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Vision 2030
The resilience of water supply and sanitation in the face of climate change

Technology projection study

UNIVERSITY OF SURREY

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Acknowledgements
The authors would like to thank the many people who have made significant contributions to the preparation and revision of this report: their efforts have led to a more comprehensive and focused review of the issues than was contained in the early drafts of this report.

In particular we would like to thank everyone who responded to the questionnaire survey; to the group of experts who gave their time to be interviewed and who gave their advice, guidance and expertise freely and willingly. We would also like to acknowledge the work of the reviewers, whose valuable comments and suggestions have helped to shape the structure and content of the report.

Contents

1. Introduction

It is now widely accepted that some degree of future climate change is inevitable and that significant impacts will be felt via water (Bates et al., 2008). The impacts of climate change on water supply and sanitation are very likely to directly affect the achievement of the Millennium Development Goals (MDGs) in some areas. Although access to safe water supplies and hygienic sanitation is relevant to all the MDGs, the most important challenge in the context of the present project is MDG target 7c: to halve, by 2015, the proportion of people without sustainable access to safe drinking-water and basic sanitation (UNDP, 2007).

If any of the predicted consequences of climate change, such as higher average temperatures, increased rainfall, or rising seawater levels, were to affect the viability of drinking-water supply and sanitation facilities, two critical problems for the future will arise:
(a) The cost of achieving the MDGs will increase, because higher-cost technologies will be required to deliver services.
(b) Households and communities currently with access to improved facilities might see that access removed by the destruction of water or sanitation infrastructure, or by the deterioration of water supplies, resulting in the reversal of progress towards the MDGs, and potentially leading to the displacement of populations.

The impact of climate change on access to drinking-water supply and sanitation facilities will vary both by region (in terms of the specifics of the change in climate expected) and by facilities (in relation to the vulnerability of the facility to the expected change in climate). To date, although such problems have been highlighted as serious and likely consequences of climate change by the Intergovernmental Panel on Climate Change (IPCC, 2007), there has been very little systematic assessment of the potential impacts. Where studies have been done, the conclusions are often quite broad (for example, that increased flooding increases the risks of contamination of water supplies) or based on limited evidence. Furthermore, the recommendations from these studies tend to make general statements about the need for research, rather than identifying needs for more targeted research on key regions and facilities most likely to be affected by climate change. This highlights the need for further research to improve water and sanitation provision.

The present report provides information on drinking-water supply and sanitation facilities and their vulnerabilities to climatic events, as background for directing policy on drinking-water supply and sanitation development to minimize the potential impact of climate change on MDG target 7c. Progress towards this target is being monitored by a joint initiative of WHO and UNICEF – the WHO/UNICEF Joint Monitoring Programme on Water Supply and Sanitation (JMP) (JMP, 2008). The JMP reports on the status of improved water supply and sanitation facilities, and relates its finding to the delivery of the MDG target 7c. The aim is to support countries in their efforts to monitor this sector, and help countries and international bodies make evidence-based policies, enabling better planning and management. The facilities described in the JMP report range from low-cost on-site systems for water supply and sanitation to large-scale piped water and sewerage networks.

Understanding the likely impacts of climate change on water supply and sanitation will help to provide a platform for the discussion of future changes to the criteria used by the JMP for assessing the progress toward the MDG target 7c. This is becoming increasingly urgent, as a new system will need to be in place and agreed by 2015 to prevent any significant gap in reporting.

The present report aims to provide data to inform policy decisions within the United Kingdom Department for International Development (DFID) and WHO for drinking-water supply and sanitation, in the light of climate change. The timescale of the project, as well as the complex interactions between climate change, water resources, and drinking-water supply and sanitation, required the scope of the project to be clearly defined to concentrate on the drinking-water supply and sanitation facilities that are most relevant for future policy development, and on climate conditions that are most likely to affect the operation and management of these facilities.

Regarding climate, the report focuses on changing rainfall patterns. While there will be impacts from other changes in climate (temperature, sea level, and so on), changes in rainfall, and their consequences for water resources, are considered to have the greatest potential impact on water supply and sanitation facilities.

Regarding drinking-water supply and sanitation facilities, the scope of the present report is limited to improved facilities because they are the focus of water and sanitation policy. An improved drinking-water source is one that is likely to provide "safe" water (JMP). Sanitation systems are considered adequate if they are private and if they separate human excreta from human contact. Improved drinking-water supply and sanitation facilities include (JMP, 2008):

Drinking-water supply

- Piped water
- Public standpipes
- Protected wells
- Protected springs
- Rainwater collection

Sanitation

- Piped sewer system
- Septic system
- Pit latrines including ventilated improved pit latrines, pour–flush latrines, and pit latrine with slabs
- Composting toilets

We recognize that a number of possible, specific impacts of climate change have not been included in the present work; for example: coastal inundation; saline intrusion; vectors of disease; emergency responses; and indirect effects of climate change. However, the significant impacts on drinking-water supply and sanitation identified within the scope of the present report provide sufficient reason for policy development within the water and sanitation sector. Future studies into more specific impacts of climate change will be important in order the refine these policies.

Two timescales (up to 2020 and up to 2030) were used for the policy decisions, and hence were a focus of this report and the corresponding report on climate change predictions. For the present study, the year 2020 was selected to represent the minimum expected lifespan of technologies that had been installed to date, including recent efforts to meet the MDG target in 2015. The projected situation in 2020 provides an indication of the potential for climate change to undermine short-term sustainability, and reflects current and historical programming, policy decisions and current climatic variability. The principal consequences of changes by 2020 relate to the management of infrastructure already, or soon to be, in operation.

The present document draws clear lines between the impact of changing rainfall patterns and the sustainability of different drinking-water supply and sanitation facilities. It provides an analysis of the number of people served in each region by different facilities as a basis for analysing the potential impact of climate change on progress towards the achievement of MDG target 7c.
The definitions of vulnerability, adaptive capacity (or adaptability) and resilience, from the IPCC Working Group II (IPCC, 2007), used throughout this report are given below.

- Vulnerability: the degree to which a system is susceptible to, and unable to cope with, adverse effects of climate change, including climate variability and extremes. Vulnerability is a function of the character, magnitude, and rate of climate change and variation to which a system is exposed, its sensitivity, and its adaptive capacity.

- Adaptive capacity: the ability of a system to adjust to climate change (including climate variability and extremes) to moderate potential damages, to take advantage of opportunities, or to cope with the consequences.

- Resilience: the ability of a social or ecological system to absorb disturbances while retaining the same basic structure and ways of functioning, the capacity for self-organization, and the capacity to adapt to stress and change.

The structure of the present report and the related fact sheets is illustrated in Figure 1. The present report includes:
- a literature review of vulnerability and adaptability of drinking-water supply and sanitation facilities, linking climate change, particularly changing rainfall patterns, to water and sanitation access;
- opinions from key water professionals on likely impacts of changing rainfall patterns on water supply and sanitation facilities;
- analysis of the available JMP data to forecast the number of people served by different technologies, by country, region and global totals in 2020;
- an overall analysis of the resilience of water supply and sanitation facilities to changing rainfall patterns.

The fact sheets on the vulnerability and adaptation of technologies identify the potential vulnerabilities of each type of improved water supply and sanitation facility for a range of changing rainfall scenarios.

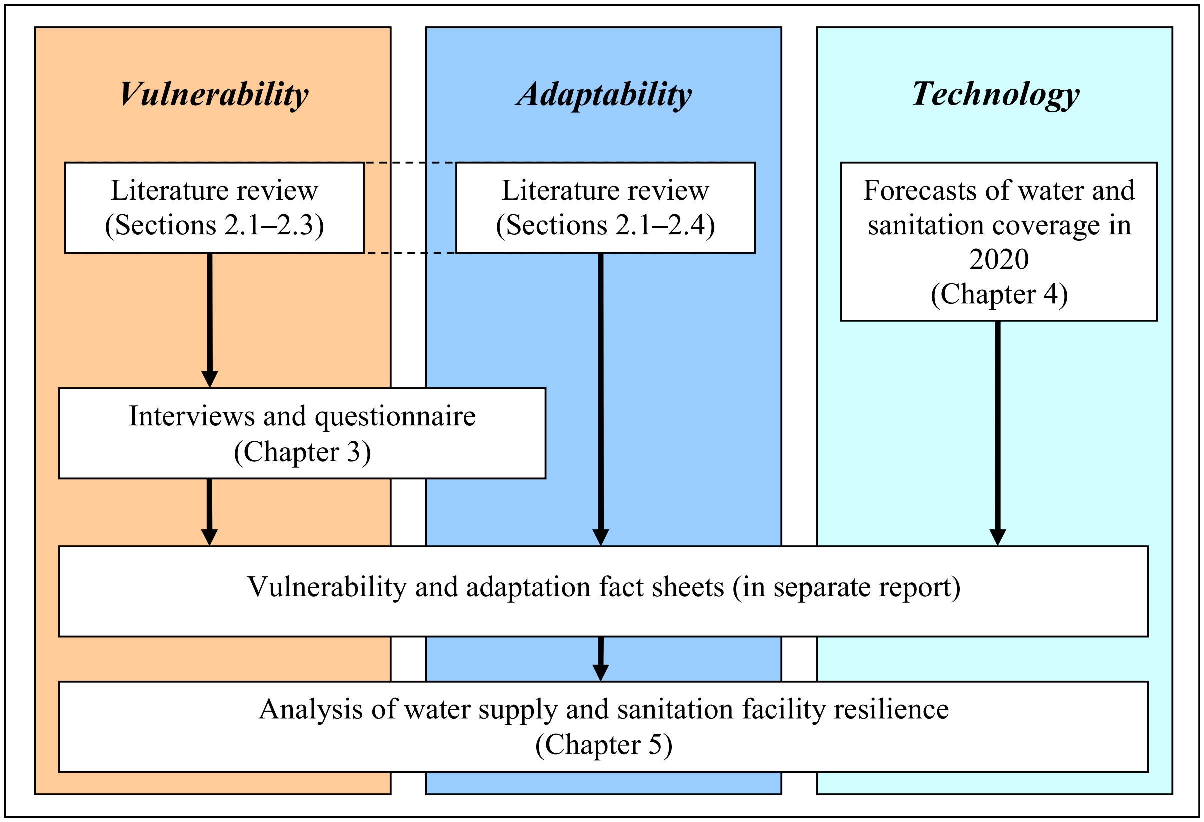


Figure 1
Overview of report structure

2. Literature review

A number of definitions have been used to describe climate change. The IPCC (2007) describes climate change as:

> "a statistically significant variation in either the mean state of the climate or in its variability, persisting for an extended period (typically decades or longer). Climate change may be due to natural internal processes or external forcings, or to persistent anthropogenic changes in the composition of the atmosphere or in land use."

The United Nations Framework Convention on Climate Change (UNFCCC) defines climate change as:

> "a change of climate which is attributed directly or indirectly to human activity that alters the composition of the global atmosphere and which is in addition to natural climate variability observed over comparable time periods."

For the purposes of this report, the IPCC definition will be used, including any natural climate variability and anthropogenic changes.

The Fourth Assessment Report of the IPCC (2007) states that:

> "Global atmospheric concentrations of carbon dioxide, methane and nitrous oxide have increased markedly as a result of human activities since 1750 and now

far exceed pre-industrial values determined from ice cores spanning many thousands of years."

These human activities include fossil fuel use and land use change, which are contributing carbon dioxide, and agriculture, which in turn is contributing methane and nitrous oxide to the atmosphere.

Global warming is already being experienced, with observations of increases in global average air and ocean temperatures, widespread melting of snow and ice, and rising global average sea level (IPCC, 2007). The eleven years between 1995 and 2006 were among the warmest years on record for global surface temperature. Measurements taken since the 1980s show that the average atmospheric water vapour content has increased over land and ocean because of warming temperatures. The oceans are heating up, which is causing seawater to expand, contributing to sea level rise. Glaciers and snow cover are declining, which is also contributing to sea level rise. Global average sea level rise is estimated to have been 1.8 mm per year between 1961 and 2003, but 3.1 mm per year between 1993 and 2003. It is not clear whether the faster rate represents variability or a longer term trend.

In terms of climate change observations, numerous long-term changes in climate have already been observed that will affect water and sanitation, including widespread changes in precipitation amounts and aspects of extreme weather including droughts, heavy precipitation, heat waves and the intensity of tropical cyclones. These observations were reported by the IPCC (2007) and represent confident findings and predictions based on, and limited by, the available data. A summary of recent trends and the likelihood of them continuing is provided in Table 1.

Table 1
Recent trends and projections for extreme weather events for which there is an observed late-20th century trend

Phenomenon and direction of trend	**Likelihood that trend occurred in late 20th century**	**Likelihood of future trends based on projections for 21st century**
Warm spells or heat waves Frequency increases over most land areas	Likely (> 66 %)	Very likely (> 90 %)
Heavy precipitation events Frequency (or proportion of total rainfall from heavy falls) increases over most areas	Likely (> 66 %)	Very likely (> 90 %)
Area affected by droughts increases	Likely (> 66 %) in many regions since 1970	Likely (> 66 %)
Intense tropical cyclone activity increases	Likely (> 66 %) in many regions since 1970	Likely (> 66 %)
Increased incidence of extreme high sea level (excludes tsunamis)	Likely (> 66 %)	Likely (> 66 %)

Over the past century, long-term trends in quantities of precipitation have been observed over many large regions, including significantly increased precipitation in the eastern parts of North and South America, in northern Europe, and in northern and central Asia. Additionally, heavy precipitation events have become more frequent over most land areas. In the future, precipitation changes are predicted to follow these observed trends with increases very likely (> 90 %) in high latitudes and decreases likely (> 66 %) in most sub-tropical land regions.

Drying has been observed in the Sahel, the Mediterranean, southern Africa and parts of southern Asia, with more intense and longer droughts observed over wider areas since the 1970s, particularly in the tropics and subtropics. Many of these semi-arid and arid areas are projected to suffer a decrease in water resources as a result of climate change (Bates et al., 2008).

Geographical patterns of warming in the 21st century are projected to be similar to those observed over the past decades, with warming expected to be greatest over land and most high northern latitudes. The IPCC (2007) consider it very likely that hot extremes, heatwaves and heavy precipitation events will continue to become more frequent. It is also likely that tropical cyclones will increase in intensity, with increases in wind speed and more heavy precipitation.

Climate change is also expected to affect water quality (Bates et al., 2008). Higher water temperatures and increasing runoff from more intense rainfall are predicted to contribute to a deterioration in water quality, including increasing algal blooms and higher turbidity. Rising sea levels and temperatures, and decreased groundwater recharge, will increase salinity problems.

The impacts of these changes on water resources, and hence on water and sanitation, are likely to be further compounded by increasing water demand from population growth, increasing affluence and changes in other water demands (Bates et al., 2008).

The literature review reported here covers the vulnerability and adaptations of improved water supply and sanitation facilities, as well as broader issues surrounding adaptation capability and resilience, such as community development and education. It also includes a review of the likely impact of climate change on water resources and health.

2.1 Vulnerability and adaptation to climate change

The aim of this and the following sections is to examine the vulnerability of water supply and sanitation facilities to changes in rainfall patterns that may be brought about by climate change, and to describe examples of adaptations that have been made to these facilities to increase their resilience in the face of current and future climate variability.

During the past 15 to 20 years a substantial volume of literature has accumulated describing the vulnerability of the water cycle to the predicted future changes in climate (see IPCC, 2007). However, despite the wealth and strength of evidence showing that water resources will be influenced by climate change, there has been only a limited analysis of the consequences of these changes to the provision of drinking-water supply and sanitation facilities, particularly in developing countries. This divide between the water resources sector and the water supply and sanitation sector that exists in many countries has the potential to jeopardize efforts to implement adaptive responses to ensure continuity of water and sanitation services in a changing climate (Cronin & Pond, 2008).

To varying degrees, all improved drinking-water supply and sanitation facilities are vulnerable to changing patterns of rainfall, because often the choice of a facility in a particular region is informed by current and past experience of the environment and socioeconomic conditions rather than by knowledge of future trends (Adger et al., 2003; Bates et al., 2008). In their review of adaptation strategies for climate change in the developing world, Adger et al. (2003) argue that an approach based on an historical perspective is not sustainable: "…historical statistics and experiences of local weather are unlikely to provide a sound basis for economic planning and resource management in the future". If, as predicted by the climate models (see Section 2.5), rainfall becomes more variable and extreme in the future, the selected interventions for water supply and sanitation will experience conditions that fall outside their normal operating range more frequently and by a greater margin. The risk and frequency of these technologies failing in a particular region, therefore, will increase (FMENCNS, 2007). The question that follows from this statement is how can these failures be prevented? According to Cromwell, Smith & Raucher (2007), "all of the advice on adaptation to climate change begins with the same message: employ a portfolio approach – maintaining a maximum degree of flexibility and resilience". But can this level of flexibility and resilience be achieved with the limited number of improved technologies available for water supply and sanitation provision? The widespread nature of many technologies suggests some flexibility, but whether these technologies will continue to perform satisfactorily with changes in climate is much less certain. Furthermore, there is a challenge to ensure that countries are aware of the type of climate conditions they will face in the future, and to learn from the experience of other regions that may be already exposed to similar climates. This is discussed further in Section 2.4.

The literature dealing with social, economic, infrastructural and environmental vulnerability to climate change is extensive (for example Lenton, 2004; Vincent, 2004; Evans, 2007; Muller, 2007; Schipper, 2007; Douglas et al., 2008; Evans & Webster, 2008). The overwhelming opinion expressed in the literature is that the greatest impacts on society will be felt through water, and that water supply and sanitation will be affected to varying degrees; however, surprisingly few authors have considered the problems that the drinking-water supply and sanitation sector will face in the future and how these problems can be addressed. Several explanations may be advanced for this omission, but the most likely is that the major problems in providing drinking-water and sanitation services are not immediately linked to climate change, particularly in developing countries (Bates et al., 2008; Evans & Webster, 2008; Hedger & Cacouris, 2008).

At the present, climate change is not considered to be the most important driver of investment in the water and sanitation sector. However, it is already clear that changes in precipitation induced by climate change (Table 2 and Section 2.5) are causing problems for drinking-water supply and sanitation facilities, and that continued climate change will compound these problems (Lenton, 2004; Muller, 2007; Bates et al., 2008; Evans & Webster, 2008; Hedger & Cacouris, 2008).

Table 2

Observed effects on precipitation of changes induced by climate change, and observed or possible impacts on water and sanitation services

Observed effect	Observed or possible impacts on water services	Observed or possible impacts on sanitation services
Shifts in precipitation patterns	Changes in water availability as a result of changes in precipitation and other related phenomena	Reduction in water resources may lead to high pollutant concentration from wastewater
Increase in inter-annual precipitation variability	Increases the difficulty of flood control and reservoir use during the flooding season	Higher precipitation in cities may affect the performance of sewer systems, and flooding can damage them directly Flooding of sanitation systems can pose a health risk
More frequent and intense extreme events	Floods affect water quality and water infrastructure integrity, and increase fluvial erosion, which introduces different kinds of pollutants to water	Wastewater treatment facilities may be put out of service by floods, leaving the population with no sanitary protection

	resources Droughts affect water availability and water quality.	Droughts result in reduced water flow in sewers

Source: Adapted from Bates et al. (2008).

The continuing impact of climate change on drinking-water supply and sanitation facilities is predicted to result in significant infrastructure costs and potential fatalities from the inability of facilities to cope with extreme events or even multiple events in a season. It was estimated that between 1994 and 2003 in Latin America and the Caribbean, natural disasters including floods and hurricanes caused economic losses in water and sanitation of approximately US$ 650 million from the destruction of urban systems, rural aqueducts, wells and latrines (Charvériat, 2000). This does not include the damage to unimproved water and sanitation sources.

In the following sections we shall examine the vulnerability of the different drinking-water supply and sanitation facilities to climate change-induced changes in precipitation, and the adaptations that have been made to increase their resilience. Various reports of disasters, both droughts and floods, and the consequent loss of essential services in the affected areas provide a strong body of evidence for the vulnerability of water supply and sanitation facilities to climate extremes. These reports provide the foundation for our assessment of vulnerability and adaptation, which are set out in the fact sheets providing guidance on vulnerability and adaptation, as well as our assessment of resilience, which is provided in Chapter 5. In contrast, the evidence for successful adaptations of technologies to increase their capacity to withstand climate extremes, especially in developing countries, is much more limited.

2.2 Vulnerability and adaptation of water supplies to climate change

Improved drinking-water sources are defined in terms of sources that by nature of their construction, or through active intervention are protected from outside contamination, particularly faecal matter (WHO, 2008a). The JMP report defines three categories of drinking-water supply: unimproved supply, and two categories of improved supply – piped to household, and other (Table 3). The present assessment of climate vulnerability is concerned solely with the improved categories of water supply.

Table 3
Categories of drinking-water supply monitored by the WHO/UNICEF Joint Monitoring Programme for Water Supply and Sanitation

Category		**Category description**
Unimproved		Unprotected dug well, unprotected spring, cart with small tank or drum, tanker truck, and surface water (river, dam, lake, pond, stream, canal, irrigation channels), bottled water
Improved	Piped into dwelling, plot or yard	Piped household water connection located inside the user's dwelling, plot or yard
	Other improved	Public taps or standpipes, tubewells or boreholes, protected dug wells, protected springs and rainwater collection

Source: Adapted from WHO/UNICEF (2008).

2.2.1 Piped water supply

Piped water supplies include utility-managed supplies and community-managed supplies. They can rely on surface water, groundwater or rainwater sources, or a combination of these. Community-managed supplies are identified as being different from utility supplies by virtue of the approaches to administration and management. The following definition is taken from the 3rd edition of the WHO *Guidelines for drinking-water quality* (WHO, 2004).

> *Community-managed drinking-water systems, with both piped and non-piped distribution, are common worldwide in both developed and developing countries. The precise definition of a community drinking-water system will vary. While a definition based on population size or the type of supply may be appropriate under many conditions, approaches to administration and management provide a distinction between the drinking-water systems of small communities and those of larger towns and cities. This includes the increased reliance on often untrained and sometimes unpaid community members in the administration and operation of community drinking-water systems. Drinking-water systems in periurban areas in developing countries – the communities surrounding major towns and cities – may also have the characteristics of community systems.*

Although the impact of climate may be similar for the two types of piped-water supplies, utility supplies are considered to be less vulnerable and more adaptable than community water supplies because of their greater access to financial, technical and trained human resources. The limitations of community water supplies are illustrated by epidemiological studies in the United States of waterborne outbreaks between 1971 and 2000, caused by zoonotic organisms, which have shown that the majority were linked to community water supplies (Craun, Calderon & Craun, 2004).

Water quality responses to storms and other extreme rainfall events

Heavy rainfall events, and the resulting surface runoff, affect surface water quality through washing in increased loads of sediments and pathogens, as well as other pollutants. More intense rainfall and extreme events, such as cyclones, will lead to an increase in suspended solids (turbidity) in lakes and reservoirs as a result of erosion by raindrops and runoff (Leemans & Kleidon, 2002), with the potential for pollutants to be introduced into the water source (Brouyere, Carabin & Dassargues, 2004).

Increased turbidity can lead to additional stress on water treatment systems (Hunter & Syed, 2001; Hunter, 2003), increasing coagulant demand, reducing the working period of the multi-stage filters and increasing the chlorine demand, which will all contribute to reduced efficacy of the treatment process. Studies have shown a correlation between increases in turbidity and illness in communities (Schwartz, Levin & Hodge, 1997), which may reflect either the increased contaminant loading during storm events or efficacy reductions in the treatment.

Melting snow packs and cyclones can also contribute to increased sediment loads in water supplies. Brouyere, Carabin & Dassargues (2004) showed that the observed increase in precipitation and temperature in southern Finland was responsible for a decrease in snow cover and increase in winter runoff, which resulted in an increase in modelled suspended sediment loads. Kostaschuk et al. (2002) measured suspended sediment loads associated with tropical cyclones in Fiji, which generated very high (around 5% by volume) concentrations of sediment in the measured flows.

Snow melt is not the only driver of erosion and sediment transport (Kundzewicz et al., 2007); however, increased erosion resulting from increased precipitation intensities would exacerbate this problem. Examples of vulnerable areas can be found in north-eastern Brazil, where the sedimentation of reservoirs is significantly decreasing water storage and thus water supply (De Araujo, Güntner & Bronstert, 2006). Evidence of heavy rainfall leading to contaminated storm water runoff into surface water sources is not new and has been shown by a number of workers since the 1970s (see for example Doran & Linn, 1979; O'Shea & Field, 1992). An outbreak of *Acanthamoeba keratitis* was reported in Iowa, United States, following flooding which inundated a treatment works. In Walkerton, Ontario, Canada, in May 2000, heavy precipitation combined with reduced disinfection contaminated drinking-water with *E. coli* and *Campylobacter jejuni*, resulting in an estimated 2300 illnesses and seven deaths (Hrudey et al., 2003).

The Great Lakes, in the United States, which serve as a drinking-water source for more than 40 million people, are particularly susceptible to faecal pollution and can become reservoirs for waterborne diseases. Ongoing studies and past events illustrate a strong connection between rain events and the amount of pollutants entering the Great Lakes. The 1993 *Cryptosporidium* outbreak in Milwaukee, which affected the health of more than 400 000 people, coincided with record high flows in the Milwaukee River, a reflection of the amount of rainfall in the watershed (Curriero et al., 2001). Recognizing these vulnerabilities, utilities in some developed countries have adapted by implementing an additional filtration step in drinking-water plants, increasing operating costs by around 30% (AWWA, 2006). An alternative approach is to undertake protection and restoration of the ecosystems that naturally capture, filter, store and release water, such as rivers, wetlands, forests and soils, increasing the availability of good quality water. This approach was taken by the New York City Department for Environmental Protection, which saved several billion dollars by investing in catchment management, enabling them to avoid upgrading filtration.

Large-scale contamination of drinking-water has been described as the most serious disease hazard from floods (Parker & Thompson, 2000). Contamination may arise from: high turbidity, making purification difficult; floodwater entering well heads; flood levels higher than well head walls or water flowing directly over wells and other intakes; fuel or chemical pollution; physical damage to water treatment plants; and animal cadavers near water intakes (PAHO, 1998; Caribbean Environmental Health Institute, 2003). Nutrient contamination can lead to additional problems of water quality in piped water supplies. Studies by LeChevallier, Schulz & Lee (1991) have shown that nutrients in water supplies can promote the re-growth of coliform bacteria in the distribution system, leading to a further deterioration in water quality.

There can also be cross-contamination from damaged sewage systems. In Bangladesh in 1998, Dhaka city's waste disposal system became almost completely ineffective (Nishat et al., 2000): many streets became flooded with water mixed with waste and sewage, the leakage of sewage contaminated most water supply lines, and the reserve water tanks of many houses became submerged and contaminated.

Infrastructure responses to storms and other extreme rainfall events

As well as direct health impacts associated with contamination of drinking-water sources, climate events can severely affect the water delivery infrastructure. Flash or high-velocity floods can do damage to water systems because their physical force can knock out key components such as water treatment works and pumping stations (McCluskey, 2001). Water treatment works can be inundated by flood water, as in the United Kingdom experience described in Box 1, potentially causing major disruption. In addition, extreme stormwater events may result in the degradation of materials used to construct water supply pipelines though impacts caused by increased ground movement and changes in groundwater (CSIRO, 2007).

Box 1
The impact of flooding on water supply systems in the United Kingdom

Floods experienced in June and July 2007 brought into focus the vulnerability of the United Kingdom's infrastructure and essential services to extreme weather. The Pitt review into the causes and consequences of the flooding (Pitt, 2008) notes "…the largest loss of essential services since World War II, with almost half a million people without mains water or electricity. Transport systems failed, a dam breach was narrowly averted and emergency facilities were put out of action."

A key example of the impact is from the Mythe water treatment works, which supplies water to 350 000 people (EA, 2007). At the height of the floods, the treatment works was inundated with up to half a metre of flood water (see photograph). For operational reasons and to protect the distribution system from contamination, the treatment works was closed for 17 days, leaving 140 000 households without water. In response to the closure, 50 million litres of bottled water were distributed and emergency water supplies in bowsers were provided.

Flood waters surrounding the Mythe water treatment works (from EA, 2007)

Severn Trent Water, the operators of the treatment works, have since increased the security of the site by building a 1.5 metre high flood barrier around the treatment works and installing extra pumping equipment to remove flood water (BBC, 2007; EA, 2007).

Climate change is also predicted to have an impact on energy supplies (Wilbanks et al., 2007) though its affect on energy demand and energy production. Energy supplies may be affected by extreme events damaging infrastructure, or by lack of water for power generation or cooling. These impacts on energy supplies will also affect water treatment facilities and distribution systems, as well as sewage pumping and treatment facilities.

Responses to droughts

Different issues arise in situations where water is scarce. One third of urban water supplies in Africa, Latin America and the Caribbean, and more than half in Asia, are operating intermittently during periods of drought (WHO/UNICEF, 2000). This adversely affects water quality in the supply system. When networks are empty and unpressurised for prolonged periods of time, contaminants enter the pipes through leaks in the supply pipes. The situation is particularly serious in cities with unhygienic excreta disposal where sewage flows in open ditches close to water distribution pipes. In

Delhi, India, an intermittent supply and the proximity of water and sewage pipelines were the prime suspects of a paratyphoid fever outbreak in 1996 (Yepes, Ringskog & Sarkar, 2000).

A critical weakness of piped water systems is their lack of flexibility when relatively sudden changes occur to the water source that feeds the system; in particular, when the source dries up during prolonged drought. The consequences are illustrated by the case of Barcelona, Spain, which, as a result of severe drought during 2008, was forced to plan to import water from abroad to supplement its own declining resources (Burnett, 2008). Slow and predictable changes in water resources can be accommodated in the strategic development plans of large utility water supply facilities, and engineering solutions implemented to mitigate the problem. However, short-term changes in water availability resulting from drought or flood highlight the vulnerability of utility piped water systems and the scale of the impact when the systems do fail.

While the size of the population affected by the disruption of utility managed water facilities will be much greater than that arising from the disruption of community managed facilities, the capacity of utilities to respond with measures to resolve the problem and mitigate future problems is also much greater. Community managed facilities, therefore, are more vulnerable to climate change and the consequences of floods and droughts that have been described above.

2.2.2 Facilities dependent on groundwater

The demand for groundwater is likely to increase in the future, because of increased water use globally and the need to offset declining surface water availability resulting from the increasing variability of precipitation (Kundzewicz et al., 2007; Bates et al., 2008). Yet, opinions differ regarding the extent to which groundwater recharge will occur in various climate change scenarios (see also Section 3). Further information on recharge with climate change is also given below, in Section 2.5.3.

Protected wells

Protected wells include both boreholes and dug wells. Boreholes or tubewells are narrow, drilled holes that can be shallow or deep. By contrast, dug wells tend to be shallow, only 3 to 10 metres deep, lined with stones, brick, tile or other material to prevent collapse and covered with a cap of wood, stone or concrete. As a consequence, dug wells are at higher risk of becoming contaminated than deeper wells. To minimize the likelihood of contamination, the dug well should have certain features which help to prevent contaminants from travelling along the outside of the casing or through the casing and into the well:

- The well should be cased with a watertight material (for example, tongue-and-groove precast concrete), and a cement grout or bentonite clay sealant poured along the outside of the casing to the top of the well.
- The well should be covered by a concrete plinth and cap that stands above ground level.
- A drainage channel should be provided, or the land surface around the well should be mounded so that surface water runs away from the well and is not allowed to collect around the outside of the wellhead.

The detection of pathogens and microbial indicator bacteria in groundwater has been reported by several authors (Curry, 2000; Borchardt et al., 2003; Powell et al., 2003; Borchardt et al., 2007), suggesting that the quality of groundwater can be compromised by the ingress of contaminants. The principal mechanisms of pathogen survival and transport into and through the subsurface are described in Section 2.4.2. This provides the foundation for assessing the vulnerability of protected wells, as well as other groundwater fed systems.

Vulnerabilities of wells include ingress of contaminated surface water into the borehole or dug well. In one outbreak of cryptosporidiosis associated with borehole extracted groundwater, it was thought that the heavy rainfall led to water running across the surface of the fields where cattle were grazing (Bridgman et al., 1995). The water and cattle faeces then gathered around the head of the borehole and leaked into the water supply. Increased concentrations of faecal indicator organisms were observed in village wells in the Gambia following heavy rainfall in the 1970s. It was concluded that faecal material washed through the porous laterite or directly around the well shaft, leading to pollution of the water (Barrell & Rowland, 1979). Some degree of protection was thought to have been given by the lining of the wells as there was a delayed rise in counts of bacteria after the start of the rains. Where there were defects in the plinths of the wells, direct seepage from the surface into the shaft may have occurred, resulting in rapid high counts of faecal organisms. Godfrey and coworkers have noted that protected wells are particularly vulnerable to contamination when their annuluses are poorly sealed or there are cracks in surface aprons (Godfrey, Timo & Smith, 2006).

Boreholes and dug wells are also vulnerable to contamination from subsurface transport of pathogens. The Walkerton outbreak, discussed in Section 2.5.3 (Hrudey et al., 2003), was the result of contamination from an agricultural area being leached into groundwater, and then transported through groundwater. Examples also exist of outbreaks resulting from contamination of boreholes from a nearby sanitation facility, such as sewers (Short, 1988) or septic tanks (Anderson et al., 2003).

The situation varies significantly in rural areas, which should be considered in the national planning of development interventions. An analysis of water scarcity and opportunities revealed that protection of water sources and environment in the upper catchments should be the priority interventions. The possible consequences for groundwater recharge and public health of failing to protect the upper catchments have been highlighted in a study by Malley et al. (2007), which is described in Box 2. Increased depth and better management of traditional wells, and improved management of dwindling natural springs would enhance the sustainable supply of drinking-water. Furthermore, increasing the number of deep boreholes would be a means of increasing the availability of safe water supplies.

Box 2
Health impacts of drought in the United Republic of Tanzania

Increasing climate variability in the Usangu plain in the United Republic of Tanzania, and in its highlands catchments, has been reported (Malley et al., 2007). Villagers reported an increase in the frequency of precipitation deficiency and of short heavy storms, as well as changes in the timing of these weather patterns. These reports were backed by an analysis of rainfall trends. This has resulted in runoff and soil erosion, which in turn has reduced rainfall infiltration to recharge aquifers. In addition, an increase in sediment loads caused pollution of water sources. The result is that during the period from August or September to November, the traditional wells and natural springs can only support a few households or they completely dry out. When this occurs, the local communities use other water sources, such as irrigation canals and rivers, or excavate deep sand deposits on the rivers, which have no surface water flow in the dry period of the year. The poor quality of the water from these sources and poor household sanitation exposes household members to increased risks of waterborne diseases and diseases associated with poor sanitary measures.

Protected springs

Springs can make an ideal source for community water supplies if they have a reliable flow (Cairncross & Feachem, 1993). Because no pumping is required to extract water, springs are easy to exploit. Furthermore, the interventions required to protect the spring from pollution are relatively simple and cheap to construct (Cairncross & Feachem, 1993).

Maintaining a reliable discharge from the spring is dependent upon complex natural processes taking place at the catchment scale (Smakhtin, 2001), but ultimately requires continued recharge that is sufficient to provide a head of water above the spring. This is also the case for artesian springs, although their water source may be geographically removed from the spring. Consequently, conditions that lead to a fall in groundwater levels, such as reduced rainfall or high volume use of groundwater in the catchment – for example, new irrigation schemes – will reduce and eventually cut off the supply of water to the spring.

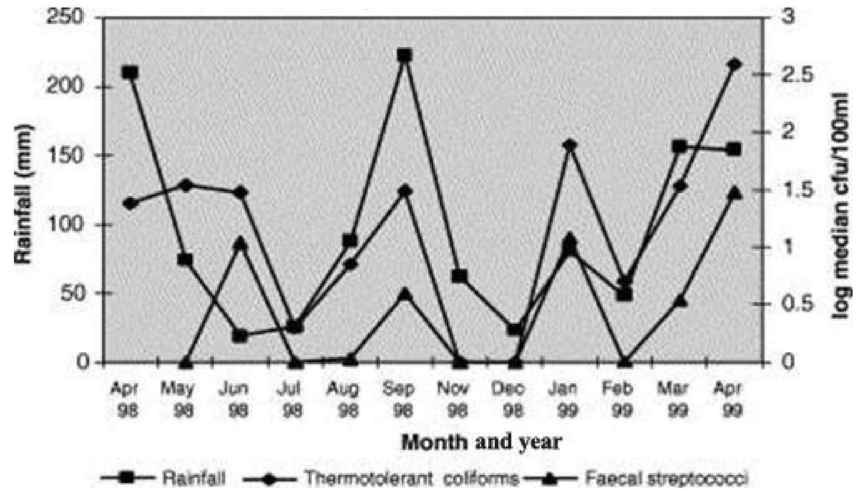
Seasonal changes in the discharge from springs have been observed worldwide as changes to the base flow of streams (Smakhtin, 2001). Reduction in flow during the seasonal dry periods is reversed in the wet periods. If long-term trends are towards reduced rainfall, and possibly drought conditions, the yield of water from springs is likely to decline and, in some cases, may eventually cease. At this point alternative sources of water will need to be found to preserve the supply of water to the community.

A common feature of protected springs, particularly in high density periurban areas in developing countries, is poor maintenance of the spring protection, creating conditions that make the spring highly vulnerable to pollution (see Box 3).

Box 3
Impact of rainfall on springs in Kampala, Uganda

Studies carried out on the protected springs in the periurban areas of Kampala, Uganda, showed widespread degeneration of the spring protection (Howard et al., 2003; Haruna, Ejobi & Kabagambe, 2005), with heavy erosion in the area above and around the spring, as shown in the photograph. During periods of heavy rainfall, these springs were susceptible to a deterioration of water quality as a result of contamination from the faecal waste in the surrounding environment, as indicated in the graph (Howard *et al.*, 2003).

Typical example of dilapidated protected spring, Kampala, Uganda



Relationship between rainfall and log-median counts of faecal indicator bacteria in spring water in peri-urban areas of Kampala (from Howard et al., 2003).

Adaptations

Artificial aquifer recharge, the process of artificially recharging aquifers by infiltrating water through permeable media or by direct injection through tubewells, is an adaptation method used throughout the world to enhance local and regional water resources (Khan et al., 2004). The aim is to store water in a suitable aquifer during times when water is available, and recover water from the same aquifer when it is needed (Dillon, 2005). Large volumes can be stored underground, reducing or eliminating the need to construct surface reservoirs and minimizing evaporation losses.

In the Murrumbidgee Region of New South Wales, Australia, up to 350 billion litres of water per year are lost from the river system as a result of evaporation, supply and storage inefficiencies, and on-farm losses (Khan et al., 2004). The recent drought and the increase in concerns about climate change have highlighted the need to manage Australia's water resources sustainably, and aquifer recharge and storage is one option that is being explored (Khan, Mushtaq & Hanjra, 2008).

A series of water briefing papers published by the International Water Management Institute (IWMI, 2002, 2003) has highlighted several benefits to groundwater resources in India of using unlined channels and irrigation tanks to capture and store the monsoon rains. Whereas the three-month monsoon season in India and south-east Asia can yield most of the annual rainfall of between 650 and 1000 mm, only a small proportion of the rain seeps into the ground to replenish the aquifers; the remainder runs off into rivers. The briefing papers describe the outcomes of two projects using unlined, earthen irrigation systems to simultaneously collect and channel the monsoon rain and recharge groundwater. These two projects (summarized in Box 4) are examples of techniques that have been used to increase groundwater recharge.

While techniques for increasing groundwater recharge provide one strategy for protecting groundwater reserves, a compatible or alternative strategy is to store groundwater during wet periods for use during dry periods. Techniques for retaining groundwater using underground dams have recently been described for Brazil (Telmer & Best, 2004). Subterranean water collecting dams have been known for over 100 years, but the example reported by Telmer & Best (2004) shows how relatively low-cost structures have been used in semi-arid regions of north-eastern Brazil as an effective method of providing water in periods of drought.

Box 4
Unplanned aquifer recharge in India

In Uttar Pradesh, north-east India, the amount of water being abstracted by farmers from the aquifers greatly exceeded the natural rate of recharge (IWMI, 2002). Up until 1988, the groundwater level had been declining at a rate of approximately 0.5 m per year. The main reason for the falling groundwater levels was the independent management of the monsoon rain and the groundwater for agricultural use.

During the monsoon, farmers grow crops, such as rice, that require large volumes of water. After the monsoon, farmers plant a second but less water-dependent crop, and use groundwater for irrigation. The flooded paddy fields did help to recharge of the aquifer, but it was insufficient to compensate for the volumes abstracted during the dry season.

In 1988, several unlined, earthen irrigation channels were constructed to transfer water from the river Ganga at peak flow to the paddy fields and sugar cane plantations. Seepage from the unlined channels, together with seepage from the paddy fields, was found to be sufficient to arrest and reverse the decline in groundwater levels. Between 1988 and 1998, the groundwater level rose from 12 m to 6.5 m below ground level (IWMI, 2002).

A second, similar innovation (IWMI, 2003) involves irrigation tanks, which have been used for several decades across much of India and south Asia as a means of storing rainwater for irrigation. Many of the older tanks (50 to 100 years) had developed leaks and were considered to have a reduced efficiency. A programme of rehabilitating the tanks was implemented to restore their original capacity for retaining rainwater. However, studies have identified several socioeconomic benefits that have accrued from the seepage of water from the tanks, to the profit of multiple stakeholder groups (IWMI, 2003). In particular, the overall productivity of the tanks in terms of water storage was greater with unsealed tanks than with sealed tanks because of the recharge of groundwater, which was then used by adjacent communities. In the opinion of the International Water Management Institute, tanks should be viewed as complex socioeconomic systems, with multiple stakeholder groups (IWMI, 2003).

Similar systems have also been used in the Horn of Africa (A. Cronin, unpublished observations). Although the examples from India and Brazil deal primarily with the provision of water for agriculture, they demonstrate that a broad view of water management, going beyond the immediate purpose of the system that is being developed, can increase water availability for the benefit of all stakeholders in regions with extreme seasonal patterns of rainfall.

During rainfall, large amounts of rainwater from watershed areas are lost through runoff, instead of recharging the underground aquifers. This shows a need to explore techniques and innovations that increase conservation and infiltration of the rainwater into the soil in the watershed areas, which are the major sources of springs, rivers and streams. This strategy would enhance the recharge of underground aquifers and naturally purify the water, while reducing destruction and pollution of water sources by floods. Examples of this type of intervention are described in Section 2.4.3 in the context of land use planning, and may include the use of terracing, providing adequate drainage, implementing reforestation, and building retention basins.

Although this section is concerned predominantly with the negative consequences of changes in rainfall patterns, in many of the areas that may experience increased levels of rainfall in the future, groundwater resources may improve in both their quality and their quantity. Under these circumstances, a shift away from surface water sources to groundwater should be considered very seriously when developing strategies for drinking-water provision.

2.2.3 Facilities dependent on rainwater catchment and storage

The FAO (2007) has emphasized the importance of fully integrating rainwater into water resource management strategies to cope with water scarcity. They note that water management strategies rarely integrate rainwater, with strategies being focused on surface and groundwater.

Although the opportunities for expanding rainwater collection are clear, there is conflicting evidence in the literature about the safety of stored rainwater for domestic use. In a study of rainwater collection systems in New Zealand, Simmons et al. (2001) found widespread microbial contamination of the water, and showed that consumption of the contaminated water was associated with symptoms of gastrointestinal infection. Furthermore, a review of health risks associated with the consumption of untreated rainwater identified several cases of infection with bacterial and protozoal pathogens and helminths (Lye, 2002). In contrast, Dillaha & Zolan (1985) have shown that roof-harvested and stored rainwater in Micronesia was suitable for drinking and cooking. Evans, Coombes & Dunstan (2006) have highlighted the importance of local meteorological and environmental conditions in determining the quality of roof-harvested rainwater, which provides a partial explanation for the lack of a consensus about water safety. Several textbooks have been published describing techniques for the collection and management of rainwater (for example Pacey & Cullis, 1986) but it is evident that the processes will be site specific, and management and treatment options need to be designed accordingly. Robust assessment techniques are required to deliver this goal. Nevertheless, some simple practical adaptations for protecting the quality of the water include: management of the collection area; water collection procedures that discard the first flush of water from the catchment surface; and design, cleaning and maintenance of the storage reservoir.

Despite the reported problems of rainwater collection and storage, in areas of increasing rainfall amounts and pattern variability, strategies to enable communities to directly harvest, store and manage rainwater could significantly improve drinking-water supply at the household level, and provide other benefits to the households (Box 5). This requires the introduction of facilities, and the development of local capacity in skills and knowledge. Facilities for harvesting rainwater include surface or underground tanks, strategically created micro-watersheds (such as impermeable roofs or surfaces), and in-built rainwater purification systems and treatment (Malley et al., 2007).

Box 5
An example of the benefits accrued from installation of a rainwater harvesting system

In the dry eastern African village of Nampuno, Hadija Suleiman and her daughter Fatuma used to walk twice a day the 4 km to the nearest reliable well with good drinking-water. Together they carried the 60 litres the family needed daily. The long trips with heavy loads exhausted them. Fatuma could attend the school only for part of the day. Then they got the roof rainwater catchment. Now, they use rainwater for drinking and cooking, and for their vegetable garden. The surplus vegetables are sold at the market. From that extra income, Hadija's husband plans to build an extra rainwater tank.

Source: Smet (2005).

Rainwater collection facilities can be used themselves as an adaptation method, for example, Kapinga et al. (2003) used rainwater harvesting technologies in Isimike village, United Republic of Tanzania, with semi-arid conditions to increase average domestic water supply from 20 to 40 litres per day per household in the dry season.

2.3 Vulnerability and adaptation of sanitation to climate change

The year 2008 was declared the International Year of Sanitation to emphasize the importance of sanitation for improving public health and well-being, and to highlight the persistent failure to meet the targets for access to improved sanitation on the way to achieving the MDGs by 2015. In 2006, when the data for the 2008 JMP report were collected, 2.5 billion people lacked access to improved sanitation, a number which included 1.2 billion people who had no facilities at all (WHO, 2008b).

The JMP report lists four categories of sanitation defined by their ability to provide hygienic separation of human excreta from human contact (WHO/UNICEF, 2008). The technologies that are included in each category are shown in Table 4.

In Section 2.5 we discuss the links between changing patterns of rainfall and human health, using examples of outbreaks of disease following heavy rainfall to demonstrate this link. Although environmental contamination of water sources has been implicated in a number of outbreaks of disease following rainfall – *Cryptosporidium* oocysts in agricultural runoff, for example – the discharge and dispersal of untreated sewage has contributed to many more. The research did not reveal much published literature on the consequences for human health attributed to droughts and sanitation. Consequently, the overriding concern about the vulnerability of sanitation to climate change lies in its response to heavy rainfall and to storms.

Within the categories of improved sanitation, the evidence for vulnerability to storms and other extreme rainfall events relates mainly to the performance of sewers, wastewater treatment works, septic tanks and pits. The consequences of these events for toilets and latrines have not been recorded, but are likely to involve physical damage at the level of the household. The broader effect on environmental health of damaging toilets connected to sewers and other wastewater storage and treatment systems will be less than the consequences of flooded pit latrines and significantly less than the effects resulting from the damage to infrastructure.

Table 4
Categories of sanitation monitored by the WHO/UNICEF Joint Monitoring Programme for Water Supply and Sanitation

Category	**Category description**
Open defecation	Defecation in fields, forests, bushes, bodies of water or other open spaces, or disposal of human faeces with solid waste
Unimproved	Facilities that do not ensure hygienic separation of human excreta from human contact Unimproved facilities include pit latrines without a slab or platform, hanging latrines and bucket latrines
Shared	Sanitation facilities of an otherwise acceptable type shared between two or more households Shared facilities include public toilets
Improved	Facilities that ensure hygienic separation of human excreta from human contact They include: • flush or pour-flush toilet/latrine to: - piped sewer system - septic tank - pit latrine • ventilated improved pit (VIP) latrine • pit latrine with slab • composting toilet

Source: WHO/UNICEF (2008).

2.3.1 Sewer systems

Sewer systems are designed to collect sanitary wastewater and to transport it to a treatment works where it is treated before being discharged back into the environment. Several different types of sewer systems exist, ranging from combined sewer systems which collect storm water runoff as well as wastewater, to small-bore systems such as simplified sewerage (Mara & Guimarães, 1999).

Responses to storms and other extreme rainfall events

One of the key risks from extreme rainfall events to sewers is to combined sewer systems. The combination of sanitary wastewater and storm water makes the combined sewer systems particularly vulnerable to storms and extreme rainfall events because once the input exceeds a certain value, the excess wastewater is discharged untreated into the environment from the combined sewer overflow, contributing to increased contamination of surface water (potentially including drinking-water supplies and recreational waters). The magnitude of the problem created by rainfall in areas served by combined sewer systems can be very significant. During 2006, in the province of Ontario, Canada, 1544 releases of sewage were reported, of which 1256 (81%) were caused by wet weather (Podolsky & MacDonald, 2008).

To avoid combined sewer overflows discharging too frequently, combined sewer systems are designed to manage a certain flow of wastewater that has been calculated using a range of environmental, social and economic factors, with additional reserve capacity to deal with particular extreme events; for example, a one in five-year or a one in ten-year storm event. However, the magnitude and frequency of these extreme events are identified from historical records, which Adger and others have argued may not be reliable in the face of climate change (Adger et al., 2003; FMENCNS, 2007; Bates et al., 2008) (see also Box 6).

Box 6
The issue of designing combined sewer systems using historical data

The potential problem arising from the use of retrospective analysis for the design of combined sewer systems is illustrated by the work of Patz et al. (2008). They have modelled the precipitation rate for southern Wisconsin, United States, and shown that extreme precipitation events are likely to become 10% to 40% stronger by 2100. To put this into the context of environmental hazard, during the 1990s, under current climate conditions, the city of Milwaukee, Wisconsin, discharged 30 billion litres of wastewater per year from combined sewer overflows (Schulz & Murphy, 2008). Patz et al. (2008) predict that, if their long-term forecasts are correct, the frequency of combined sewer overflows into Lake Michigan will rise by 50% to 120%, with significant consequences for human health and the environment.

Combined sewer overflows are just one issue associated with the flooding of sewers during storms and other extreme events. Serious consequences also arise when sewers overflow into houses and other built up areas, leading to major disruption of services, severe damage to buildings, and immediately threatening the health of the population exposed to the floods. After the floods have receded the contamination of household furnishings and the fabric of the house may continue to represent a risk to the health of the occupants for a considerable length of time.

In addition to sewer overflows occurring during floods, sewer systems and supporting infrastructure can suffer physical damage if the force of the flood causes land movement or erosion around buried sewer pipes, or if sewer pipes above ground are washed away by the flood waters (CSIRO, 2007). Physical damage to the sewers may also occur as a result of differential ground settlement, which can occur after floods or heavy rainfall, or during periods of drought (Fehnel, Dorward & Mansour, 2005). The immediate response following physical damage to the sewer system is to undertake repairs to the damaged section of pipe to bring the system back into operation. However, we can find no examples in the literature of adaptations to sewer systems that will increase their resilience to the potential effects of climate change. The implication of this is that repairs made to damaged pipework will not affect the overall ability of the system to withstand future extreme events. In addition to the physical damage to infrastructure, the loss of electricity supplies, as discussed for piped water networks, is also a significant risk, especially to major sewer pumping stations during a flood.

In many coastal areas, sewer outfalls discharge into the sea, either as short or long sea outfalls. As sea levels rise in the future, water levels in the sewers may rise in response, causing wastewater to back up and flood through manholes in roads and the toilets and washbasins of homes and buildings (PAHO, 1998; Caribbean Environmental Health Institute, 2003). In April 1997, the Grand Forks floods in North Dakota and Minnesota, United States inundated sewer pumping stations, causing sewers to flood and overflow in residential areas. Shut-off valves can prevent such back-flow, but in many cases in developing countries these have not been installed (Few et al., 2004).

The infrastructure and the operational components of a wastewater treatment works can be damaged or taken out of service by flood waters, resulting in the discharge of untreated sewage and sewerage overflows (Box 7).

Box 7
Flooding of sewage pumping stations in the United Kingdom

During the summer of 2007, the United Kingdom experienced several periods of extreme levels of rainfall compressed into relatively short periods of time (EA, 2007; Pitt, 2008). River flooding was extensive along the rivers Severn, Don and Thames, but the consequences were compounded in many cities and towns by widespread surface water flooding. In Yorkshire, 136 sewage treatment works were flooded, affecting the services to two million people (EA, 2007), and in Gloucestershire 11 sewage treatment works, including the Sedgeberrow sewage treatment works (see photograph), and 40 sewage pumping stations needed replacement equipment (Worcestershire County Council, 2008).

Sedgeberrow sewage treatment works (United Kingdom), after being flooded on 20 July 2007.

In eastern Europe, heavy rains and floods overwhelmed the drains and sewer systems, and washed away the activated sludge treatment facilities at several treatment works. The work to rebuild the activated sludge treatment facilities alone took 12 months, during which time untreated sewage was being discharged into the environment (B. Evans, unpublished observations, 2008). Similarly, in the aftermath of Hurricane Katrina, sewer systems and sewage treatment works were inundated with flood waters (A. Rachwal, unpublished observations, 2008).

Responses to droughts

Droughts and water shortages may act as a barrier to sanitation coverage, depending on the technology chosen (Fry, Mihelcic & Watkins, 2008). Waterborne sanitation systems are the traditional technologies used in urban developments, but may not be suitable for water scarce areas. There is no evidence of significant damage to sanitation infrastructure from periods of low rainfall and drought, apart from the potential for pipes and other infrastructure to be damaged by differential ground settlement (Fehnel, Dorward & Mansour, 2005). Nevertheless, droughts will have some effect on the operation and maintenance of these sanitation systems. Sewer systems receive a variety of gross solids, in addition to faecal stools, from domestic and commercial properties (Littlewood & Butler, 2003). The potential for reduced water flows in sewer systems, as a result of water conservation measures implemented to mitigate the effect of drought, has raised concerns about the transport of gross solids and the prospect of blockages.

Adaptations

Adaptive responses to increase the resilience of combined sewer systems to extreme rainfall events and to control combined sewer overflows are available (Walker et al., 1993), but the interventions generally require management or engineering responses that are technically demanding and relatively expensive, making them unaffordable for many developing countries. Several cities in the United States, including Milwaukee, Chicago, Washington and Boston, and the city of Sydney, Australia, have constructed deep tunnel conveyance and storage systems that are designed to intercept and store the combined sewer overflow water until it can be conveyed to the wastewater treatment works (Schulz & Murphy, 2008). Alternatively, separate systems for transporting storm water and sanitary wastewater can be introduced as a replacement for ageing combined sewer systems or as a new development. However, the success of these schemes in reducing storm discharges is variable, since discharges may still occur from the storm drains during heavy rainfall, and can be specific to a particular location (De Toffol, Engelhard & Rauch, 2006).

Re-engineering the sewer system to provide additional storage for storm water is likely to be the most promising adaptive response to extreme rainfall, but there are other strategies that can be adopted in conjunction with improved sewers that reduce infiltration and the inflow of storm water runoff (Walker et al., 1993; Podolsky & MacDonald, 2008), or manage the storm water effluent if the capacity of the system is exceeded (Kinzelman, 2004). Inflow controls can take many forms, from the introduction of special gratings and restricted outflow pipes (Hrudey et al., 2003), to the use of so called “green infrastructure” to capture runoff and retain it before it reaches the sewer system (Podolsky & MacDonald, 2008). Small-scale systems for treating storm water effluent do not reduce the volume of water discharged, but will reduce the level of contamination in the storm water before it is released into the environment. The ability of managed reed beds to treat wastewater is well known, but studies in Racine, Wisconsin, United States, have shown that they can be used effectively as both a sink and a treatment system for combined sewer overflows (Kinzelman, 2004).

2.3.2 Septic tanks

Septic tanks and cesspits are vulnerable to the effects of increased rainfall and storms. In areas of high groundwater tables, Parry-Jones & Scott (2005) suggest considering shallow cesspits and septic tanks, provided that facilities for emptying are available and reliable. However, Cairncross & Alvarinho (2006) have shown that septic tanks can represent a significant hazard for environmental contamination. In 2000, major floods affected the cities of Chokwi and Xai-xai in Mozambique, causing approximately 3000 septic tanks to overflow. Although the international response to these floods was swift and effective, Cairncross & Alvarinho (2006) note that donors were less willing to support future programmes of work to mitigate the problems and increase preparedness for future flooding events.

Methods for reducing the discharge of wastewater from septic tanks during floods have been proposed by Reed (2008). These include: installing sealed covers to prevent odours and mosquito breeding; raising the toilet pan above the flood level; fitting non-return valves to pipes to prevent back flows; and ensuring that any vents on the sewer line are above the expected flood level. Floods can also cause structural damage to septic tanks. Reed (2008) recommends that water should be allowed into the tank, if the tank is not full, to balance pressures and prevent the tank from collapsing.

2.3.3 Pit latrines

Responses to storms and other extreme rainfall events

The problems of maintaining low cost on-site sanitation, principally pit latrines, in flood prone areas have been reported by several authors (Kazi & Rahman, 1999; Chaggu et al., 2002; Parry-Jones & Scott, 2005; IFRC, 2008). The nature of the problem is self-evident from the simple design of these systems, which separate the waste from human contact by containing it in a pit. When the pit floods, either as a result of rising groundwater or by inundation of surface water, or both, the excreta may readily dissipate into the groundwater or be discharged into the surface flood waters (UN-Habitat, 2008). In areas where pit latrines are present in high numbers, often the low-income suburbs of cities in developing countries, the contamination of surface water can be particularly severe (UN-Habitat, 2008). This is a significant problem that has been observed in many locations, on many occasions under present climate variability (Kazi & Rahman, 1999; Chaggu et al., 2002; Cairncross & Alvarinho, 2006; IFRC, 2008) (see also Box 8). During October and November 2008, large areas of eastern Kenya experienced exceptionally heavy rainfall leading to serious flooding events in five provinces: Western Province; North Western Province; Rift Valley Province; Coast Province; and Nyanza. The nature and extent of the emergency has been described by the International Federation of Red Cross and Red Crescent Societies in an emergency appeal for aid (IFRC, 2008). In many of the affected areas, the International Federation of Red Cross and Red Crescent Societies note that "...flood waters have submerged most of the sanitation facilities causing contamination of both surface water and shallow groundwater sources". During the floods in Mozambique in 2000, between 40 000 and 100 000 pit latrines were destroyed (Cairncross & Alvarinho, 2006). Studies in Dar es Salaam, United Republic of Tanzania, have highlighted the same problem of flood water inundating and destroying pit latrines, leading to widespread contamination of groundwater and surface water (Chaggu et al., 2002; BDP, 2008).

Box 8
Flooding of latrines in poor urban areas of Bangladesh

Bangladesh currently experiences a range of climate conditions which challenge the sustainability of the city's water and sanitation systems, and the resources of the government and the people to cope (Bangladesh, 2008). The government's climate strategy predicts that the impacts of climate change on the country's weather patterns "…will exacerbate many of the current problems and natural hazards that the country faces" (Bangladesh, 2008). In particular, the urban areas of Bangladesh are vulnerable to the effects of higher and more intense rainfall through flooding, because of inadequate drainage and sewers backing-up, a feature that is common to many low-income districts of cities in developing countries (Douglas & Alam, 2006). The UN-Habitat report on the state of the World's cities highlights the severe problems of flooding in Dhaka, where floodwaters in the slums mix with raw sewage, and water supplies become contaminated through damaged pipes (UN-Habitat, 2008). In their evaluation of strategies for flood-prone areas, Kazi & Rahman (1999) recognized that "…a lack of appropriate sanitation facilities in flood-prone and high water-table areas in Bangladesh is one of the most important contributing factors for health and environmental degradation." In their three study areas – Dhaka, Patuakhali and Suylhet – all latrines were inundated during floods, and the flood waters were heavily contaminated with faecal waste.

In many areas the problems created by the natural inundation of pit latrines have been aggravated by the actions of the residents. Studies by Chaggu et al. (2002) in Dar es Salaam have shown that residents take advantage of floodwater to flush out their latrines. While these releases may be deliberate and add to the problem created by natural inundation of pit latrines, the residents do not have any cheap and accessible alternative means of extending the life of their latrines. The only intervention to prevent this problem and to reduce the widespread contamination of flood waters from pit latrines is to introduce pit-emptying services.

Pit latrines can be rendered inoperable when groundwater levels rise and intersect at some level of the pit adding to its total volume, to the point where it completely fills. Not only does this hinder the use of the latrine but also presents a risk of contamination of water sources downstream from the latrine. In loose soils, this has caused the pit to collapse.

Response to droughts

In general, reduced rainfall and developing drought conditions will favour pit latrines and other forms of on-site sanitation. Although there is no published evidence to support this supposition, the recommendations in design manuals related to the siting of latrines in relation to water sources would suggest that it is accurate. The appropriate separation distance between on-site sanitation and sources of untreated drinking-water has been the subject of several studies (see Lawrence et al., 2001). Guidelines for separation distances aim to protect the source of drinking-water, for example a protected well, from pathogens that may be transported through the subsurface from a pit latrine. Appropriate guidelines to address this issue are difficult to construct because the distances travelled by pathogens are influenced by many different factors that combine to create circumstances that are very specific to a particular site (see Section 2.4.2). However, a general principle that emerges from the guidelines is that the greater the distance between the base of the latrine and the water table, the lower the risk of pathogens reaching the groundwater. Applying this principle to reduced rainfall and drought conditions provides the rationale for the supposition that pit latrines are suitable for use in drought conditions, depending also on cultural and socioeconomic factors.

Adaptations

In areas prone to floods, or where an increase in rainfall is expected to raise the level of the groundwater table, unmodified pit latrines may not be a suitable option for sanitation provision. In this context the term unmodified is used to refer to a latrine that has been constructed with the slab covering the pit being flush with the ground. However, several adaptations can be made to the latrines to reduce their vulnerability to floods and rising groundwater, and to reduce their impact on the local environment: the latrines can be raised on mounds so that the depth of the pit does not extend deep into the ground (Kazi & Rahman, 1999; Parry-Jones & Scott, 2005); short-life pits can be introduced (Parry-Jones & Scott, 2005); the pits can be emptied regularly to reduce the volume of waste in the pits and to avoid the need to construct new pits each time one fills up; and covers can be fitted to the pits to prevent the release of solids during floods (Reed, 2006).

In Bangladesh, such problems arising from flooding and high groundwater tables are particularly acute. From their analysis of the particular challenges faced by three areas in Bangladesh, Kazi & Rahman (1999) have proposed a simple strategy for selecting suitable latrines in flood prone areas (see Table 5).

Table 3
Latrines suitable for flood-prone areas (from Kazi *et al.*, 1999)

Area	Local conditions				Suitable latrines
	Soil type	Groundwater level	Flood		
			Type	Depth	
Dhaka	Stable Semi-stable	> 2 metres	Normal Rainwater	0–181cm	Earth-stabilized latrine Step latrine Mound latrine
Patuakhali	Stable Unstable	0 to 1 metre	Normal Tidal	0–90cm	Sand-enveloped latrine Sand-enveloped raised latrine
Sylhet	Stable Semi-stable Unstable	0 to >2 metres	Flush Rainwater	0–181cm	Earth-stabilized latrine Step latrine Mound latrine

Parry-Jones & Scott (2005) have reviewed the suitability of several types of on-site sanitation for areas with a high groundwater table and suggested adaptations to the basic designs to increase resilience. In common with the recommendations of Kazi & Rahman, Parry-Jones & Scott (2005) advocate the use of raised latrines in areas with a high groundwater table, with the slab being constructed at least half a metre above the highest water level: "Where there is a seasonal high water table, a raised latrine may be the most appropriate option for on-site sanitation". Under these conditions, compositing latrines, with the receptor for faecal waste mounted on the surface of the ground, would also be appropriate. However, the introduction of raised, on-site sanitation needs to be considered in the context of the population that will be using the facilities. Although raised pit latrines and compositing latrines may be more resistant to the effects of floods, they can present problems of access for the elderly, children and the disabled.

Some pit latrines have been constructed so that a cover can be placed over the hole in the slab. This design intervention was principally to prevent access to the pit by flies, but also acts to prevent the discharge of faecal waste into flood waters (Reed, 2008). However, unpublished reports indicate that while the cover prevents the loss of solids from the pit during floods, it does not prevent seepage of the liquid phase (A. Bastable, unpublished observations, 2008).

While modifications can be made to low-cost sanitation to reduce its vulnerability to increased rainfall and floods, the prevailing social and environmental conditions in low-income, periurban areas of many cities in developing countries significantly aggravates flooding by restricting the natural dispersion of flood waters (Douglas & Alam, 2006; Douglas et al., 2008). For example, cities in the developing world rarely have an effective drainage system, relying on natural drainage channels, and it is common for buildings to be constructed within these channels, thus obstructing drainage. In Dhaka, many natural drainage channels are obstructed by buildings or roads (Alam & Golam Rabbini, 2007), and similar problems are seen in Mombasa (Awuoe, Orindi & Adwerah, 2008). This problem is frequently exacerbated by inadequate solid waste collection (leading to obstruction of drains with garbage), together with inadequate drain maintenance. Thus, the interventions that can be made to adapt sanitation systems will be largely ineffective without concomitant efforts to manage urban flooding and reduce the impact on the urban poor.

2.4 Broader strategies for adaptation

Climate change adds a new challenge to populations through changes in geophysical, biological, environmental and socioeconomic systems. The degree to which systems (and populations) are susceptible to and unable to cope with adverse impacts defines their vulnerability (Schneider et al., 2007).

Although climate change has been shown to influence water availability (Arnell, 2004), water quality, and human lives and health (see Section 2.5.3) populations are not vulnerable because of climate change; rather, climate change will exacerbate the existing vulnerabilities, and may overwhelm the coping mechanism of many. The most vulnerable are those that are most exposed to perturbations, who have limited coping capacity, and who are least resilient (Bohle, Downing & Watts, 1994). Evans (2007) identified a number of characteristics that make populations vulnerable in regard to water supply and sanitation. These include:

- living far from trunk infrastructure, leading to constraints on self-provisioning;
- living in areas which are technically difficult to serve, often prone to flooding or on steep hillsides;
- being priced out of accessing formal services.

While there are many technological advances available to adapt water supply and sanitation facilities to cope with climate change, the characteristics of vulnerable populations highlight some of the other issues that need to be overcome to implement the adaptations. It is not within the remit of this document to discuss in detail the financial programmes and policy changes required to achieve the MDGs. However, through better understanding of the vulnerabilities of communities to climate change in terms of water supply and sanitation, we can identify broader adaptation strategies that will help increase the resilience of communities to climate change.

This section explores the basis of vulnerability at a community level, and reviews some examples of how communities have increased their resilience to climate change, including informed decision-making through monitoring programmes, and understanding pollutant transport and risk reduction through water safety plans and land use planning.

2.4.1 Understanding vulnerability at a community level

By 2030, three-quarters of the world's population will be urban, with the largest and fastest-growing cities located in the developing world. Climate change exacerbates poverty and challenges poverty reduction strategies for the urban poor (UN-Habitat, 2008). UN-Habitat (2008) estimates that around one billion people live in slums and a significant proportion of this population will become environmental refugees. According to the IPCC (2007), flooding in urban areas will likely damage water treatment facilities as well as wells, pit latrines and septic tanks; sewage treatment systems and solid waste disposal areas will likely be equally affected, contaminating water supplies.

Where overall rainfall will decrease, droughts will likely compromise the replenishment of water tables and thus the normal sources of water supply for urban areas. Although the number of people that could be affected in urban areas will be significant, communities in rural areas will also experience the impacts of climate change and may migrate to urban centres to escape their difficulties. Significant levels of migration into urban centres will compound the already serious problems that exist.

Developing countries are particularly vulnerable to the impacts of climate change because of exposure and sensitivity, and their limited capacity to adapt (McCarthy et al., 2001). Africa is thought to be at particular risk, for example, because of over-dependence on rain-fed agriculture, which means that livelihoods are closely related to resources such as water, which in turn are sensitive to climate change (UNEP, 2001). There have been a number of attempts to develop global and national-level indicators for human aspects of vulnerability, taking into account economic as well as social, cultural and institutional factors (see Vincent, 2004). However, variations in vulnerability exist at lower levels, with some populations showing resilience and others not; therefore, country-level analyses of vulnerabilities are more appropriate (Vincent, 2004).

Economic factors inevitably play a key role in vulnerability; however, experience shows that even economically developed nations may be vulnerable in the case of exposure to a hazard, as was seen in the United States in 2003 following Hurricane Katrina, and more recently in eastern Europe where floods have resulted in loss of life and loss of infrastructure because of a lack of anticipatory adaptation or maladaptation in some cases.

In addition to economic well-being and stability, the structure and health of a population may also be an important factor in determining vulnerability. The elderly and the young tend to be more susceptible to environmental risk and hazard exposure, whereas populations with a high proportion of working age adults in good health are likely to cope better and thus be the least vulnerable (O'Brien & Mileti, 1992). Africa, by contrast, consists of a number of countries which are of low- or middle-income status, which have high birth rates and declining death rates, making a vulnerable population.

A further factor contributing to the vulnerability of a population is disease epidemics. HIV/AIDS, for example, is at epidemic levels in a number of countries. Not only does this increase the vulnerability of the affected people to natural disasters and the effects that follow, but also increases the vulnerability of the country as a whole by diverting scarce financial resources into health care provision (Vincent, 2004).

Following a natural disaster or environmental hazard, the institutional stability and strength of public infrastructure are important in determining a the vulnerability of a population. If there is a lack of institutional capacity in terms of knowledge about an event, ability to deal with it and prevent it affecting the human population, then the population could be considered vulnerable. Even if a strong institutional structure exists, there are cases where political issues such as corruption may increase social vulnerability by impeding the distribution of entitlements and relief aid (Vincent, 2004).

Vulnerability is generally hazard-specific: it is possible for a population to be vulnerable in one set of circumstances but resilient in another. What turns a hazard-related shock into a crisis for a community, household or individual is a lack of capacity to respond to and withstand threats to well-being. This in turn depends on the relationship between the susceptibility to risk, the differential vulnerability of the household, and underlying factors and trends which contribute to vulnerability (Chars Livelihoods Programme, 2004). For example, a population that has a history of exposure to rainfall variability may be able to reduce their vulnerability by adapting their lifestyle (through migration, for example) and livelihoods (by adopting a flexible strategy). The Char communities in Bangladesh provide an example (see Box 9). In such a situation, it may arguably be more appropriate to install low-cost temporary water and sanitation technologies, rather than expensive permanent structures which would regularly be abandoned (B. Evans, unpublished observations, 2008).

Box 9
Adaptation to flooding: the Char communities in Bangladesh

In Bangladesh, the Char communities regularly suffer from floods. The everyday lives, livelihoods and culture of Char dwellers are associated with risk and vulnerability. Because of seasonal flooding and erosion, social and spatial mobility is high for both individuals and households. Temporary or permanent displacement is common. People face fluctuating access to productive land and their other resources are also highly vulnerable. Almost all Char-dwellers have well-established livelihood strategies which enable them to survive the extreme environment and obvious vulnerabilities of the area.

Source: Chars Livelihoods Programme (2004).

Therefore, to assess the potential harm caused by climate change, the ability of individuals, groups, societies and nature to adapt to impacts must be considered. Adaptation can significantly reduce many potential adverse impacts of climate change and reduce the risk of many key vulnerabilities (Schneider et al., 2007), not only through adjustments to behaviour, but also through technology or infrastructural changes that maintain existing livelihoods (Schipper, 2007). It is clear that the scope for adaptation is great, particularly in developing countries, where communities are already struggling to cope with existing challenges, providing that existing and developing scientific understanding and technology can be applied (Box 10). However, it should be recognized that some solutions to climate change may be temporary, because they are inflexible, for example when technology or infrastructure becomes obsolete.

Throughout the history of human settlements much of the simplest traditional water infrastructure (e.g. household rainwater cisterns) has allowed households and communities to manage variability's in water availability, which in turn reflects climate change. This is also true for other water management options such as dams, canals, tunnels and pipelines which not only respond to water supply demands but, suffer less variability and therefore provide water supply security. Similarly, wastewater disposal and storm water drainage systems help communities to maintain their activities and protect public health during extreme weather events (Muller, 2007).

Box 10
Planning for vulnerability on a city scale – Dhaka, Bangladesh

The location of Dhaka makes it extremely vulnerable to climate change. The city is situated between four flood-prone rivers, between the Himalaya mountain range and the sea, which is moving inland. It is predicted that climate change will result in flooding and drainage congestion, and heat stress in Bangladesh. High urban growth rates and high urban densities have made Dhaka susceptible to human-induced environmental disasters. A recent mapping of slums conducted by the Centre for Urban Studies in Dhaka shows that nearly 60% of the slums in the city have poor or no drainage and are prone to frequent flooding. The problems associated with flooding are made worse by overcrowding and poor quality housing. The survey found that almost one third of Dhaka's population live in housing that is too weak to withstand large-scale environmental disasters. *(to continue next page)* (continued from page 27) Floods in these dense, poorly serviced settlements can lead to waterborne diseases if the flood waters in the slums mix with raw sewage. Water supplies also become contaminated during floods, as pipes in slum areas are likely to be damaged or leak.

Experts agree that cities such as Dhaka can adapt to reduce the impacts of flooding by improving planning, putting in effective infrastructure and establishing disaster preparedness. In Dhaka, the government has completed construction of embankments, concrete reinforced walls and pumping stations in the most dense parts of the city as a measure against flooding. Technical solutions are also possible but these must take into account development problems.

Source: UN-Habitat (2008).

2.4.2 Informed decision-making

One of the key factors in increasing the resilience of communities is communication. As has been described in Sections 2.2 and 2.3, there are many adaptations that are already in use around the world to deal with different and variable climates. As climate changes, many regions will have to adapt to new conditions for which other countries have long been adapted. Hence, communication is one of the best adaptation tools available as it can provide the basis for informed decision-making.

Two of the other tools for informed decision-making are discussed here briefly. First is monitoring programmes that provide the information on which to base adaptation decisions and policy decisions. Second is an understanding of the transport of waterborne diseases in groundwater.

Monitoring programmes

Good quality hydrological data is fundamental to the development of policies to support the improvement of water supply and sanitation. However, Muller (2007) has observed that the work of collecting and processing of hydrological data has become a victim of the lack of water investments over the past few decades. Under-investment in data collection has led to the established networks of hydrological stations in many developing countries falling into disrepair, reducing both the quantity and quality of the data that are available. Reversing this trend will be neither simple nor quick. To be informative, hydrology requires long and relatively complete records (Muller, 2007). The continuity of data collection that may have existed but was then broken cannot be filled retrospectively, so new monitoring programmes need to be implemented. Muller (2007) argues that these monitoring programmes should begin to collect data to provide hydrological design parameters that reflect the risk of variability induced by climate change.

Understanding the fate and mobility of pathogens in groundwater

Faecal matter released into the environment from improved sanitation facilities will vary from highly concentrated material from pit latrines, which receive minimal water inputs, to more dilute, and potentially treated, wastewater from sewer systems. Faecal matter, and more broadly sewage, contains soluble and particulate organic and inorganic matter, pathogens (in the main, bacteria, viruses and protozoa, but also parasites) and several nutrients (in particular nitrogen and phosphorus).

Pathogens in faecal matter can cause a range of diseases if people come into contact with it, which can happen when there is inadequate means of disposal of the waste or improper water sources are used. Nitrate can also cause health problems, and other contaminants can cause taste and odour problems (see, for example, Cronin et al., 2007). Improved sanitation facilities are those that are considered to reduce the risk of people coming into contact with faecal matter, and include subsurface disposal via improved pit latrines and septic tank disposal fields, or removal from site via septic tank pump-outs or sewer systems. However, these systems can still contribute to the spread of disease if they are not properly designed, installed and managed, and if subject to extreme conditions or changes in conditions that might arise through climate change.

Many millions of people rely on water supplies derived from groundwater with minimal or no treatment, while at the same time disposing of their wastes in the subsurface. The choice of drinking-water supply and sanitation facilities to be installed in a particular location can greatly increase the vulnerability of one to the impacts of the other: the literature dealing with separation distances between on-site sanitation and groundwater sources of drinking-water provides a good example of that outcome (see Lawrence et al, 2001; Pedley et al., 2006). In this context, knowledge about the fate and mobility of pathogens in the subsurface is particularly relevant to making informed decisions about the siting of water and sanitation. This subject is reviewed briefly below. Better understanding of pathogen transport can aid in planning and managing both sewage disposal and water supplies, and can also help understand the impact of climate changes such as increased groundwater recharge and rising groundwater levels.

The discussion here is restricted to subsurface disposal of faecal matter because groundwater is a hidden resource which can form the supply for up to 80 % of people in rural areas and low-income periurban areas in Africa and Asia (Pedley & Howard, 1997), and because the movement of pathogens into and through groundwater is poorly understood. However, it is known that pathogens in groundwater are a hazard and represent a risk to the health of those who use untreated groundwater as a source of drinking-water (USEPA, 2006).

A comprehensive review of groundwater protection for public health has been published by the WHO (Schmoll et al., 2006). The following discussion aims to give an overview of the issues as they relate to the vulnerabilities of the systems to climate change.

The value of soil and aquifer matrices in treatment of both drinking-water and faecal matter is widely recognized (Schijven & Hassanizadeh, 2000; Pedley et al., 2006). Soil and aquifer matrices provide filtration for faecal matter, rapidly removing much of the particulate matter and hence a large proportion of the nutrients and pathogens which can be associated with it. However, significant numbers of pathogens will remain unattached and mobile in groundwater. Once pathogens are in the subsurface, their die-off rate and mobility are influenced by temperature, moisture, soil and hydraulic properties, as well as many other factors.

The main component of pathogen transport is determined by the flow of the water, which for the case of sewage disposal and drinking-water is illustrated in Figure 2. In unsaturated soil, the flow is predominantly downwards, with only localized lateral movement in uniform soils. However, where there is a reduction in the permeability of the soil, lateral movement of water can occur over the surface of the less permeable material. When the water reaches the groundwater table, movement is dictated by the direction of the groundwater flow. While this is depicted in Figure 2 as being with the slope of the land surface, this will not necessarily be the case. Investigation of water depth in neighbouring boreholes will provide a better indication of the direction of water flow.

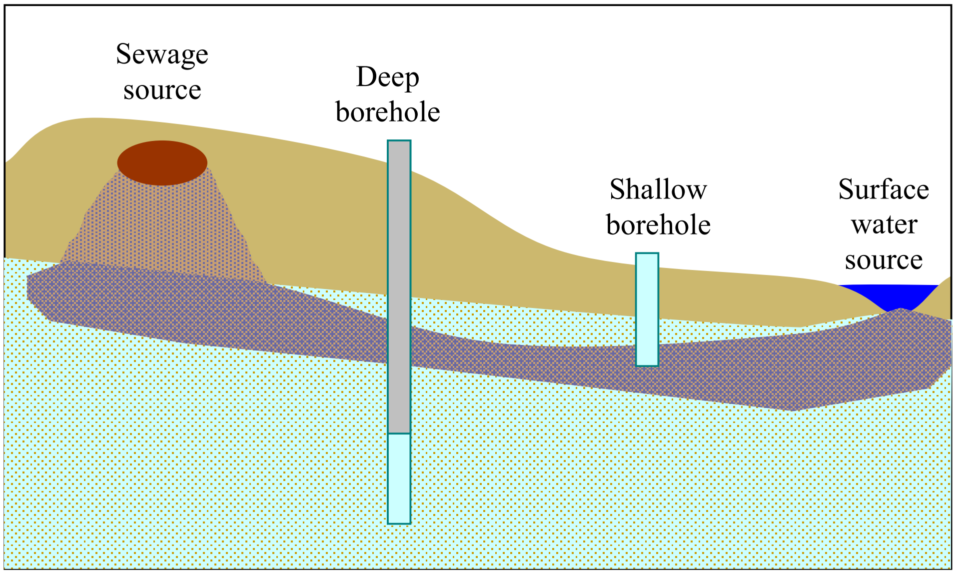


Figure 2
Diagram of sewage and sewage contamination flow in the subsurface. This example illustrates the importance of understanding the movement of sewage in the subsurface. In this case, the drinking-water source that is nearest to a sewage source at the surface, the deep borehole, is less impacted than the water sources that are further away.

Because of the tendency for groundwater flow to be approximately horizontal, and for layers in aquifer sediments to limit vertical transport, deep groundwater is often of better quality than shallow groundwater. For example, in areas of New York, United States, and in some regions of Bangladesh, deep boreholes located within a short distance of sewage disposal areas are used to provide good quality water for drinking, because the deep groundwater is not affected by the nearby sewage disposal (Curry, 2000; Lawrence et al, 2001). However, it should be noted that viruses, which have lower rates of decay than bacteria in groundwater, have been detected in deep groundwater, including in confined aquifers (Powell et al., 2003; Borchardt et al., 2007). Thus, deep groundwater does not always provide safe drinking-water, for example where there is rapid transport (Price et al., 1992; McKay et al., 1993) and transport to deep groundwater (Borchardt et al., 2007), commonly associated with fractures in the rock or soil. Rapid transport pathways can also come from anthropogenic sources which provide cross-connections between aquifer layers, such as abandoned mines and poorly sealed well-casings.

Unsaturated soil provides filtration of sewage. Where sewage enters the ground, a biomat or clogging layer will form. This biomat inhibits movement of faecal bacteria (Howard et al., 2006). Increased predatory microorganisms within the biomat can permanently remove some of the pathogens. The interface between air and water in unsaturated soil provides a surface to which pathogens can attach and where accelerated inactivation of the pathogens can take place (Thompson & Yates, 1999). Unsaturated conditions can also increase pathogen decay through desiccation.

Saturated soil also provides filtration. However, saturated conditions will generally allow greater mobility and lower decay rates of pathogens than unsaturated soils because of lower temperatures and increased moisture.

Climate change will affect the fate and mobility of pathogens in groundwater in several ways. In general, increased water in the ground will aid the spread of pathogens through greater mobility and survival. More rainfall and more frequent or larger floods will result in increased water flow in soil and groundwater, promoting microorganism transport, and mobilizing attached pathogens as a result of changes in water chemistry. Increased interflow in the soil will also increase the rate and extent of horizontal pathogen transport in unsaturated soil. Greater saturation of soil will increase pathogen survival. Rising groundwater may reduce the amount of unsaturated soil, and therefore the amount natural soil treatment before waste reaches groundwater.

Conversely, decreases in rainfall and groundwater recharge, with increases in evapotranspiration, will potentially decrease the water content of the soil and increase the depth of unsaturated soil, improving the ability of soil to treat water and waste.

2.4.3 Risk reduction

Risk reduction in the context of this report is the development and application of policies and practices that minimize risks to vulnerable populations and risks to drinking-water supply and sanitation facilities as a result of climate change. There are a far greater number of practices that could be discussed in this context than we have room for here. However, we have highlighted water safety plans as a key action to ensure specifically the safety of a drinking-water supply; land use planning and building or adapting infrastructure are discussed as ways of reducing the vulnerabilities of communities to climate change disasters. Huge benefits are to be gained from increased collaboration and communication, and integrated planning, such as integrated water resources management (Bates et al., 2008). Chapter 3 of this document discusses this need for increased collaboration and communication, further highlighting the need for representatives from the various water sectors and stakeholders to collaborate over reducing the risk of significant disruption to water and sanitation systems from climate change.

Water safety plans

The impacts of climate change on water quality need to be managed in order to consistently ensure the safety of a drinking-water supply. At a community or utility level this can be done through the use of a comprehensive risk assessment and risk management approach that encompasses all steps in water supply from catchment to consumer (WHO, 2008a). The water safety plan is a flexible approach that allows this, the aim being to ensure the safety and acceptability of a drinking-water supply. There are now many examples of water safety plans being applied in a variety of settings, including utilities in developed and developing countries and small community supplies, to achieve this aim (AS/NZS, 2004; Mahmud et al*.,* 2007; Godfrey & Howard*,* 2005).

The implementation of a water safety plan consists of a number of steps which are undertaken by a water safety plan team consisting of individuals from the utility and, where appropriate, from a wider group of stakeholders, with the collective responsibility for understanding the water supply system and identifying hazards that can affect water quality and safety throughout the water supply chain. The team identifies all the hazards that can affect the safety of the water supply, from the catchment, through treatment and distribution, to the consumer; assesses the risk presented by each hazard; identifies and validates the effectiveness of controls or barriers in place for each risk; implements an improvement plan where necessary; and regularly reviews the hazards, risks and controls. Full details of the approach can be found in the WHO *Water safety manual* (WHO, 2008a).

Land use planning

Land use planning can substantially reduce the vulnerability of communities to water-based natural disasters if the plans are supported by reliable data on floods and droughts. Resilience can be achieved by building infrastructure such as floodwalls, or by communities deciding not to settle in vulnerable areas, but often a mix of "hard" and "soft" approaches are most appropriate. In Europe, it is being recognized, for example, that there is a need to make room for flood waters, store them or evacuate them, rather than simply building barriers to try and keep them out. Different strategies are also being applied to combat droughts. These include initiatives to encourage people to use groundwater and domestic water appropriately, and the construction of water reservoirs like the Alqueva Dam in Portugal.

As discussed previously, seasonal flooding is a severe problem in many cities of the developing world, particularly in slum areas which are often on flood-prone sites and which often lack effective drainage (Douglas et al., 2008). It seems likely that the frequency of flooding will increase in many cities, irrespective of climate change, simply because of increasing urbanization and poor urban planning. As noted by Satterthwaite (2007), urbanization reduces rainfall infiltration into the soil, leading to more intense runoff in response to rainfall events. In the developed world, this is rarely a problem because effective systems exist for stormwater drainage, and because planning ensures that naturally flooded areas are generally not built upon. But cities in the developing world rarely have effective drainage systems, relying on natural drainage channels that may be obstructed by buildings or other forms of construction, thus obstructing drainage. In Dhaka, for example, many natural drainage channels are obstructed by buildings or roads (Alam & Golam Rabbini, 2007), and similar problems are seen in Mombasa (Awuoe, Orindi & Adwerah, 2008). This is frequently exacerbated by inadequate solid waste collection (leading to obstruction of drains with garbage), together with inadequate drain maintenance.

A recent World Bank appraisal of a project in Lagos (World Bank, 2006), states that "regular flooding of large parts of the city, including at higher elevations, is the single most important infrastructure problem for Lagos". According to this report, 43% of households in metropolitan Lagos experienced flooding in their streets in 2005, and 16% experienced flooding inside their homes, with floods often sweeping raw sewage and refuse into the home: "flood waters are a black mix of runoff, overflowing sewage from backed-up drains, and swamp water". Similarly, about 45% of Dar es Salaam has a high water table and floods in the rainy season (Mato, Kassenga & Mbuligwe, 1997). Other African cities reported to be vulnerable to seasonal flooding include Cotonou (Dossou & Glehouenou-Dossou, 2007), Banjul (Jallow et al., 1999), Port Harcourt (Abam et al., 2000), Nairobi, Kampala, Accra, Freetown, and Maputo (Douglas et al., 2008). Heavy rains and cyclones in Mozambique in 2000 brought wide-spread devastation, disrupting water and sanitation services to one million people and causing outbreaks of dysentery and cholera (Douglas et al., 2008).

2.5 Climate change: implications for water resources and health

While there are predictions on the long-term impacts of climate change on water resources (Campbell-Lendrum & Corvalan, 2007; Kundzewicz et al., 2007; Bates et al., 2008), the long-term impacts on public health are less well known, primarily because of the uncertainty in prediction of local effects of global changes in climate. However, all populations are likely to be affected to some extent by changing climate, the risks being particularly high in the poorest countries of the world, primarily because these countries have a high incidence of climate-sensitive diseases, and lack resources and institutional capacity to control them. Direct health impacts will be caused by death or injury in floods; indirect health impacts will arise though decreases in availability of safe water, resulting in increasing reliance on poor quality water sources.

In 2004, climate change was estimated to be responsible for approximately 3% of worldwide diarrhoea cases (WHO, 2009). Almost 90 % of the burden of diarrhoeal disease is attributable to lack of access to safe water and sanitation (WHO, 2009). Reductions in the availability and reliability of freshwater supplies caused by climate change are expected to increase this hazard. The impacts will fall disproportionately upon developing countries and low-income groups within all countries.

A detailed review of the possible changes in rainfall has been carried out by the United Kingdom Met Office, Hadley Centre, and should be read in conjunction with this report (see *Climate change projection study*, on this CD-ROM). The aim of this section is to briefly review the impacts of climate change, initially focusing on the published observed and predicted changes in precipitation, then looking at the implications of these changes for water resources and the resulting potential health impacts. Significant drivers of climate change are not discussed here, in order to keep the section short and focused on impacts.

2.5.1 Climate observations

Changes in precipitation

Observations of changes in precipitation are limited by the measurement of precipitation. Both in situ and remote sensing measurements have limitations, and are often combined to give a better estimate. Because of these issues with measurement, and the spatial limitations of historical data sets, a number of variables are used to examine the consistency of changes in precipitation.

Changes have been observed in the amount, intensity, frequency and type of precipitation. Increases in heavy precipitation events have been widespread, even occurring where total rainfall has decreased. These changes are associated with increasing water vapour in the atmosphere.

As temperature increases, the moisture-holding capacity of the atmosphere increases at a rate of about 7 % per 1 °C (Kundzewicz et al., 2007). It is estimated that atmospheric water vapour increased by about 5 % over the oceans in the 20th century. Because precipitation comes mainly from weather systems that feed on the water vapour stored in the atmosphere, these increases in water vapour have generally increased the amount of precipitation and the risk of heavy rain and snow events. However, particularly where total precipitation is decreasing, increases in the intensity of precipitation will correspond with longer dry periods between rain events.

In addition, as temperature rises, precipitation is more likely to fall as rain rather than snow. This is especially true at the beginning and end of the snow season. The impact of rising temperatures on snowfall will affect the seasonality of river flows, particularly where snowfall is already more marginal. In many cases, peak flow would occur at least a month earlier (Bates et al., 2008). Glacial melt water from the Andes provides water supply for tens of millions of people, but many small glaciers are expected to disappear within a few decades (Kundzewicz et al., 2007). In the past two decades there have been decreases in the Hindu Kush–Himalaya ice mass, an area which provides water for hundreds of millions of people in China and India (Barnett, Adam & Lettenmaier, 2005). In these areas with glacier melt fed rivers, higher temperatures will increase the melting of these glaciers in the short term, providing higher water flows and the potential for the formation of glacial melt-water lakes, which may pose a serious threat of outburst floods (Coudrain et al., 2005). Over the longer term, as the glaciers disappear, the contribution of glacier melt to summer river flows will decrease, increasing the risk of droughts. The overall impact will depend on whether the reducing flows from glaciers can be off-set by increased water storage (Bates et al., 2008).

The spatial patterns of annual precipitation in the past century, and in recent decades, are shown in Figure 3, which presents data from in situ monitoring with rain gauges only. Increasing precipitation over the past century is evident over high latitude areas from 30°N to 85°N over land in North America, Europe and Asia, as well as in the Amazon Basin and south-eastern South America, and north-western Australia. In particular, central North America, eastern North America, northern Europe, northern Asia and central Asia all experienced significant increases in precipitation of between 6% and 8% from 1900 to 2005 (Trenberth et al., 2007). Also over high latitudes, there have been general increases in runoff, river discharge and soil moisture, consistent with the observed precipitation changes.

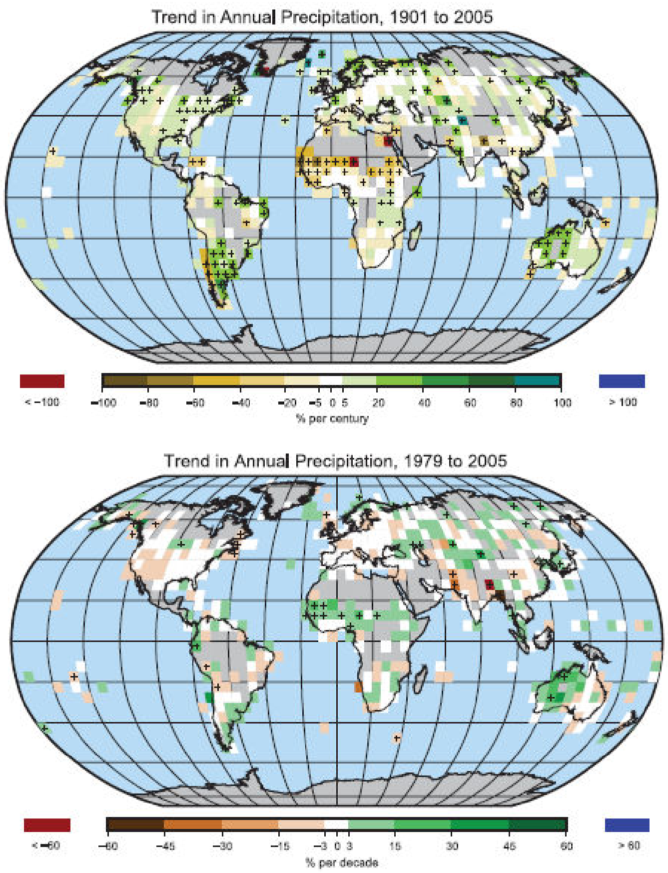


Figure 3

Trend of annual land precipitation amounts for 1901 to 2005 (top, % per century) and 1979 to 2005 (bottom, % per decade): the percentage is based on the means for 1961 to 1990

Note: Areas in grey have insufficient data; trends significant at the 5% level are indicated by black + marks.
Source: Trenberth et al. (2007).

Changes in frequency and extent of drought

Drought is a “prolonged absence or marked deficiency of precipitation”, a “deficiency of precipitation that results in water shortage for some activity or for some group” or a “period of abnormally dry weather sufficiently prolonged for the lack of precipitation to cause a serious hydrological imbalance” (Heim, 2002).

The Palmer Drought Severity Index (PDSI) (Palmer, 1965; Heim, 2002) uses precipitation, temperature and locally available data on water content to assess soil moisture. Using this index, very dry areas have been calculated to have more than doubled (from ~12% to 30%) since the 1970s. This includes a large jump in the early 1980s attributable to an El Niño–Southern Oscillation related precipitation decrease over land and subsequent increases primarily resulting from surface warming. Warming accelerates land surface drying and increases the potential incidence and severity of droughts; this has been observed in many places worldwide.

Since the middle of the 20th century, the PDSI shows a large drying trend over many northern hemisphere land areas, with widespread drying over much of southern Eurasia, northern Africa, Canada and Alaska, and an opposite trend in eastern North and South America. In the southern hemisphere, land surfaces were wet in the 1970s and relatively dry in the 1960s and 1990s, and there was a drying trend from 1974 to 1998. These trends are evident in the spatial and temporal patterns of the PDSI in Figure 4. it should be noted that these trends do not necessarily reflect the projections for future climate change.

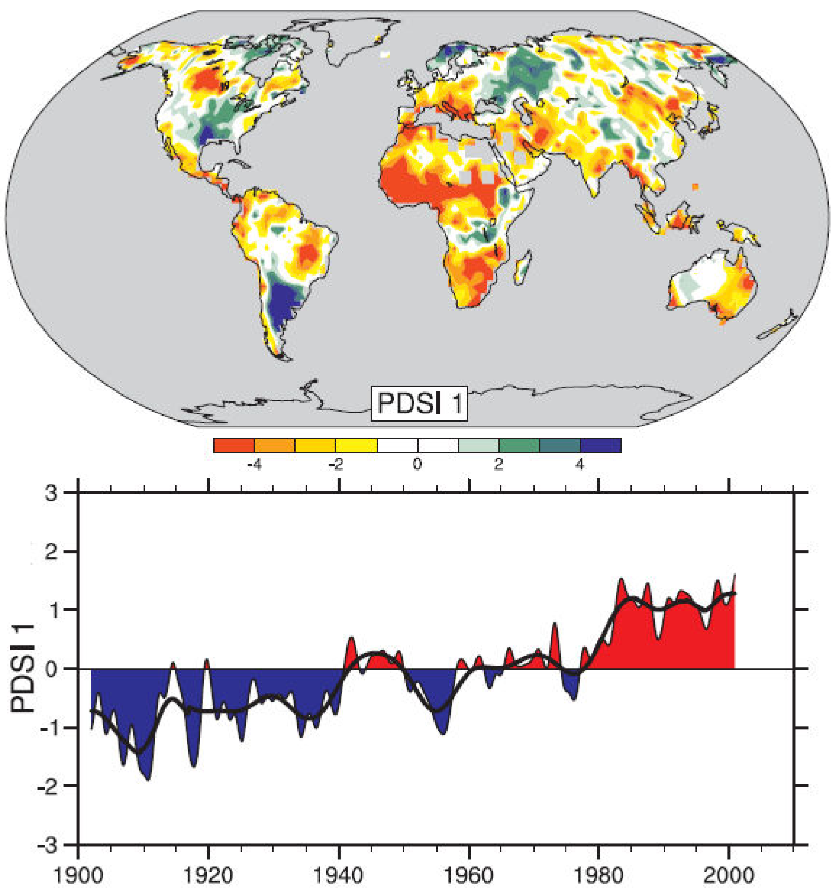


Figure 4

The spatial pattern (top) of the monthly Palmer Drought Severity Index (PDSI) for 1900 to 2002. The lower panel shows how the sign and strength of this pattern has changed since 1900. Red and orange areas are drier (wetter) than average and blue and green areas are wetter (drier) than average when the values shown in the lower plot are positive (negative). The smooth black curve shows decadal variations.

Source: Adapted from Dai et al. (2004) (Trenberth et al., 2007).

Changes in extreme events

> "Extremes refer to rare events based on a statistical model of particular weather elements, and changes in extremes may relate to changes in the mean and variance in complicated ways. Changes in extremes are assessed at a range of temporal and spatial scales, for example, from extremely warm years globally to peak rainfall intensities locally." (Trenberth et al., 2007)

The availability of data on extreme events is limited by the nature of such events; there are few data with which to undertake statistical analyses. The Intergovernmental Panel on Climate Change (IPCC, 2007) reports that very few regions have sufficient data to assess trends reliably even at lower percentiles.

Extreme events that have been reviewed by the Intergovernmental Panel on Climate Change include heat waves, droughts, flooding, heavy precipitation, tropical storms and hurricanes, the findings for some of which are provided in Table 6. In general, globally, the contribution of very wet days to total annual precipitation has increased in recent decades.

Table 6
Change in extremes for phenomena over the specified region and period, with the level of confidence

Phenomenon	Change	Region	Period	Confidence
Heavy precipitation events (that occur every year)	Increase, generally beyond that expected from changes in the mean (disproportionate)	Many mid-latitude regions (even where reduction in total precipitation)	1951 – 2003	Likely (> 66 %)
Rare precipitation events (with return periods > ~ 10 years)	Increase	Only a few regions have sufficient data for reliable trends (e.g., United Kingdom and United States)	Various since 1893	Likely (> 66 %) (consistent with changes inferred for more robust statistics)
Drought (season or year)	Increase in total area affected	Many land regions of the world	Since 1970s	Likely (> 66 %)
Tropical cyclones	Trends towards longer lifetimes and greater storm intensity, but no trend in frequency	Tropics	Since 1970s	Likely (> 66 %); more confidence in frequency and intensity

Source: Adapted from Trenberth et al. (2007).

Heavy daily precipitation events increase the risk of flooding. There has been an observed increase in heavy precipitation events over the mid-latitudes in the past 50 years (Figure 5). Europe has experienced an increased number of moderately wet (> 75th percentile) and very wet (> 95th percentile) days since the middle of the 20th century. The contiguous United States of America, particularly the eastern United States, has experienced statistically significant increases in heavy (upper 5%) and very heavy (upper 1%) precipitation of 14% and 20%, respectively, much of which has occurred since 1970. The relative increase in these heavy precipitation events in Europe and the United States is larger than the increase in average precipitation, with heavy events contributing increasing amounts of the total precipitation (See Figure 5, Trenberth et al., 2007).

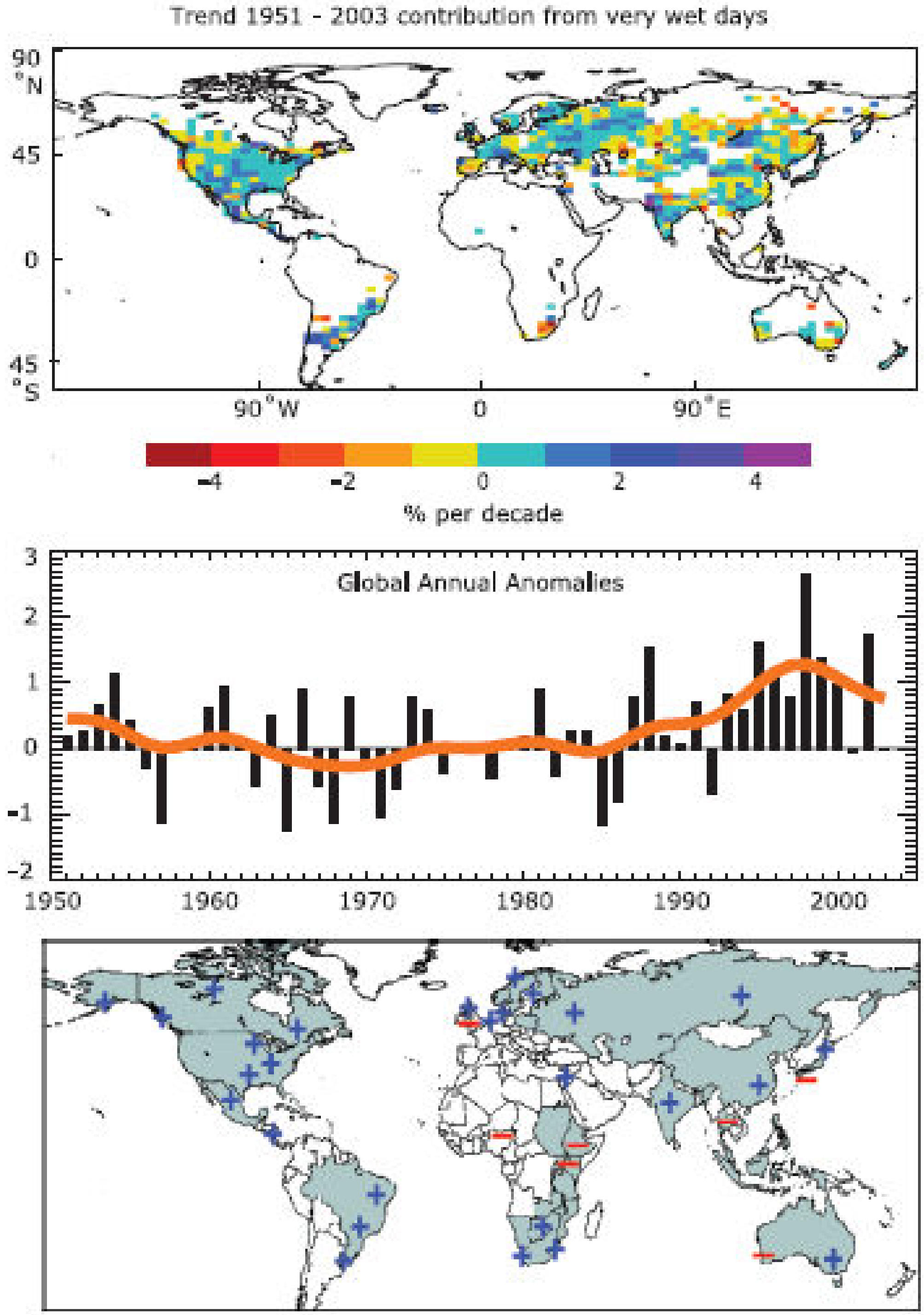


Figure 5
(Top) Contribution of very wet days (95th percentile) to total annual precipitation for 1951 to 2003.
(Middle) The percentage change of contributions of very wet days from the base period average (1961 to 1990; 22.5%). The smooth orange curve shows decadal variations (from Alexander et al., 2006).
(Bottom) Regions with disproportionate changes in heavy and very heavy precipitation during the past decades, noted as an increase (+) or decrease (–) compared to the change in the annual or seasonal precipitation (Trenberth et al., 2007, updated from Groisman et al., 2005)

However, heavy precipitation events have also been increasing in areas where average annual precipitation is not increasing, such as in South Africa, Siberia, central Mexico, Japan, north-eastern United States and large parts of the Mediterranean (Trenberth et al., 2007). Similar increases in rainfall intensity have been observed over Central America and northern South America where no significant increases in total precipitation have been recorded.

2.5.2 Climate predictions

The predictions for climate change, by the Intergovernmental Panel on Climate Change, are based on a range of scenarios (Nakicenovic et al., 2000). Briefly, some of the key climate predictions reported by the Intergovernmental Panel on Climate Change (Meehl et al., 2007) include:

- Precipitation intensity is projected to increase over most regions (Figure 6), resulting in intense and heavy downpours interspersed with longer relatively dry periods.
- The increase in precipitation extremes is expected to be greater than changes in mean precipitation (Meehl et al., 2007).
- Wet extremes are projected to be more severe in areas with increased mean precipitation, and dry extremes where the mean precipitation decreases.
- Increases in the water holding capacity of the atmosphere is expected to increase the potential for more flooding with the Asian monsoon and in other tropical areas.
- Intense precipitation events are expected to increase peak river discharges, resulting in an increased risk of floods in a number of major river basins.
- Tropical cyclones are predicted to become less frequent but more severe, with greater wind speeds and more intense precipitation (Meehl et al., 2007).

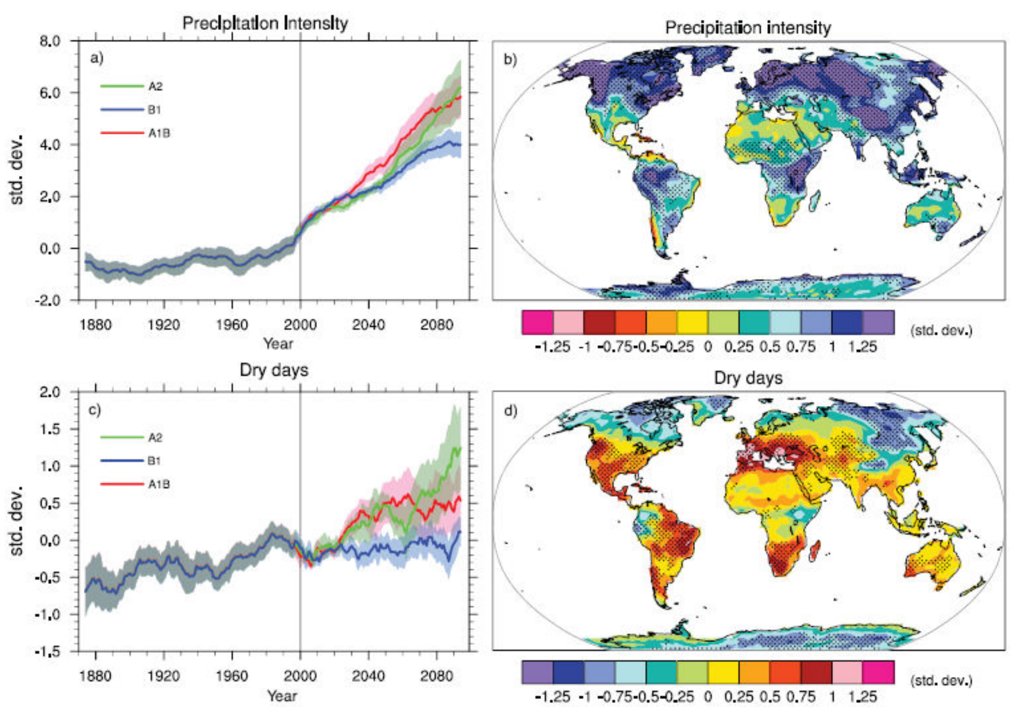


Figure 6

Changes in extreme events: (a) globally averaged changes in precipitation intensity for a low (SRES B1), middle (SRES A1B) and high (SRES A2) scenario; (b) predicted changes in precipitation intensity between two 20-year means (2080–2099 minus 1980–1999), for the middle scenario; (c) globally averaged changes in the annual maximum number of consecutive dry days; (d) predicted changes in dry days between two 20-year means (2080–2099 minus 1980–1999) for the middle scenario.

Note: Stippling in (b) and (d) denotes areas where the change is statistically significant.
Source: Meehl et al. (2007).

2.5.3 Observations and predictions of the impact of climate change on water resources and health

Water resources are already under stress in many areas from a combination of climatic factors and anthropogenic factors such as population growth, changing economic activity, land-use change and urbanization (Figure 7). Water demand is predicted to increase in the future as a result of population growth and increased affluence, with large changes in irrigation water demand also possible as a result of climate change (Bates et al., 2008). Water scarcity will have a significant impact on health, as will degradation of water quality.

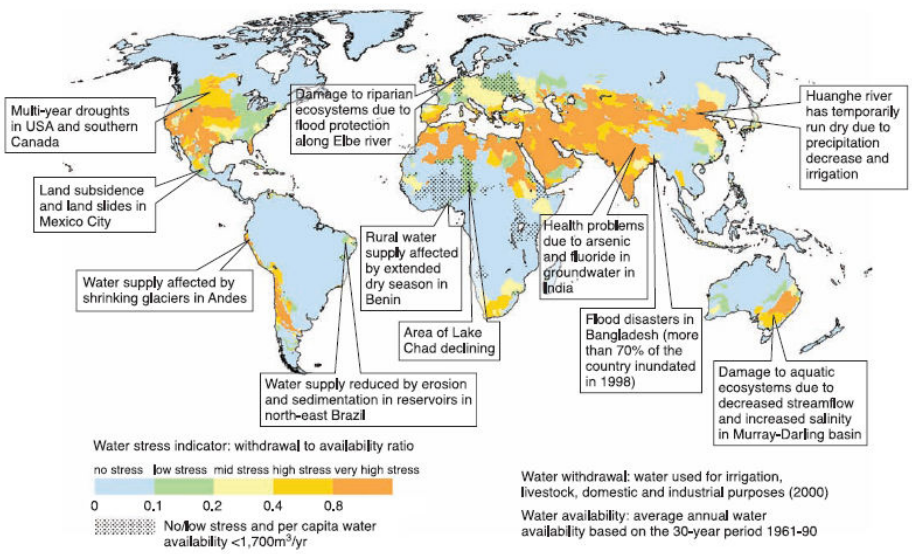


Figure 7
Examples of current vulnerability of freshwater resources and their management, overlain on a water stress map

Source: Alcamo et al. (2003), adapted from Kundzewicz et al. (2007).

The negative impacts of climate change on freshwater systems have been predicted to outweigh its benefits, with an overall net negative impact of climate change on water resources and freshwater ecosystems for all regions (Kundzewicz et al., 2007; Bates et al., 2008). These impacts are attributable to observed and projected increases in temperature, sea level and precipitation variability. A summary of climate-related trends that have been observed in the global freshwater system are provided in Table 7.

Table 7
Climate-related trends observed in the global freshwater system

	Observed climate-related trends
Precipitation	Increasing over land north of 30°N over the period 1901 – 2005 Decreasing over land between 10°S and 30°N after the 1970s Increasing intensity of precipitation
Cryosphere	
Snow cover	Decreasing in most regions, especially in spring

Glaciers	Decreasing almost everywhere
Permafrost	Thawing between 0.02 m/year (Alaska) and 0.4 m/year (Tibetan Plateau)
Surface waters	
Streamflow	Increasing in Eurasian Arctic, significant increases or decrease in some river basins Earlier spring peak flows and increased winter base flows in Northern America and Eurasia
Evapotranspiration	Increased actual evapotranspiration in some areas
Lakes	Warming, significant increases or decreases of some lake levels and reduction in ice cover
Groundwater	No evidence for ubiquitous climate-related trend
Floods and droughts	
Floods	No evidence for climate-related trend, but flood damages are increasing
Droughts	Intensified droughts in some drier regions since the 1970s
Water quality	No evidence for climate-related trend
Erosion and sediment transport	No evidence for climate-related trend
Irrigation water demand	No evidence for climate-related trend

Source: Kundzewicz et al. (2007).

Current water management practices need to adapt to cope with the changing climate. Both existing water infrastructure and water management practices will be affected by changes in climate, and current water management practices will most likely not be able to mitigate the negative impacts of climate change on water supply reliability, flood risk and aquatic ecosystems (Kundzewicz et al., 2007). Even in areas where water resources benefit from increased annual runoff, there will be negative effects of increased precipitation variability, seasonal runoff shifts on water supply, flood risks and impacts on water quality.

Surface waters

There are limited data on the effects of climate change on surface waters, with the available modelling generally focused on Europe, North America, and Australasia. These models illustrate that there is greater uncertainty between the results from global climate models than between the climate scenarios being modelled. This is illustrated in Figure 8 in the differences in runoff predicted by different models for Australia, South America, and Southern Africa.

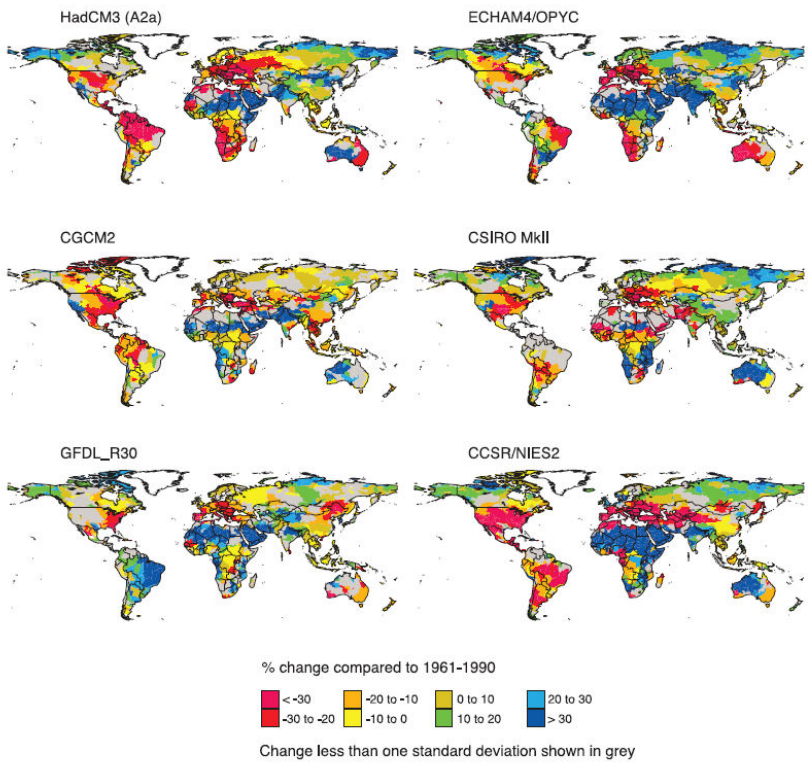


Figure 8
Change in average annual run-off by the 2050s (SRES A2 emissions scenario for six different climate models)

Source: Arnell et al. (2003).

Globally, changes in annual runoff will vary, with some regions experiencing an increase in runoff and others experiencing a decrease in runoff (Bates et al., 2008). Figure 9 shows the mean runoff change until 2050 for an ensemble of 24 climate model runs from twelve different global climate models (Milly, Dunne & Vecchia, 2005). In general, between the late 20th century and 2050, the areas of decreased runoff will expand (Milly, Dunne & Vecchia, 2005). Runoff is predicted to increase by 10% to 40% in the high latitudes of North America and Eurasia. With higher uncertainty, runoff can be expected to increase in the wet tropics. Decreasing runoff is predicted for the Mediterranean, southern Africa, and the western United States and northern Mexico.

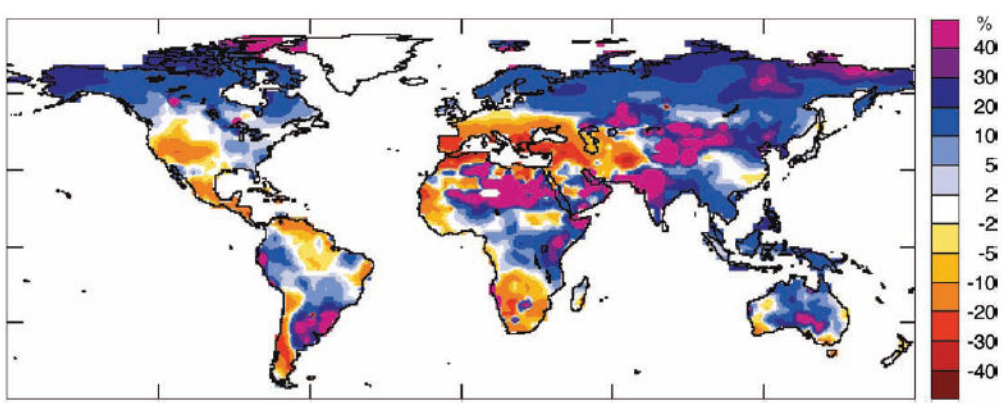


Figure 9
Percentage change in annual run-off by 2041-2060 compared to 1900-1970 using an ensemble of 12 climate models for SRES A1B emissions scenario

Source: Milly et al. (2005).

More intense rainfall is linked with greater runoff, which will lead to greater rates of erosion and greater transport of sediments into waterways, as well as nutrients, fertilizers, pesticides, pathogens, heavy metals, organics and other contaminants on the land surface. Increased nutrients, combined with higher water temperatures, and longer periods of low flows, will promote algal blooms (Hall, D'Souza & Kirk, 2002) and an increase in bacteria and fungi content which may have an impact on ecosystems and human health, and potentially lead to bad odour and taste issues in regard to chlorinated drinking-water (Environment Canada, 2001).

For rain dominated catchments, flow seasonality is also predicted to increase, with increased flows in the peak flow season and either decreased flows or extended dry periods in the low flow season. Generally, the timing of peak and low flows are not predicted to change in rain-fed catchments, although changes in monsoons would change the peak flows, for example the east Asian monsoon in China (Bueh, Cubasch & Hagemann, 2003).

Lake levels will vary with changes in river inflows, precipitation and evaporation. Predictions for changes in lake levels tend to vary between studies, but can also vary over time with the changing climate. The Great Lakes in North America are predicted to have changes in water levels of between −1.38 m and +0.35 m by the end of the 21st century (Lofgren et al., 2002; Schwartz et al., 2004). The levels in the Caspian Sea are predicted to change by 0.5 m to 1.0 m according to Shiklomanov & Vasiliev (2004), but to drop by 9 m by the end of the 21st century according to Elguindi & Giorgi (2006). Water levels in Lake Victoria are predicted to fall initially with increases in evaporation, but then rise as precipitation increases (Tate et al., 2004). These changes are likely to affect water and wastewater infrastructure in the lake. As lakes and waterway levels drop, there is also the increased likelihood of bottom sediments being re-suspended, which will increase turbidity but may also release pollutants associated with the sediments back into the water column. Increases in CO_2 will also affect vegetation through reducing evapotranspiration and increasing plant growth, which may in turn increase evapotranspiration (Kundzewicz et al., 2007).

It is not clear yet if one of these effects will be more significant than the others and, as modelling has not been undertaken on a catchment scale, what regional differences might be. However, when CO_2 enrichment is accounted for, global mean runoff is predicted by ensemble to increase by 5% – 17% as a result of climate change alone (Betts et al., 2007).

Groundwater

The demands on groundwater are increasing with population pressure and other water demands discussed above, but there is also an additional demand, which will continue to increase in the future, as climate change degrades the quantity, reliability and quality of surface water supplies. At present, there is poor knowledge of groundwater recharge and levels, particularly in developing regions, which limits the ability to predict future impacts.

Opinions differ on the effect of climate change on groundwater recharge. Bates et al. (2008) conclude that groundwater recharge may decrease with increased precipitation variability in humid areas as a result of more frequent heavy rainfall events causing the soil infiltration capacity to be exceeded more often. However, in semi-arid and arid areas increased precipitation intensity may increase groundwater recharge, as high-intensity events are more able to infiltrate before evaporating, and flooding can recharge alluvial aquifers. Chapter 3 contains examples of the views of experts who debate this finding. Overall, there has been limited research with very site specific results, on the impacts of climate change on groundwater, and further research is required.

Global models indicate that average groundwater recharge will increase less than runoff, with total runoff (including recharge and fast surface and sub-surface runoff) predicted to rise by 9% by 2050, but groundwater recharge predicted to increase by only 2% (Kundzewicz et al., 2007). Three regions are highlighted in Figure 10 as predicted to have dramatic decreases in groundwater recharge: north-eastern Brazil, south-west Africa and the southern Mediterranean. Decreases in groundwater levels will affect the ability of people to access safe drinking-water supplies, and may reduce the productivity of wells and springs. However, this model is based on the assumption that in semi-arid areas groundwater recharge only occurs if daily precipitation exceeds a certain threshold. Thus, because increased variability of rainfall was not considered, these predictions may not represent the recharge contribution during heavy rainfall and flooding, which can be a major source of groundwater recharge in semi-arid and arid areas. Vegetation and land-use changes will also affect groundwater recharge. Key areas with predicted increases in groundwater recharge were the Sahel, the Mediterranean, the Middle East, northern China, Siberia and western United States (Kundzewicz et al., 2007). Increased groundwater recharge may increase the transport of pathogens in groundwater. As seen in Figure 10, variability exists between models. As for the runoff models in Figure 8, variability is greater between models than between climate scenarios.

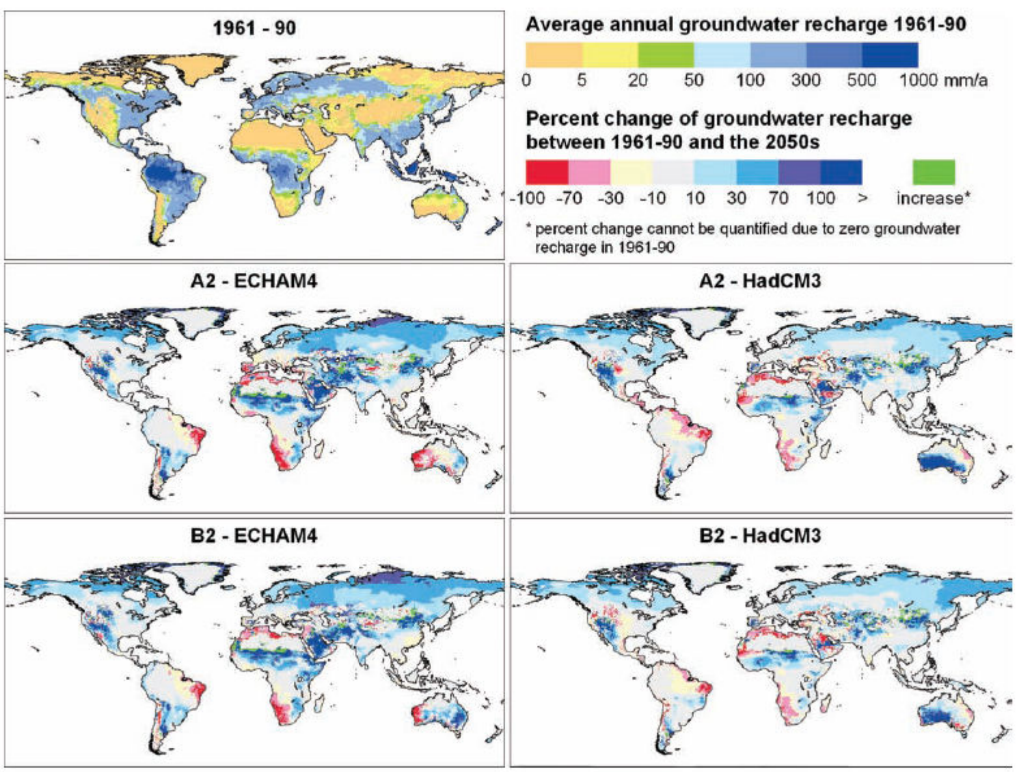


Figure 10

Simulated impact of climate change on long-term average annual diffuse groundwater recharge: percentage changes of 30-year average groundwater recharge between present day (1961 to 1990) and the 2050s (2041 to 2070), as computed by the global hydrological model WGHM applying four different climate change scenarios (using ECHAm4 and HadCM3 models) each interpreting the two IPCC greenhouse gas emissions scenarios A2 and B2

Source: Döll et al. (2003).

Groundwater will be subject to increased salinization in some areas. Increases in evaporation and decreasing recharge may increase the salinity of some groundwater resources. Salinization is expected to be a major problem in semi-arid and arid areas with decreasing runoff. Sea-level rise will also affect groundwater resources, extending areas of salinization of groundwater and estuaries. One example is of two flat coral islands off the coast of India, where the freshwater lenses are predicted to decrease from 25 m to 10 m and from 36 m to 28 m for a 0.1 m sea-level rise (Bobba et al., 2000).

Floods

With a warming climate comes increased variability in rainfall, resulting in a greater risk of droughts and floods (UNDP, 2006). Floods include river floods, flash floods, urban floods or sewer floods, and can be caused by intense or long-lasting precipitation, snowmelt, dam break, or blockages to the water system.

Floods are predicted to increase in severity, with 15 of 16 large river basins worldwide predicted to exceed the 100-year peak volumes more frequently if CO_2 levels quadruple (Kundzewicz et al., 2007). In some areas, the current 100-year flood is predicted (with large uncertainty) to have a return period of as little as two to five years. In Bangladesh, an area already subject to severe floods, the flooded area is projected to increase by 23% – 29% with a 2°C increase in temperature (Mirza, 2003). River basins that are likely to be affected by flood are currently home to up to 20% of the world population (Kundzewicz et al., 2007).

Diarrhoeal disease is a major cause of childhood mortality and morbidity in developing countries, and seasonal peaks are, in some cases, associated with seasonal rains and floods (Few et al., 2004). Populations with poor sanitation infrastructure and high burdens of disease often experience increased rates of diarrhoeal diseases after flood events (Confalinieri et al., 2008). Post-flood increases in cholera (Korthuis et al., 1998; Sur et al., 2000); cryptosporidiosis (Katsumata et al., 1998); non-specific diarrhoea (Centers for Disease Control, 1990); poliomyelitis (van Middelkoop et al., 1992); rotavirus (Fun et al., 1991); typhoid and paratyphoid (Vollaard et al., 2004); and hepatitis E have been reported. Hepatitis E and diarrhoeal disease have followed floods in Khartoum, Sudan (Homeida et al., 1988; McCarthy et al., 1994); acute diarrhoea and acute respiratory diseases increased in Nicaragua following Hurricane Mitch and the associated flooding (Campanella, 1999). Emch et al. (2008) suggest that environmental and climatic factors partially control the temporal variability of cholera. Floods in Mozambique in January–March 2000 led to an increase in the incidence of diarrhoea, and floods in West Bengal in 1998 led to a large cholera epidemic.

During the 1997–1998 El-Niño, severe flooding occurred in Peru, Ecuador, Argentina and Uruguay (Box 11). In Peru, this resulted in an increase of over 200% in hospital admissions for childhood diarrhoea over expected trend data from the previous five years (Checkley et al., 2000). A retrospective review of cholera-like dysentery between 1990 and 1991 concluded that El-Niño had caused hypergrowth of plankton which contributed to the dispersal of *Vibrio cholera* organisms along the coast of Peru, resulting in thousands of cases of cholera from ingestion of contaminated water and person-to-person transmission exacerbated by nonexistent or poor sanitation infrastructure (Checkley et al., 2000). Most reports of an increase in diarrhoeal disease following a flood are from low-income countries, however Ahern et al. (2005) have reviewed a number of studies which show a similar effect in developed countries following major floods.

Additionally, a broader range of health outcomes from flooding includes: mortality; injuries; infection from soil-transmitted helminths; vector-borne diseases, such as malaria, dengue and dengue haemorrhagic fever; yellow fever; and West Nile Fever; rodent-borne diseases; and mental health (Few et al., 2004). The main acute threat to health is drowning. Between 1900 and 2004, flood disasters led to over 6.8 million reported deaths and 1.3 reported injuries (Table 8). In the 2002 floods experienced in Europe, around 250 people died (European Environment Agency, 2004).

Table 8
Number of people killed or injured following floods 1999-2004

Region	Floods (1900–2004)	
	Number killed (thousands)	Number injured (thousands)
Africa	19	23
Americas	96	41
Asia	6757	1777
Europe	10	22
Oceania	<1	<1

Source: Few et al. (2004).

In addition to direct mortality and injury, which usually occur during the onset phase of the flood, there is an increased risk of infection of waterborne diseases contracted through direct contact with polluted waters, such as wound infections, dermatitis, conjunctivitis, and ear, nose and throat infections. As well as human morbidity and mortality, the floods also cause heavy damage to major infrastructure such as roads, bridges, railways, embankments, irrigation systems and rural infrastructure. Millions of people on small islands and along low-lying coastal areas are at particular risk from sea level rise and storm surges (van Aalst & Helmer, 2003).

Box 11
Effects of El Niño floods on water and sanitation in Ecuador

In late 1982 and early 1983, intense, prolonged rainfall brought severe floods and landslides to many coastal regions of Ecuador. The floods caused extensive damage to infrastructure across Ecuador, affecting drinking-water and sewage facilities. In the city of Babahoyo, Ecuador, discharges from the sewerage system (via inspection wells) directly into the standing floodwaters that lay across much of the city created a level of coliform contamination that "corresponds to raw wastewater" Source: Hederra, 1987.

Droughts

Droughts include meteorological drought (low precipitation), hydrological drought (low water levels or flow), agricultural drought (low soil moisture), and environmental drought (a combination of the above). Overall, the proportion of the land surface in extreme drought is projected to increase from 1% – 3% to 30 % by the 2090s, with the number of extreme droughts expected to increase by a factor of two and the mean drought duration by a factor of six (Kundzewicz et al., 2007). Droughts are particularly likely to increase over continental interiors, over low to medium latitudes, in summer.

In regions suffering from droughts, a greater incidence of diarrhoeal and other water-related diseases will reflect the deterioration in water quality (Environment Canada, 2004). Reduced freshwater availability will become a serious problem because of low river flows, resulting in low agricultural output, malnutrition, and increased water-related diseases arising because populations are forced to drink from unsafe sources.

Drought has a major impact on infection because there is less water available for drinking and for personal hygiene, leading to increases in the diseases linked to poor hygiene, such as trachoma and scabies. Studies have shown than in times of water shortage, people tend to use water for cooking rather than for hygiene (WHO, 1999). Work by Thompson et al. (2003) has confirmed this finding by showing that when water availability increases, hygiene has the biggest uptake. Hand washing with soap can reduce the rate of diarrhoeal disease by one third (Ejemot et al., 2008).

Meningitis transmission appears to be affected by warming and reduced precipitation, as meningitis infections and epidemics are prevalent in areas of low humidity (IPCC, 2001).

Water quality

Water quality impacts associated with changes in runoff and groundwater recharge have already been discussed. This section looks at more general issues around water quality impacts associated with climate change and health.

Heavy rainfall events, which may increase in volume and frequency, will overload the capacity of sewer systems and water and wastewater treatment plants more often (Bates et al., 2008). Temperature changes will affect the growth and survival of pathogens, potentially leading to an increase in waterborne diseases. Increases in waterborne disease outbreaks with intense rainfall have already forced some developed countries to improve water treatment by adding filtration (Ferguson & Neden, 2001).

Reduced rainfall may also have an impact on irrigation practices, resulting in an increase in the number of people consuming wastewater-irrigated crops. Effluent reuse for agriculture should be practised with good management to reduce human health effects that could be caused by uncontrolled use; so the effluent intended for reuse should be treated adequately and monitored to ensure that it is suitable for the intended use. Other health protection measures including crop restriction, irrigation technique, human exposure control and chemotherapeutic intervention. These measures should all be considered in conjunction with partial wastewater treatment. In some cases, community interventions using health promotion programmes could be considered, in particular where no wastewater treatment is provided or where there is a time delay before treatment plants can be built (Blumenthal et al., 2000).

Higher water temperatures and variations in runoff are likely to produce adverse changes in water quality, affecting human health. Correlations between rain events and the amount of pollutants entering surface waters and groundwater are well documented. Rainfall and runoff have been implicated in waterborne disease outbreaks throughout the world for many years (Rose et al., 2000). In fact, more than half of the waterborne disease outbreaks in the United States in the past 50 years were preceded by heavy rainfall, according to a number of studies (Anonymous, 2001; Curriero et al., 2001), including the world's largest documented outbreak of a waterborne disease. This occurred in Wisconsin, United States, where 403 000 cases of intestinal illness and 54 deaths were recorded (Hoxie, 1997).

In May 2000, 2300 people became ill and seven died in Walkerton, Ontario, as a result of contaminated drinking-water following a severe rain event (Auld, MacIver & Klaassen, 2004). A study by Schuster (2005) analysed information on waterborne outbreaks occurring between 1974 and 2001 in Canada. The finding was that severe weather, close proximity to animal populations, treatment system malfunctions, and poor maintenance and treatment practices were associated with the reported disease outbreaks resulting from drinking-water supplies. A study published the following year examined spring snowmelt and extreme rain events in relation to 92 outbreaks of waterborne disease in Canada (1975 – 2001) and suggested that increased temperatures and precipitation were contributing factors to past waterborne disease outbreaks in Canada (Thomas et al., 2006).

Patz et al., (2008) report on the predicted increase in heavy rainfall in southern Wisconsin, United States, and the corresponding increases in pollution expected to enter the Great Lakes. It is suggested that extreme precipitation may overwhelm the combined sewer systems and lead to overflow events that could threaten human health and recreation in the region. Curriero et al, (2001) highlight the role of extreme wet weather conditions in the fate and transport of micro-organisms (under conditions of high soil saturation, the rapid transport of microorganisms could be enhanced) and as a contribution to waterborne disease outbreaks. This is a particular problem in rural areas, where contaminated manure gets washed into watercourses. Other studies have reached similar conclusions. Atherholt et al. (1998) found that concentrations of *Cryptosporidium* oocysts and *Giardia* cysts in the Delaware River were positively correlated with rainfall. A survey of south-west Florida estuaries conducted by Lipp et al. (1999) showed higher concentrations of faecal indicator organisms during the heavy rainfall that accompanied El Niño of 1997 and 1998, than occurred throughout the year.

The risks for outbreaks associated with flooding and drought can be minimized if the risk is well recognized and health adaptation measures are implemented. In Tajikistan in 1992, the flooding of sewage treatment plants led to the contamination of river water (WHO, 2008x). Despite this risk factor, no significant increase in incidence of diarrhoeal diseases was reported, because adequate risk minimization measures were in place. Damage caused by floods and droughts is exacerbated in developing countries because of their vulnerability resulting from the greater role of natural resources in economic activity and livelihood generation (Lenton, 2004).

Climate change is likely to have the greatest impact in countries where populations already suffer from diseases such as malaria, as well as facing other challenges. Rising temperatures will not only spread the zones of disease transmission vectors, such as the mosquito, but will also increase rates of transmission in existing areas, via reduced breeding times linked with warmer temperatures (European Environment Agency, 2004). A WHO assessment of the burden of disease associated with climate change in the period 1961–1990 concluded that climate change had already been responsible for over 150 000 deaths (or the loss of over 5.5 million disability-adjusted life years) annually by the year 2000 (Campbell-Lendrum & Corvalan, 2007). A recent report on potential climate change effects in Asia and the Pacific region detailed, through modelling predictions, that malaria prevalence in the region could increase by almost five times by 2050 (Potter, 2008). However, where there is adequate public health and medical infrastructure to control transmission, the risk of spread of disease is low and changes in climate will not necessarily lead to an increase in incidence of vector-borne and other water-related diseases in places where they currently do not exist. This should not be a reason to be complacent, however, since there are many infectious diseases with unknown epidemiology that may emerge. The adverse effect of climate change is more likely to be felt in countries which already face diseases such as malaria as well as other challenges.

2.6 Key outcomes

- The operation of all drinking-water supply and sanitation facilities is vulnerable to impacts from changes in precipitation brought about by climate change.
- The vulnerability of drinking-water supply and sanitation facilities to climate change is intrinsically linked to social, economic and environmental factors, as well as the technology used to operate the facility. Effective strategies for reducing the vulnerability of water supply and sanitation facilities require interventions that integrate the social, environmental and economic factors with the adaptation of the technologies.
- Improved drinking-water supply and sanitation facilities are available and operate effectively on every continent and in every type of climate. Current drinking-water supply and sanitation facilities are suitable for most climates, perhaps with minor adaptation; the challenge is in selecting the technology to suit the predicted future climate.
- Examples of adaptations to drinking-water supply and sanitation facilities are available and have been shown to increase the resilience of facilities in the face of changes in precipitation.
- The main reported impacts to sanitation facilities from climatic events are from floods.
- Drinking-water supply facilities are affected by both floods and droughts.
- The resilience of communities to climate change can be increased by using education and communication in the development of adaptation plans, adopting water safety plans to help provide safe drinking-water, and employing land-use planning to mitigate the effects of flooding.
- Climate change is predicted to continue in line with the trends already observed: drying in the Sahel, the Mediterranean, southern Africa and parts of southern Asia; and increased precipitation in eastern parts of North and South America, northern Europe and northern and central Asia. While no climate-related increase in floods has been observed, the costs of floods in terms of the damages they cause have increased.
- As well as the impacts that changes in total rainfall will have on water supplies and sanitation, increased variability will result in the additional challenges of droughts and floods. Areas predicted to have greater rainfall are also more likely to have more extreme rainfall events, increasing the risk of flooding. Areas predicted to have less rainfall are more likely to have more severe dry extremes (for example, droughts).
- Water quality will be affected by climate change. In regions suffering from droughts, a greater incidence of diarrhoeal and other water-related diseases will reflect the deterioration in water quality. An increase in precipitation amounts and intensity may also increase the transport of pathogens in groundwater where there is increased groundwater recharge.

3. Opinions: views from professionals in the water industry

In many areas of water and sanitation research and practice there is important information that will not be readily picked up in a literature review, such as grey literature, unpublished studies, or new research, as well as recent policy developments. This is particularly relevant when dealing with issues of climate change and water and sanitation. To address this gap, we sought the opinions of water experts on the likely impacts of climate change on water supply and sanitation facilities. For this we used two approaches: an Internet-based questionnaire to reach a global cross-section of professionals; and semi-structured interviews with a number of selected experts. The questionnaire focused on the impacts of changes in rainfall patterns on water supply and sanitation facilities.

The questionnaire was designed to gauge opinions and, where possible, obtain any further information on the current impact of rainfall and other climate-related events on water supply and sanitation facilities, including:

- identifying further information that could be used to enhance the literature review, such as local reports on the vulnerabilities of water supply and sanitation facilities;
- gauging opinion about the likely impacts of rainfall changes on water supply and sanitation facilities, by region and climate scenario;
- gauging the degree of awareness amongst decision-makers with regard to the potential impact of climate change on drinking-water supply and sanitation;
- identifying changes in the use of water supply and sanitation facilities, and the drivers thereof;
- investigating the vulnerabilities of different regions, including social, geophysical, technological and climatic aspects.

The interviews were designed to gauge opinion on, and gather examples of, the potential impact of climate change on water and sanitation, including:

- importance of predicted climate change in the planning and selection of facilities in water supply and sanitation programmes;
- vulnerability of facilities to different rainfall scenarios and climate change, with examples of facilities that have failed or performed unexpectedly well during extreme events;
- potential for and nature of adaptations that can be made to technologies to better resist the impacts of climate change;
- type of policies that will be required to address the impacts of climate change, and how to develop and implement them;
- requirements for future research.

3.1 Methods

3.1.1 Questionnaire survey

An electronic questionnaire (Appendix 1) was developed. The target audience for the questionnaire was professionals working in the water and sanitation sector who had experience with a range of drinking-water supply and sanitation facilities in the field. However, the questionnaire was also made available on the Internet, and the design allowed for non-specialists to access and complete the form.

The selection of the principal themes for the questionnaire was informed by the findings of the literature review, particularly the knowledge gaps that were emerging. The authors drafted a series of questions in each of the themes to capture the information that was required to fill the knowledge gaps, if it was available. Both open and closed questions were used with single and multiple answers. The first draft of the questionnaire was sent for review by a single external person with experience of questionnaire surveys, and that person's comments and suggestions were incorporated into a second draft. The second draft was sent for testing by five people who would form a part of the target audience. They were asked to comment upon the clarity and relevance of the questions, the relevance of the multiple choice answers, the ease of completing the questionnaire, and the length of time that it took to complete. Their comments and suggestions were incorporated into the final questionnaire that was used for the survey.

The questionnaire was focused on the current vulnerability of drinking-water supply and sanitation facilities, and the causes of that vulnerability. It was developed to provide background information about the respondents and their geographical and professional areas of expertise, as well as their awareness of climate change. For questions about observations on climate and vulnerability, the source of their evidence was requested. An overview of the key themes and key questions within the questionnaire are given in Table 9.

Table 9
Overview of the questionnaire

Theme	Summary of key questions
Background information	Organization and position
	Geographical area in which respondent has experience in water and sanitation sector, and a description of that area
Awareness of climate change	Are you aware of any changes in long-term rainfall? What are the changes? Rainfall seasons? And the basis for answers: own perception, reports, monitoring data, discussion with local community, etc.
	Are you aware of any changes in water availability or quality? What evidence is there for these changes?
	What changes in hydrology and water quality do you anticipate with climate change? What evidence is this based on?
	Are you changing your strategy for implementation of drinking-water supply and sanitation based on your awareness of changes in rainfall?
	Is there enough information available on climate change?
Drinking-water supply and sanitation facilities	What drinking-water supply and sanitation facilities are currently in use in urban and rural areas?
	How is use changing and what are the drivers behind the changes? And the basis for answers: own perception, reports, monitoring data, discussion with local community, etc.
	How frequently have you experienced failures in drinking-water supply and sanitation facilities? What circumstances caused the failures?
	Personal opinion of respondent on vulnerability of drinking-water supply and sanitation facilities to failure under future climate scenarios (increased rainfall, decreased rainfall, increased frequency and severity of storms).
Policy	Are drinking-water supply and sanitation policies appropriate for current or predicted climate conditions?
	Are there any drinking-water supply and sanitation policies in place or in draft that deal with climate change?

The questionnaire was hosted through the surveymonkey.com web site and was open from 17 July to 22 September 2008.

Links to the questionnaire were placed on the web site of the Robens Centre for Public and Environmental Health. Participants from the following organizations and groups were invited to complete the questionnaire:

- the United Kingdom Department for International Development (DFID);
- WHO;
- the United Kingdom Sanitation Connection organized by the Water Engineering Development Centre;
- the International Water Association specialist group on Climate Change and Adaptation;
- the International Water Association specialist group on Small Water and Wastewater Systems;

- over 300 nongovernmental organizations and individuals working in the field of water and sanitation (from a database which had been maintained by the Robens Centre for Public and Environmental Health.

The software used to create the questionnaire includes some analytical features that were used to monitor the completion rate of the questionnaire and the main issues that were emerging in the answers. For the final analysis of the data, the responses were transferred into an Excel spreadsheet.

For analysis, the data were separated into countries in developed regions or developing regions as per the MDG definitions (United Nations, 2003). Responses were only included in the analysis if the respondent had completed more than the first two sections on contact details and a description of the relevant area (see Appendix 1). Partially completed responses were also removed if respondents returned a completed second questionnaire.

The results are presented in terms of the number of respondents, where possible their geographic area or whether they are from developed or developing regions, and what proportion of respondents they represent (%). Rankings are reported based on weighted averages for all responses. For questions asking the respondent to report on any failures experienced within the last two years (questions 34 and 36), responses were weighted: 5 for "yes, commonly"; 3 for "yes, intermittently"; and 1 for "yes, rarely". The score was then divided by the total number of responses (not including N/A responses). For questions relating to the potential impact of climate change on water and sanitation facilities (questions 38 to 43), weighted averages were calculated by multiplying the number of responses by 1 for "increased vulnerability", -1 for "decreased vulnerability", and 0 for "no change", and then dividing the sum of these by the total number of responses.

The information was used to inform the literature review and the development of the technology fact sheets (included in the CD-ROM), which provide guidance on vulnerability and adaptation.

3.1.2 Telephone interviews

Semi-structured telephone interviews were conducted with a selected group of international water and sanitation experts. An initial list of 30 experts was compiled using recommendations from personal contacts and from key authors identified by the literature review. Each expert was sent a letter of invitation to participate in the telephone interview. A total of 15 experts responded positively. The respondents were contacted by telephone and e-mail to arrange a suitable date and time for the interview. Only 11 of the 15 initial respondents were available for interview during the time available to the project.

The interviews were conducted using a detailed interview guide developed by the Robens Centre for Public and Environmental Health to ensure consistency in approach. The primary aim of the interviews was to collect more detailed opinions from experts in the drinking-water supply and sanitation fields on the current impact of rainfall and other climate-related events on water and sanitation technologies.

In contrast to the questionnaire, the interview was designed to allow interviewees to give wide-ranging responses, to express their opinions and to describe their experiences. The guide focused on the themes of vulnerability of drinking-water supply and sanitation facilities to climate, awareness of climate change and identification of relevant policies. Within each theme, several topics were identified, using the outputs of the literature review and the responses to the questionnaire, which were perceived to be of particular relevance to the project. Prompt questions and the outcomes sought by each theme were incorporated in the guide to assist the interviewers.

The first draft of the interview guide was sent for review by a single external person with experience of interview surveys, and that person's comments and suggestions were incorporated into a second draft. The second draft was tested by interviewing two people who would form part of the target audience. Their comments and suggestions were incorporated into the final draft of the guide.

An overview of the interview guide is provided in Table 10 (see Appendix 2 for the complete version). All interviews were recorded and transcribed in full. The transcripts were checked for accuracy by a second internal reader and then sent to the interviewees for verification.

Table 10
Overview of the interview guide

Theme	Topic	Sought outcomes
Drinking-water supply and sanitation facilities	Vulnerability to climate change	Identify the vulnerability of technologies to different rainfall scenarios, and examples of failure due to, or good performance during, rainfall events. Establish the expert's opinion on the importance of climate change in the failure of technologies in the future.
Drinking-water supply and sanitation facilities	Adaptation	To determine the expert's opinion about the potential for and nature of adaptations that can be made to technologies to greater resist the impacts of climate change. To establish which technologies should be prioritized for modification. To determine the expert's opinion about the long-term viability of current technologies, and the need for new technologies. To establish which technologies should be prioritised for future water and sanitation programmes. To establish which technologies should be discontinued.
Policy	Current situation	To get examples of policies that are in existence or development, that specifically address the impact of climate change on water supply and sanitation facilities. To establish how successful the policies have been, or are likely to be. To determine the nature of these policies, their strengths and weaknesses. To establish the reason why these policies have been introduced at this time.
	Policy requirements	To get the expert's opinion about the importance of policies to address the impacts of climate change. To get the expert's view of the type of policies that will be required. To get the expert's view of the need for policies to address the needs of vulnerable groups beyond the 2015 deadline for the MDGs
	Policy development	To get the expert's view of the strengths and weaknesses of current scientific evidence to support policy development. To get the expert's view of additional scientific evidence to support policy development. To get the expert's view about other factors that will be required to develop robust policies. To establish the requirements for future research.
	Policy implementation	To get the expert's view of the timescales for policy implementation. To get the expert's view on the processes for monitoring the effectiveness of policy implementation.
Climate change	Impact on drinking-water supply and sanitation	To get the expert's opinion about other climate factors that may impact water and sanitation technologies.

The transcripts of the interviews were analysed for responses, views and experiences that fell within each of the main themes of the interview guide. Henceforth, "interviewees" refers to the people who provided responses to the interviews.

3.2 Results

A total of 70 questionnaire responses were received, with 43 sufficiently complete to include in the analysis (61% useable questionnaires). Henceforth, "respondents" refers to the people who provided responses to the questionnaire.

The majority of respondents (27 respondents, 63%) were answering for areas in developing regions, with 30% (12) in Africa, 25% (11) in Asia, 7% (3) in South and Central America, and 2% (1) in the Middle East. Figure 11 shows the geographical distribution of the responses. Respondents mostly worked at nongovernmental organizations (44 %) or were academics (19 %) or consultants (19 %), with the remainder working for government (16 %) or international or donor agencies (2 %). Details about each interviewee and a further overview of the respondents is provided in Appendix 3. A more detailed analysis of the questionnaire results is provided in Appendix 4.

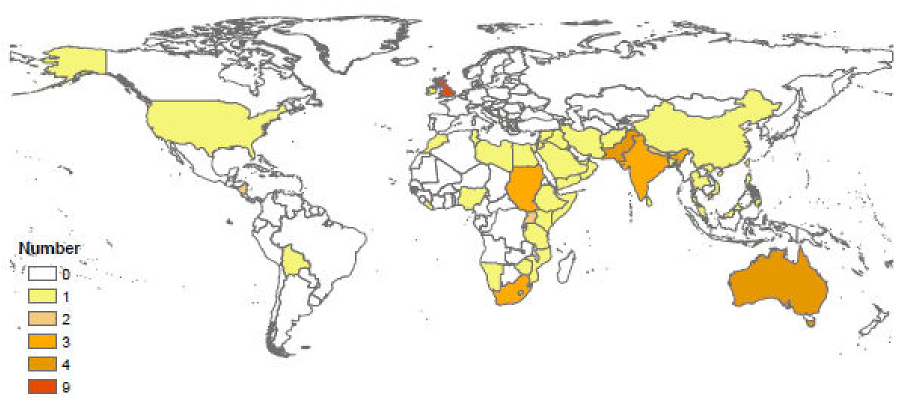


Figure 11
Countries covered by the respondents of the questionnaire

Despite the international significance of climate change, and the volumes of literature that are available describing the potential impact of climate change on water resources (Section 2.5), the results of the questionnaire survey revealed that climate change was not high among the respondents' priorities. Moreover, where concern was expressed about climate change, the impacts mostly related to water supply, with less attention being given to sanitation. This may reflect the emphasis in the literature on water resources and the consequences in terms of quality and quantity that may come about as a result of climate change. It may also reflect the relative importance of water supply and sanitation in development programmes, where, historically, sanitation has been under-represented. These themes were also reflected in the interviews, with climate change generally not being seen as a current high priority driver for changes in technology, planning or policies. Several reasons for this emerged from the interviews but the two most frequently quoted were poor communication between the water resources sector and the water and sanitation sector, and the widespread failure of developing countries to manage the water and sanitation sector for current climate variability. However, some interviewees emphasized that climate change would increase in prominence in the future.

> "I think it is reasonable that it [climate change] is not a priority consideration, particularly in large parts of Africa. They are preoccupied by trying to deal with what they have got and manage with what they've got and sort out what they have that, the issue is not about greater difficulties in the future; they are still grappling with what is in front of them now." (Interviewee 5)

> "The challenge … is the disconnection between those that look at water resources and those that look at water and sanitation." (Interviewee 4)

One interviewee noted that the issue of climate change was taking funding away from work already looking at the extreme conditions. The comment made by the interviewee also relates to a theme that emerges later, that operation and maintenance, and the application of best practice in water and sanitation provision, will overcome many of the vulnerabilities that may develop as climate changes in the future.

> "Whilst there is an increased budget for climate change…, what we are not seeing is an increase in funding for our arid lands programming, or our flood programming. What we need is to do what we are already doing, but doing it better and more of it." (Interviewee 11)

Water was seen as more vulnerable than sanitation to climate change; however, it was recognized that there was a lack of data about sanitation and flooding.

> "I think water treatment is more likely to be impacted than wastewater treatment, because we are looking at having to deal with a different water resource regime; i.e. surface water being much more variable in flow and that having an impact on quality, which ultimately impacts on treatment technology." (Interviewee 5)

In general, respondents answering the questionnaire from developing regions were more concerned about the impacts of climate change on water and sanitation than respondents in developed regions. This was a surprising result given the levels of awareness of climate change in developed countries and the level of activity that is being put into mitigation measures. It is possible that the greater concern in the water and sanitation sector of developing countries emerges from the generally higher vulnerability of facilities in these countries to current climate variability, and the generally lower amount of resources to address the issues.

3.2.1 Observations related to changes in weather patterns

Among respondents, 48% (19) were aware of official statements from their country or region on observed climate trends, with 43 % (16) aware of similar statements on predicted climate trends. These statements reported increases in temperature and frequency of extreme events, with these trends expected to continue (Figure 12). Rainfall observations and predictions for different regions varied, but the majority of responses suggested increased rainfall predictions, although there was a lot of uncertainty (Figure 13). However, when asked about personal observations, the majority reported decreases in average annual rainfall in the area in which they were working, but with 79 % (26) reporting increases in rainfall intensity.

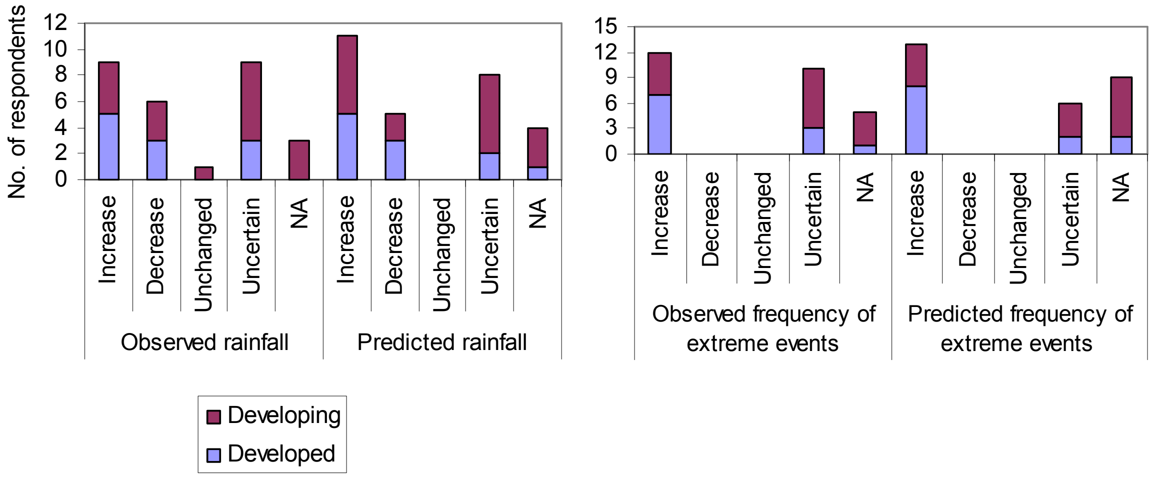


Figure 12
Responses indicating the nature of statements from national meteorological and hydrological services regarding rainfall and frequency of extreme events
NA, not applicable.

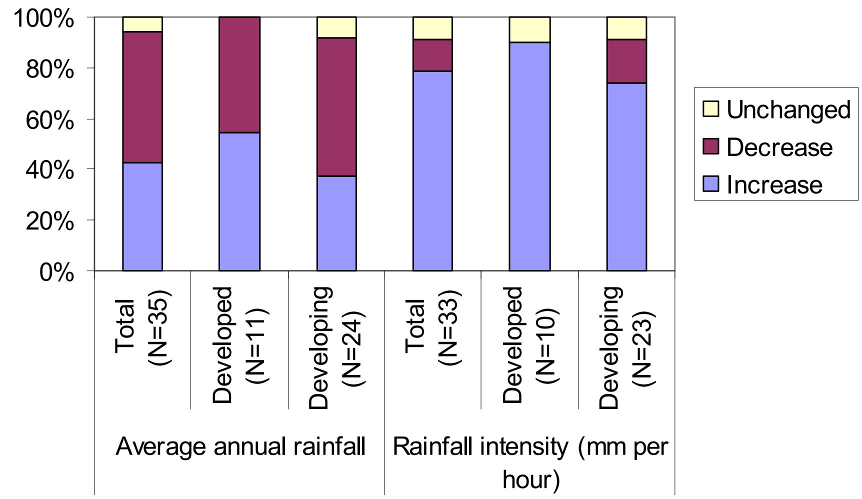


Figure 13
Perception of respondents about long-term annual rainfall patterns

While 60% (25) of respondents were changing their drinking-water supply implementation strategy based on their awareness of changes in long-term annual rainfall, only 40 % (16) were changing their implementation strategy for sanitation. This response is consistent with the relative levels of concern expressed by respondents to the impacts of climate change on water and sanitation. None of the respondents from South or Central America (an engineer, a water resources manager and a director at an nongovernmental organization) were changing either their strategies for water or sanitation. Africa was the only region where over half of respondents (6/11) were changing their implementation strategy for sanitation.

As many as 65% (26) of respondents thought there was inadequate information on climate change predictions, including educational information. Several of the interviewees thought that the lack of available information on climate change was hampering the development of policy. It was also noted by some that there was a need for more information on drinking-water supply and sanitation facilities, and how they respond to water availability and drought.

> "People wanted to know what policies should be put in place immediately while the science base is not in place to answer these questions." (Interviewee 1)
>
> "Global trends are well rehearsed and agreed but take it down a scale and there are bigger bands of uncertainty. Translating that into a policy response is difficult and quite how politics copes with uncertainties in this area is an interesting question." (Interviewee 7)
>
> "…choices need to be informed by an understanding of water availability both now and across periods of drought. That doesn't happen very well at the moment on lots of programmes, but factoring in climate change scenarios at that scale is very difficult." (Interviewee 7)

3.2.2 Year-to-year changes in drinking-water sources

Most respondents reported vulnerabilities in their water supplies to current climate variability. The major issues raised by respondents were low availability and declining quality. Within these issues the common themes raised were falling water levels in groundwater, rivers and lakes, increased flooding and droughts, and deteriorating quality of groundwater, rivers and lakes (Figure 14). Respondents answering for areas in developing regions indicated fallen and variable levels of groundwater, rivers and lakes, with increased flooding and droughts.

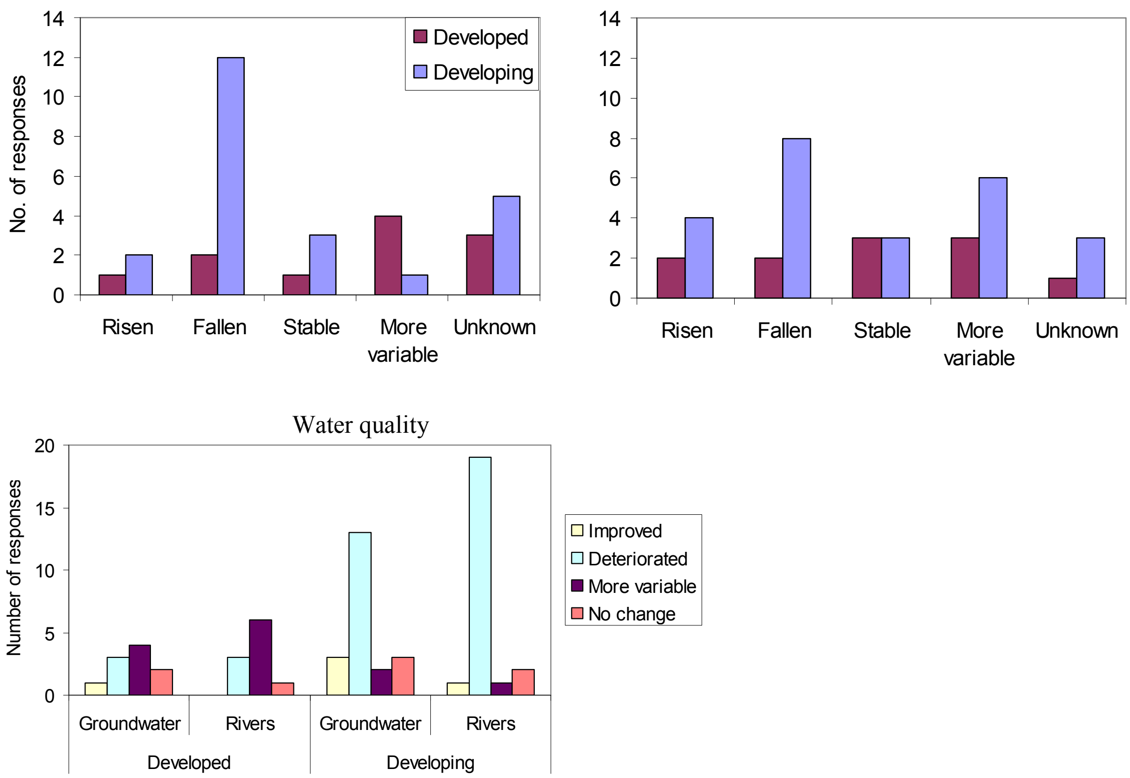


Figure 14. **Long-term changes reported by respondents to average groundwater (top left) and river (top right) levels, and to water quality (below)**

3.2.3 Climate predictions

When asked to consider the impact that predicted changes in climate might have on components of water resources in the area, most respondents indicated a concern about their water sources, including increases in run-off, floods, storms and droughts, decreased groundwater recharge, and deterioration in water quality (Figure 15).

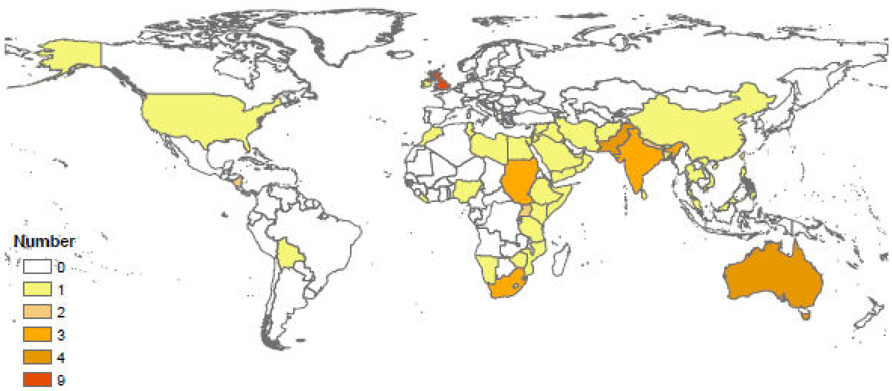


Figure 15
Countries covered by the respondents of the questionnaire

There were conflicting predictions about the impact of more intense rainfall on groundwater recharge among the interviewees, with one interviewee predicting a decrease in recharge, and others predicting potential increases, in line with the predictions made by the Intergovernmental Panel on Climate Change. It was recognized by all interviewees, however, that the process would be area-specific and dependent on soil type (it was suggested that clay rich soils for example will have low infiltration capacity and may result in less groundwater recharge under a shift towards fewer but more intense rainfall events). The response of groundwater to climate change, particularly the residence time of water in aquifers and storage capacity, were raised as areas where more research is needed.

> " [One theory is that] these rainfall events will lead to reduced recharge as soil infiltration capacities are exceeded more frequently and more water will run off at the surface. In my opinion, soil infiltration capacities will continue to be rarely exceeded so fewer but more intense rainfall events will lead to increased groundwater recharge." (Interviewee 8)

> "It has been well reported in the 2007 IPCC report and from my own experiences, the first impact of increases in the intensity of precipitation will result in an increase in vulnerability of shallow groundwater sources to contamination." (Interviewee 8)

> "If we do not know [how old the water is that is being pumped out of a well] , we have no idea how it will respond to climate change: is it a fast response, dependent on water that has fallen in the last few years, or is it a slow response and more aggregated over the last 30 to 40 years? That is crucial to how many of these sources are going to respond to climate change." (Interviewee 1)

> "The move towards promoting family wells, shallow wells 6-10m deep, is concerning as they are much more responsive and vulnerable to drought and we

just don't know how they respond to drought or increased demand" (Interviewee 1)

"… there are concerns about the reliability/vulnerability of shallow hand dug wells to changes in recharge … I believe that this risk is being exaggerated and the impacts of variable climate will not render the sources unreliable for the moment … most groundwater-fed interventions are not at risk in the short term, although it is harder to predict in the long term." (Interviewee 8)

3.2.4 Vulnerability and reliability (in terms of quality and quantity) of the facilities

The vulnerabilities of present water supply facilities were investigated in terms of system failures. The most vulnerable water supply facility in developing regions was considered by the respondents to be piped water, followed by public standpipes and rainwater, with reasons for failure varying from technology failures to managerial shortcomings to climate issues:

"Technology failure such as power cuts resulting in pumping failure in urban areas." (Respondent 7)

"As the area, in spite of heavy rainfall during monsoon, experiences a fairly long dry season, drinking-water sources often dry up, leading to supply failures. Paradoxically, flooding also disrupts water supply, especially in low-lying, flood and water logging-prone areas." (Respondent 7)

"Insufficient infrastructural capacity, i.e., the municipality does not have capacity to provide purified water to a growing population. The municipality resorts to rationing the available purified water whilst embarking on upgrading the water treatment works." (Respondent 16)

The most vulnerable sanitation facilities were identified as public sewers, and unimproved latrines. The reasons for failure varied from no water available for flushing, to flooding, to managerial issues:

"Flooding can lead to sanitation disruptions. In urban areas, technology failure in the form of power cuts can disrupt water supply which in turn leads to sanitation failure." (Respondent 7)

"There is no water from the distribution pipes as a result of municipal rationing and therefore no water to flush the toilets. Now resort to keeping a container of water nearby." (Respondent 16)

"The problem in urban areas with public sewerage is socio-economic, the infrastructure is, in many cases, built but many houses do not connect due to lack of money. In urban areas the introduction of latrines has been well received, but still some consider it a source of pollution due to misplaced and poorly built infrastructure." (Respondent 22)

In developed regions, the respondents reported less vulnerability for both drinking-water facilities and sanitation compared with developing regions. This response is consistent with the previous finding that respondents from developing countries were more concerned about the impacts of climate change on water and sanitation, and may reflect the greater ability to manage and respond to climate change in developed countries.

For the three climate scenarios described (increased rainfall, decreased rainfall, and increased frequency and severity of heavy rainfall events), most respondents thought that there would be increased vulnerability in drinking-water supply facilities, particularly in developing regions.

For the increased rainfall climate scenario in developing regions, protected dug wells and springs were all considered to be subject to increased vulnerability, as were piped water facilities and public standpipes. The majority of respondents considered sanitation facilities in general to have increased vulnerability. A higher proportion of the respondents from developed regions indicated a greater expectation of increased vulnerability than respondents from developing regions.

Several of the experts interviewed suggested that water and sanitation facilities were very vulnerable to floods. For drinking-water supply facilities, floods raised issues of infrastructure being washed away or being overloaded by silt, as well as linkages in groundwater between sanitation and water systems:

> "…during flooding… a lot of water intake infrastructure gets badly damaged; reservoirs get flooded with silt, particularly some of the river reservoirs. You get a lot of water quality issues; you get a lot of damage to the productivity of sources due to silt loads and pollution. A lot of infrastructure just gets washed away." (Interviewee 2)

> "… flooding is an issue. More intense events can lead to more run-off and shallow groundwater flow in the permeable soils. Under intense rainfall the water gets mobilized very quickly laterally and the wells can fill up very quickly so linkages between latrines, wells and boreholes occur and this could become a major issue." (Interviewee 1)

> "Floods and flash floods could cause damage not only to water supply pipes but to infrastructure generally, to roads, to drainage networks, to water supply pipes, to electrical supplies, and if you get intense rainfall or unpredictable rainfall then there could be damage to infrastructure generally." (Interviewee 6)

Sanitation facilities were generally seen as more vulnerable to floods than drinking-water supply facilities, although replies to earlier questions had suggested that drinking-water supply was more vulnerable to general climate change than sanitation. Examples were given by the experts of serious failures of sewer systems, following heavy rainfall and flooding, that took several months to repair:

> "Sewerage systems are very vulnerable [to floods] because, especially in Europe, they are often combined systems so we deliberately channel heavily silt loaded flood water into our incredibly valuable sewerage assets and they get destroyed and we are surprised that this should happen. And then the wastewater treatment plants get washed out and they don't work for a year after that because you have no flora in the treatment plants." (Interviewee 2)

> " [Sewers are] expensive to fix and it is big infrastructure that is vulnerable at a range of levels. In a way, an on-site latrine either gets washed away or doesn't, but a sewerage system is almost bound to get damaged if we are talking about catastrophic flooding." (Interviewee 2)

> "We are going to get much more of this short-scale urban flooding. As we know from London, our sewers will be over flowing but also pit latrines will be overflowing and we will get much more contaminated surface water moving quite quickly into rivers and into ponds and into groundwater." (Interviewee 3)

> "The other system that is vulnerable to flooding is our water distribution system and our sewer network. Normally the sewer systems and water pipes run side by side and should there be any problem with fractures in the pipes, after flooding there is a possible problem with contamination. Also our pipes are very old and there is a lot of rust and that kind of thing. Flooding will also affect that." (Interviewee 9)

Secondary effects of rainfall were also identified as being significant, with faster flows potentially leading to more erosion and more polluted run-off that would present additional challenges for water treatment systems. In particular, increasing levels of turbidity can exceed the design criteria of the treatment works, leading to fouling of the filters and a closure of the treatment works. Furthermore, as shown in Section 2.5.3, polluted run-off from the catchment area can lead to outbreaks of waterborne disease. However, all interviewees who raised this issue believed that the problems were not insurmountable and that current engineering expertise supported by adequate resources would be able to provide appropriate solutions.

> "It is not the rainfall directly; it is the secondary spin-offs. More flooding will wash away pipes… the erosion due to more run-off; shorter rainstorms leading to less infiltration and less recharge; more erosion leading to siltation and eutrophication" (Interviewee 3)

> "The issue in dams and reservoirs is about spill-way capacity… The spill-way is vital to prevent the dam wall being washed out even if you encounter a combination of the worst possible events." (Interviewee 5)

> "Turbidity problems and modifications to the filtration system are likely to be the most common issues facing water treatment… You can deal with the flooding by building flood walls around the treatment works." (Interviewee 5)

Improved water supply facilities were generally considered to become more vulnerable in situations of decreased rainfall, but there was a clear split between the responses from developed and developing regions in answer to questions about the vulnerability of improved sanitation facilities. The responses from developed regions indicated that a decrease in vulnerability is expected with decreased rainfall. In contrast, responses from developing regions revealed that there was generally expected to be similar or higher vulnerability of improved sanitation facilities with decreased rainfall. Once again, this difference may reflect the limited amount resources available in developing countries to protect vulnerable systems and to renovate damaged facilities. The responsiveness of groundwater to climate change in terms of residence times of water in aquifers and storage capacity was identified in the interviews as an area where further research is needed.

> "For rural water supplies [in Africa] we need to understand the responsiveness of the groundwater to climate, looking at storage, residence times, etc.... Also more work is needed on the wet season response – the issues of connections between systems in laterite areas." (Interviewee 1)

Sewer systems were also identified as being more vulnerable with decreased rainfall.

> "In some areas, e.g. south America where there are small-bore sewers, there is a risk in droughts that they may become blocked if flows are insufficient." (Interviewee 6)

All of the improved water supply facilities were considered to become more vulnerable with increased heavy rainfall events. There was a clear agreement between developed and developing regions that increased heavy rainfall events would result in increased vulnerability for all forms of sanitation facilities, with public sewers particularly at risk. One interviewee identified the need for more research on the impact of intense rainfall on the lateral transport of pathogens in shallow groundwater, because this may lead to contamination of wells and boreholes from latrines.

> "Under intense rainfall the water gets mobilized very quickly laterally and the wells can fill up very quickly so linkages between latrines, wells and boreholes occurs and this could become a major issue… So it is vitally important to construct water supplies so that they seal out the shallow soil to prevent the ingress of this contamination... The more intense rainfall together with more intense construction of latrines and poor quality water sources will make this lateral flow a potentially major issue. Quite a bit of work has been done on how pathogens move out of latrines downwards into groundwater but not on lateral movement, which is what is missing. If this happens slowly then the pathogens die off, but where rapid connections occur then this will be a major issue." (Interviewee 1)

Overall, the impacts of climate change were considered to exacerbate existing problems. For example, climate change may reduce the ability of the soil to treat wastewater from pit latrines, such as through increased groundwater recharge or rising groundwater levels. In such cases, the pit latrines may start to have an impact on water quality or increase their impact on water quality. Flooding of sanitation systems was seen as an underestimated route of pollution, which again, climate change may exacerbate.

Using the data collected from the questionnaire, the water supply and sanitation facilities were ranked according to their vulnerability to four different climate scenarios: current climatic conditions; a significant increase in rainfall; a significant decrease in rainfall; and a significant increase in the frequency and severity of heavy rainfall events (stormier). These rankings were calculated from weighted averages. The results of the analysis are shown in Tables 11 and 12 for improved water supply and sanitation facilities, respectively.

Table 11

Ranked vulnerabilities of six different improved water-supply facilities: respondents selected from a total of nine facilities, the remaining three being unimproved sources which are not reported here (a ranking of 1 indicates the highest rate of failure, and a ranking of 9 the lowest)

Regions	Facilities	Climate			
		Current	Wetter	Drier	Stormier
All	Piped water supplies	2	6	5	6
	Public standpipes	1	2	8	3
	Borehole	7	8	2	9
	Protected well	5	2	3	1
	Protected spring	8	4	9	8
	Rainwater	3	9	1	7
Developed	Piped water supplies	6	4	3	4
	Public standpipes	3	1	7	2
	Borehole	3	5	1	6
	Protected well	7	2	4	7
	Protected spring	7	2	7	2
	Rainwater	1	8	2	5
Developing	Piped water supplies	1	4	7	4
	Public standpipes	2	5	8	6
Developing	Borehole	9	8	4	9
	Protected well	4	2	2	1
	Protected spring	7	6	9	8
	Rainwater	3	9	1	7

Table 12

Ranked vulnerabilities of three different improved sanitation facilities: respondents selected from a total of nine facilities, the remaining six being unimproved facilities which are not reported here (a ranking of 1 indicates the highest rate of failure, and ranking of 9 the lowest)

Regions	Facilities	Climate			
		Current	Wetter	Drier	Stormier
All	Public sewer	3	2	4	1
	Septic system	4	6	2	7
	Ventilated improved pit latrine	5	4	6	2
Developed	Public sewer	2	1	1	2
	Septic system	4	1	1	1
	Ventilated improved pit latrine	1	3	3	3
Developing	Public sewer	1	3	3	2
	Septic system	4	8	2	8
	Ventilated improved pit latrine	6	4	6	1

3.2.5 Changing use of drinking-water supply and sanitation facilities

Investigations into changing use of drinking-water supply and sanitation facilities suggested that there was a general trend for increasing use of improved facilities, in line with the results of the JMP projections presented in Chapter 4. However, cases were reported where there were decreases in use of the improved facilities, such as decreases in piped water supply coverage in Sudan and Kenya, in borehole coverage in Nepal, and in sewer connections in Kenya. Climate change was considered by more respondents to be a driver for change in use of water supply facilities than for sanitation facilities. Overall, finance was the most common reason to change facility use (both water and sanitation), followed by community preferences and, in developing countries, the availability of improved facilities. The rankings for the different drivers for water and sanitation facilities were the same (see Appendix 4), but differences between developed and developing regions were evident (Table 13). Climate change was the strongest driver for change for drinking-water supplies in developed regions, but only sixth for developing regions. For sanitation, the rankings were sixth and eighth respectively.

Table 13
Ranking of the drivers for the changes in use of water and sanitation facilities in developed and developing regions (1 being the strongest driver for change; 9 being the weakest driver for change)

	Developed regions		**Developing regions**	
Driver for change	Water	Sanitation	Water	Sanitation
Economy	5	4	1	1
Ease of use	7	7	4	3
Climate change	1	6	6	8
Improved technology	2	2	3	4
Community preferences	6	5	2	2
Risk assessments	3	1	7	7
Government policy or legislation	4	3	5	5
Nongovernmental organization policy	8	9	8	6
Other	**9**	**8**	**9**	**9**

In common with the questionnaire responses, many of the interviewees did not recognize climate change as a driver in facility choices and commented that finance was often the main factor in choosing the type of facility installed. However, climate change was considered to be an indirect driver as donors like to see climate change included in bids for funding. China was highlighted as an example of where climate change has been used as a driver for informing choices of facility. Water resource managers were noted as becoming more interested in climate change, especially in Asia, the Caribbean and small island states. In other areas, such as central Africa, other issues take priority.

> "My experience of China was that the climate change angle was suddenly being pushed by most of the donors quite quickly. There is a question about whose policy and whether the different actors share similar views about the importance of climate change and the need to adapt… The donors were starting to bolt climate change onto their existing portfolio of projects. Timing is important in these things and it's easier for them to do that in the context of a recent drought or flood." (Interviewee 7)
>
> "We are dealing with developing countries and middle-income countries that are receiving large amounts of donor money, and if you want to attract the donor money you have to mention climate change, so there are drivers there." (Interviewee 5)

3.2.6 Policy issues

The final section within the questionnaire dealt with policies and their implementation. For present climatic conditions, government policies for water were generally considered adequate (71%; 5/7) in developed regions but inadequate (61%; 11/18) in developing regions. The policies of nongovernmental organizations (local and international) were seen as inadequate (75%; 9/12) in developing regions. For future climatic conditions, a greater proportion of respondents thought that the policies were inadequate, including 81% (13/16) of government and 92% (11/12) of nongovernmental organization policies. In total, there were only four respondents who thought that policies were suitable for predicted climatic conditions; they were from Australia, South Africa, the United Kingdom, and the United Republic of Tanzania.

A similar picture is seen regarding sanitation policies. Respondents in developed countries generally thought the government policies were adequate for the present situation, but not for predicted climate conditions. Respondents from developing countries were more inclined to feel that government, nongovernmental organization and other policies were all inadequate for current and predicted climatic conditions. Five respondents thought that the policies were adequate for predicted climatic conditions. These were from Australia, South Africa, the Maldives, Sri Lanka, the United Kingdom, and the United Republic of Tanzania. The Maldives, of course, is being threatened by rising sea levels.

Approximately half the respondents were aware of policies that deal with issues surrounding potential climate change and drinking-water and sanitation facilities, with a higher proportion of respondents from developing countries confirming that they were aware of such policies.

The interviews provided the opportunity to go much deeper into the issues surrounding policy. Interviewees thought that there was a lack of scientific information available on climate change predictions, which was a barrier to policy development, particularly at the local level. One interviewee noted that policies need to be informed by practice and that data collection is required to provide evidence for policy development. More broadly than climate change, there is a need for water and sanitation facilities to be backed by informed understanding of water availability and drought.

> "… policy decisions are not always made on the basis of sound science. There is a lot of discussion in Uganda about improving the resilience of water supplies to climate change. The normal approach is for people to move towards groundwater-fed water systems as improved water sources, i.e. boreholes and other groundwater-fed systems, despite the thoughts that climate change is drying up the boreholes! So there is some contradiction." (Interviewee 8)

Prescriptive policy decisions were not seen as the answer, but rather that there is a need to increase education and awareness about the range of facilities available, so that people can choose the most appropriate one to their situation. Similarly, independent of climate change, there is a need to educate people about reliable water sources and where to site facilities.

> "It needs to avoid very prescriptive policy response and thinking more about how do we get good people in the right places to make difficult decisions: incentivizing utilities to be motivated by the delivery of a service rather than by pipes and infrastructure. Its not about building things it's about delivering a service. Climate change adds an incentive to start thinking this way." (Interviewee 2)

> "Chennai is in a monsoon area where water capture and recharge systems could be beneficial. This example, however, does emphasize the need to treat policy and policy implementation at a local level. Water management strategies

from other areas of India may not be suitable for the Chennai environment." (Interviewee 10)

Education also has an important role in adaptation. Overwhelming opinion from the interviewees was that there is no need to develop new technologies to deal with climate change. Rather, there is a need to transfer the appropriate technologies that are in existence now to different areas affected by climate change, identifying good practice from communities that are already dealing with extreme weather events and transferring knowledge about adaptation to areas which are experiencing floods and droughts for the first time. In some cases this may be changing behaviour rather than the facility.

> "The key is to understand how regions cope with their present climate and then transfer these lessons to the regions that are expected to develop these conditions in the future. In areas where there is adequate rainfall at the moment, but may get less rainfall in the future, they need to adopt the technologies from the drier climates. It may also be a case of adopting technologies that have been used in the past but have now gone out of use." (Interviewee 3)

> "We are probably not looking in terms of global perspective at new technologies but that in certain areas using new technologies for that area – technologies that have been used previously elsewhere but not applied in a particular area … there is a greater need of education, dissemination and awareness of the range of technologies available" (Interviewee 6)

The main point to emerge from these statements is that robust systems, knowledge transfer and soft skills are all key ingredients of targeted responses.

In some cases, it may be more appropriate to install cheap and temporary facilities which can be replaced if communities are forced to move; for example, in the Chars of Bangladesh (see Section 2.4.1) communities are forced to be transient because of the frequent flooding. In this case, the most appropriate technical innovation may be to make cheaper temporary latrines. In addition, there is a need to study water sources at the end of current dry seasons and learn lessons for future drought periods. A key message from the interviewees was the need for policy-makers to be flexible about the types of facilities that are appropriate, and not to generalize across countries. There is a need to have technical advisors working at the community level who are able to advise and make judgements about budgets and the most appropriate type of facility.

> "If people ask me how they should adapt their systems for climate variability, I suggest that they look towards the end of the dry season at the drought." (Interviewee 1)

> "Basically projects, rural supply programmes and policies should be adapted to cope with recurrent drought anyway; it's simply good practice. In many cases they are not." (Interviewee 7)

Examples and suggestions for adaptations given in interviews included the need to install boreholes or wells in the most productive part of the groundwater system to deal with demand; and ensure that wells are sealed at the top and 3-4 metres down. In practice, however, the knowledge and data requirements to be able to identify productive groundwater systems are considerable, and out of the reach of many countries. Once again, this highlights the need for data collection and analysis to be an integral part of adaptation strategies for drinking-water supply and sanitation. Examples were given from Zimbabwe, where collector wells withstand severe droughts; from Northern Ghana, where shallow wells are installed with extra casing in case they need to be deepened in the future; and from Botswana, where relief boreholes are drilled that can be uncapped in water stress periods.

> "Collector wells…are a wide diameter shallow well in hard rock area with horizontal collectors drilled out from inside the well to access fractures and weathered materials from a wider area. Consequently, the well pulls in water from a much bigger distance around. This was done in the 1980s/1990s and they were put in place in Zimbabwe and … withstood some very severe droughts." (Interviewee 7)
>
> "In Asia, they enjoy the most frequent of floods. In these areas they have raised hand pumps so that they do not flood. Not all hand pumps let water in, particularly the ones that have the cylinder at the top rather than at the bottom. So there are technology choices if you think that your hand pump will get flooded every now and then… However, you do not want your raised hand pumps in the villages, you want them on embankments where the people are going to flee to. The governments in India and Bangladesh now understand the issue and have started to construct hand pumps along the embankments." (Interviewee 11)
>
> "I experimented with bolted hatch on the top of the latrine to try to prevent dispersal of the faeces during floods, but it didn't work. You can stop a lot of the solids being released, but the pressure builds up in the latrine will force the liquids out of the lid." (Interviewee 11)

One interviewee noted that adaptations are often just good practice:

> "If you are in a flood area then you build back raised latrines, and latrines that are in areas that are less likely to be flooded, you can introduce compost latrines. This sort of technology choice is being made if you are in a flood zone. The climate change lobby would call that adaptation to climate change; I would call it good practice." (Interviewee 11)

Areas using facilities with low mechanical or maintenance requirements were identified as vulnerable if climate change means that new facilities will have to be introduced, requiring money and developing knowledge capacity for the operation and maintenance of the facilities.

> "If you take a zero-technology option, for example a spring piped directly to a village, then we find that as a result of changed rainfall patterns that the quality and quantity available from the spring changes ... then that is quite difficult to change because you are introducing technology into what was a zero technology solution. This is quite a challenge, because as soon as you introduce technology you have a need for knowledge for operation and maintenance and that may not currently exist, so that brings in other things as well as technology… I think the vulnerability and the difficulty of meeting the challenges could be greater in the zero-technology areas than in the areas that already have technology." (Interviewee 5)

In Europe, mitigation, rather than adaptation, is the focus of the political dialogue.

> "The political level agenda is dominated by mitigation and not by adaptation, and adaptation is almost forgotten in the process… The political dialogue at the European level is dominated by mitigation and adaptation is given little more than

lip service. Despite funds coming in from carbon-trading, not enough emphasis is given to look at adaptation." (Interviewee 5)

Several of the interviewees identified diversification in facilities as an adaptation strategy, rather than focusing on just one facility or a centralized system. This would allow a mix of facilities to be used, increasing resilience and thereby spreading risk. One interviewee commented that even in cities it would be better to have smaller localized networks and treatment plants, which would be easier to protect from flooding and easier to operate.

> "I think that there are parts of the city that need networks, but the idea of having a whole city wide network attached to a single plant is not practical. It would be harder to run and therefore more vulnerable, so what we need to be doing is moving towards a more vertically and horizontally disaggregated system so that it all becomes much more robust. In dense areas of the city you probably do need sewers because you cannot put on-site sanitation everywhere, but there should be much more thinking about small localized networks and localized treatment plants, which would be easier to protect from flooding and easier to operate." (Interviewee 2)

> "One thing I thought of was discourage centralized treatment facilities; it may be better to spread the risk by having several small decentralized facilities for drinking-water and wastewater." (Interviewee 6)

Lack of communication was identified as a barrier to effective water and sanitation policy by a number of the interviewees. Many commented on the lack of communication between water resource, water quality and sanitation professionals, and suggested that future discussions about the impact of climate change on water supply and sanitation facilities should include professionals working in other sectors, such as agriculture and energy. Large-scale interventions for irrigation, for example, will have major impacts for water sources, and this will be exacerbated by climate change. But the reverse can be achieved with effective interactions between different sectors, as described in Section 2.4.3. Such collaboration needs to be identified and raised in future discussions.

> "One of my biggest concerns about climate change and rural water supplies is that if there is a big policy intervention for agriculture then it will have major impacts for improved water sources. Large-scale interventions for irrigation would have a major impact for rural water supply. This is an indirect impact of climate change." (Interviewee 1)

> "With respect to groundwater, changes in the use of water by other sectors as a result of climate change (e.g. increased use of water by agriculture because of changing climatic conditions), rather than climate change itself, will have the greatest influence on the water resource and this can be addressed by a change in the groundwater management regime." (Interviewee 10)

> "The problem we face when we look at water resources is that we tend to deal with water people, and you tend to find that the people who are looking at water supply do have much more of a say and are much more evident than those that are looking at other things such as agriculture and irrigation or energy. We are trying to push out to get away from the very heavy dominance of water people so that we have a bigger dialogue because water resources are about not just water supply

> (it is a very small element), it is also about, for example, food security and energy security.” (Interviewee 5)

One interviewee noted that policy-makers look at water resource management in terms of catchment management, which may not be appropriate in all cases in the developing world. There is still a lack of agreement on current integrated water resource policies among many organizations, and many have not begun to discuss climate change policies.

> “The catchment is a totally meaningless unit to the people at an individual level and at an institutional level, because we organize our lives around cities and states and regions, and often the rivers are boundaries.” (Interviewee 3)

There is general agreement that, at present, climate change does not feature heavily in decision-making regarding water supply and sanitation facilities, but that it will become more important in future decisions. At present there is a need for further information on the potential effects of climate change and for data collection so that policy decisions can be informed by practice.

> “We had a joint meeting… in 2002 to discuss water resources, and water and sanitation. What was interesting was that the general audience we were talking to had not really thought of climate change. The assumption was that domestic water is such a small percentage of withdrawals compared with agriculture, so whatever water and sanitation does it does not have a major impact on the wider water resource.” (Interviewee 3)

3.3 Key outcomes

The questionnaire and interviews helped to raise new issues concerning the impacts of climate change on water and sanitation facilities, and support issues that have already been discussed on the basis of the published literature. For example:

- Personal observations confirmed the findings of published reports that changes in rainfall patterns are already occurring, with decreases in average annual rainfall and increases in rainfall intensity being most commonly noted.
- Respondents and interviewees the findings of published reports that water and sanitation facilities are vulnerable to changing patterns and intensities of rainfall. However, the impacts of climate change were considered to exacerbate existing problems, not necessarily to create new ones.
- Climate change is not a high priority for the design of water supply and sanitation strategies, particularly in developing countries. Respondents to the questionnaire felt that climate change was given more of a priority in water and sanitation than that indicated in the responses of interviewees. Water supply was a bigger concern than sanitation in the context of climate change, with more respondents changing their water supply strategies.
- There was agreement between all respondents and interviewees who expressed an opinion, that there was not a requirement to develop new water supply and sanitation facilities to deal with climate change. The challenge is to select the appropriate facility for the climate conditions that are predicted to occur in the future.
- The vulnerability of centralized systems was identified in both the questionnaire and the interviews. In particular, centralized systems for piped water supply were seen as being highly

vulnerable. This vulnerability is thought to be related to the potential for problems with centralized systems to affect large numbers of people.

- More research is required to understand the responsiveness of groundwater to climate change. This information is vital for decision-makers in the water and sanitation sector.
- Climate change is a stronger driver for changing the type of water facilities than for changing the type of sanitation facilities. However, when choosing the type of facility to install, finance is generally the main factor considered.
- In developing countries, climate change policies are generally considered inadequate at present. It was considered that there is currently inadequate scientific information available on climate change predictions, and the lack of sound science may be a factor inhibiting the development of policies.
- In terms of policy decisions regarding the most suitable types of water supply and sanitation facilities, it was emphasized that prescriptive policy decisions are not the answer; rather there is a need to improve education and awareness of the types of facilities available and appropriate to specific situations.
- There is a need to improve the dialogue between the water and sanitation sector and the water resources sector, in order to deal with climate change impacts. The majority of respondents thought that existing information regarding climate change was inadequate.
- Policies that advocate the use of specific water supply and sanitation facilities may be inappropriate for dealing with climate change. Policies that support a flexible response in water and sanitation provision are more likely to aid adaptation to the impacts of climate change.

4. Forecast of water and sanitation coverage in 2020

The WHO/UNICEF Joint Monitoring Programme on Water Supply and Sanitation (JMP) reports the coverage of improved water supply and sanitation facilities; that is, the proportion of the population using improved water supply and sanitation facilities. The results are based on estimates from household surveys and censuses, including from the Demographic Health Surveys, UNICEF's Multiple Indicator Cluster Surveys and World Health Surveys (JMP, 2008).

A forecast was made, using the JMP data, of the number of people with access to each type of improved water supply and sanitation facility in each country by 2020, to better understand the impact that predicted climate change might have on water and sanitation provision in the country. The year 2020 was selected to represent the minimum expected lifespan of technologies that had been installed to date, including recent efforts to meet the MDG target in 2015. The forecast for the year 2020 also provides an indication of the potential for climate change to undermine short-term sustainability, and reflects current and historical programming, policy decisions and current climatic variability. The principal consequences of changes by 2020 relate to management of infrastructure already, or soon to be, in operation. The data are reported in three ways: total access; rural access; and urban access.

4.1 Forecasting method

As part of the JMP reporting by WHO and UNICEF, some forecasting is undertaken using the available data. For example, forecasting may be used to provide initial estimates of progress, before survey data become available. The JMP linear regression method was the basis for the long-term forecasting method used in the present report. Both the JMP and the forecasting methods are outlined below. The forecast uses linear regression and was based on the available estimates for the years 1990, 1995, 2000 and 2006. This is the first time such time such long-term projections have been undertaken for drinking-water supply and sanitation facilities using JMP data. The long-term forecast for the world population in 2020 was 7.7 billion, including all countries irrespective of information on water and sanitation access. This is a slightly higher estimate than the United Nations prediction of 7.6 billion (United Nations, 2005).

4.1.1 JMP linear regression method

The method developed to support the preparation of the JMP reports (WHO, 2004) uses linear regression to forecast water and sanitation coverage where data are not available. The projection requires that at least two survey data points are available, and they are spaced five or more years apart. The linear regression makes the assumption that short-term (four years) rates of change in access to water and sanitation are linear. Thus the regression line may be extrapolated up to four years after, or before, the latest or earliest survey data point. Outside of these time limits, the extrapolated regression line is flat for up to four years. If the extrapolated regression line reaches 100% coverage or beyond, or 0%, a flat line is drawn from the year prior to the year where coverage would reach 100% (or 0%).

Where insufficient data exist for linear regression, the slope of the regression is assumed to be zero; that is, it is assumed that no progress is made. This might occur in two scenarios: when only one valid datum is available, in which case the value is therefore taken forward; or when there are two or more valid data points available, but they are spaced four or fewer years apart, in which case the average of the available data points is used. When the slope of the regression is assumed to be zero, the projection can be made up to a maximum of six years forwards and backwards in time from the data point. When coverage is at 95% or above, or at 5% or below, the projection can be made without limitations (WHO, 2004).

4.1.2 Long-term forecasting method

The analysis presented here, while not carried out as part of the JMP, was based on the JMP country files containing all the datasets used by JMP. First, the JMP pooled datasets for improved water supply and sanitation facilities for each country were disaggregated to provide the data for the proportion of the population with access to each of the facilities within this category. The disaggregation was carried out for the total population of each country, and for the rural and urban population.

Second, the proportion of the population using improved water supply or sanitation facilities was forecast using linear extrapolation. Forecasts were undertaken only if all four data points (1990, 1995, 2000 and 2006) were available. The values were constrained to a minimum of 0% and a maximum of 100%. Calculations were undertaken using the forecast function in Microsoft Excel.

Lastly, the proportion of the population using a particular type of improved water supply or sanitation facility was forecast using linear extrapolation. For this, individual facilities were forecast as the proportion of total population using improved facilities. For example, in a population with 50% total coverage of improved water sources, and 25% coverage of piped water, the piped water coverage would be forecast as 50% of total water coverage. These forecasts were scaled so that the sum of the individual facility usages, where there were data for more than one facility, was equal to the total coverage.

For example, in Figure 16, the total proportion of the population served by improved water sources is linearly extrapolated to 2020, but the use of piped water supply has been increasing as a proportion of the improved water sources being used and is predicted to account for 100% of improved water sources by 2020.

Because of the uncertainty in the data and in the predictions, the results are categorized for the mapped outputs into the following ranges: 76 – 100%, 51 – 75%, 26 – 50%, 11 – 25% and 0 – 10%.

Coverage in rural, urban and total populations were forecast, by country. The aim was to provide data for assessing the impact of climate change in terms of the population using different facilities. Population forecasts were made using the same linear regression method as for the proportion of the population using improved water supply or sanitation facilities. As with the water and sanitation data, there are limitations to this method, and the numbers should only be used to give a relative guide. Population forecasts were used to calculate regional population statistics for access.

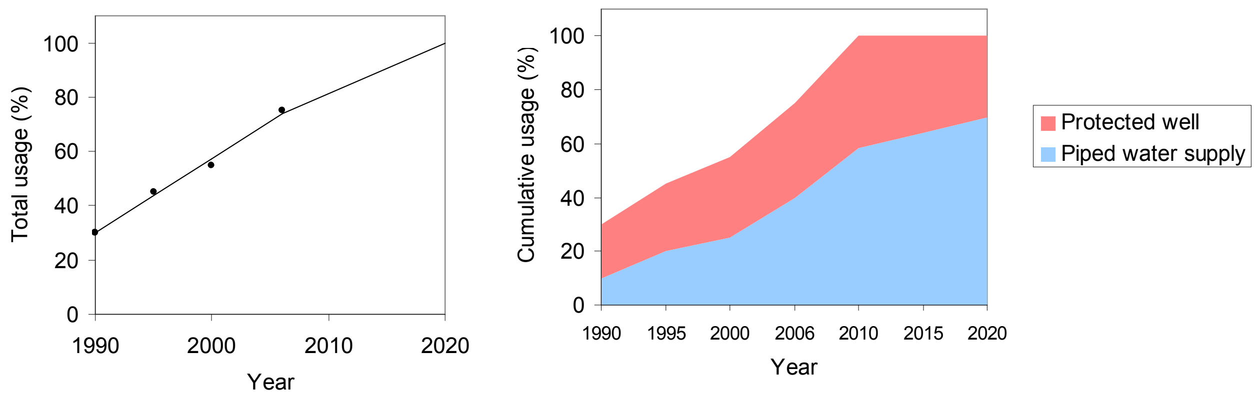


Figure 16
Example of calculation of the predicted level of access to improved water supplies
(Left) The total usage of improved water supplies is forecast using linear extrapolation (line) from the data points (●)
(Right) The proportions of piped water and protected well supplies are forecast: in this case, the rate of increase of protected wells is lower than for piped water supplies (piped water supplies increase from 10% to 40% from 1990 to 2006, protected wells increase from 20% to 35% over the same period); as these are forecast through to 2020, the greater rate of increase of piped water supplies results in the prediction that once 100% usage of improved supplies has been achieved, piped water supplies will start to replace protected wells

4.2 Limitations of the forecasting data and method

There are key limitations to the JMP data and the long-term forecasting method that need to be taken into consideration when using these forecasts.

Although major improvements in the method have been made since the start of the JMP, there are still a number of limitations of the data which are acknowledged by the programme. For example, the definition of safe, or improved, water supply and sanitation facilities can differ between countries, and within countries over time, and therefore reporting may be inconsistent. Furthermore, facilities which are counted as improved may not be functioning properly, and may therefore not actually meet the requirements of improved water supply or sanitation (UNDP, 2006). Data coverage is incomplete, and there is a lack of standard indicators and methods for conducting household surveys, between countries, which makes it difficult to compare information.

The main limitation of the long-term forecasting method is its simplicity. There are many factors which will influence the rate of development of a country, and thus affect the installation of water supply and sanitation facilities, but which are beyond the scope of this project. These include levels of capital, human and technological development of a country. In addition, there are a number of issues that are unpredictable but can dramatically halt the development of a country – for example natural disasters such as earthquakes, hurricanes and floods, as well as conflict and disease epidemics. The infrastructure of all countries would be affected by such events; however, vulnerable countries have the least capacity to adapt to these changes because they lack the necessary institutional, economic and financial capacity to cope, and to rebuild damaged infrastructure. In some instances, it may take many years to restore the damage.

In contrast, countries may develop at a faster rate than previously, and make better progress in installing technologies than the prediction. However, because of the complexity of accounting for external factors that may influence the installation of technologies, we have assumed that each country will continue at the same rate of development as its rate between 1990 and 2006. This is obviously a simplistic approach; however, the results are intended to provide a platform for discussion.

4.3 Forecasts for water supply and sanitation facilities

The availability of data for water and sanitation is summarized in Tables 14 and 15, respectively. A total of 135 countries had complete data sets for water sources, with statistics covering all water supply types for both rural and urban areas; 127 countries had complete data sets for sanitation technologies. The availability of data was particularly limited in Oceania for different types of systems, so the Oceania region was removed from some later analyses. Data availability was also limited in developed countries and in Latin America and the Caribbean region. However, for the latter, data were generally comprehensive for mainland countries. A more complete summary by country is available in Appendix 5.

Table 14

Statistics on the number of countries per MDG region with rural and urban data for improved water supply facilities in 2020, and as a proportion (%) of the total number of countries

MDG region	No. of countries	Piped water		Public standpipe		Protected well		Protected spring		Rainwater collection		Total water		All data	
		No.	%	No.	%	No.	%	No.	%	No.	%	No.	%	No.	%
Western Asia	15	10	67	9	60	9	60	9	60	9	60	11	73	9	60
Sub-Saharan Africa	50	47	94	47	94	47	94	47	94	47	94	48	96	47	94
South-east Asia	11	9	82	9	82	9	82	9	82	9	82	9	82	9	82
South Asia	9	9	100	9	100	9	100	9	100	9	100	9	100	9	100
Oceania	22	8	36	2	9	2	9	2	9	2	9	16	73	2	9
Northern Africa	6	4	67	4	67	4	67	4	67	4	67	4	67	4	67
Latin America and Caribbean	46	37	80	24	52	24	52	24	52	24	52	38	83	24	52

Eurasia	12	11	92	11	92	11	92	11	92	11	92	11	92	11	92
Eastern Asia	6	4	67	4	67	4	67	4	67	4	67	4	67	4	67
Developed countries	52	31	60	16	31	17	33	16	31	16	31	34	65	16	31

Table 15
Statistics on the number of countries per MDG region with rural and urban data for improved sanitation facilities in 2020, and as a proportion of the total number of countries

MDG region	No. of countries	Sewer connection		Septic system		Pit latrine		Total sanitation		All data	
		No.	%	No.	%	No.	%	No.	%	No.	%
Western Asia	15	9	60	8	53	8	53	10	67	8	53
Sub-Saharan Africa	50	40	80	40	80	40	80	46	92	40	80
South-east Asia	11	9	82	9	82	9	82	9	82	9	82
South Asia	9	9	100	9	100	9	100	9	100	9	100
Oceania	22	9	41	2	9	2	9	15	68	2	9
Northern Africa	6	4	67	4	67	4	67	4	67	4	67
Latin America and Caribbean	46	34	74	22	48	22	48	37	80	22	48
Eurasia	12	11	92	11	92	11	92	11	92	11	92
Eastern Asia	6	4	67	3	50	3	50	4	67	3	50
Developed countries	52	27	52	19	37	19	37	30	58	19	37

Countries in which the coverage of water supply and sanitation facilities was reported to decrease between 1990 and 2006, and therefore was forecast to continue to decrease, include Algeria, the Maldives, the Marshall Islands, and the Solomon Islands, with full details available in Appendix 5.

4.3.1 Summary of progress

The maps of coverage for different water supply and sanitation facilities are included in Appendix 6. The maps of total coverage for improved water supply and sanitation options in 2020 are provided in Figures 17 and 18.

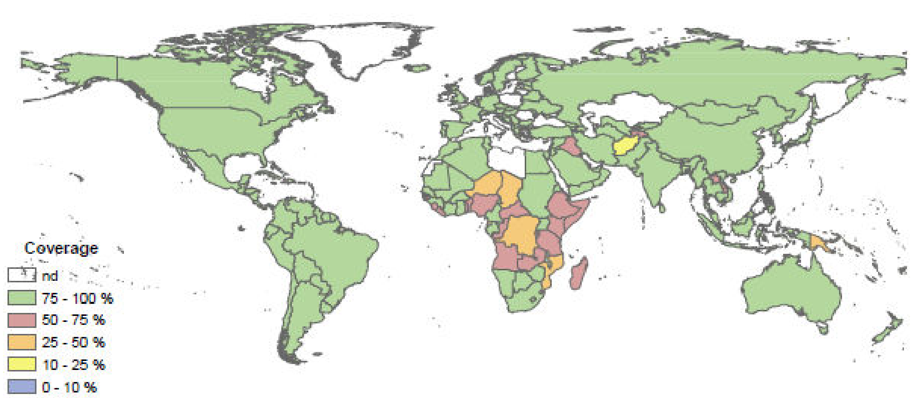


Figure 17
Forecast coverage of improved water supply facilities by 2020
nd, no data.

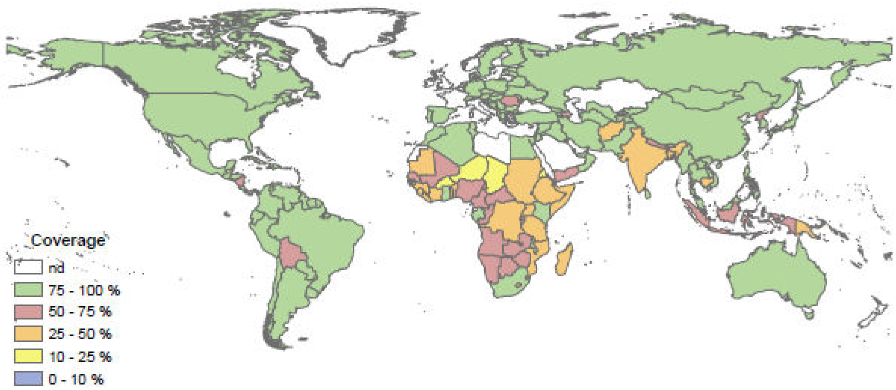


Figure 18
Forecast coverage of improved sanitation facilities by 2020
nd, no data.

A total of 115 countries (48% of the 238 countries) are predicted to have increased total coverage by 2020 of improved water supply facilities, with 58 (24%) predicted to have no change and 17 (7%) predicted to have decreases in total improved water supply coverage. There were insufficient data available to make forecasts for 48 (20%) countries. A total of 107 (45%) countries were predicted to have increased improved sanitation coverage, with 61 (26%) predicted to have no change and 14 (6%) predicted to have decreases in total improved sanitation coverage. Insufficient data were available for 56 (24%) countries.

The countries predicted to make the biggest gains in total proportion of population with access to improved water supply facilities between 2006 and 2020 were Burkina Faso, Cambodia, Ethiopia, Malawi, Mali, and Uganda. The countries predicted to make the biggest gains in total proportion of population with access to improved sanitation facilities between 2006 and 2020 were the Central African Republic, the Lao People's Democratic Republic, Nepal, Paraguay, Viet Nam, and Yemen.

In 2020, the lowest levels of coverage of improved water supply facilities are predicted to be in Afghanistan, Chad, the Democratic Republic of Congo, Equatorial Guinea, Fiji, Mozambique, Niger, Norfolk Island, Papua New Guinea, and the Solomon Islands. There are 35 countries which are predicted to have less than 50% of their population with access to improved sanitation facilities, with the lowest levels of coverage predicted to be in Burkina Faso, Chad, Eritrea, Haiti, Micronesia, Niger, Norfolk Island, Togo, and the Solomon Islands.

The total number of people without access to improved water supply facilities in 2020 (Table 16) is forecast to be 0.5 billion, the majority (66%) of whom will be in sub-Saharan Africa (representing 31% of the population there), with a further 15% in southern Asia (representing 4% of the population there).

Table 46
Predicted population in 2020 by MDG region without access to improved water-supply and sanitation facilities, for countries where data are available (for complete lists see Appendix 5)

MDG region	Without access to improved water-supply facilities			Without access to improved sanitation facilities		
	Population (in millions)	% of population in region	% of those without access	Population (in millions)	% of population in region	% of those without access
Sub-Saharan Africa	311	31	62	467	46	26
Northern Africa	13	7.2	2.6	12	6.7	0.7
Eurasia	21	7.8	4.1	13	5.0	0.7
Western Asia	16	6.9	3.3	18	8.8	1.0
South Asia	75	3.8	15	917	46	51
South-East Asia	40	5.9	8.0	126	19	7.0
Eastern Asia	0.4	0.0	0.1	177	11	9.8
Latin America and Caribbean	13	2.0	2.6	60	9.0	3.3
Oceania	5.8	52	1.2	6.1	54	0.3
Developed Countries	3.7	0.4	0.7	10	1.1	0.5
Total	499	6.6	100	1805	24	100

It is predicted that there will be 1.8 billion people without access to improved sanitation facilities in 2020 (Table 16), the majority (51%) of whom will be in south Asia (representing 46% of the population there), with a further 26% in sub-Saharan Africa (representing 46% of the population there). Oceania was also predicted to have low coverage, with 54% of population there without access to improved sanitation facilities. Tables 17 and 18 provide data on access in rural and urban areas.

Table 57

Predicted rural population in 2020 by MDG region without access to improved water supply and sanitation facilities, for countries where data are available (for complete lists see Appendix 5)

MDG region	Without access to improved water-supply facilities			Without access to improved sanitation facilities		
	Population (in millions)	% of population in region	% of those without access	Population (in millions)	% of population in region	% of those without access
Sub-Saharan Africa	264	42	65	376	60	24
Northern Africa	8.2	10	2.0	13	17	0.9
Eurasia	17	17	4.3	8.8	8.5	0.6
Western Asia	8.5	11	2.1	17	22	1.1
South Asia	61	4.5	15	810	60	52
South-East Asia	28	8.7	6.9	81	25	5.3
Eastern Asia	0.5	0.1	0.1	198	26	13
Latin America and Caribbean	12	9.9	3.0	33	26	2.1
Oceania	5.2	60	1.3	4.7	57	0.3
Developed Countries	3.5	1.8	0.8	8.0	4.2	0.5
Total	409	11	100	1549	43	100

Table 18

Predicted urban population in 2020 by MDG region without access to improved water-supply and sanitation facilities, for countries where data are available (for complete lists see Appendix 5)

MDG region	Without access to improved water-supply	Without access to improved sanitation

	facilities			facilities		
	Population (in millions)	% of population in region	% of those without access	Population (in millions)	% of population in region	% of those without access
Sub-Saharan Africa	74	19	46	101	26	30
Northern Africa	6.9	6.9	4.3	0.5	0.5	0.2
Eurasia	4.2	2.6	2.6	4.8	2.9	1.4
Western Asia	9.9	6.3	6.1	4.1	2.6	1.2
South Asia	20	3.1	12	126	20	37
South-East Asia	28	7.8	17	52	15	15
Eastern Asia	11	1.3	6.7	7.4	0.9	2.2
Latin America and Caribbean	7.1	1.3	4.4	38	7.1	11
Oceania	0.6	24	0.4	0.7	27	0.2
Developed Countries	0.1	0.0	0.1	2.2	0.3	0.7
Total	161	4.1	100	337	8.8	100

No forecasts of coverage were made in countries which had missing data. However, the total populations without access to improved water supply and sanitation facilities in these countries were forecast. The total population in 2020 in countries without sufficient data to forecast access to improved water supply facilities was approximately 200 million. Many of the countries without data, and the majority of the population (69%) for which data were unavailable, were from the developed world. The total population in 2020 in countries without sufficient data to forecast access to improved sanitation was approximately 330 million, with 72% from developed countries.

4.3.2 Types of improved water supply and sanitation facilities

Data were available for five improved water supply facilities: piped water, public standpipes, protected wells, protected springs, and rainwater collection. Piped water and protected wells typically constitute the highest proportion of coverage (Table 19). Of the types of improved water supply facilities considered, rainwater collection was predicted to be most commonly found in south-east Asia in 2020, protected springs are predicted to be most commonly found in sub-Saharan Africa, and protected wells are predicted to be most commonly found in south Asia, followed by south-east Asia. Standpipes are predicted to be most commonly found in south Asia and sub-Saharan Africa.

Table 19

Predicted percentage of the population in 2020 served by improved water sources and improved sanitation facilities by MDG region, for countries where data are available (for complete lists see Appendix 5)

	Sub-Saharan Africa	Northern Africa	Eurasia	Western Asia	South Asia	South-east Asia	Eastern Asia	Latin America and Caribbean	Oceania[a]	Developed Countries
Water										
Piped water	18	86	62	79	23	42	83	89	24	95
Public standpipe	16	2.6	6.7	2.6	19	6.3	0.1	1.8	ND	1.3
Protected well	28	3.6	18	10	53	34	17	5.1	ND	7.6
Protected spring	5.4	0.1	0.8	0.6	0.4	4.0	0.0	1.1	ND	0.6

Rainwater collection	1.6	0.4	0.0	0.4	0.1	8.1	0.0	0.9	ND	0.3
Total	69	93	88	93	96	94	100	98	48	100
Sanitation										
Sewer	8.0	71	47	54	7.0	5.3	37	61	7.5	81
Septic	10	5.3	7.8	33	36	56	31	22	ND	18
Pit latrine	35.9	17	40	3.8	11	20	23	7.4	ND	1.8
Total	54	93	95	91	54	81	89	91	46	99

ND, insufficient data.
[a] Limited data included for Oceania as data available for too few countries (see Tables 14 and 15)

Differences exist between rural (Table 20) and urban areas (Table 21). Connection to a piped water supply is predicted to provide less coverage in rural areas in all regions. Conversely, protected wells and protected springs are predicted to provide more coverage in rural areas. Public standpipes, however, do not show a general trend, with the prevalence in rural or urban areas dependent on the region.

Data were available for three improved sanitation facilities: connection to a sewer, connection to a septic tank, or an improved pit latrine. It is predicted that by 2020, connection to a sewer will provide the most coverage of any sanitation facility except in regions with low overall access to improved sanitation such as sub-Saharan Africa or south Asia. South-east Asia is predicted to have the lowest rate of connection to public sewers in 2020 (Tables 17, 18 and 19).

Table 20
Predicted percentage of the rural population in 2020 served by improved water sources and improved sanitation facilities by MDG region, for countries where data are available (for complete lists see Appendix 5)

	Sub-Saharan Africa	Northern Africa	Eurasia	Western Asia	South Asia	South-East Asia	Eastern Asia	Latin America and Caribbean	Oceania[a]	Developed Countries
Water										
Piped water	7.2	78	28	61	12	22	62	69	14	81
Public standpipe	16	3.7	13	5.9	19	6.6	0.1	2.7	ND	2.2
Protected well	28	6.9	40	21	63	42	38	13	ND	30
Protected spring	4.5	0.0	1.5	1.1	0.6	7.0	0.0	2.4	ND	1.6
Rainwater collection	2.0	0.7	0.1	0.5	0.1	14	0.0	3.3	ND	0.7
Total	58	90	83	89	95	91	100	90	40	98
Sanitation										
Sewer	2.4	37	10	23	1.3	2.5	3.2	22	2.3	40
Septic	4.2	11	9.1	49	33	45	23	35	ND	56
Pit latrine	37	35	72	5.3	4.8	27	48	20	ND	6.3
Total	40	83	91	78	40	75	74	74	43	96

ND, insufficient data.
[a] Limited data included for Oceania as data available for too few countries (see Tables 14 and 15).

Table 21
Predicted percentage of the urban population in 2020 served by improved water sources and improved sanitation facilities by MDG region, for countries where data are available (for complete lists see Appendix 5)

	Sub-Saharan Africa	Northern Africa	Eurasia	Western Asia	South Asia	South-East Asia	Eastern Asia	Latin America and Caribbean	Oceania [a]	Developed Countries
Water										
Piped water	32	90	87	91	46	59	96	92	59	99
Public standpipe	20	1.9	3.3	0.4	21	5.6	0.1	1.7	ND	0.7
Protected well	27	1.1	6.4	1.7	31	24	0.5	3.8	ND	2.2
Protected spring	2.6	0.1	0.3	0.3	0.0	1.1	1.8	0.8	ND	0.1
Rainwater collection	0.3	0.2	0.0	0.3	0.0	2.2	0.0	0.4	ND	0.0
Total	81	93	97	94	97	92	99	99	76	100
Sanitation										
Sewer	16	94	65	68	21	9.0	66	70	38	92
Septic	20	2.6	6.5	28	43	66	34	19	ND	8.0
Pit latrine	38	2.9	25	1.4	16	11	1.1	4.7	ND	0.7
Total	74	99	97	97	80	85	99	93	73	100

ND, insufficient data.
[a] Limited data included for Oceania as data available for too few countries (see Tables 14 and 15).

4.4 Key outcomes

These forecasts indicate the number of people who will have access to each type of improved water and sanitation facility in each country by 2020. This information can be used to assess the potential limitations to the development of water and sanitation facilities that may arise from climate change.

These data are intended to be coupled with climate projections in the "Climate change projection study" being undertaken by the Hadley Centre, United Kingdom for DFID. Some examples of how the data might be used are provided at the end of the next chapter.

5. Determining the resilience of water supply and sanitation facilities to climate change

As discussed in the introduction (Chapter 1), resilience is “the ability of a social or ecological system to absorb disturbances while retaining the same basic structure and ways of functioning, the capacity for self-organisation, and the capacity to adapt to stress and change” (IPCC, 2007). For drinking-water supply and sanitation facilities, resilience is defined by the vulnerability of the facility to changes in climate, as well as the ability of the facility to adapt to these changes to reduce the vulnerability.

This discussion uses the information on the vulnerabilities and adaptations for water supply and sanitation facilities described in the literature review (Chapter 2) and opinions chapter (Chapter 3) to assess the resilience of each facility. A more comprehensive list of vulnerabilities and adaptations is provided in the fact sheets included on this CD-ROM. The guidance provided in the fact sheets covers four key areas for adaptations: long-term changes to policy and planning, in the form of capital expenditure; retrofitting of existing systems, in the form of operational expenditure; data gathering, including monitoring; and socioeconomic tools.

One of the overarching vulnerabilities identified in the literature review, questionnaire and interviews undertaken is that the choices of water supply and sanitation facilities are generally being informed by historical records rather than by knowledge of future trends. For example, a sewage treatment plant might be designed based on a one-in-twenty year flood level, such that it is expected that operation will only be hampered by floods approximately once every twenty years. With the changing climate, the average recurrence interval for that size flood may drop dramatically. Design standards, manuals and codes of practice will need to change to reflect forecast climate, rather than historical climate.

Another overarching vulnerability is that the demand for water is likely to increase. Increasing population and affluence, combined with higher temperatures and more variable rainfall – meaning more irrigation in agriculture – will contribute to increased water demand. If this demand is not met, or if drought causes water supplies to fail, people will have to rely on unimproved water sources.

One of the key adaptations relevant to all climate scenarios and facilities is knowledge transfer. The literature review and the opinions gathered from the experts all agreed that it was not new technology or innovation that was required, but transfer of knowledge from places where techniques had already been adapted to a particular climate condition, such as regular flooding or low water availability. Furthermore, communication between the water and sanitation sector and the water resources and climate change sectors needs to improve to ensure continuity of water and sanitation services in a changing climate. Put simply, decisions need to be informed by good practice and good quality data.

Many of the other general adaptations have already been discussed in Section 2.4: diversifying and decentralizing, as discussed in Chapters 2 and 3, provide a greater degree of flexibility and a smaller, more localized impact of failure; monitoring of current conditions can provide the appropriate scientific background for decision-making; improved land management, such as through planting schemes and storm water diversions, can reduce the impacts of floods; and understanding the fate and mobility of pathogens in the environment can help site sanitation systems to mitigate any impact on drinking-water facilities.

One of the adaptations only briefly mentioned was construction and maintenance. The facilities discussed in this document are assumed to provide “safe” water and sanitation; however, this is dependent on appropriate construction and maintenance. The importance of construction and maintenance as an adaptation was also implicit in the different perceived vulnerabilities of drinking-water supply and sanitation systems in developed and developing countries: the facilities being perceived to be more vulnerable in developing countries.

Using three climate scenarios related to precipitation, the vulnerabilities, adaptive capacity and resilience of water supply and sanitation facilities will be discussed below. The climate scenarios are:
- increased rainfall
- decreased rainfall
- increased rainfall intensity.

The impacts of these changes in precipitation on water resources are summarized in Table 22.

Table 22
Summary table of key impacts of climate change on water resources, and on improved water supply and sanitation facilities

Climate scenario	Impacts on water resources	Impact on water supply and sanitation facilities
Increased amount of rainfall	Increased frequency of flooding Deterioration of water quality Increased groundwater recharge and rising groundwater levels	Damage to both water supply and sanitation facilities Flooding of sanitation systems resulting in contaminated flood waters which further contaminate the water supply and distribution system Ingress of groundwater into pipe networks, septic tanks and pit latrines Increased transport of contamination in soil and groundwater
Decreased amount of rainfall	Falling groundwater levels Low flows in surface waters Deterioration of water quality Changes compounded by increased temperatures and evapotranspiration	Low water availability causes problems for hygiene and cleaning Salinity of groundwater affects water supplies Sewage in rivers becomes less diluted causing contamination issues Increased algal growth Insufficient water makes flush-sanitation systems redundant
Increased intensity of rainfall	Changes in groundwater recharge More run-off resulting in more erosion and greater transport of contaminants to surface waters Flash flooding Deterioration of water quality	Increased turbidity resulting in requirement for better sedimentation and filtration in surface water treatment plants Damage to both water supply and sanitation infrastructure from flash flooding

The vulnerabilities and adaptations identified from the literature review and the expert opinions are discussed here and below, and have been used as the basis for rating the vulnerabilities and adaptive capacity, and hence the resilience of each of the improved facilities. The ratings for water supply and sanitation facilities are provided at the end of this chapter.

5.1 Piped water supplies

Piped water supplies, including utility managed supplies, community managed supplies and standpipes, were considered the drinking-water supply facility most prone to failure in developing regions by the questionnaire respondents (Table 11). This response may reflect the current problems of operation and maintenance of piped-water in developing countries, and the perception that climate change is likely to amplify these problems in the future. The perceived vulnerability of piped water supplies was also reflected in the interviews. These comments by the respondents and interviewees highlight the importance of developing and implementing comprehensive risk assessment systems to inform operation and maintenance, such as the Water Safety Plan approach that is being promoted by WHO.

This perception may relate to the large populations served by single systems, which therefore can be affected by a single failure. It is also likely that the majority of respondents had considerable experience with piped water systems because of their high prevalence, particularly in urban areas. As discussed in Chapter 4, piped water supplies (excluding standpipes) are forecast to have the highest proportion of coverage in all but three of the MDG regions in 2020 (Table 17). Sub-Saharan Africa is the only region where piped water supplies are not forecast to have the highest proportion of coverage in urban areas in 2020 (Table 19).

One of the vulnerabilities of these large centralized systems is their reliance on energy. Piped water supplies require energy for treating and distributing water. Similarly, sewerage systems require energy for treatment and potentially for pumping. As discussed in Chapter 2, energy supplies are likely to be disrupted by climate change. If the energy supply becomes intermittent, the reduction of pressure in pipes may cause ingress of contaminated water, as well as potentially causing damage to the pipes. If the energy supply fails for an extended period, people will need to find alternative water sources, placing the most vulnerable people at risk.

Based on questionnaire responses, piped water supplies were not expected to be as vulnerable to climate change-induced changes in precipitation as some of the other improved water supply facilities.

5.1.1 Increased rainfall

The key vulnerabilities identified for piped water systems, particularly those supplied from surface water sources, under conditions of increased rainfall were the deterioration of water quality and increased frequency of flooding. The deterioration of surface water quality was identified both in the literature review and in the questionnaire and interviews as putting stress on the water treatment works. Floods can affect water quality at the source and in the distribution system. Source water quality can be affected by flooding of sanitation systems, and water in distribution systems can be affected by ingress of contaminated floodwater. Heavy rainfall and floods can cause infrastructure damage through erosion, leading to the failure of supplies to large areas. Standpipes are considered to be susceptible to additional damage at the tap.

An increase in rainfall may affect pipe networks through the ingress of groundwater as groundwater levels rise. This will be a particular problem in areas where piped water supplies are intermittent, or will become intermittent in the future. (The vulnerabilities of groundwater supplies are discussed more fully in Section 5.2, in the context of protected wells.)

In general, piped-water supplies as a technology are considered to have a low adaptive capacity. Adaptations for treatment systems, such as additional filtration to cope with changes in water quality, are available but due to the scale of these systems and the level of infrastructure they are not readily adaptable for major shifts in climate or for extreme events. However, due to the personnel and financial resources often available for utility-managed piped water supplies, their adaptive capacity was considered to be high for all climate scenarios, as current engineering expertise, supported by adequate resources, is considered capable of providing appropriate solutions. For the majority of utility-managed piped water supplies, monitoring systems will already be in place and should be able to be adapted to meet changing needs.

As discussed in Section 2.2.1, community-managed piped water systems are considered less adaptable for all climate scenarios because of their reduced access to financial, technical and trained human resources. In order to improve the resilience of these systems to climate change, it may be appropriate to develop national or regional networks of support, perhaps in collaboration with the utility-managed supplies, to assist communities to operate and maintain their facilities. The adaptability of standpipes will be dependent on the management system of the piped water supply.

As a technology, piped water systems are not considered to be resilient due to their high ulnerability and low adaptive capacity. However, the resilience of utility-managed piped water supplies to increased rainfall is considered to be high because of the high adaptive capacity, although this is dependent on the financial resources, as well as technical and trained human resources, being available. The resilience of community-managed piped water supplies to increased rainfall is considered to be moderate, because of the low adaptive capacity.

5.1.2 Decreased rainfall

The key vulnerability identified for piped water supplies under conditions of decreased rainfall was water scarcity, particularly for systems relying on surface water. One of the secondary potential impacts of water scarcity is that the water supply becomes intermittent, damaging pipes and increasing infiltration into distribution network. Other vulnerabilities include deterioration in water quality from resuspension of sediments with falling water levels, and decreased dilution of sewage disposed of to waterways.

As for increased rainfall, the adaptive capacity of utility-managed piped water supplies was considered to be high. For situations of reduced rainfall, this may include seeking alternative water supplies, or upgrading the treatment to enable the use of poor quality water supplies, or developing greater water storage capacity in the network. These adaptations may be expensive; hence, community-managed piped water supplies are considered less able to adapt.

The resilience of utility-managed piped water supplies to increased rainfall is considered to be high because of this high adaptive capacity, but low for community-managed supplies because of the lack of expertise and the expense of many of the adaptations.

5.1.3 Increased intensity of rainfall

The key vulnerabilities identified for piped water supplies under conditions of increased rainfall intensity were deterioration of water quality and infrastructure damage during flash flooding. Increased run-off during intense rainfall events will increase erosion, increasing turbidity in waterways and increasing the transport of contaminants associated with eroded sediments. Flash flooding can damage water supply infrastructure.

The adaptive capacity is considered to be high, with similar adaptations required under these conditions as discussed above for increased rainfall. Hence, the resilience is also considered high under these conditions for utility-managed systems, but low for community-managed systems.

5.2 Protected wells

Deep boreholes and shallow dug wells have different vulnerabilities. In general, shallow wells are more vulnerable to dropping groundwater levels and contamination of groundwater. For either type of well, good construction is essential to prevent the ingress of contaminated flood waters or contaminated shallow groundwater. Protection zones are also important to reduce the potential for contamination.

One of the key vulnerabilities for all groundwater sources is the lack of knowledge of groundwater recharge and levels, particularly in developing regions, which limits the ability to predict future impacts.

5.2.1 Increased rainfall

Protected wells were considered the most vulnerable water supply facility to increased rainfall in questionnaire responses, with boreholes considered one of the least vulnerable (Table 11).

The key vulnerabilities identified for protected wells under conditions of increased rainfall were deterioration of groundwater quality, particularly shallow groundwater, as a result of increased recharge, and ingress of contaminated water during floods into the well if it is not sealed properly.

For existing protected wells, the main adaptation for increased rainfall is to ensure the integrity of the structure. This will minimize extraction of shallow groundwater and surface water ingress. Long-term adaptation through policy and planning based on monitoring programmes is, however, likely to be more successful, along with siting boreholes within appropriate protection zones to protect water quality or installing deeper wells to avoid contaminated shallow groundwater. The adaptability of shallow wells is considered limited because of the vulnerability of shallow groundwater supplies in terms of both quality and quantity.

The resilience of deep protected wells, such as boreholes, to increased rainfall is considered to be high. The resilience of shallower wells is considered to be low because of the higher vulnerability and low adaptability of these facilities.

5.2.2 Decreased rainfall

Wells were identified as vulnerable to decreased rainfall by the questionnaire respondents. The key vulnerabilities for protected wells under a scenario of decreased rainfall include falling groundwater levels, and increased salinity of groundwater.

The key adaptation options for protected wells were identified as long-term changes through policy and planning, including siting boreholes in higher yield areas and investigating aquifer recharge options. The resilience of protected wells to decreased rainfall was considered to be medium for deep wells and low for shallow wells.

5.2.3 Increased intensity of rainfall

The key vulnerabilities of protected wells to increased intensity of rainfall will depend on the impact on groundwater recharge. Decreases in groundwater recharge will potentially reduce the quantity and quality of available water. Increases in rainfall are also likely to affect water quality. Infrastructure is also vulnerable to flash floods. Respondents to the questionnaire saw protected wells as vulnerable to increased storms, particularly in developing countries. The resilience of protected wells to increased intensity of rainfall was considered to be medium for deep wells and low for shallow wells.

5.3 Protected springs

Protected springs have much greater geographic limitations than any other water source discussed here, and for that reason they have very low adaptive capacity. Furthermore, they have similar vulnerabilities to wells accessing shallow groundwater.

5.3.1 Increased rainfall

The key vulnerabilities of protected springs under conditions of increased rainfall were identified as the potential for deterioration of water quality and damage to infrastructure. Spring water is vulnerable to contamination via infiltration of surface water through soil, as the groundwater passes close to the surface before discharge at the spring. The spring infrastructure may be damaged by erosion and flooding.

The adaptive capacity of springs is limited. To reduce contamination, protection zones can be provided or extended around the spring and at the source of the spring, if known. Alternatively, water treatment can be provided. The construction of the spring housing can be improved to reduce erosion or infrastructure damage during flooding or run-off events.

Overall, the resilience of the protected springs is considered to be medium, as the primary vulnerabilities associated with increased rainfall can be addressed with sufficient skills and funding.

5.3.2 Decreased rainfall

Protected springs are very vulnerable to decreases in rainfall, as they rely on the groundwater level. If the groundwater level drops, this may result in the water quantity from springs decreasing or the springs drying up altogether. However, there are fewer concerns about water quality with decreased rainfall. Respondents to the questionnaire did not consider that protected springs were vulnerable to decreased rainfall, which may reflect a focus on water quality issues.

If the water quantity available from a spring is affected by decreases in rainfall, then the potential adaptations to keep the spring functioning are limited to increasing the groundwater recharge at the source through artificial or managed recharge. However, the adaptive capacity of protected springs is considered to be medium because of the potential to install boreholes and collector wells to access the groundwater.

Because of the consequences of dropping groundwater levels and significant adaptations required, the resilience of protected springs in this case is considered to be low.

5.3.3 Increased intensity of rainfall

The level of vulnerability of protected springs to an increase intensity of rainfall will depend on whether the rainfall leads to an increase or decrease in groundwater recharge. As for decreased rainfall, springs are very vulnerable to decreases in groundwater recharge. Increases in recharge will potentially impact negatively on water quality, and increased intensity of rainfall may damage infrastructure.

The adaptive capacity in this scenario is considered to be low, as for the increased rainfall scenario. The resilience of protected springs to increased intensity of rainfall is considered to be low because of the low adaptive capacity and high vulnerability.

5.4 Rainwater collection

Rainwater collection systems are designed for, and therefore dependent on, a certain volume of rainfall. Hence, adaptability to low rainfall is limited, but issues of high rainfall are easier to address.

5.4.1 Increased rainfall

While increased rainfall will ensure long-term feasibility for rainwater collection systems, they are still vulnerable to infrastructure damage and deterioration in water quality. Roof catchment systems are vulnerable to damage by storms, with storage systems vulnerable to damage and contamination by flooding. Catchment surfaces are vulnerable to contamination, including microorganisms from bird and animal droppings, as well as dust and particulate matter, which can be washed into the collection system.

While the adaptive capacity of rainwater collection systems is generally low to very low, there are a number of adaptations for protecting the quality of the water and the infrastructure from damage. Water quality protection measures might include: management of the collection area; discarding the first flush of water from the catchment surface; water treatment and design; and cleaning and maintenance of the storage reservoir. Because of these adaptation measures, the resilience of rainwater collection systems is considered to be high for increased rainfall.

5.4.2 Decreased rainfall

Under conditions of decreased rainfall, rainwater collection systems are considered to be highly vulnerable. A rainwater system is designed based on historic rainfall data to provide sufficient water for household or community needs, so existing systems in areas of decreasing rainfall quantities are likely not to provide sufficient water. While new systems can be designed to take account of predicted changes in rainfall, in some areas there will not be enough rainfall to provide a viable water supply facility, and there will also be problems with deteriorating water quality. This vulnerability to decreased rainfall was reflected in the questionnaire responses.

The adaptive capacity of rainwater collection systems is limited. Larger collection infrastructure can be used to increase the volume of water collected, and larger storage infrastructure can be used to mitigate the impact of seasonable or variable rainfall. However, these adaptations are expensive and unlikely to be feasible on a household scale. Because of this, the resilience of these facilities is considered to be low.

5.4.3 Increased intensity of rainfall

If increased rainfall intensity is associated with increased variability in rainfall, rainwater collection systems will be vulnerable to these changes, as they may not be able to reliably provide appropriate quantities of water. Greater intensity of rainfall may overload the collection facilities, resulting in less water being collected, as well as potentially damaging the collection infrastructure. Water storage systems are also vulnerable to flash flooding and erosion.

Adaptations to minimize these vulnerabilities include increasing the storage volume and improving the ability of the infrastructure to cope with high intensity events. The resilience is considered to be medium.

5.5 Connection to public sewers

Public sewers have similar vulnerabilities to those of piped water systems. They are vulnerable to variability or disruption of energy supplies, which may result in pumps or treatment failing. They are vulnerable over a large area, potentially affecting many people. But they commonly have the benefit of centralized management and a certain level of expertise and funding available. However, despite their similarities, public sewers were considered to have a lower adaptive capacity than piped drinking-water supplies. While the technology is available to provide safe disposal of sewage, it was considered that the necessary funding or resources would be less readily available than for drinking-water facilities in some countries.

Sewers were rated by questionnaire respondents as the sanitation facility with the most failures associated with it in developing countries, and rated second in developing countries.

5.5.1 Increased rainfall

Sewer systems were considered to have high vulnerability to flooding because of the potential for their failure to affect large areas and populations. As discussed in Section 2.3, flooding of sewer systems can have serious implications for the infrastructure through washing away components, erosion and silt deposition. Sewage treatment plants are typically at the lowest elevation, and therefore prone to flooding. As discussed in Section 2.5.3, there are also serious implications for public health through overflowing of sewage into the flood waters and backing up of sewers into homes.

Increased rainfall will also result in more overflow events for combined sewers. Rising groundwater may increase ingress of water into sewers, affecting treatment capacity, and may make any contamination that leaks out more mobile.

From the questionnaire responses, sewers were perceived to have increased vulnerability with increased rainfall, particularly in developed countries.

The adaptive capacity of public sewers was considered to be medium for increased rainfall. Adaptations to cope with increased rainfall might include storage for combined sewer overflows, separate sewer and storm water systems, valves to prevent back-flow into houses, and infiltration management.

Because of the high vulnerability of these systems, and their centralized management, resilience is considered to be moderate.

5.5.2 Decreased rainfall

Decreased rainfall is generally beneficial for managing sewer systems, but there can be secondary impacts if there is water scarcity. In order to maintain the transport of solids and avoid blockages, sewer systems require the continuous flow of a certain amount of water. Consequently, reduced water flows, resulting from water conservation measures, will affect the transport of gross solids and increase the prospect of blockages. Reduced dilution of sewage may also impact the efficacy of any treatment system. Other vulnerabilities from decreased rainfall include the potential for pipes to be damaged by movement in soils. From the responses to the questionnaire, sewers were seen to have increased vulnerability with decreased rainfall in developing countries. Overall, the vulnerability was considered to be moderate.

There are limited adaptations to address low flow situations, particularly if there are severe water shortages. Adaptations might include a programme of sewer flushing or increasing water availability. The resilience of these systems is considered to be low for decreased rainfall, due to the serious impacts associated with large reduction in water availability.

5.5.3 Increased intensity of rainfall

Public sewers were considered to have similar vulnerabilities and adaptive capacity for increased rainfall intensity as for increased rainfall quantity, because of the similar impacts of erosion and flooding. Resilience was considered to be moderate.

5.6 Connection to septic tanks

Decentralized sanitation facilities, such as septic tanks and pit latrines, have several advantages over centralized sewer systems. There are similar vulnerabilities for both centralized and decentralized systems, but the impact of failure of a decentralized system is much more contained geographically. While there are few adaptations for existing decentralized systems, there are a number of ways to adapt new systems for different conditions.

Septic tanks where effluent is disposed offsite (that is, pumped out and transported offsite) will have similar vulnerabilities to systems where effluent is disposed of onsite, with the added vulnerability associated with the dependency on regular pumping and appropriate disposal of the effluent.

5.6.1 Increased rainfall

According to the questionnaire responses, septic tanks are perceived to have increased vulnerability with increased rainfall in developed countries, but not in developing countries. The key vulnerability was identified as flooding of the septic tank discharging sewage to the house or environment. There is also a risk of longer-term structural damage to the tank during flooding. An onsite effluent disposal area is also vulnerable to flooding with sewage or floodwater, and if there is increased groundwater recharge or increased groundwater levels, may result in greater contamination of the environment. Overall, the vulnerability was considered to be medium.

The key adaptation for septic tanks is appropriate siting and construction to minimize the impacts of changes in rainfall and flood levels. Other adaptations available to reduce the impact of floods on septic tanks include pumping out sewage regularly, but also ensuring that the tank does not float either as a result of rising groundwater or floodwater. Effluent disposal areas can be altered or extended to cope with increased rainfall. The adaptive capacity was considered to be medium.

The resilience of septic tanks to increased rainfall was considered to be moderate because, while they will be affected by increased rainfall and flooding, new systems can be sited to minimize those impacts.

5.6.2 Decreased rainfall

Decreased rainfall will have contrasting impacts on septic tank systems. Low water contents in soils may result in better performance of effluent disposal areas, with reduced transport of contaminants. However, water scarcity may reduce the dilution of the sewage and, with severe reductions in water availability, the ability of the system to function. However, the vulnerability to water scarcity is lower than for connection to sewers due to the lower amount of water required. For systems with offsite effluent disposal, reduced water use will reduce the required frequency of pump-outs, but may require different pump-out methods for the higher solids content. High solids loads in the effluent may pose problems for onsite disposal. According to the questionnaire responses, septic tanks were perceived to have increased vulnerability with decreased rainfall in developed and developing countries. Overall vulnerability was considered to be medium.

The adaptive capacity was considered to be medium to reflect the options for adapting pump-out methods and disposal fields to cope with increased solids loads. Resilience was considered to be moderate.

5.6.3 Increased intensity of rainfall

Septic tanks were considered to have similar vulnerabilities for increased rainfall intensity as for increased rainfall quantity, because of the similar impacts of erosion and flooding. Adaptive capacity was considered to be low. Although there are similarities in the adaptations required for increased rainfall and increased intensity of rainfall, the latter represents a more difficult process to adapt to than a more gradual increase in rainfall. Resilience was considered to be moderate.

5.7 Improved pit latrine

Improved pit latrines have similar advantages to those of septic tanks, with the additional benefit of not being reliant on water. These decentralized systems will have very localized impacts on water quality when they fail, and there are many adaptations used throughout the world for different climatic conditions, as discussed in Section 2.3.3.

Improved pit latrines were rated by questionnaire respondents as the sanitation facility with the most failures associated with it at present in developed countries, but the least vulnerable in developing countries.

5.7.1 Increased rainfall

The vulnerability of pit latrines to increased rainfall was considered to be medium. Individual pit latrines can be flooded by rising groundwater or by floodwaters, discharging excreta into the environment. Rising groundwater levels can also increase the impact of pit latrines on groundwater quality, although generally pit latrines should have a lower impact on surrounding groundwater quality than waterborne sewage from septic tanks. Pit latrines can become inaccessible in floods, and have their structure damaged by flooding and erosion. Deliberate discharge during flooding has also been noted.

However, through appropriate siting and modifications they have a high adaptive capacity. As has been discussed, pit latrines can be adapted for wet and frequently flooded areas, such as by raising them on mounds and having covers fitted during floods. Additionally, pit latrines can be installed as low-cost temporary facilities, in the place of expensive permanent structures that would be need to be abandoned on a regular basis. For existing systems, however, there are limited adaptations available. Resilience was considered to be high.

5.7.2 Decreased rainfall

Vulnerability was considered to be low to very low because decreased rainfall will not generally have an effect on improved pit latrines, and may reduce any impact on surrounding groundwater. Hygiene and cleaning practices may be affected if water is scarce.

The adaptive capacity was considered to be high due to the limited vulnerabilities expected under conditions of decreased rainfall. Resilience was considered to be high for decreased rainfall.

5.7.3 Increased intensity of rainfall

Increased intensity of rainfall may cause increased erosion around, and damage to, the structure. Other vulnerabilities to increased intensity of rainfall will depend on the impact on groundwater recharge. Increased recharge and rising groundwater levels may result in greater contamination of groundwater and potentially flooding of the pit. Decreased recharge and rising groundwater levels would result in less contamination of groundwater. Overall the vulnerability to increased intensity of rainfall was considered to be medium.

The adaptive capacity of improved pit latrines was considered to be medium for increased intensity of rainfall, with adaptations including building more robust structures, with appropriate ditches and planting to protect the latrine from damage from run-off, and appropriate siting. Resilience was considered to be high.

5.8 Resilience matrices

The information collected, through a combination of literature review, questionnaire responses and expert opinion, has identified many vulnerabilities in improved water supply and sanitation facilities to changes in rainfall patterns, as well as many adaptations. As identified in the interviews, many of the adaptations will come, not from new technologies, but from education about how existing technologies are being used or adapted in different climatic conditions worldwide. Based on this review, the vulnerabilities and adaptive capacity, and hence the resilience of each of the improved facilities, are presented below. Table 23 summarizes the degree of vulnerability and adaptive capacity of improved water supply facilities to various changes in rainfall, and identifies their resilience. Table 24 provides the same information for improved sanitation facilities.

These results are also displayed graphically in resilience matrices for the different climate change scenarios discussed: increased rainfall (Figure 19), decreased rainfall (Figure 20) and increased rainfall intensity (Figure 21).

Table 23

Levels of vulnerability, adaptive capacity and resilience of improved water-supply facilities under different climate scenarios (ratings are based on research reported in Chapters 2 and 3, and rankings against other drinking-water supply facilities): vulnerability ratings range from least vulnerable (+) to most vulnerable (+ + +); adaptive capacity ratings range from low (+) to high (+++); resilience ratings range from least resilient (♦) to most resilient (♦♦♦)

	Utility-managed piped water	Community-managed piped water	Protected wells (deep)	Protected wells (shallow)	Protected springs	Rainwater collection
Environmental vulnerability						
Increased rainfall	+ +	+ + +	+	+ + +	+ +	+
Decreased rainfall	+ +	+ + +	+	+ + +	+ + +	+ + +
Increased intensity	+ +	+ + +	+	+ + +	+ + +	+ +

Adaptive capacity						
Increased rainfall	+ + +	+	+ +	+	+	+
Decreased rainfall	+ + +	+	+ +	+	+	+
Increased intensity	+ + +	+	+ +	+	+	+
Resilience						
Increased rainfall	♦♦♦	♦♦	♦♦♦	♦	♦♦	♦♦♦
Decreased rainfall	♦♦♦	♦	♦♦	♦	♦	♦
Increased intensity	♦♦♦	♦	♦♦	♦	♦	♦♦

Table 24

Levels of vulnerability, adaptive capacity and resilience of improved sanitation facilities under different climate scenarios (ratings are based on research reported in Chapters 2 and 3, and rankings against other drinking-water supply facilities): vulnerability ratings range from least vulnerable (+) to most vulnerable (+ + +); adaptive capacity ratings range from low (+) to high (+++); resilience ratings range from least resilient (♦) to most resilient (♦♦♦)

	Connection to public sewers	Connection to septic tanks	Improved pit latrine
Environmental vulnerability			
Increased rainfall	+ + +	+ +	+ +
Decreased rainfall	+ + +	+ +	+
Increased intensity	+ + +	+ +	+ +
Adaptive capacity			
Increased rainfall	+ +	+ +	+ + +
Decreased rainfall	+	+ +	+ + +
Increased intensity	+ +	+	+ +
Resilience			
Increased rainfall	♦♦	♦♦	♦♦♦
Decreased rainfall	♦	♦♦	♦♦♦
Increased intensity	♦♦	♦♦	♦♦♦

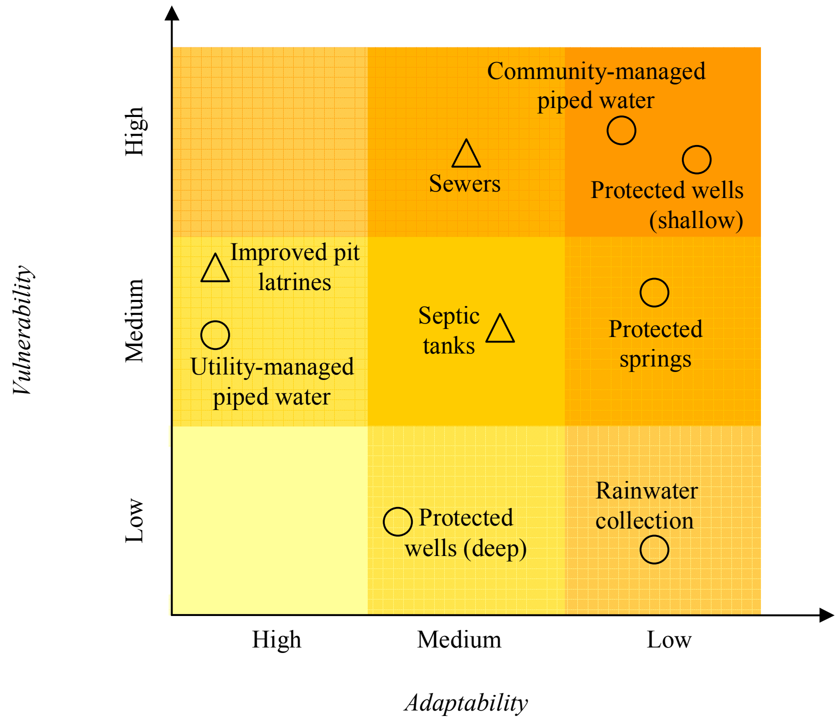


Figure 19
Resilience matrix: vulnerabilities and adaptability of improved drinking-water supply (O) and sanitation (Δ) facilities under conditions of increased rainfall

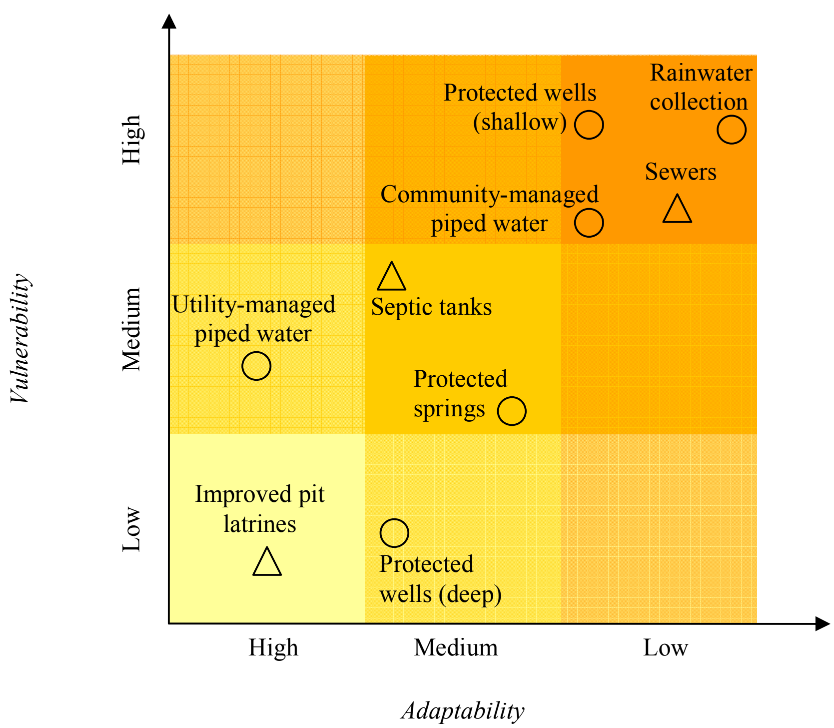


Figure 20
Resilience matrix: vulnerabilities and adaptability of improved drinking-water supply (O) and sanitation (Δ) facilities under conditions of decreased rainfall

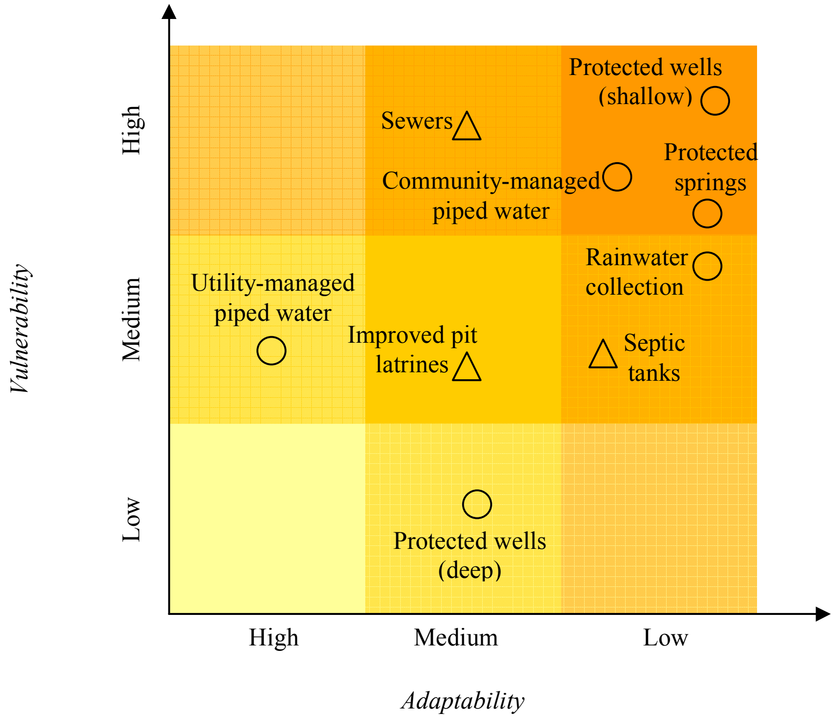


Figure 21
Resilience matrix: vulnerabilities and adaptability of improved drinking-water supply (O) and sanitation (Δ) facilities under conditions of increased rainfall intensity

These matrices are provided to aid in the selection of appropriate water supply and sanitation facilities for the expected climate change. However, local situations should also be taken into account during decision-making. A complementary report (*Climate change projection study*), produced by the Met Office Hadley Centre and included in this CD-ROM, provides detailed predictions of the impact of climate change on rainfall. A few examples are provided below of how the matrices can be applied, using the forecast data from Chapter 4 and the information on climate change. These examples use the climate change predictions from Section 2.5. These climate predictions are generally over longer timescales than the water and sanitation forecasts. However, the trends are likely to be the same.

From Figure 10, Brazil is forecast to have a dramatic decrease in groundwater recharge. This has the potential to interrupt and degrade water supplies for the estimated 11% of its population that will be using protected wells and 2% that will be relying on protected springs in 2020.

Northern China is predicted to have an increase in groundwater recharge. Overall, 17% of China's population is forecast to be dependent on protected wells for their water supply. The quality of this water supply has the potential to be affected by the 11% of the population that will be without access to improved sanitation facilities (a further 53% are forecast to be using septic tanks and pit latrines).

Thailand is forecast to be relying on rainwater for 38% of the population. It is forecast to have more dry days, and more intense rainfall, suggesting that storage facilities for harvested rainwater will need to be increased.

The United States is predicted to have an increase in heavy daily precipitation events, which may have implications for water supply and sanitation in rural areas where 48% of the population are forecast to rely on protected wells for their drinking-water, and 76% are forecast to use septic tanks to manage their sewage.

Drying has been observed in southern Africa and is projected to continue with increasing amounts of dry days. Angola is one country in particular in this region that is forecast to have low access (62%) to improved water sources in 2020. The drying will place stress on existing improved water supplies, potentially slowing development. As a result of drying, there will be less water available, and the water quality in unimproved water supplies will deteriorate.

6. Conclusions: the resilience of water supply and sanitation facilities to climate change

The resilience of water supply and sanitation facilities, and the communities they service, to climate change will depend on understanding and planning for the future climate. Water supply and sanitation are a key sector that is vulnerable to climate change, and this vulnerability will have a direct impact on the ability of some nations to achieve the Millennium Development Goals (MDGs). Changes in rainfall amounts and patterns have the potential to cause significant health impacts. Provision of safe water supply and sanitation facilities can reduce the risk from water-related diseases associated with changes in rainfall amounts and intensities. However, the changing climate may also affect the provision of access to improved water supply and sanitation facilities.

Global warming is already being experienced, resulting in widespread changes in precipitation amounts, and aspects of extreme weather including droughts, heavy precipitation, heat waves and the intensity of tropical cyclones. Significantly increased precipitation has been observed in eastern parts of North and South America, northern Europe, and northern and central Asia, with heavy precipitation events already more frequent over most land areas. Droughts have increased in intensity and length over wide areas since the 1970s, including the Sahel, the Mediterranean, southern Africa and parts of southern Asia.

In the future, climate change is projected to have significant impacts on rainfall amounts and intensity in many areas. Precipitation is very likely to increase in high latitudes and likely to decrease in most sub-tropical land regions. Precipitation is likely to become more intense and more variable over most regions, resulting in heavy downpours and longer dry periods. More intense precipitation events are expected to increase the risk of floods, with floods predicted to increase in severity. Personal observations supported the view that changes in rainfall patterns are already occurring, with decreases in average annual rainfall and increases in rainfall intensity being most commonly noted.

Water quality will be affected by climate change. In regions suffering from droughts, a greater incidence of diarrhoeal and other water-related diseases may arise from deteriorating water quality, populations forced to use unsafe sources, and through a reduction in water use for hygiene. An increase in precipitation amounts and intensity may also lead to a decline in water quality by increasing erosion in the catchment, producing high turbidity in the source water and mobilizing other contaminants, and by increasing the mobility of contaminants, such as pathogens, in groundwater where there is increased groundwater recharge.

Water supply and sanitation facilities will also be affected by the amount of water available, and changes in the timing and intensity of rainfall. The main impacts to sanitation facilities from climatic events in the literature are from floods, whereas drinking-water supply facilities are affected by both floods and droughts.

The vulnerability of drinking-water supply and sanitation facilities to climate change is intrinsically linked to social, economic and environmental factors, as well as the technology used to operate the facility. Effective strategies for reducing the vulnerability of water supply and sanitation facilities require interventions that integrate the social, environmental and economic factors with the adaptation of the technologies.

The literature review and the opinions of respondents to the questionnaire and the interviewees suggest that the operation of all drinking-water supply and sanitation facilities are vulnerable to impacts from changes in precipitation brought about by climate change. However, the impacts of climate change were considered to exacerbate existing problems, not necessarily to create new ones.

In general, respondents answering the questionnaire from developing countries were more concerned about the impacts of climate change on water and sanitation than respondents in developed countries. Yet climate change is not a high priority for the design of water supply and sanitation strategies, particularly in developing countries. Water supply was a bigger concern than sanitation in regard to climate change, with more respondents changing their water supply strategies. Africa was the only region where over half of respondents were changing their implementation strategy for sanitation.

Responses also suggested that climate change is a stronger driver for change of the type of water facilities than for changing the type of sanitation facilities. However, when choosing the type of facility to install, finance is generally the main factor considered.

The vulnerability of centralized systems, particularly for piped water supply systems, was identified in both the questionnaire responses and interviews as being highly vulnerable. This vulnerability was thought to be related to the potential for problems with centralized systems to affect large numbers of people.

Improved drinking-water supply and sanitation facilities of one type or another are available and made to operate effectively on every continent and in every type of climate. There was agreement between all respondents and interviewees who expressed an opinion, that there was not a requirement to develop new water supply and sanitation facilities to deal with climate change. Examples of adaptations to drinking-water supply and sanitation facilities are available and have been shown to increase resilience in the face of changes in precipitation. The challenge is to select the appropriate facility and adaptations for the climate conditions that are predicted to occur in the future.

Although some collaboration was reported to occur between the water and sanitation sector and the water resources sector, it was the overwhelming opinion of the interviewees and respondents that there is a need to improve the dialogue between the sectors in order to deal with climate change impacts. The majority of respondents thought that existing information regarding climate change was inadequate.

The resilience of communities to climate change can be increased by using education and communication in the development of adaptation plans, adopting water safety plans to help provide safe drinking-water, and employing land-use planning to mitigate impacts of flooding.

Communication and research are also required to support policy development. Policy development was considered by interviewees to be inhibited by a lack of sound science. Policies need to be informed by practice, and data collection is required to provide evidence for policy development. More broadly than climate change, there is a need for water and sanitation facilities to be backed by informed understanding of water availability and drought. Interviewees emphasized that prescriptive policies were not seen as the sole answer, rather that there is a need to increase education and awareness of the range of facilities available.

The challenge to the water and sanitation community is to communicate effectively the resilience of water supply and sanitation facilities to different climate conditions, and to disseminate best practice in design, construction, operation and maintenance under these climate conditions to ensure sustainability of the facilities.

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