, the Russian region, North Africa and the Middle East, improvements in the sewage system and wastewater treatment will be enough to compensate for population growth. In China (East Asia region), improvements in wastewater treatment will exceed population growth.

Emissions of nitrogen and phosphorus from households to surface water will increase in most regions (Table 4.2; Figures 4.3 and 4.4). In developed countries, nutrient emissions decreased between 1990 and 2010 and will continue to decrease up to 2050. Wastewater treatment

Text box 4.1 The city of Accra (Ghana)

Accra is a rapidly growing coastal city and the capital of Ghana. The number of inhabitants in the Accra Metropolitan Area is currently estimated to be around four million. There are large differences in income between different areas of the city, but the majority of inhabitants live in non- or poorly-planned residential areas, some of which are slums. The city is sprawling and this further complicates the provision of water services to its inhabitants. This is characteristic of the situation in many cities in sub-Saharan Africa. In Ghana, only 13% of the total population has access to improved sanitation, but nearly 60% has shared, unimproved sanitation, which means that most people do not have a toilet.

Only a minor part of the city (5% to 10%) is connected to a central sewerage system, which discharges to a treatment plant that is mostly out of operation. The faecal sludge from public toilets or private latrines and septic tanks is collected in private tanker trucks. These trucks dump about 100 tanks of faecal sludge on the beach near the city centre each day. This is the largest source of pollution and causes major marine pollution. Only 20% of the urban population has access to improved sanitation, but many people have a shared sanitation system.

The population will certainly increase, to between 8 and 16 million inhabitants by 2030, with a corresponding increase in wastewater and sludge. Management of the water, waste and wastewater system is mostly ad-hoc, without long-term planning. Expansion of the city into the upper catchment areas will also result in increased storm water flows and flooding by polluted water in the lower parts of the catchment area, with negative consequences for health. (Miller and Parker, 2013).

Table 4.2

The relative change in population size, urban population, the population connected to a sewage system and nitrogen and phosphorus emissions to surface water between 2010 and 2050

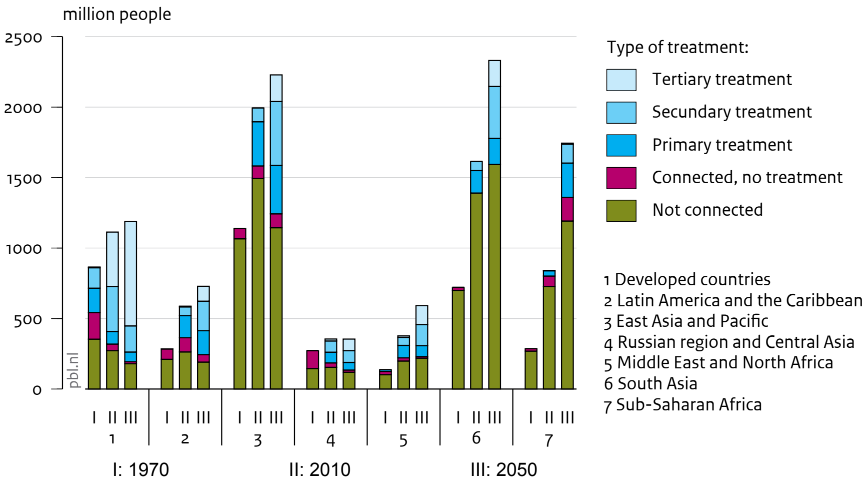
	Total population, in %	Urban population, in %	Population connected to sewage system, in %	Nitrogen emissions, in %	Phosphorus emissions, in %
Developed countries	+7	+22	+20	-16	-26
Latin America & the Caribbean	+24	+38	+66	+15	+32
East Asia and Pacific	+12	+73	+117	+52	+88
Russian region and Central Asia	~	+18	+17	-10	+3
Middle East and North Africa	+57	+94	+108	+40	+55
South Asia	+44	+162	+225	+121	+135
Sub-Saharan Africa	+107	+236	+387	+236	+248

plants are being upgraded to tertiary treatment systems with 80% nutrient removal or with 95% or more nutrient removal using new technologies in wastewater treatment. International agreements are important for countries to invest in wastewater treatment to improve water quality downstream. In the European Union, the guideline is that all cities have a tertiary treatment plant for their wastewater (EEC, 1991).

An increase in emissions is projected for other continents. Emissions in the Russian region and Central Asia show a slight increase. Emissions in Latin America and the Middle East and North Africa region will increase by 15% to 50%. The increase in emissions will be less than expected from population growth as wastewater treatment improvements will be considerable. An important driver in improving wastewater treatment will be reuse of the effluent in agriculture (Text box 4.2).

A substantial increase in emissions is expected in Africa and South Asia, mainly due to population growth and urbanisation and the construction of sewage systems without appropriate wastewater treatment. Although progress will take place in the connection of households to sewage systems, population growth will be higher. Total global emissions of nitrogen will increase from 9.5 to 13.5 million tonnes and phosphorus emissions from 1.3 to 2 million tonnes. Figure 4.4 shows the spatial distribution of nitrogen and phosphorus emissions in 2050 and the differences between 2050 and 2010. This map shows the contrast between developed countries – with a reduction in emissions – and the countries in which there will be a major increase in South and East Asia.

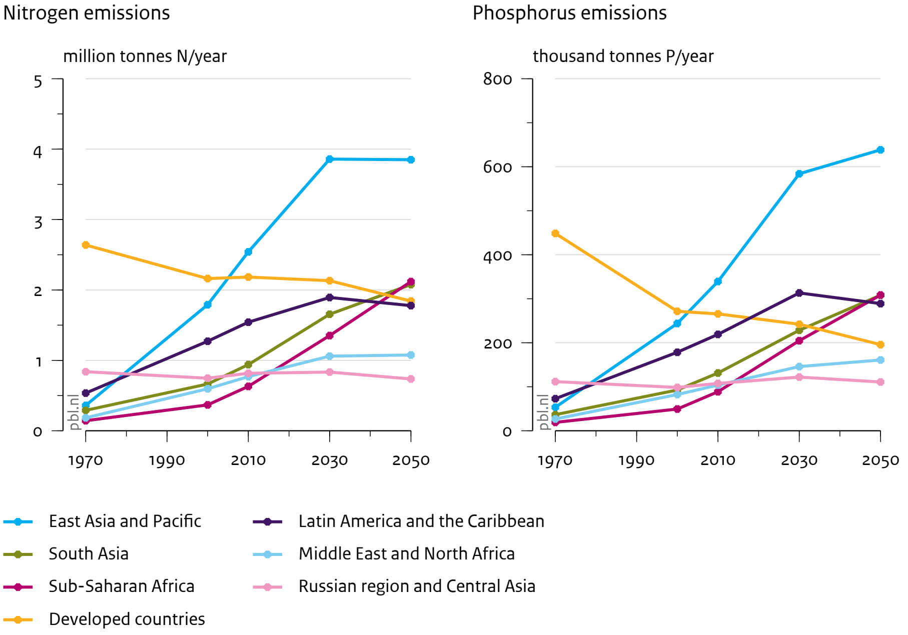
Figure 4.2
Population grouped according to type of waste-water treatment



Source: PBL

Total population grouped by type of wastewater treatment showing the absolute growth and the improvement in wastewater treatment between 1970 and 2050

Figure 4.3
Household nutrient emissions to surface water



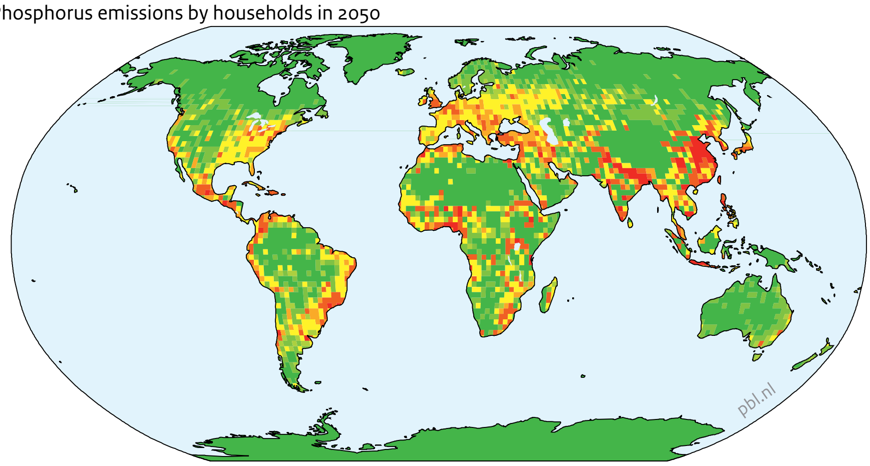
Source: OECD (2012)

Nitrogen and phosphorus emissions to surface water from households

Figure 4.4

Spatial distribution of phosphorus emissions in 2050

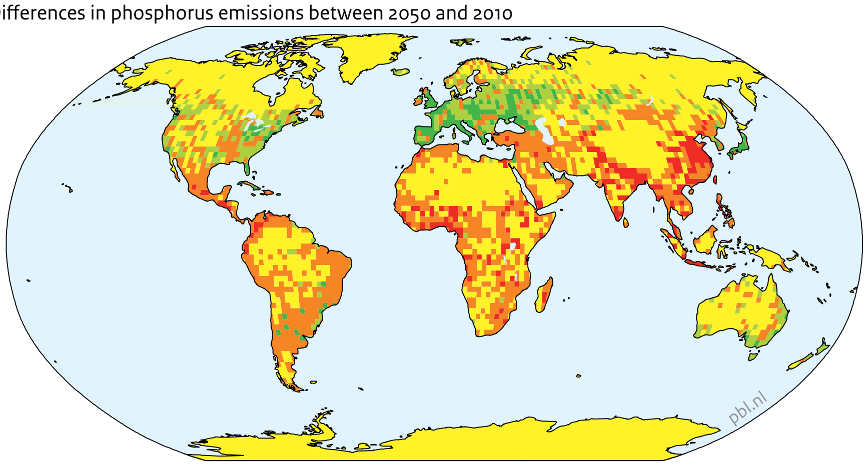
Phosphorus emissions by households in 2050



Tonnes P/ (2*2 degrees)

- > 5,000
- 1,000 - 5,000
- 500 - 1,000
- 100 - 500
- 50 - 100
- 1 - 50
- 0 - 1

Differences in phosphorus emissions between 2050 and 2010



Tonnes P / (2*2 degrees)

- Decrease more than 100
- Decrease less than 100
- Stable
- Increase less than 1,000
- Increase more than 1,000

Source: PBL

Spatial distribution of phosphorus emissions in 2050 and the difference in emissions between 2010 and 2050

4.5 Negative effects of eutrophication on cities and coastal areas

Increasing nutrient loads caused by human activities lead to eutrophication, as well as changing ratios between nitrogen, phosphorus and silica (the stoichiometry; Garnier et al., 2010). The most important group of algae in oceans with respect to photosynthesis are diatoms, which need silica to form their cell walls. Many human activities on the land result in a changed stoichiometry, for example the construction of dams results in the retention of silica, and untreated wastewater flows cause elevated nitrogen and phosphorus levels. Thus, N:Si and P:Si ratios have increased in many parts of the world, often resulting in limited diatom growth and the stimulation of other, often harmful, phytoplankton such as dinoflagellates. This can lead to a proliferation of Harmful Algal Blooms (HABs) (Heisler et al., 2008). HABs cause loss of natural resources, destruction of aquaculture production and human sickness and death, for instance if shellfish are consumed that contain toxins

Text box 4.2 Israel/Tel Aviv

Tel Aviv city was established in 1909 and since then has developed into a metropolitan region of around 2.5 million inhabitants. The city has a separate sewerage system, which is operated by a publicly-owned company. The sewerage system, with nearly 6,000 kilometres of pipeline, transports about 114,000 m3 of wastewater a day to the regional sewage treatment plant. The wastewater is subjected to secondary treatment with nutrient removal (single-stage simultaneous nitrification-denitrification) and the effluent is further treated in a Soil Aquifer Treatment (SAT) system. The SAT system consists of large infiltration basins and a ring of recovery wells at considerable distance from the infiltration basins for a residence time of up to 100 days. As a result, the quality of the recovered water is good enough for unrestricted irrigation and conveyed towards the northern parts of the Negev desert.

Several future changes are expected to affect the city's water system. Due to further urbanisation and increasing land prices, the infiltration area will be reduced. One option will be to replace the SAT system with membrane systems (e.g. ultra-filtration with reverse osmosis) or to combine membrane systems with short retention time SAT systems. The goal is then to use less – expensive – land. The membrane systems have the additional advantage that they can remove micro-pollutants from the reclaimed water, such as endocrine disruptors, antibiotics and other pharmaceutical micro-pollutants. This will further protect public health and enable the continued export of fruit and vegetables to high-value markets in Europe and other regions. A disadvantage of the membrane systems is their relatively high energy cost, although the systems are becoming more energy efficient each year.

produced by these algae. Several cases of human illness and death have been reported in the United States and Mexico (Lewitus et al., 2012). Well-known health problems include paralytic, amnesic, neurotoxic and diarrheic shellfish poisoning. Cyanotoxic poisoning may cause skin or respiratory irritation, tumour promotion and liver cancer.

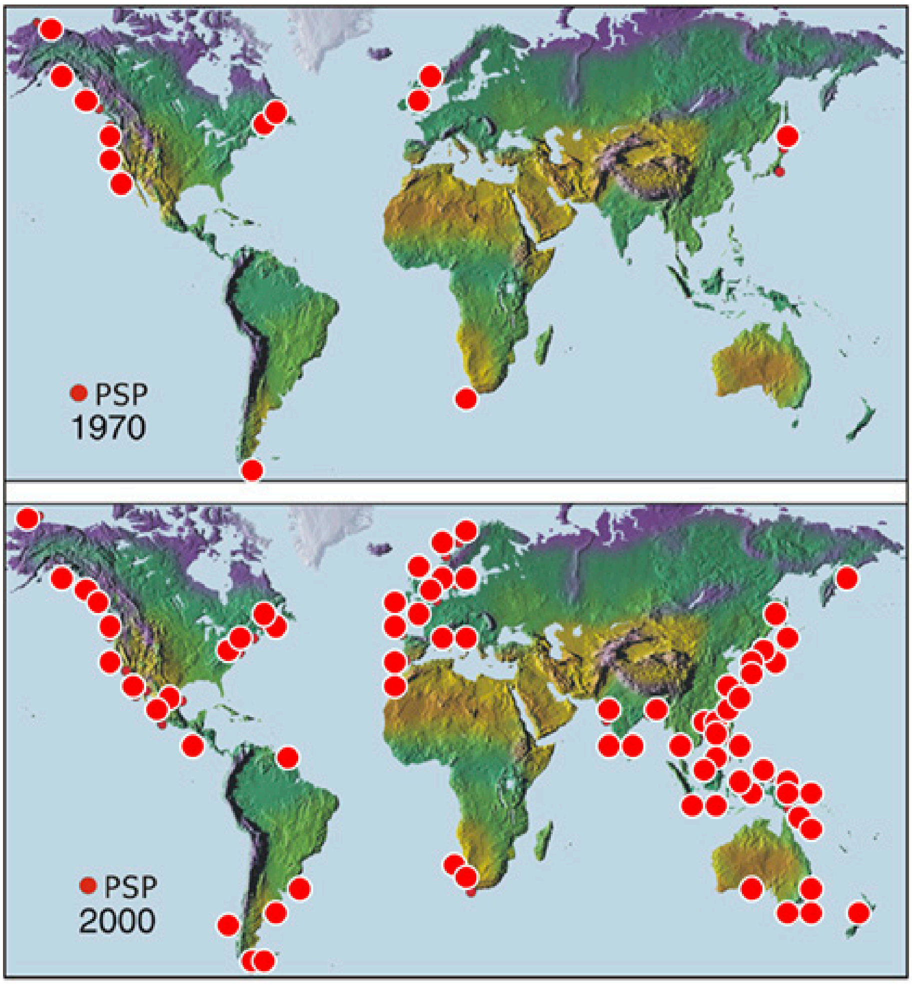
Several algal blooms have been reported in recent years with negative effects on ecosystem services. For example, large algal blooms of dinoflagellates have been seen since 2000 in the Changjiang (Yangtze River) Estuary and the adjacent area of the East China Sea (Li et al., 2009). A total of 440 million people live in the Yangtze catchment area, which also includes 4 of the 10 most populated cities in China, but the hydrology has also changed with the construction of the Three Gorges Dam. The Yangtze River has high nutrient loads, but nitrogen concentrations are particularly elevated relative to phosphorus. The molar ratio N:P is normally 10:1, but in the Changjiang Estuary it is 40:1. Combined with the coastal sea currents, the mix of nutrients has resulted in the massive growth of harmful algae. Before 2000, diatoms bloomed frequently during spring but after 2000 algae blooms with dinoflagellates have become dominant. The area of algal blooms increased from 1,000 km2 in 2000 to 15,000 km2 in 2005, and were associated with massive fish kills on reaching the coastal aquaculture areas.

Several recent examples of massive die-offs of fish and aquaculture have also been seen in other coastal seas in Southeast Asia. In the Philippines, fishery and aquaculture are important for food production. In Manila Bay, for example, fish cages cover 40 km2 and even larger areas in other bays. Several fish-kill events have occurred due to hypoxia from algal blooms (David et al., 2009). Algal blooms have been reported to cover over 500 kilometres of coastline in the Philippines. In Malaysia, the first Harmful Algae Blooms were reported in 2005 (Anton et al., 2008). These blooms caused red discoloration of coastal waters, coinciding with extensive mortalities of caged fish in local aquaculture farms. There are also incidents of Harmful Algae Blooms and fish-kills in Indonesia and Korea, for example in Jakarta Bay.

Figure 4.5 shows the locations of observed Harmful Algae Blooms in 1970 and 2000. The change over this 30-year period illustrates the increasing proliferation of paralytic shellfish poisoning. In freshwater lakes too, high nutrient levels are a risk for drinking water in cities. Tai Hu in China, one of the largest freshwater lakes, has suffered from high concentrations of cyanobacteria for several decades. The combined effect of nutrient enrichment and industrial pollution pushed Tai Hu to a rapid and massive die-off of cyanobacteria (Zhang et al., 2010), and drinking water extraction from the lake for Wuxi city with its two million inhabitants had to be stopped.

In addition to toxic algae, a special type of Harmful Algae Blooms is high-biomass of green macroalgae, which grow rapidly in nutrient-rich waters. The vast accumulations and rapid growth of unattached green macroalgae are called 'green tides'. In the Yellow Sea, large-scale green tides broke out continuously between 2007 and 2013, and in 2008 in particular the algal bloom covered an area of 13,000–30,000 km2 near Qingdao (Zhang et al., 2013). Although 700,000 tonnes of algae were removed at a total cost of over USD 100 million to maintain algae-free

Figure 4.5
Increase in Paralytic Shellfish Poisoning (PSP) from Harmful Algae Blooms



Source: Glibert et al. (2005)

Increase in Paralytic Shellfish Poisoning (PSP) from Harmful Algae Blooms (Glibert et al., 2005)

water for the Olympic sailing games, the beach of Qingdao is still unusable for tourism.
The negative effects of a disturbed nutrient load have increased in the last 20 to 40 years and nutrient loads will further increase in the next 40 years. Negative effects on fishery, aquaculture and tourism are expected to increase in the coming period as the nutrient load continues to increase. This can have negative effects on the sustainable development of cities and coastal areas and on the ecosystem services of coastal seas and freshwater lakes and rivers.

4.6 Policy options

Various options are available for reducing pollution from wastewater. In developing countries with a low degree of connection to sewage systems and no wastewater treatment, small-scale solutions with sludge treatment are an interesting option. In developed countries, advanced wastewater treatment with more nutrient removal and a lower energy consumption or small-scale advanced treatment systems are options for improving water quality.

Developing countries link local sanitation with faecal sludge management

In slum areas, small-scale, local options are often the best way to improve sanitation and water treatment. The coverage of sewerage systems in cities is extremely low; many African capitals have coverage rates of less than 10%. The cost of expanding sewerage systems is in many cases prohibitive. New technologies and incentives for local reuse may provide an alternative to centralised options. There should be a particular focus on dealing with faecal sludge from septic tanks, pit latrines and public toilets, since this is by far the most common form of 'waste water' in the developing world.
Shared toilets with waste collection and treatment are a significant improvement in the slums of many cities. One example of an integrated sanitation system is the Sanergy model: shared toilets are built in slum areas, the waste is collected daily and transported to a centralised facility and this is used to make compost, which can be used in agriculture (http://saner.gy/). The Sanergy company has built 242 sanitation facilities in Nairobi's slums in the past 2 years. These facilities are run by 130 local entrepreneurs who earn USD 2,000 a year to provide hygienic sanitation for 10,000+ people. Another project to improve sanitation in slums involves the collection of urine from private toilets.
Unfortunately, there is little practical experience available in the large-scale application of decentralised advanced infrastructure. A greater focus is therefore required to further develop and finance infrastructure for faecal sludge treatment (Strande et al., 2013). If a sewerage infrastructure is already in place, the economies of scale of large centralised treatment plants will probably favour this option, in most cases. For smaller communities at some distance from the sewerage network, a small treatment plant could be an interesting option.

Separated waste systems in decentralised sanitation project

In small-scale systems used to treat the waste produced by 100 to 5,000 people, the cleaner production principle allows for the treatment of domestic wastewater and domestic waste together and reuse of the resources. In Sneek, the Netherlands, a pilot project has been realised in which the waste is kept as concentrated as possible and brown/black, yellow and grey wastewater are separated. Brown/black wastewater is collected by vacuum toilets, which use much less water (about one litre/flush) than regular flush toilets. The brown/black wastewater is therefore more concentrated. Kitchen waste is ground and mixed with the brown/black wastewater and transported by vacuum sewer to a district-scale anaerobic digester. The biogas produced in the digester is used for heating. The liquid effluent from the digester is rich in nutrients. To recover these nutrients, the anaerobic effluent is further treated in a struvite reactor, in which conditions are created for struvite (magnesium ammonium phosphate) precipitation.
The struvite settles and is collected for use as fertilizer in agriculture. The final effluent could subsequently be used for irrigation, provided that sufficient disinfection is provided and that there are no prohibitive concentrations of micro-contaminants that may have passed through the treatment steps. The greywater in this system is collected in systems that cover only a few households. After simple treatment in a septic tank followed by an aerobic filter, the effluent is disposed of in local gardens or in an infiltration wadi. Implementation of this system has shown that it saves water (a 25% reduction) and that it is energy-neutral. It also reduces the cost of sewage systems and the collection of organic household waste.

New technologies in wastewater treatment plants make reuse of nutrients or water possible

New technologies in wastewater treatment plants improve the removal of nutrients and make reuse of the effluent possible. Developments in membrane technology have made the production of extremely high quality effluents possible. These could even be used as drinking water (as in Singapore and Windhoek, Namibia), or for the production of ultra-pure water for industrial applications. The direct application of membranes in MBRs (Membrane Biological Reactors) for a variety of wastewaters is well established. However, continued innovation in the membrane components and the biology of the system has led to applications in increasing numbers of treatment plants (both municipal and industrial). The excellent effluent quality produced by such technologies could also allow reuse in cities to improve the urban environment through green space irrigation or waterscapes.
One innovation concerning the main biological reactors is the use of aerobic granular sludge. The good settling characteristics of granular sludge allow the entire process – both the biological conversions as well as the physical separation (i.e. sedimentation) of the biomass – to take place in one relatively small tank. This type of sequencing batch reactor does not require secondary sedimentation tanks and sludge return pumps and therefore the reactor operates with a smaller footprint, while using less energy and producing a better effluent quality (with regards to both N and P removal; De Kreuk et al., 2005). The first full-scale plants making use of this technology are already operational, and removal rates of 95% for nitrogen and 97% for phosphorus are being achieved, at one third of the energy consumption compared with conventional plants. The effluent produced by the treatment plant, with very low residual organic, nitrogen and phosphorous concentrations, could be discharged in vulnerable ecosystems or reused for various purposes.

Flood risks

5.1 Main messages

- Analyses show that in the historical trend up to 2010, climate change could not be related to flood disasters. The dominant drivers of the historical increase in the number of people affected and economic losses due to coastal and river floods were population growth and economic development.
- As urban areas expand, hundreds of trillions of dollars of infrastructure, industrial and office buildings and homes are increasingly at risk from river floods and coastal floods, particularly in Asia. According to the Baseline Scenario, there may be 670 cities with 500,000 inhabitants or more by 2050, of which 88 will have over 5 million inhabitants. Of these cities, 50% will fall in the highest vulnerability ranking with respect to flooding, based on exposed population and GDP per capita. The most vulnerable megacities will be Dhaka, Kolkata, Shanghai, Mumbai, Jakarta, Bangkok and Hoh Chi Minh City.
- Comparing different flood protection levels, for example by means of levees, shows that the annual number of people and assets exposed to floods can be substantially reduced. For example, applying a protection level of a once in a one hundred year flood (1:100) for rural regions and a once in a one thousand year flood (1:1000) for urban areas reduces the annual exposed population and assets by more than 90% compared with an overall protection of 1:10.
- The cost of adequate flood protection is not necessarily high, and the high concentration of assets and people in cities may provide an opportunity for highly cost-effective flood protection strategies. There is a wide range of measures available, and given the potentially large effect of flood risk reducing measures, it would seem worthwhile for cities and countries to pay due attention to an appropriate flood risk strategy.
- Vulnerability to floods is unevenly distributed within cities, and often the poorest suffer disproportionally. Within the context of environmental justice, public authorities face a challenge to improve protection against flooding without increasing inequality with respect to flood risk.

5.2 Introduction

Floods, either from the sea or from rivers, are one of the main weather-related disasters occurring worldwide (Figure 5.1). One of the major disasters in 2010 was the extreme flood in Pakistan, which affected about six million people. In the historical trend up to 2010, no climate change signal can be detected in flood disasters. The dominant drivers of the increase in the number of people affected and economic losses due to coastal and river floods were population growth and economic development (Visser et al., 2012; IPCC, 2012).

Of all weather-related disasters, floods annually affect the most people: over the past 30 years, an average of almost 90 million people were affected by flood disasters each year (Table 5.1). The only exceptions were the Middle East/North Africa and sub-Saharan Africa, where temperature extremes, and in particular drought, affected more people than floods.
The figures given below are based on reported losses in the CRED EM-DAT database. Not all losses are reported.

The reported global economic losses due to floods amount to almost USD 20 billion a year. In four of the seven regions, more losses were due to floods than to other weather-related disasters (Table 5.2).

Future flood risks are analysed in the following sections. A global flood model was used in combination with a global demographic model to explore possible developments in annual expected impacts in terms of exposed population and exposed economic value.
A distinction is made between urban and rural impacts. Results with a low and a high flood protection standard were compared. Based on these, the large cities (with a

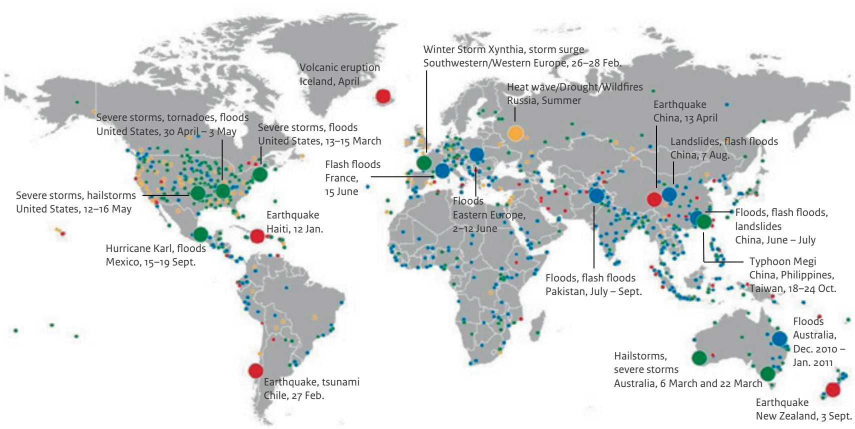
Table 5.1
Reported number of people affected

World Bank regions	Coastal and river floods [million people affected]	Temperature extremes and droughts [million people affected]	Tropical and extra-tropical storms [million people affected]
Developed countries	26.2	14.1	20.5
Latin America/the Caribbean	30.3	6.9	21.0
East Asia/Pacific	1,788.3	318.8	369.9
Russian region and Central Asia	3.0	3.1	0.0
Middle East/North Africa	4.0	37.3	0.1
South Asia	887.8	652.8	96.1
Sub-Saharan Africa	10.1	35.8	6.5
Global	2,749.7	1,068.8	514.1
Global average per year	88.7	34.5	16.6

Source: Visser et al. (2012).

Data are total values over the 1980–2010 period and are taken from the CRED EM-DAT database. Maximum values for each region are highlighted in yellow

Figure 5.1
Natural catastrophes, 2010



- Natural catastrophes
- Selection of events of significant loss
- Geophysical events (earthquakes, tsunamis, volcanic activity)
- Meteorological events (storms)
- Hydrological events (flood, mass movement)
- Climatological events (extreme temperature, drought, wildfire)

Source: NatCat database, Munich Re (2011)

Overview of weather-related disasters in 2010, showing the large number of flood events. Source: NatCat database, Munich Re (2011, pp. 54–55)

Table 5.2
Reported economic losses due to weather-related disasters

World Bank region	Coastal and river floods [billion USD]	Temperature extremes and droughts [billion USD]	Tropical and extra-tropical storms [billion USD]
Developed countries	230.5	144.0	739.9
Latin America/the Caribbean	44.9	9.5	77.6
East Asia/Pacific	221.7	69.9	76.0
Russian region and Central Asia	13.0	6.6	0.0
Middle East/North Africa	19.2	7.2	4.3
South Asia	73.2	3.7	24.1
Sub-Saharan Africa	2.7	7.7	3.4
Global	605.2	248.5	925.3
Global average per year	19.5	8.0	29.8

Source: Visser et al. (2012).

Data are total values over the 1980–2010 period and are taken from the CRED EM-DAT database. Maximum values for each region are highlighted in yellow

population of 0.5 million inhabitants or more) most vulnerable to floods were selected. The comparison of protection standards is not linked to cost but shows the result of theoretical improved protection standards by building levees or from other measures. Based on other studies, the section on costs shows that the potential cost of flood protection is limited.
The next section in this chapter is about environmental justice; in this case the distribution of flood risk amongst different communities in society. Finally, the last two sections describe potential measures and the major governance challenges faced by many cities in reducing the flood risk.

5.3 Modelling flood risks

To explore future trends in flood risks, two model frameworks were used. GLOFRIS (GLObal Flood Risk with Image Scenarios; Winsemius et al., 2013; Ward et al., 2013) was used for river floods, and DIVA (Dynamic Interactive Vulnerability Assessment; DINAS-COAST Consortium, 2006) for coastal floods. The potential effects of climate change were omitted in all explorative calculations; in other words we only examined changes in risk trends due to socio-economic developments. Further research will be carried out in the coming years to also assess the impacts of climate change. As far as coastal flooding is concerned, the potential effects of climate change up to 2030–2050 may be limited. For example, even in the case of a high-end sea-level rise scenario of +1.2 m by 2100, the main effects will only become apparent towards the end of this century (see for instance Hinkel et al., 2013).

River floods

GLOFRIS was used to simulate the river flood risk. GLOFRIS is a cascade of models that estimates flood risk at a spatial scale of 30” x 30”, or about 1km x 1km at the equator, expressed in various risk indicators such as ‘annual exposed population’ and ‘annual exposed GDP’. The model cascade used here is described in detail in Ward et al. (2013), and its development is described in Winsemius et al. (2013). In brief, the model cascade involves: a) hydrological and hydraulic modelling to develop daily time series of flood volumes, b) extreme value statistics to estimate flood volumes for different return periods, c) inundation modelling to develop inundation maps for different return periods, and d) impact modelling. Each step is described briefly below, but for a detailed description please refer to the aforementioned references.

(a) Hydrological and hydraulic modelling
Daily gridded flood volumes at 0.5° x 0.5° were first simulated using PCR-GLOBWB-DynRout (Van Beek and Bierkens, 2009; Van Beek, 2008). This model was forced using daily gridded climate data. For this report, the model was forced using daily gridded precipitation, temperature and radiation data from 1958 to 2000 taken from the EU-WATCH project (Weedon et al., 2011).

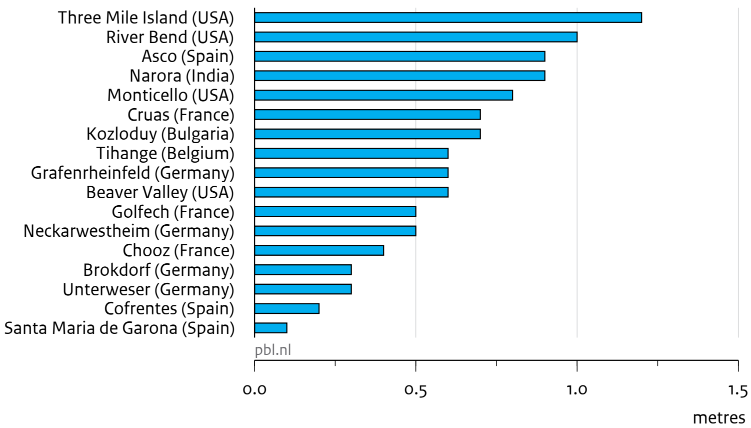
Text box 5.1 River floods and nuclear risk

The Fukushima accident raised considerable concern around the globe on the overall safety of nuclear power plants when faced with natural hazard-induced risks. It became apparent that natural hazards, and in particular flooding, can be a large threat to the safety of nuclear power plants. Since nuclear power plants are often located near or in river flood zones, an important question is whether nuclear facilities will face increased risk from flooding in the near future.

Using the GLOFRIS flood-risk modelling cascade (Winsemius et al., 2013; Ward et al., 2013), flood depths for all 441 locations of nuclear power plants in the world were simulated for two return periods: a once in 30 year flood depth and a once in 100 year flood depth (Aerts et al., 2013). Inundations for both return periods are provided in meters of flood water for the whole globe at a resolution of 30” x 30” (about 1km x 1km at the equator). The results show that the number of nuclear reactors that could potentially be affected by river floods is projected to increase. Without taking into account flood protection measures, which are indeed in place around most nuclear power plants, the results show that a flood with a return period of 30 years could potentially affect 28 global nuclear reactors and a flood with a return period of 100 years could potentially affect 35 reactors (Figure 5.2). Additional analyses will focus on how nuclear plants may be affected by earthquakes, tsunamis and coastal surges. A joint analysis will rank the most vulnerable nuclear installations to natural hazards.

Figure 5.2

Increase in flood depth near nuclear power plants



Source: IVM Institute for Environmental Studies

Top 17 vulnerable nuclear power plants with the largest increase in flood depth, calculated as the difference in 1:30 flood depth and 1:100 flood depth

(b) Extreme value statistics

From these daily gridded flood volume time series, an annual time series of maximum flood volumes was extracted for the hydrological years 1958 to 2000. By extrapolating this time series using extreme value statistics – in this case the Gumbel distribution – flood volumes per cell for different return periods (10, 100 and 1,000 years) were estimated.

(c) Inundation modelling

The next step was the conversion of these coarse resolution flood volumes (0.5° x 0.5°) into high resolution (30” x 30”) inundation maps, showing flood extent and inundation. This was carried out using the downscaling module described in Ward et al. (2013). In brief, the module distributes the flood volumes from the low resolution grid cells onto the high resolution (30” x 30”) grid, based on elevation data from a digital elevation model. Here, the assumption was made that flood volumes with a return period of two years or less would not lead to overbank flooding.

Text box 5.1 gives an example of modelling the risk of river floods at nuclear power plants using GLOFRIS.

Coastal floods

Coastal flood calculations are based on the DIVA database (DINAS-COAST Consortium, 2006). DIVA covers all coastal nations in 12,148 coastal segments and gives sea-level estimates per segment for different return periods. The sea levels include tides and storm surges (Visser, 2012). These storm surges are used in combination with the Shuttle Radar Topographic Mission (SRTM) Digital

Table 5.3

People (in millions) living in flood-prone areas, i.e. areas that will be affected by a flood with the dimensions of a flood occurring once in 1000 years, either from the sea or from rivers (1:1000 floods)

	2010	2030	2050
Developed countries	140	148	148
Latin America & the Caribbean	59	69	73
East Asia and Pacific	372	428	448
Russian region and Central Asia	25	26	26
Middle East and North Africa	46	64	79
South Asia	294	378	435
Sub-Saharan Africa	55	88	125
Total	991	1,203	1,334

Elevation Model (DEM) assuming that, as a wave moves inland, its height diminishes (Dasgupta et al., 2009). Because DIVA only provides return periods of 10, 100 and 1000 years, the combination of DIVA and GLOFRIS results are only presented for these three return periods.

(d) Potential impacts

Each inundation map was combined with gridded socio-economic data to estimate the flood impacts for each return period. For this report, gridded population and GDP datasets (30" x 30") were used, taken from the IMAGE model (Bouwman et al., 2006). Annual expected impacts (i.e. annual exposed population and annual exposed GDP) were then calculated as the area under a standard exceedance probability-impact risk curve, assuming that the impact for a two-year event is always zero. It is important to note that, at the global scale, insufficient information on flood protection levels is available, whilst in reality many areas are protected by flood protection measures. Absolute estimates of risk are highly sensitive to assumed flood protection standards (Ward et al., 2013). The results in this study therefore compare the risk that would exist assuming different protection levels for 2010 and 2050.

Each impact indicator was calculated for return periods of 10, 100 and 1000 years. Annual expected impacts (e.g., annual expected exposed population) were then calculated as the area under the risk curve (Meyer et al., 2009; Aerts et al., 2012; Ward et al., 2013).

Indirect damage in terms of disruption to economic growth was not considered. However, this is highly significant, particularly for poor countries and major events (Hallegatte et al., 2007).

5.4 Trends and projection

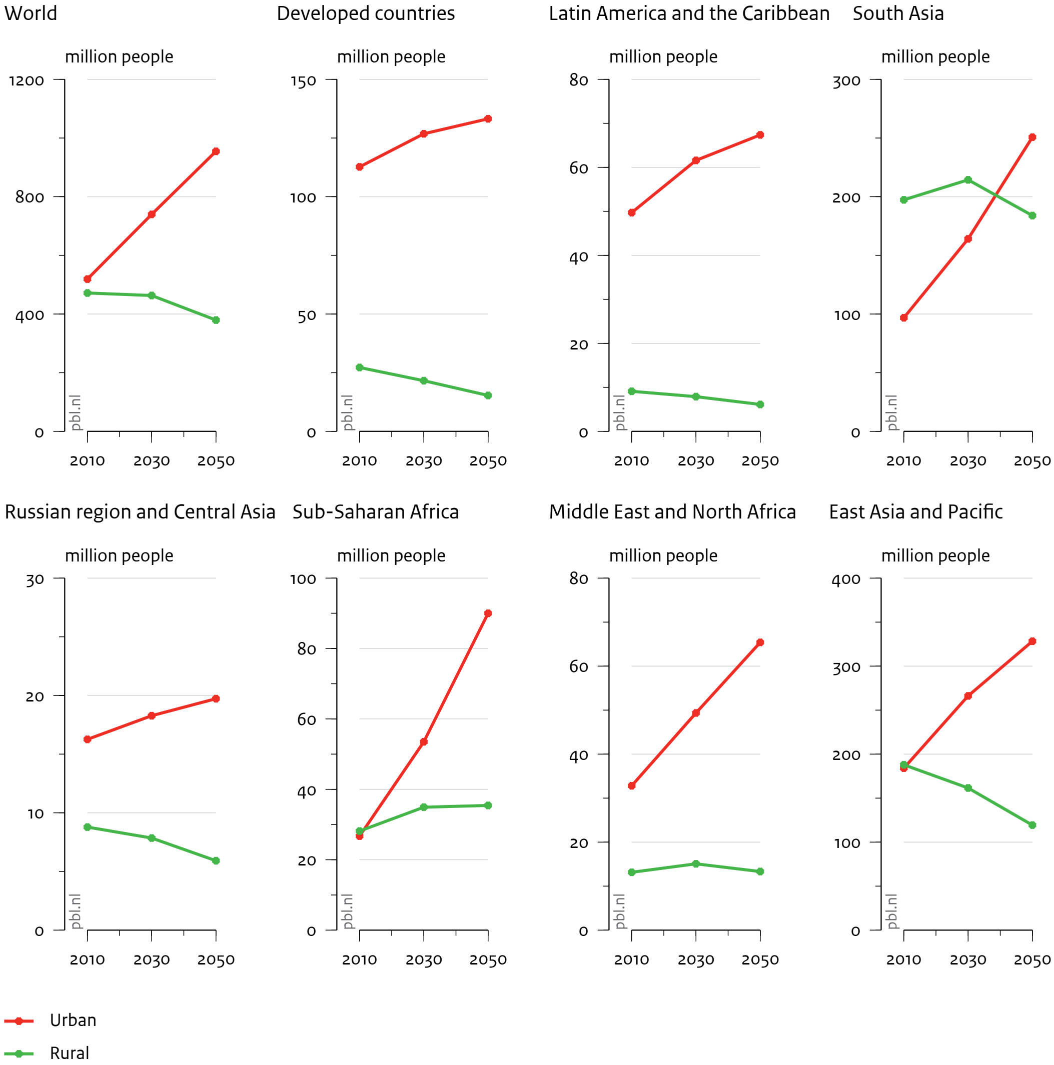
Annual population and economic value exposed to floods

In 2010, almost one billion people worldwide lived in flood-prone areas (Table 5.3), with the largest share in South Asia, East Asia and the Pacific. This will still be the case in 2050, when 1.3 billion people are projected to live in flood-prone areas. A flood-prone area is defined as the area that will be affected by a flood with the dimensions of a flood occurring once in 1000 years, either from the sea or from rivers.

In all regions, the urban population living in flood-prone areas is projected to grow rapidly, while the rural population living in flood-prone areas is projected to decline in almost all regions. This is in line with overall demographic growth patterns (see Chapter 2). Only in sub-Saharan Africa may the rural population living in flood-prone areas continue to grow after 2030. However, the growth of the urban population in flood-prone areas is also much larger than the growth of the rural population in flood-prone areas in this region (Figure 5.3).

People living in flood-prone areas are often protected, or protect themselves, against floods to some degree, although many regions suffer a safety deficit (World Bank, 2012). Unfortunately, the actual protection levels are not known globally, nor are the future flood risk strategies and protection levels in cities and regions of the world. As further explored in Section 5.7, a flood risk strategy may involve a wide range of measures, both structural (such as levees, dams, storm barriers and shelters) and non-structural (warning systems, disaster and evacuation plans, risk communication and spatial planning). Because of the lack of information on flood risk strategies around the world, it is not possible to explore

Figure 5.3
Population in flood-prone areas



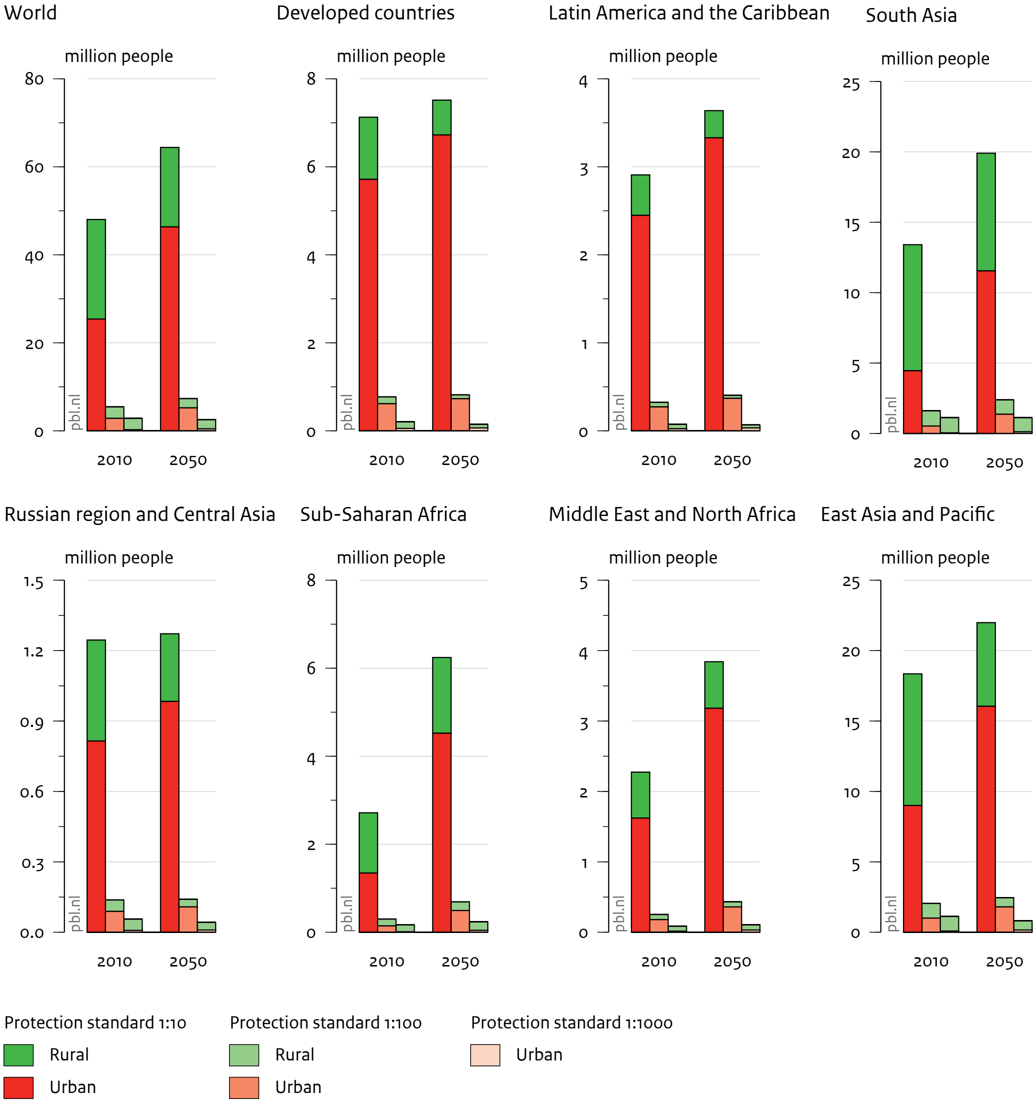
Source: PBL

People (in millions) living in flood-prone areas (1:1000 floods) in the World Bank regions under the Baseline Scenario. Note the different y-axis scales

the current and future situations for different kinds of flood impact reduction measures. However, it is possible to explore the potential effects of structural measures providing a certain protection level.
Based on different protection levels, the annual expected exposure method was applied (Meyer et al., 2009; Aerts et al., 2012; Ward et al., 2013). Comparing the annual exposed population for low and high safety levels shows the potential reduction in flood risk in time for the different World Bank regions. In this study, the differences are shown in annual exposed population and annual exposed GDP to floods, applying protection levels against floods occurring once in 10 years (1:10), or once in 100 years (1:100) or even once in 1000 years (1:1000).

Safety levels of 1:10 and 1:100 were applied for both urban and rural areas in 2010, 2030 and 2050. As the urban assets and population in flood-prone areas are growing much faster than the rural population, a high protection level of 1:1000 was also applied for urban areas.
Protection levels of 1:10 or less may occur in many regions where there are few resources for structural measures, or where flood risks are neglected in spatial and urban development. A protection level of around 1:100 or more is most common in urban areas where specific measures are taken, often after a disaster has occurred. For example, a protection level of 1:100 is to be applied in New York, and a protection level of 1:200 has been applied in New Orleans. Only the city of London along the

Figure 5.4
Annual exposed population to floods



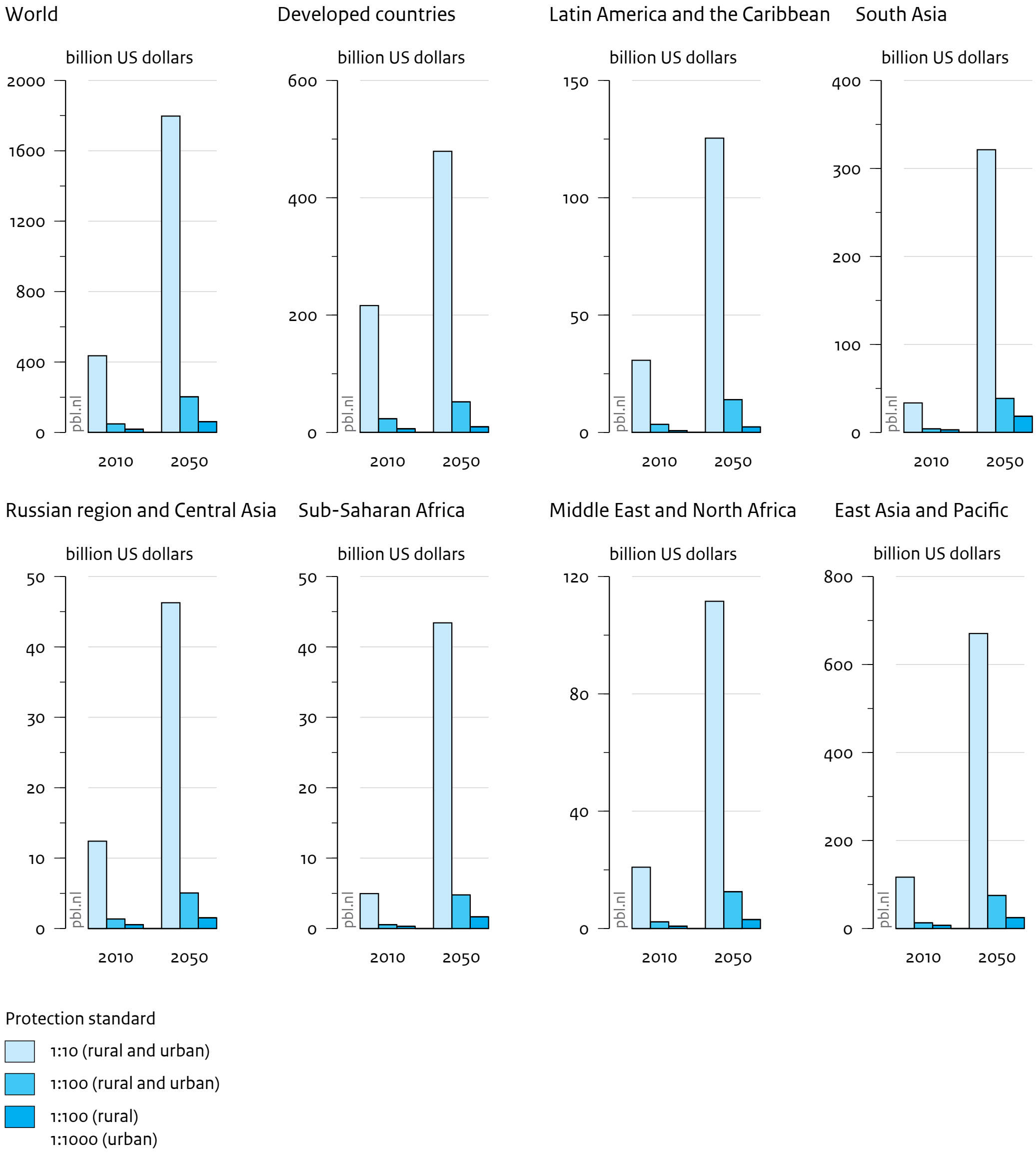
Source: PBL

Comparison of urban and rural populations' annual exposure to floods, in 2010 and in 2050 applying different protection standards. Note the different y-axis scales

Thames Estuary, with a protection level of 1:1000 years, and the Netherlands with protection levels ranging from 1: 1,250 to 1:10,000 years are known places with much higher safety levels. The figures below compare the situation in 2010 and 2050. The figures for 2030 are given in Appendix 1.

Assuming a minimum 1:10 protection, the annual exposed population will increase by 34%, from 48 million to 64 million people worldwide, between 2010 and 2050. The annual exposed *urban* population will increase even more, by 82%, from 117 million in 2010 to 166 million people by 2050. The annually exposed, rural population shows a decline of 20%, although, by 2050, 18 million people will still be exposed to floods each year. Relatively speaking, the regions with the largest growth in annual exposed population will be South Asia, the Middle East and North Africa, and sub-Saharan Africa. In the latter, the exposed population is projected to more than double.
At the other end of the protection spectrum – 1:100 for rural areas and 1:1000 for urban areas (the assumed maximum protection) – the annual exposed population to floods worldwide in 2010 was 3 million people, of

Figure 5.5
Annual exposed GDP to floods



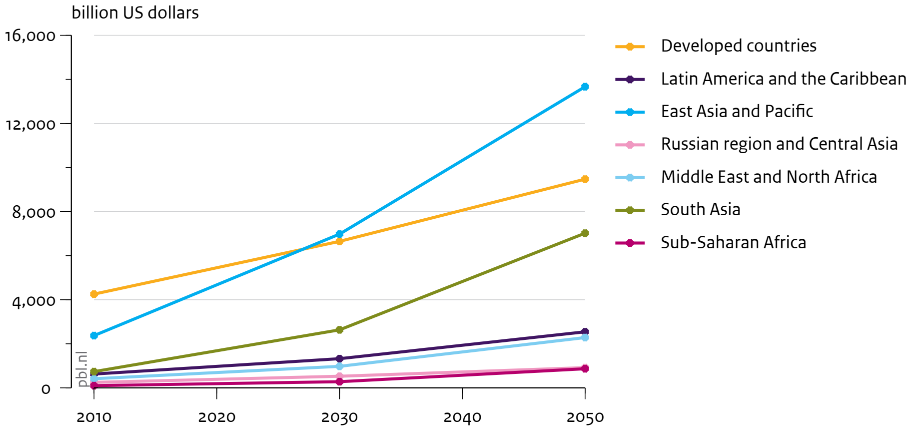
Source: PBL

Comparison of GDP exposed to flooding, either from rivers or the sea, across regions, in 2010 and 2050, applying protection standards of 1:10, 1:100 and 1:1000, showing the large effects of improving flood protection. Note the different y-axis scales

which 260,000 were in urban areas. For 2050, these figures are 2.5 million, of which 477,000 will be living in urban areas. This is 4% to 6% of the annual exposed population, assuming a minimum protection of 1:10 for all regions. The total exposed population by 2050, therefore, will be lower than in 2010. This is due to the high protection standard in urban areas, which causes a smaller increase in exposed urban population in addition to the large decline in the exposed rural population (see Appendix 1).

To estimate the value of assets annually exposed to floods in all regions, GDP was used as a proxy for potential damage. Between 2010 and 2050, the annually exposed GDP is projected to increase more rapidly than the population (compare Figures 5.4 and 5.5). In 2010, assuming a 1:10 protection for all regions, the annual exposed GDP to floods was USD 435 billion, or 1% of total global GDP. With no action, the GDP annually exposed to floods is projected to increase rapidly to an estimated USD 1,797 billion by 2050 – a growth of 313% compared

Figure 5.6
GDP in flood-prone areas



Source: PBL

Comparison of regional trends in GDP at risk, 2010–2050

with 2010. The annual exposed GDP will grow tremendously in all regions if protection levels are not increased. Some regions are growing faster than others, in particular South Asia, which is growing very rapidly in terms of annual exposed GDP. The range of the growth is between 121% for developed countries and 859% for South Asia (Figure 5.5 and Figure 5.6).
Applying high-end safety levels (1:100 for rural areas and 1:1000 for urban areas), the global annual exposed GDP was USD 19 billion in 2010, rising to USD 62 billion by 2050. Compared with the assumed lowest safety standard, this is about 4% of the calculated annual exposed GDP. As with exposed population, therefore, the results show that applying protection measures can strongly reduce the annual exposed economic value.

As protection levels are unknown for many parts of the world, the same level for all regions at the same time is assumed. In reality this is not true, as some regions are more protected than others. Using different protection levels, again for all regions at the same time, the results also show that the model is highly sensitive to flood protection standards. Flood risk assessments would benefit greatly from a global database of flood protection standards (Ward et al., 2013).

Vulnerable cities

Towards 2030 and 2050, more and more people will live in an urban environment (Figure 5.3) and city sizes are expected to grow substantially (Table 5.4). In the urbanisation discourse, megacities have captured the human imagination (Nicholls, 1995; Mitchell, 1999), and the flood risks associated with megacities are well recognised (e.g. see Mitchell, 1999; Oumeraci et al., 2009; Adikari et al., 2010). However, secondary cities – typically defined as those with populations between 500,000 and 3 million inhabitants – are equally important (Brillembourg and Klumpner, 2011; compare Table 5.4). Secondary cities in the global south are expected to undergo massive expansion in the next few decades, comparable to city growth in Europe and North America 100 to 200 years ago.
As cities and their populations grow, everything else grows with them, including exposure to floods (Cissé et al., 2011; Huong and Pathirana, 2013). In the southern hemisphere in particular, secondary cities are often severely underserviced in terms of basic infrastructure and flood protection, making them highly susceptible to floods. Figure 5.7 shows a map of cities with a population of more than 500,000 in 2010 and 2050, with an indicator of their vulnerability to flooding, ranging from less vulnerable to more vulnerable. Here, vulnerability is defined as the expected annual exposed population combined with the country's capacity to adapt, which is expressed as the GDP per capita. A large annual exposed population combined with a low GDP per capita means a relatively high vulnerability. It is important to recognise that the definition of vulnerability based on exposed population and GDP per capita is simplistic and indicative, based on available data. The lack of information means that it is not possible to distinguish differences within cities. The score in rank is divided into 4 equally divided classes. The low vulnerability category also includes cities of 500,000 inhabitants or more that are not vulnerable to floods at all.
In 2010, there were 468 cities with 500,000 or more inhabitants. About 350 of these cities were vulnerable to floods, evenly distributed over the vulnerability

Table 5.4
Overview of number of cities with more than 500,000 inhabitants by vulnerability rank in 2010 (top) and 2050 (bottom)

	Vulnerability				
Inhabitants 2010	**low**	**..**	**..**	**high**	**Total**
0.5–1 m	65	67	46	34	212
1–5 m	49	46	65	66	226
5–10 m	3	1	6	8	18
> 10 m		2	1	9	12
Total	**117**	**116**	**118**	**117**	**468**
Inhabitants 2050	**low**	**..**	**..**	**high**	**Total**
0.5–1 m	84	73	82	54	293
1–5 m	74	79	68	69	290
5–10 m	7	12	11	22	52
> 10 m	4	4	6	22	36
Total	**169**	**168**	**167**	**167**	**671**

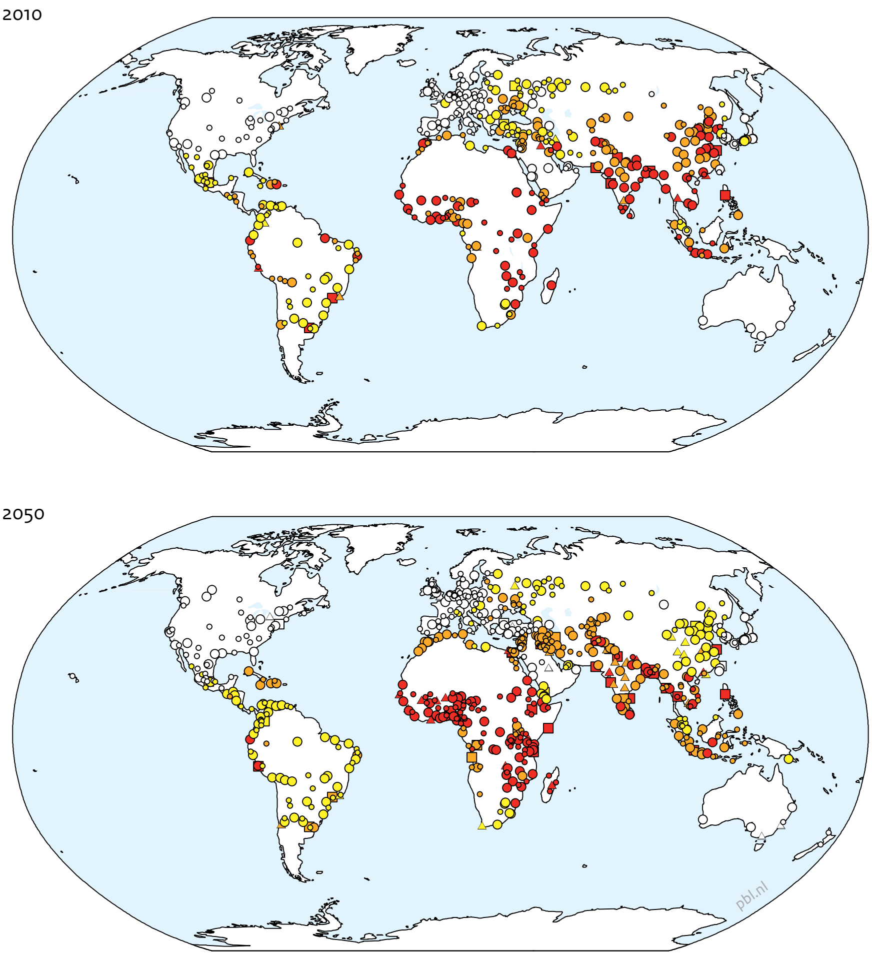
categories (Table 5.4), with over 100 cities in the highest vulnerability category. Of these cities, 17 had more than 5 million inhabitants. These are cities such as Mumbai, Shanghai, Jakarta, Delhi, Dhaka and Lahore, but also Tokyo and Lima, amongst others.

By 2050, the number of large cities – cities with 500,000 inhabitants or more – will have grown to 670, by which time 88 cities will have over 5 million inhabitants (Table 5.4), and 50% of these cities score in the highest rank of vulnerability. In 50 years' time, some of the cities with the most at-risk assets today will have been surpassed by Calcutta, Shanghai, Mumbai, Tianjin, Bangkok, Ningbo and Ho Chi Minh City. These are booming Asian coastal metropolitan areas where trillions of dollars in economic assets will be vulnerable, as well as many millions of these cities' residents, most of them poor and living in low-lying areas. The number of large and vulnerable cities is also expected to grow strongly in Africa (Figure 5.7). In the United States, Europe and Australia, the vulnerability of cities based on GDP and population is classified as relatively low, but this assumes that the adaptive capacity is sufficient in these cities and that budgets for adequate flood protection strategies are made available.
Most of the cities in the top 25 are located in South Asia and East Asia. There were 5 cities with more than 10 million inhabitants in 2010: Delhi, Mumbai, Shanghai, Sao Paulo and Manila, and the most vulnerable city was Mumbai. By 2050, 9 cities in the top 25 most vulnerable cities will have more than 10 million inhabitants. Amongst them are cities such as Baghdad, Chittagong, Dhaka and Jakarta. Some cities in sub-Saharan Africa will also enter the top 25 most vulnerable cities to floods by 2050 – Lome in Togo and Sofala in Mozambique being just two examples. Cities in Latin America which were ranked in the top 25 in 2010 will score better on the list by 2050, due to higher growth in GDP per capita, which is the indicator for the opportunity to adapt to flood risk.

5.5 Cost of reducing flood risk

We have not estimated the cost of improving flood risk strategies. Other studies that have explored the potential cost of flood protection measures based on cost-benefit analyses show that these costs are limited at the global level. Hinkel et al. (2013) estimated that the global annual cost of flooding, including levee upgrade costs, maintenance costs and residual damage costs, may reach USD 210 billion a year in 2100 under a business-as-usual scenario, with no mitigation or adaptation beyond the currently-implemented measures. Assuming adaptation and adjusted protection levels, the global annual flood cost in coastal zones relative to world GDP falls throughout the century from about 0.06% to between 0.01% and 0.03% by 2100 under all scenarios, including the high-end sea-level rise scenario. From this perspective, reducing flood impacts and adaptation can be meaningfully widely-applied, irrespective of the level of mitigation.
The Netherlands is one of the best protected deltas in the world, with high safety standards protecting people and assets from floods, from 1 in 10,000 years in coastal areas to 1 in 1 250 years in the river areas (Text box 5.3).
The total cost of the flood management system in the Netherlands, including construction costs, maintenance

Figure 5.7
Ranking of vulnerability to floods



Vulnerability		Population	
○	Less vulnerable	◦	0.5 - 1 million
● (yellow)	----	○	1 - 5 million
● (orange)	----	△	5 - 10 million
● (red)	More vulnerable	□	> 10 million

Source: PBL

Geographical distribution of and potential vulnerability to floods in large cities in 2010 (upper panel) and 2050 (lower panel), showing the large increase in the number of megacities and vulnerability, especially in Africa, Asia, South Asia and the Pacific

costs and institutional costs, currently amounts to about USD 2.0–2.7 billion a year (Delta Programme, 2013), equivalent to about 0.3% of GDP, or USD 120 to 160 per person per year. These figures show that paying serious attention to reducing flood risk does not necessarily result in very high burdens on GDP. However, in an environment of scarce resources for local authorities, especially in poor countries, mobilising enough resources will nevertheless be a substantial political and institutional challenge.
Looking forward to 2030 and 2050, the potential impacts of climate change, sea-level rise and changing peak discharges in rivers are also not included in this study. Further research will be carried out in the coming years to also assess the impacts of climate change. In a study using the DIVA model, Hinkel et al. (2013) showed that if protection standards are adequately adapted to the expected sea-level rise, the number of people affected in coastal zones hardly differs between the sea-level rise scenarios, including a high-end scenario of a 1.2 metre sea-level rise by 2100.

Text box 5.2 Flood protection in Jakarta

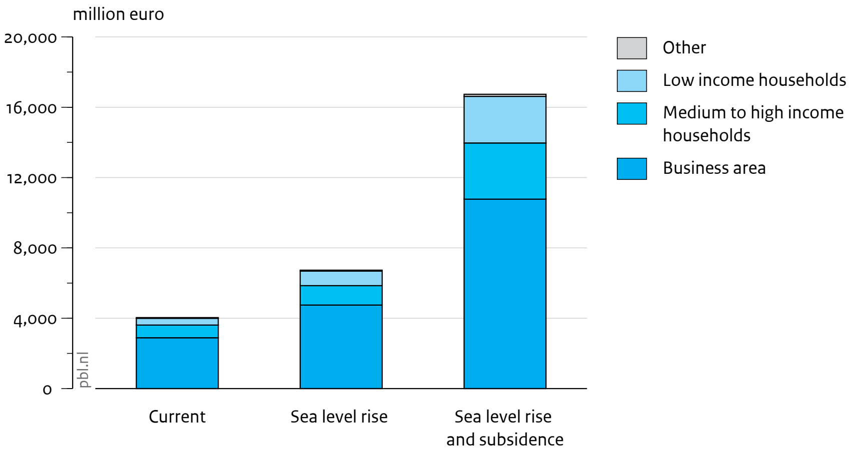
Jakarta: very vulnerable to floods
Jakarta, the capital city of Indonesia, has experienced frequent flooding, including several major events with high impacts in terms of fatalities and economic damage in 2003, 2007 and 2013. The devastating flood of February 2007 led to the death of between 58 and 79 people, and direct economic losses of between USD 890 million* (according to the National Planning Development Agency, BAPPENAS) and USD 1.7 billion (according to Munich Re). The indirect impacts were also huge, including the displacement of over 400,000 people, the closure of many roads and rail lines, including the main highway to the international airport, telephone lines being cut off, and an upsurge in water-related diseases such as dengue fever, leptospirosis and diarrhoea.
Flooding in Jakarta is not new, as historical documents show a large number of floods throughout history as a result of its naturally flood-prone location and seasonal rainfall intensity. However, rapid development has led to an increase in risk in recent decades through many drivers, including population growth, land-use change, land subsidence, the clogging of drainage channels with sediment and solid waste and, possibly, climate change.

Future flood risk
There has been an increased interest in determining the possible future flood risk in Jakarta in recent years, with an eye to assessing possible adaptation strategies for flood risk reduction. The ongoing *Jakarta Climate Adaptation Tools* project has already assessed how the exposure of economic assets to coastal flooding may change over the coming century, due to changes in climate and subsidence. Ward et al. (2011) developed a model to assess economic assets exposed to a 1 in 100 year flood event under the current situation, and in the year 2100 as a result of sea-level rise and land subsidence (see Figure 5.8). If land subsidence is not addressed and continues at the present rate this, together with a sea-level rise of 59 cm during the 21st century, will result in an increase in the value of assets exposed of a factor of 4 by 2100.
However, while sea-level rise will increase the flood risk for Jakarta, ongoing land subsidence will have an even greater impact on the overall risk, at least in the short term. Moreover, these figures do not include the impacts of changes in the value of the assets located in potentially flood-prone parts of the city. Since these are expected to increase rapidly, the overall growth in risk will be higher.

Managing flood risks
Given its long history of flooding, Jakarta does have much flood management experience. This has traditionally focused on infrastructural measures to keep the water away from people, such as canals, dams and sluices. A number of recent successes in this regard include the completion of an Eastern Flood Canal, to complement the already completed Western Flood Canal, and the thorough dredging of the 13 main rivers running through the city as well as the Eastern and Western Flood Canals. Ongoing and planned measures include the development, rejuvenation and maintenance of polder systems in Jakarta. Polder systems consist of an urban drainage system, retention basins, embankments and dikes, water pumps and water gates spread throughout Jakarta.
To reduce the rate of land subsidence, an aquifer storage system is also under development by the Public Works Agency. The aim of the aquifer storage system is to optimise existing wells by adding an artificial aquifer. As well as these sophisticated technologies, more simple efforts to enhance rain infiltration at the local house level are also being executed by using biopores – infiltration holes – or zeolite and gravel to infiltrate water.
There is also an increasing awareness of complementary measures aimed at reducing the exposure and/or vulnerability to flooding. Several programmes to enhance non-structural flood mitigation and preparedness measures have been developed in Jakarta, either by the government or other private institutions. People living in informal settlements, especially in the northern part of Jakarta, have implemented local strategies to face the flood. Several activities that have been carried out locally include the construction of small dams surrounding settlement areas, the building of second stories on houses to which assets can be moved during floods, and the raising of houses to prevent flood waters from entering.
Other non-structural measures have also been developed, such as the strengthening of law enforcement, early warning systems and community capacity enhancement, as well as watershed planning and management, which mainly focus on the upper stream area.

* Original values in Indonesian Rupiah (IDR) were converted to USD values (2010) for 2007 using exchange rates and GDP deflators from the International Monetary Fund.

Figure 5.8
Simulation of three coastal scenarios for different land-use types



Source: IVM Institute for Environmental Studies

Simulations for three coastal inundation scenarios showing exposed assets for different land-use types in million euros

5.6 Inequality and flood risks

Environmental justice raises questions about how the environment impacts on different people's lives (Walker, 2012). Flood hazards and risks are not equal in their distribution and effects: the inherent natural differences in the landscape and the legacy of human interventions over time mean that some areas are flooded much more frequently than others (e.g. see Sayers et al., 2013). Historically, villages built on the higher-lying parts of many flood-prone areas have flooded less frequently either from the sea or rivers. As settlements have grown, and continue to grow, so too have the number of people and economic value of assets located in flood-prone areas. This trend is expected to continue with further migration to cities and continued expansion in lower-lying areas.

In most urban areas, the flood risks are unequally distributed: low-income groups, including migrants, often live in the most flood-sensitive areas and are more vulnerable to floods because of poor quality, insecure and clustered housing, inadequate infrastructure, and often lack of adequate provision for health care, emergency services and measures for disaster risk reduction (IPCC, 2012). In Bangladesh, lower income households were found to face a higher exposure to flooding risk (Brouwer et al., 2007). Also, disparity in income and asset distribution at the community level tends to be higher at higher risk-exposure levels, implying that low-income and vulnerable households are collectively more vulnerable. Interestingly, Brouwer et al. (2007) found that people who face the highest risk of flooding are the least well prepared, both in terms of household-level preparedness and community-level flood relief. This unequal distribution of flood risk and other environmental risks over the population is seen not just in cities in developing countries, but also in developed countries and cities, for example in the United Kingdom (Walker, 2013) and the United States (e.g. see Maantay and Maroko, 2008).

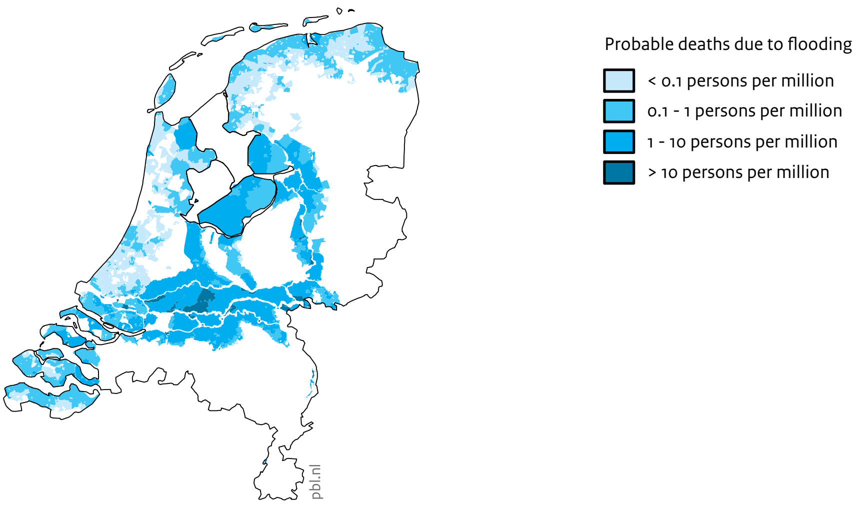
Almost one billion of the world's population currently lives in slums (e.g. see UN-Habitat, 2008). A host of socio-economic reasons make slum dwellers much more vulnerable to flood hazards. For example, in the slums of Mumbai, 'illegal' slum dwellers may be afraid to make their homes more flood-proof for fear that the authorities will evict them and they will lose their investment (Cannon, 2008). Squatters and slum dwellers living in flood-prone plains will endure dangerous conditions to be close to sources of income, while in the rental sector many families may share crowded, poor quality, illegally divided tenements. In central Delhi, for instance, a large and notorious squatter settlement has existed within the designated flood plain of the Yemuna River for more than 25 years. The people of the settlement are forced to evacuate at least once a year to the busy roadside, while their shelters remain flooded for over a month. Even so, the settlement is thriving, with small businesses, a school and a lively property market. The regular flooding is seen as the price to pay for living in the centre of the city at low cost (Sanderson, 2000).

In a study on the capacity of slum dwellers in Mumbai to cope with floods in the recent past, Chatterjee (2010) concluded that to address existing discrepancies in urban societies and within slum areas, flood risk strategies will have to be more inclusive of marginal populations and sensitive to the limitations and scope of old and new social structures.

Text box 5.3 Equality – a basic risk level for everyone in the Netherlands

The current flood risk management policy in the Netherlands is being revised. At present, the policy consists of a set of six different safety standards for the main system, giving protection against floods that may occur between once in 1 250 years and once in 10,000 years. Protection is provided by about 3 500 kilometres of primary defences such as levees, dams, dunes and storm surge barriers. The safety standards are loosely based on a risk approach, with higher standards applied to the densely-populated areas and areas of most economic value along the coast and lower standards applied to the less-populated areas along the major rivers. Although the relatively limited spatial differentiation in flood protection is rather inefficient in economic terms, it does create a fairly simple system with little inequality. In revising the flood risk strategy, the government intends to increase the economic efficiency of investment in flood protection, and as a consequence there will be a much higher regional differentiation in flood protection levels, primarily reflecting the differences in economic value in regions.
The introduction of a basic individual risk level for everyone living behind a levee is now considered a new policy objective. The envisioned level is set at a probability of dying from a flood of no more than 1:100,000 years. The choice of this level is based on two considerations: current policy with respect to external safety such as for the production and storage of chemicals also uses a risk level of 1:100,000 years, and implementation of a level of 1:1,000,000 years would require considerable investment in flood protection (Figure 5.9), thus reducing the economic efficiency. A level of 1:100,000 therefore satisfies the Dutch approach towards equality at a reasonable cost.

Figure 5.9
Distribution of the individual risk of exposure to floods, 2013



Source: Kind et al. (2013)

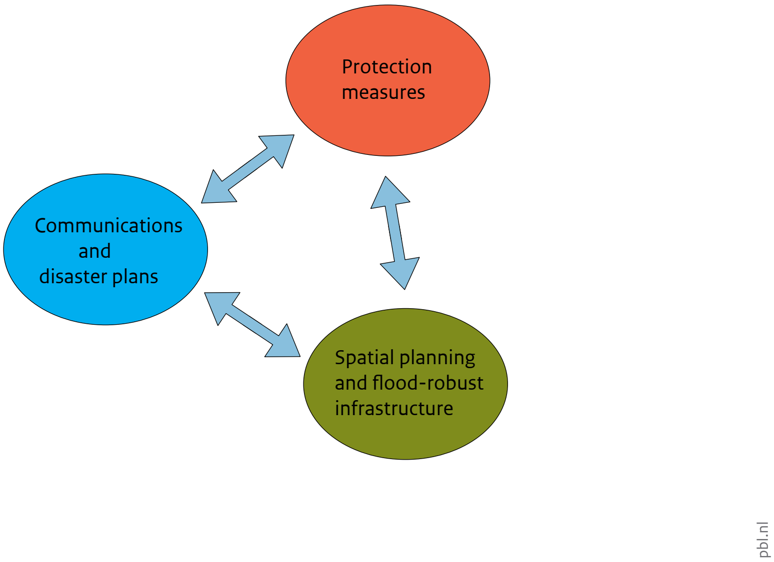
Distribution of individual risk (the probability of dying from a flood) in the Netherlands, showing that only small areas (dark blue) need extra protection to provide the considered standard of individual risk of less than 1:100,000 (Kind et al., 2013)

5.7 Policy options

There are a large number of potential measures for reducing flood risk. These relate not only to levees, storm surge barriers and dams, but also to flood-proof construction, spatial development, warning and evacuation systems and disaster and recovery plans. An integrated flood-risk strategy is based on a careful exploration of options involving different types of measures (Figure 5.10). Often, structural and non-structural measures are distinguished. Table 5.5 gives an overview of potential measures, categorised as structural/non-structural measures, protection/spatial measures or communication/disaster plans.

Only the option of increasing protection levels by building levees is considered in this study. While acknowledging that other measures should be considered as well, the exploration indicates what can be achieved if due attention is given to flood risk in the coming decades.

Figure 5.10
Flood protection strategy requires the integration of various types of measures



Source: PBL

A flood protection strategy requires the integration of various types of measures

Flood events may result in systemic risks, affecting infrastructural networks in combination with a break-down in critical services, such as electricity and the water supply, and health and emergency services. As well as the direct measures that reduce the potential effects of floods, policies that may indirectly contribute to reducing vulnerability to floods are also important. These are mentioned in Table 5.5 under the heading 'Facilitating measures and policies'.
Reducing flood risks obviously costs money, especially when countries or cities face a deficit in protection levels. However, as shown above, flood protection strategies do not necessarily mean a heavy burden on GDP, but in developing countries in particular mobilising enough resources will be not easy. Major bottlenecks for developing an adequate flood risk strategy are often the institutional complexity and the lack of available budgets and financing mechanisms (e.g. see World Bank, 2012).
A general difficulty for decision-makers promoting investment in flood risk strategies is the time delay between the public investment in risk reduction and the benefits that are either infrequently visible due to the infrequent occurrence of hazards or visible over many decades and in the form of avoided losses that nobody can see today.

Governance challenges

Reducing flood risks in cities located in flood-prone areas is a major challenge involving multiple governance challenges. In cities in particular, the development process is complicated by the large number of actors operating in different sectors and at different levels within the city. The following major governance challenges can be identified:

- bridging scales: from river basin to flood-proof buildings;
- integration of flood risks in urban planning and design;
- integration of climate change in urban planning and design;
- integration of environmental justice in flood risk strategies and urban planning;
- communication and involvement of stakeholders.

Bridging scales: from river basin to flood-proof buildings
Spatial, urban and infrastructural planning and development at the national, regional and city level is a powerful instrument for flood-proof development. The long lead time of spatial and infrastructural development requires integration and the anticipation of flood risk challenges. The river flood risk in a city depends on the protection levels of the city itself, but also on river management at the scale of the river basin as a whole and on measures taken by cities upstream. If a region upstream improves the protection standard of its own growing urban areas and the surrounding land, then the water retention capacity of the river system will decrease and the probability of flooding downstream may increase. This functioning of the river as a system therefore requires a strategy at the level of the river

Table 5.5

Overview of possible non-structural and structural measures grouped by flood-related measures and conditional measures

Flood-related measures	Non-structural	Structural
Protection measures		Levees, floodwalls Storm surge barriers Storage compartments, retention areas and buffer zones Beach nourishment and dune re-enforcement Mangrove development Artificial reefs
Spatial development and infrastructural design	Develop building codes and zoning regulations to stimulate flood-robust spatial planning, at level of: – river basin – regions – cities – city districts	Flood-proof: – infrastructure – buildings Creating: – shelters – evacuation routes – room for water: emergency water storage areas around cities – blue/green infrastructure within cities
Disaster plans and communication	Develop peak discharge warning and forecasting systems Develop warning systems for evacuation Develop disaster and recovery plans Communicate flood risk strategy, risks and disaster plans	
Facilitating measures and policies		
Institutional organisation	Effective institutional organisation Clear responsibilities and regulations Disaster organisation and management Recovery organisation and management	
Legislation and financing system	Legal basis for flood risk strategy Financing system for protection measures and warning systems Financing of disaster plans and recovery plans Disaster funds Insurances	
Integration of policy fields	Flood risk policy Health policy and health care system Long-term policy planning addressing climate change and socio-economic trends Urban development policy Regional spatial development policy River basin management and trans-boundary cooperation	

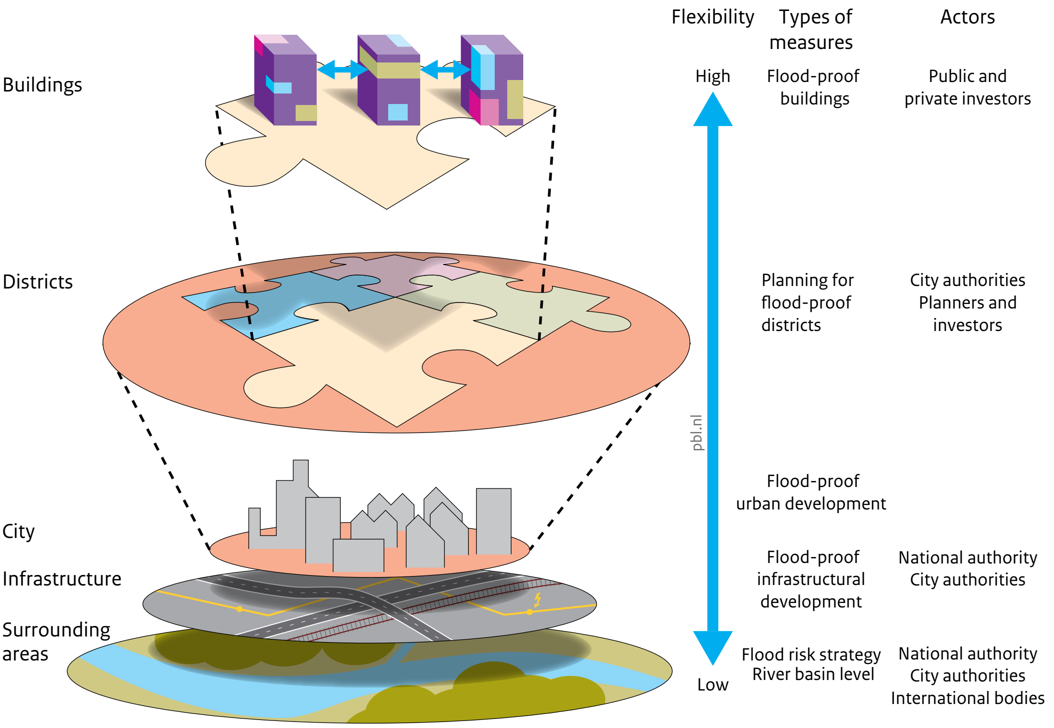
system as a whole, including coordinated decisions on protection standards along the river stream. These coordinated protection levels have to be considered to be the boundary conditions for a flood risk strategy plan at the city, district and building levels. At the scale of the river basin and national flood strategy, international bodies and the national government will be the dominant players.

If such a framework of protection levels does not exist, inequality between cities with respect to flood risk may increase, for example because cities with larger budgets may increase their protection standards at the cost of increasing flood risks downstream. Knowing the boundary conditions and developing a consistent and effective flood protection strategy for and within a city requires good planning and communication and clear responsibilities for the public and private parties involved (see Figure 5.11; Table 5.5).

Integration of flood risks in urban planning

The integration of flood risk reduction in urban development planning is a powerful and robust instrument, but not easily implemented. Cities can manage their flood risk by preventing new urban development in locations that are too high-risk or too costly to protect. If there are no other expansion options, they should turn to flood-proof development. This requires a timely acknowledgement of the flood

Figure 5.11
Adaptation measures at various scales within the urban environment



Source: PBL

Governance challenge: a flood risk strategy encompasses a consistent approach covering various scales

risk challenges and innovative solutions in urban design and planning processes. It appears that exploring solutions and reducing risks while developing new urban infrastructure or redeveloping old infrastructure often pays off. There are various examples of how reducing flood risks and vulnerability may be combined with improvements to the spatial quality and living environment of such areas (Text box 5.4).

Integration of climate change requires an adaptive strategy
Climate change adds another challenge to the reduction of flood risks (e.g. see IPCC, 2011; 2012). The still large uncertainties require an adaptive strategy in order to prevent either serious underinvestment or overinvestment. In an adaptive strategy, a thorough analysis of the flexibility in the system and the lead time of measures or developments versus the expected ranges of climate change should form the basis of a well-designed flood risk strategy (e.g. see Ligtvoet et al., 2012). Figure 5.11 shows that the flexibility of spatial and infrastructural developments is low, due to the usually long lead times. This means that – especially with spatial planning and infrastructural investments – options to integrate adaptation with climate change should be considered in the planning and design phases.

Integration of environmental justice in urban development strategy
As described in the section on inequality and flood risks, vulnerability to floods is often unevenly distributed within cities. When assessing vulnerability to floods, these inequalities within cities in terms of exposure and ability to deal with flood events should be recognised, to design 'fair' flood risk strategies and to prevent an increase in inequality.
Flood risk strategies may be based on different premises, such as: i) minimising the probability of large numbers of casualties due to floods; ii) economic optimal protection measures, protection levels based on cost-benefit calculations; iii) equity in mortality risk due to floods (e.g. defining a minimum level for everybody; Tekst box 5.3).
A flood risk strategy for a specific city requires a balanced mix of warning systems and disaster/recovery plans, protection measures and spatial and infrastructural measures, acknowledging the spatial physical and social differences within the city. In combination with various supportive and facilitating measures (such as health care and recovery funds; Table 5.5), a wide range of strategies can be composed that address the challenges with respect to inequality. Both public authorities and private parties have a role to play in managing and sharing risks. Securing the interests of the poor and vulnerable populations within cities requires the due attention of the

Figure 5.12
Climate proof design District 4 Ho Chi Minh City

Flood- and climate-proof design of District 4 in Ho Chi Minh City (from VCAPS, 2013)

Text box 5.4 Flood-proof urban planning in Ho Chi Minh City

Ho Chi Minh City (HCMC) is the largest city in South Vietnam and is regularly exposed to flooding. The flood risk is projected to increase due to three factors. These are population and economic growth, subsidence due to groundwater extraction, and a change in flooding frequency due to sea-level rise and discharge changes in the Saigon and Dong Nai Rivers (VCAPS, 2013; FIM, 2013).

Between 2001 and 2010, mean annual GDP growth was 7.3%. The number of inhabitants rose from 3.8 million to 7.1 million between 1986 and 2010, excluding an additional 2 million unregistered migrants (Storch and Downes, 2011). By 2025, the city is expected to grow further to at least 10 million people (VCAPS, 2013), and according to Vietnam's Socio-Economic Development Strategy 2011, annual economic growth will be 7% to 8%.

Of the current urban area of HCMC, 55% lies 1 metre above mean sea level and only 28% is above 2 metres above sea level. Of the urban area, 32% is flooded each year at high tides during the monsoon months November and December. Although the old city is located at a higher elevation, urban expansion has taken place in lower areas such as wetlands. This makes the city particularly vulnerable to inundation from even small changes in sea level (Storch and Downes, 2011). Climate change projections show a sea-level rise of 30 cm by 2050, and between 65 and 100 cm by 2100. Precipitation and temperature are projected to increase, and the discharge of the Saigon River will also be affected.

If no additional measures are implemented, the flood risk for the city is projected to increase by a factor of three to four between 2010 and 2025 due to these developments (Storch and Downes, 2011; Lasage et al., in prep; FIM, 2013).

Adaptation to climate change

Several projects have been carried out in recent years to study the impacts of floods and climate change on the city. These have produced different adaptation measures, ranging from improving the sewerage system to constructing a barrier in the sea in front of HCMC. Recently, two projects were implemented, focusing on the prevention of urban flooding (FIM) and the development of an adaptation plan for HCMC (VCAPS, 2013).

The adaptation strategy has been developed jointly by the Vietnamese staff of several government organisations and Dutch experts. During the development, existing knowledge on flooding and other climatic impacts from other projects was used to create an integrated approach to addressing the issues of the city.

The strategy document indicates which issues are most pressing and gives general rules, or strategic directions, on how to assess and respond to the impact of climate change. It does not prescribe the adaptation plan in detail, but aims to support the people who will develop this plan over the coming years.

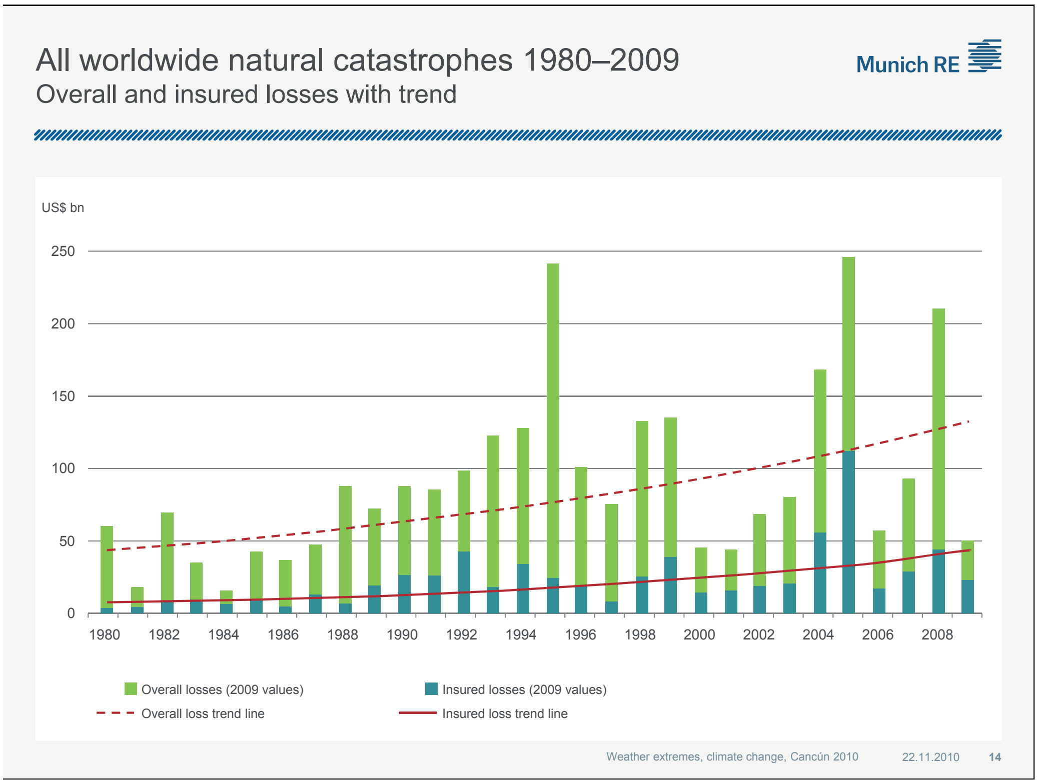
The urban planning strategy is successful because it combines a vision on how to reduce flood risks and respond to climate change with improving the quality of life of the inhabitants of the city district. It is therefore an integrated and inclusive strategy that goes beyond simply addressing flood risks and climate change challenges. Figure 5.12 shows the flood- and climate-proof design of District 4 resulting from the project. It has been adopted by the city government and will be used to update the spatial plan for 2025.
As well as designs and plans at the district scale, technical measures have also been implemented. These aim to reduce flood probability by improving dikes in the various districts, and to reduce vulnerability by raising street levels and elevating new and existing buildings.

Text box 5.5 Insurance a solution?
Global economic losses from natural disasters have increased significantly over the past few decades and are projected to increase further in certain regions of the world as a result of climate change and population and economic growth in at-risk areas. This has initiated a discussion amongst insurers and governments in several countries about whether or not natural disaster risks are insurable using current arrangements. There are three main reasons why insurers in many countries find it difficult to offer natural disaster insurance at a low cost. Firstly, it is difficult to estimate uncertain low-frequency high-impact risks and, therefore, insurance premiums. Secondly, property and casualty (P&C) insurers have limited capacity to cover the, potentially, large and correlated natural disaster losses. Thirdly, there could be a problem with adverse selection if, in the absence of significant premium differentiation, only individuals with a high natural disaster risk were to purchase insurance.

At the other extreme, fully public natural disaster insurance may be considered, which is usually provided in the form of ex post relief. The disadvantages of such a system are that it diverts financial resources away from other important public projects, it works against the free market principle, and incentives for individual risk prevention measures are often limited in the absence of risk-based insurance premiums. Most of the existing international catastrophe insurance systems, such as those for floods, have been developed with some sort of government involvement, either through private markets or by providing compensation through public reinsurance or a state guarantee. These systems are commonly set up as a Public Private Partnership (PPP) with the participation of private insurance companies with varying degrees of roles and responsibilities for the involved participants. In PPP insurance systems, the government and the private sector cooperate in sharing risks or selling insurance policies with the aim to achieve a high market share and to make optimal use of the expertise and capacity to carry the risks of both sectors. The government role in a fully private system is very limited, for example a regulatory role only.

Insurance and inequality
Standard insurance markets will not protect low-income urban dwellers (Hallegatte et al., 2013; Ranger et al., 2009). This population is not served by insurance because of the inability to pay for high risks and the high transaction costs for insurance companies of administering many small policies. Low-income groups rely instead on local solidarity and government assistance when disaster hits (Hallegatte et al., 2007). In addition, where risk levels exceed certain thresholds, insurers will abandon coverage or make premiums unaffordable to those at risk. Insurance reduces the net risk and loss potential in urban areas, but can also increase security inequality within districts or across cities unless coupled with government action to help manage risk in low-income communities (da Silva, 2010).
Introducing insurance arrangements should therefore be part of a well-designed flood disaster management strategy, to prevent increasing inequality. In establishing a risk management and insurance system for flood disasters, important lessons can be learned about how existing insurance arrangements for extreme events are designed in different countries, what their main components are and how they are integrated into disaster management systems. Their main characteristics, funding and achievement of risk reduction and distribution are important components that determine the financial viability and long-term social robustness of an insurance system.

Figure 5.13
Example of a trend estimate of weather-related disasters, according to Munich RE



Total global losses due to natural disasters and the share of insured losses, 1980–2009

public authorities involved. They may compensate for possible increases in inequality if the private sector is the dominant force in reducing flood risk, for example in its focus on more capital-rich districts within cities and/or the application of insurance (Text box 5.5).

Communication challenges – involvement of stakeholders

Communication between public authorities, scientists and societal stakeholders is highly relevant in all stages of a flood risk strategy and flooding event, including the planning and design phase. Do the relevant stakeholders understand the challenges and chosen solutions? In the disaster phase, do people know what to do and what can be expected of the managing authorities? In the recovery phase, is there a disaster fund? Which losses are insured? Do stakeholders know the recovery plan? How quickly can crucial services be restored? Effective communication, participation and the sharing of information about flood risks and flood risk management plans is therefore important for reducing the number of victims of flood events, economic losses and societal disruption during the recovery phase.

SIX

Concluding remarks

This chapter provides an overview of the main findings of the report. These are listed in the order of the relevant chapters.

6.1 Outlook on water-related challenges in cities: main findings

- Major changes in socio-economic and environmental trends are projected under the Baseline Scenario. The world's population is expected to grow by more than 2 billion, to 9.2 billion by 2050. Most of this growth will take place in developing countries and, more specifically and more relevant for this report, in urban areas in developing countries.
- Developing countries also show relatively high economic growth, especially in sub-Saharan Africa, where economic growth is projected to be around 5% a year, comparable with India and China.
- As a result, the demand for water, food and energy will increase and is expected to put pressure on the environment. Climate change, with higher average temperatures and changing precipitation patterns, combined with increasing competition for available water resources, may result in substantial increases in the number of people living under severe water stress. Without major policy changes, substantial improvements in water management and techniques as well as 'smart' spatial development, this trend is likely to affect quality of life; for example, through increasing impacts on human health.
- In the coming years, substantial progress may be expected in the access to safe drinking water and improved sanitation. As a result of income increases (which make a higher standard of living more affordable) and increasing urbanisation (which enables more cost-efficient higher coverage rates), the Millennium Development Goals that target water supply have already been attained, globally, and further progress is projected. With respect to access to sanitation, however, current developments show that many countries still lag behind, particularly in sub-Saharan Africa, although here future progress also is projected. Despite this progress, policy challenges remain. First of all, the Millennium Development Goals only focus on halving the number of people without access to improved sanitation. Secondly, the MDGs also only aim to achieve improved drinking water services, which even then would still be far from those ensuring a decent standard of living (i.e. in the form of household connections). Thirdly, achieving coverage still does not necessarily mean that connections are safe. For example, increasing water stress may affect water quality, causing negative health impacts. Policy simulations show that investments in water supply and sanitation have a positive cost-benefit ratio, in terms of cost, health impacts and valuation of the health impacts. Aiming for universal coverage by 2050, 70,000 deaths could be avoided, annually, in sub-Saharan Africa alone.
- Higher sanitation coverage rates could have a direct positive effect on human health, but may also have adverse effects on the environment if these improved sanitation connections are not combined with waste-water treatment. Population growth combined with higher income levels will further increase nutrient emissions from cities. This poses an increased risk to the quality of drinking water and food production in and around cities. Under the Baseline Scenario, nutrient emissions in Asia and Africa are projected to double or triple over next 40 years. This will lead to increased eutrophication and biodiversity loss, as well as an increased threat to drinking water, fishery, aquaculture and tourism ecosystem services. In developed countries, however, emissions of nutrients will decrease.
- It is increasingly recognised that the urban water system is best designed, planned and managed in an integrated manner. Waste-water treatment should be part of a larger system, aimed at delivering services to

urban dwellers without compromising on sustainability. Options for reducing emission levels and achieving a more sustainable city include better sewage and waste-water treatment systems and the reuse of nutrients in agriculture. New technologies and incentives for local reuse may change the balance in the discussion in favour of decentralised options. For local communities, on-site sanitation and better faecal sludge management opportunities are possible, especially in developing countries.

- In transboundary catchment areas, agreements between countries are necessary to improve water quality and prevent excessive pollution of coastal waters, resulting in large-scale fish kills and algae blooms. There are many examples of successful developments in sanitation, sewage systems and wastewater treatment and reuse.
- Over the past 30 years (1980–2010), on average, close to 90 million people were affected by flood disasters, and each year around 5,000 people were killed. Average annual global losses due to floods over this period amounted to almost USD 20 billion. Floods make up over 40% of all weather-related disasters, affect the most people and are the second-largest natural cause of economic loss. No climate change signal has been detected in flood disasters in the historical trend up to 2010. Population growth and economic development were the dominant drivers of increases in the numbers of people affected and economic losses suffered due to coastal and river floods.
- As urban areas expand, hundreds of trillions of dollars in infrastructure, industrial and office buildings and homes will be increasingly at risk from river and coastal flooding – particularly in Asia. Under the Baseline Scenario, by 2050, there could be 670 cities of 500,000 inhabitants or more, and 88 of which will have more than 5 million inhabitants. Of these 88 cities, 50% will rank highest with respect to vulnerability to flooding, based on the size of the population exposed and GDP per capita. The most vulnerable megacities could be Dhaka, Kolkata, Shanghai, Mumbai, Jakarta, Bangkok and Hoh Chi Minh City. Leaving aside the effects of climate change, the population living in flood-prone areas is estimated to be 1.3 billion by 2050, or 15% of the global population. This is an increase of 0.3 billion compared with the present situation.
- There is a wide range of measures available to reduce flood risk. Given the potentially large effect of these measures, it is important for cities and countries to pay serious attention to the development of adequate flood risk strategies. The costs of adequate flood protection measures may not necessarily be high, and the high concentration of assets and people in cities may provide an opportunity for highly cost-effective flood protection strategies, strongly reducing both loss of lives and economic losses.
- Flood vulnerability is unevenly distributed within cities and often the poorest suffer disproportionally. Within the context of environmental justice, public authorities face the challenge of improving the level of protection against flooding without increasing the inequality with respect to flood risk.

6.2 Towards integrated urban development

The findings of this report show that, in the coming decades, major changes and challenges lie ahead. Despite positive developments policy challenges remain; for example, regarding the health impacts of improved water supply and sanitation. Each chapter identifies potentially successful policy options that would result in an improvement regarding the issues at hand. However, there are also important interconnections between the various water issues. For example, investing in sanitation without adequate investment in waste-water treatment would, in fact, deteriorate the water quality in rivers, lakes and coastal waters. In turn, poorer water quality could impact human health. Also, despite sufficient investment in water supply, sanitation and waste-water treatment infrastructure, urban expansion – which will take place particularly in developing countries – could still be at risk if flooding is not taken into account. This calls for a more integrated approach in urban development, in which these aspects are considered in combination. A promising concept that allows for such an integrated approach is that of 'smart cities'. Applying such a concept to the water challenges of the future ('smart water') may help create cities that use water and energy more efficiently, reuse water and waste-water treatment products (such as nutrients), and achieve the smart and climate-proof design of sewage and waste-water treatment systems, urban development plans and green and blue infrastructure, preventing urban flooding and reducing flood risks.

Networks of cities

Given the strong growth and power of cities around the world, exchanging of experience and information can be a powerful way to improve policy development in urban environments and stimulate the learning and innovation capacity of municipal authorities (e.g. Barber, 2013). All over the world, choices are being made, solutions explored and flood-risk measures and strategies implemented; thus, providing an enormous pool of experiments and experience. Numerous networks of cities profit from this continuous process of learning and innovation, as, for instance, the networks around the concept of smart cities (see text box 6.1) and the International Council for Local Environmental Initiatives (ICLEI). The ICLEI, founded as early as in 1990, is committed to exchange and promote sustainable development in cities. Presently, nearly 1200 cities from over 80 countries are members of ICLEI; thus, providing an interesting platform for interaction, innovation and learning. Within ICLEI, the global forum of 'Resilient cities' is actively focused, among other things, on risks and risk management (http://resilient-cities.iclei.org/). The goal of these city networks primarily is to exchange knowledge, understand the common challenges and share best practices and innovations that may support cities in their economic, spatial and social development strategies.

With respect to flooding, relatively new networks are the Delta Alliance and Connecting Delta Cities. The Delta Alliance focuses on the sustainable development of deltas, including flood-risk management challenges, with the participating deltas of California Bay (United States), Ciliwung and Mahakam (Indonesia), Mekong (Vietnam), Rhine-Meuse (the Netherlands), Nile (Egypt), Pantanal (Brazil), Ganges-Brahmaputra (Bangladesh), Mississippi (United States), Yangtze (China) and Parana (Argentina) (www.delta-alliance.org/about-delta-alliance). The network of Connecting Delta Cities creates ties between, at the moment, 40 cities lying in deltas and focuses on how to cope with flood risks (www.deltacities.com/about-c40-and-cdc).

Text box 6.1 Smart cities

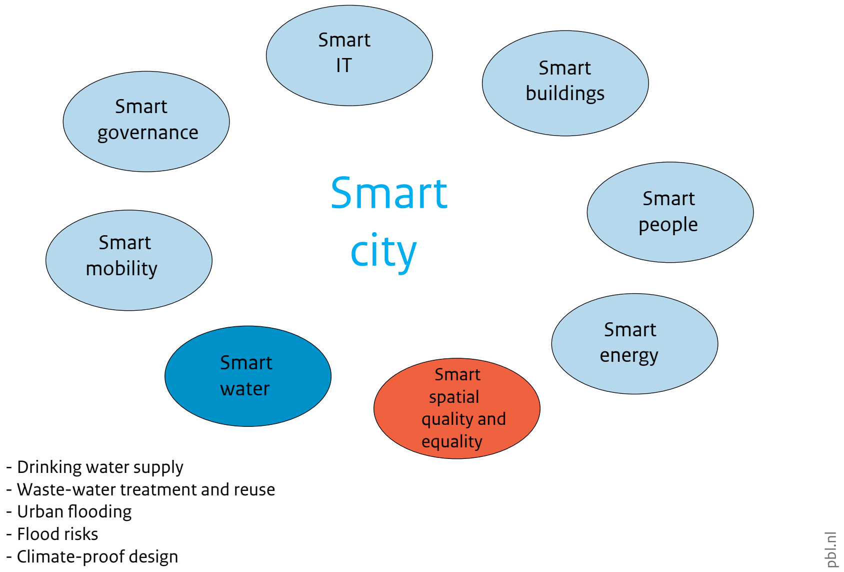
The concept of smart cities is broadly applied to embrace the multiple challenges faced in developing cities and creating a better future. A city can be defined as 'smart' if investments in human and social capital and in traditional (i.e. transport) and modern (i.e. ICT) communication infrastructures fuel sustainable economic development and a high quality of life. This assumes the wise management of natural resources and participatory action and engagement of the urban community (Caragliu et al., 2009). The smart city thus embraces a complex matrix of issues, solutions, technologies, operations and infrastructural requirements. Important components of the smart city concept often considered are a smart economy, smart mobility, a smart environment, smart people, smart living and smart governance. These six axes connect with traditional regional and neoclassical theories of urban growth and development. In particular, the axes are based on theories of regional competitiveness, transport and ICT economics, natural resources, human and social capital, quality of life and public participation in the governance of cities respectively (Giffinger et al., 2007). However, cities are free to define their own components of a smart city, with possible additional components such as smart energy, smart buildings, smart working and smart public facilities.

In addition to the components mentioned, we suggest the inclusion of two more: smart water and smart spatial quality and equality (Figure 6.1). As we have shown in this report, there are many challenges with respect to water-related services and, given the risk of inequality within cities with respect to spatial and environmental quality, the incorporation of these components in the overall smart city concept may contribute to the systematic acknowledgement of these challenges in future development strategies for cities.

Smart water involves the efficient use of water and energy, the reuse of water and wastewater treatment products (such as nutrients), and the smart, climate-proof design of sewerage and wastewater treatment systems, urban development plans and green and blue infrastructure for preventing urban flooding and reducing flood risks. Smart spatial quality and equality refers to the creation of an attractive and safe living environment for all inhabitants and the prevention of social inequality with respect to flood risks and health risks related to air pollution and water quality.

Figure 6.1

Smart cities include smart water and spatial quality and equality



Source: PBL

Within the concept of smart cities we propose the inclusion of 'Smart water' and 'Smart spatial quality and equality' as fundamental features

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Appendix

Table 1

Comparison of annual expected exposure levels for urban and rural populations, per region. Protection level for all regions and all years 1:10

	2010		2030		2050	
	Urban	**Rural**	**Urban**	**Rural**	**Urban**	**Rural**
Developed countries	5,717,933	1,409,097	6,404,258	1,116,131	6,725,412	789,738
Latin America & the Caribbean	2,449,701	458,174	3,036,279	397,610	3,330,203	307,667
East Asia and Pacific	9,007,918	9,343,807	13,140,172	8,035,900	16,055,383	5,932,509
Russian region and Central Asia	815,239	429,950	912,326	382,185	983,936	287,971
Middle East and North Africa	1,622,446	652,085	2,420,587	745,192	3,183,431	658,259
South Asia	4,461,455	8,948,633	7,560,061	9,731,140	11,552,715	8,352,797
Sub-Saharan Africa	1,347,540	1,367,007	2,694,424	1,697,654	4,525,206	1,718,899
Total	25,422,231	22,608,755	36,168,106	22,105,812	46,356,287	18,047,840

Table 2

Comparison of annual expected exposure levels for urban and rural populations, per region. Protection level for all regions and all years 1:100

	2010		2030		2050	
	Urban	**Rural**	**Urban**	**Rural**	**Urban**	**Rural**
Developed countries	619,869	149,791	697,318	118,848	732,465	84,234
Latin America & the Caribbean	273,427	50,074	338,639	43,437	370,570	33,637
East Asia and Pacific	1,012,041	1,033,507	1,463,654	888,495	1,805,550	656,467
Russian region and Central Asia	89,425	48,300	100,492	43,158	108,482	32,554
Middle East and North Africa	180,414	72,326	271,445	82,914	359,631	73,297
South Asia	532,417	1,085,088	902,324	1,178,905	1,378,782	1,011,297
Sub-Saharan Africa	146,916	154,810	294,289	192,144	495,025	194,858
Total	2,854,509	2,593,898	4,068,162	2,547,902	5,250,504	2,086,344

Table 3

Comparison of annual expected exposure levels for urban and rural populations, per World Bank region. Protection level for all regions and all years 1:100 for rural populations and 1:1000 for urban populations

	2010		2030		2050	
	Urban	Rural	Urban	Rural	Urban	Rural
Developed countries	56,352	149,791	63,393	118,848	66,588	84,234
Latin America & the Caribbean	24,857	50,074	30,785	43,437	33,688	33,637
East Asia and Pacific	92,004	1,033,507	133,059	888,495	164,141	656,467
Russian region and Central Asia	8,130	48,300	9,136	43,158	9,862	32,554
Middle East and North Africa	16,401	72,326	24,677	82,914	32,694	73,297
South Asia	48,402	1,085,088	82,029	1,178,905	125,344	1,011,297
Sub-Saharan Africa	13,356	154,810	26,754	192,144	45,002	194,858
Total	259,501	2,593,898	369,833	2,547,902	477,319	2,086,344

Table 4

Comparison of annual expected exposed GDP, per region, in billion USD. Protection level for all regions and all years 1:10

	2010	2030	2050
Developed countries	216.3	336.6	479.1
Latin America & the Caribbean	30.7	65.1	125.4
East Asia and Pacific	116.6	345.3	670.5
Russian region and Central Asia	12.4	26.4	46.3
Middle East and North Africa	20.9	48.6	111.5
South Asia	33.5	120.1	321.2
Sub-Saharan Africa	5.0	13.9	43.4
Total	435.5	956.0	1,797.3

Table 5

Comparison of annual expected exposed GDP, per regio,n in billion USD. Protection level for all regions and all years 1:100

	2010	2030	2050
Developed countries	23.4	36.6	52.1
Latin America & the Caribbean	3.4	7.3	14.0
East Asia and Pacific	13.0	38.4	75.2
Russian region and Central Asia	1.4	2.9	5.0
Middle East and North Africa	2.3	5.4	12.6
South Asia	4.0	14.5	38.6
Sub-Saharan Africa	0.5	1.5	4.8
Total	48.1	106.5	202.2

Table 6

Comparison of annual expected exposed GDP, per region, in billion USD. Protection levels for all regions and all years 1:100 for rural GDP and 1:1000 for urban GDP

	2010	2030	2050
Developed countries	6.3	8.2	9.6
Latin America & the Caribbean	0.8	1.4	2.3
East Asia and Pacific	7.2	16.7	25.1
Russian region and Central Asia	0.6	1.1	1.5
Middle East and North Africa	0.8	1.6	3.1
South Asia	2.8	8.8	18.4
Sub-Saharan Africa	0.3	0.7	1.7
Total	18.7	38.4	61.6

Table 7

People living in flood-prone areas (1:1000 floods), per region

	2010	2030	2050
Developed countries	140	148	148
Latin America & the Caribbean	59	69	73
East Asia and Pacific	372	428	448
Russian region and Central Asia	25	26	26
Middle East and North Africa	46	64	79
South Asia	294	378	435
Sub-Saharan Africa	55	88	125
Total	991	1,203	1,334

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