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DEVELOPMENT AND CLIMATE CHANGE

Costs of Adaptation Related to Industrial and Municipal **Water Supply** and **Riverine Flood** Protection

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Costs of Adaptation Related to Industrial and Municipal **Water Supply** and **Riverine Flood** Protection

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All dollars are U.S. dollars unless otherwise indicated.

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1. INTRODUCTION

This background paper describes the work carried out on one component of a larger World Bank study entitled The Economics of Adaptation to Climate Change (EACC), whose aim is to estimate the costs of adapting to climate change in developing countries over the period 2010–50. The overall objective of the EACC study is to help decision makers in developing countries to better understand and assess the risks posed by climate change and to better design strategies to adapt to climate change. The study is further intended to inform the international community's efforts, including UNFCCC and the Bali Action Plan, to provide access to adequate, predictable, and sustainable support, and to provide new and additional resources to help the most vulnerable developing countries meet adaptation costs.

1.1 MAIN AIMS OF THE CONSULTANCY

Within the framework of the EACC study, the World Bank has commissioned this research to examine the costs of adaptation to climate change in developing countries for (a) industrial and municipal raw water supply, and (b) riverine flood protection.

This paper provides the main findings of this work, and addresses the following research aims of the consultancy:

i. Develop a data base of adaptation policies, programs, and projects that can be used in the water supply sector;
ii. Develop a data base of adaptation policies, programs, and projects that can be used for riverine flood protection;
iii. Estimate climate change adaptation costs in the industrial and municipal water supply sector;
iv. Estimate climate change adaptation costs for riverine flood protection.

The potential effects of climate change on the hydrological cycle are also expected to lead to changes in other water-related sectors, such as health (Confalonieri et al. 2007; Kabat et al. 2003); agriculture (Bates et al. 2008; Easterling et al. 2007; Kabat et al. 2003); industry, transport, and energy supply (Wilbanks et al. 2007); ecosystem services (Fischlin et al. 2007); fisheries (Easterling et al. 2007; FAO 2009); and forestry (Easterling et al. 2007). The impacts of climate change on these sectors are investigated separately in other contributions to the EACC project, and are not discussed further here. Importantly, while agricultural irrigation withdrawals account for almost 70 percent of global water withdrawals, and 90 percent of global consumptive water use (Shiklomanov and Rodda 2003), irrigation is considered in the EACC study as part of agricultural sector work. Hence, in this paper we assume no changes in agricultural water demand in order to avoid double-counting. It should also be noted that coastal and estuarine water resource issues are not considered here, since they too are addressed elsewhere in the EACC project.

All costs in this report are given in 2005 U.S. dollars, unless otherwise stated.

1.2 STRUCTURE OF THE PAPER

In Section 2, the background context of the study is developed, outlining the potential impacts of climate change on water supply and riverine flooding, which regions and population groups are likely to be most severely affected by climate change, and what experience exists in the sectors in terms of adaptation. We also provide information on, and examples of, adaptation policies, programs, and projects that can be used to adapt to climate change in terms of water supply and flood protection, thereby addressing aims i and ii.

A summary of previous research on economic aspects of climate-change-related adaptation in the water sector is provided in section 3. In section 4, we present the methods used to address aims iii and iv of the consultancy; that is, estimating the costs of adaptation to climate change in terms of industrial and municipal water supply and riverine flood protection. The results of the quantitative assessment are presented and discussed in section 5. Finally, conclusions, limitations, and recommendations of the study are presented in section 6.

2. CONTEXT

2.1 WHAT ARE THE POTENTIAL IMPACTS OF CLIMATE CHANGE ON THE SECTOR?

There is a large body of research available on the impacts of climate change on the water sector. Here, we provide an overview of some key findings, based on the Fourth Assessment Report (AR4) of the Intergovernmental Panel on Climate Change (Kundzewicz et al. 2007) and a number of other sources. First, we briefly outline the main physical effects of observed and projected climate change on the water cycle, and then we provide an overview of the impacts of those changes on water supply and flooding. The impact of climate change on these two aspects of water is also strongly dependent on socioeconomic development, as discussed in section 2.1.2.

2.1.1 Physical effects of climate change on the water cycle

There is now strong evidence that climate change is affecting the hydrological cycle. The IPCC AR4 (Kundzewicz et al. 2007) and the IPCC technical paper on climate change and water (Bates et al. 2008), provide comprehensive reviews of recent research on observed and projected hydrological changes over the last several decades. Here we present a summary of these findings:

- **Mean annual precipitation** over land has generally increased over the 20th century between 30°N and 85°N, but notable decreases have occurred in the past 40 years from 10°S to 30°N. The strongest negative trends are observed over western Africa and the Sahel. Over the extra-tropical land masses of the Southern Hemisphere, there are no strong overriding trends. However, increasingly wet conditions have been observed over southeastern areas of South America and the Amazon, while negative trends have been observed over parts of the continent's western coast. In the 21st Century, mean annual precipitation is projected to increase at high latitudes and in some tropical monsoon regions, and decrease in some subtropical and lower mid-latitude regions, except for increases in eastern Asia.
- **Heavy precipitation events** have shown a widespread increase in occurrence during the second half of the 20th century, even in regions where mean annual precipitation has decreased. In the 21st Century, it is very likely that heavy precipitation events will become more frequent, especially in tropical and high-latitude regions that experience increases in mean precipitation.
- The **water vapor** content of the troposphere has increased in recent decades, which is consistent with the observed global warming and near-constant relative humidity. **Potential evapotranspiration** is projected to increase almost everywhere due to increasing temperatures, and an increase in the water-holding capacity of the atmosphere (due to projected higher temperatures combined with little change in relative humidity).
- Globally, **soil moisture** has decreased, especially in the tropics and subtropics. Annual mean soil moisture is projected to decrease in the subtropics and the Mediterranean regions, and at high latitudes where snow cover diminishes. On the other hand, soil moisture is projected to increase in East Africa, central Asia, and some regions with increased precipitation.

- **Snow cover, permafrost, seasonally frozen ground, and glaciers** have all shown significant decreasing trends globally; this is of concern since the cryosphere stores about 75 percent of the world's freshwater, and more than one-sixth of the world's population lives in glacier- or snowmelt-fed river basins (Stern 2006). In the 21st century, increases in global temperatures are projected to lead to further decreases in the various components of the cryosphere.
- The effects of climate change on **groundwater** are less well studied. Groundwater levels in shallow aquifers are affected by changes in climate via the recharge process (Chen et al. 2002). Although there is an observed decreasing trend in groundwater levels during the last few decades, this has been mainly attributed to overextraction; little is known of the impacts of future climate change.
- Observed **annual runoff and river discharge** show a broadly coherent pattern of change at the global scale, with increases in some regions (for example, high latitudes) and decreases in others (for example, parts of west Africa, southern Europe, and southernmost South America). Runoff trends are, however, not always consistent with precipitation changes; they are also influenced by land use and temperature change, and human interventions such as reservoir impoundment. Annual average river runoff is projected to increase as a result of climate change at high latitudes and in some wet tropical areas, and decrease over some dry regions at mid-latitudes and in the dry tropics.
- Changes in the **seasonal discharge pattern** are expected in many regions. A very robust finding is that warming will lead to changes in the seasonality of river flows in areas where much winter season precipitation currently falls as snow, with spring flows decreasing because of reduced or earlier snowmelt, and winter flows increasing. The discharge of rivers draining areas covered by glaciers or snow may increase and experience changes in seasonality in the short term as the cryosphere responds to warming, and decrease in the longer term as the area and volume covered by glaciers or snow is reduced.
- Although the costs of adaptation to changes in **water quality** are not assessed in this study, this will also be affected by climate change. Climate change is expected to worsen many forms of water pollution as a result of higher water temperatures, increased precipitation intensity, and low flow periods. In Box 2.1, the main findings of the IPCC on water quality are summarized.

2.1.2 Impacts of climate change and non-climate drivers on water supply and flooding

Water supply. Section 2.1.1 gives an overview of how the availability of water is expected to change as a result of climate change. However, many other

BOX 2.1. IMPACTS OF CLIMATE CHANGE ON WATER QUALITY

Climate change is expected to worsen many forms of water pollution, including the load of sediments, nutrients, dissolved organic carbon, pathogens, pesticides, and salt, as well as thermal pollution, as a result of higher water temperatures, increased precipitation intensity, and low flow periods (Kundzewicz et al. 2007). This may promote algal blooms (Hall et al. 2002; Kumagai et al. 2003), and increase the bacterial and fungal content of water (Environment Canada 2001). In turn, these processes will impact on ecosystems, human health, and the reliability and operating costs of water systems. Rising temperatures are likely to lower the water quality of lakes (Kundzewicz et al. 2007), as a result of increased thermal stability, resulting in reduced oxygen concentrations and an increased release of phosphorus from sediments (Nicholls 1999). However, rising temperatures can also improve water quality during the winter and spring due to the earlier break-up of ice; this can lead to higher oxygen levels, and as a result a reduction in winter fish-kill (Kundzewicz et al. 2007). More intense rainfall may lead to an increase in suspended solids (increasing turbidity) in lakes and reservoirs due to increased soil fluvial erosion (Leemans and Kleidon 2002), thereby increasing the delivery of adsorbed pollutants such as phosphorous and heavy metals (Boers 1996; Bouraoui et al.,2004; De Wit and Behrendt 1999; Mimikou et al. 2000; Neff et al. 2000; Verstraeten et al. 2002). However, soil erosion and the delivery of sediments to rivers is also highly dependent on land use (Houben et al. 2006; Toy et al. 2002; Van Rompaey et al. 2002; Ward et al. 2009). In addition, more frequent heavy rainfall events may overload the capacity of sewer systems and water and wastewater treatment plants more often. Increased occurrences of low flows will lead to decreased contaminant dilution capacities, and therefore higher pollutant concentrations. Water quality deterioration is expected to be a particular problem in many arid and semi-arid areas, where climate change is *likely* to increase salinization of shallow groundwater due to increased evapotranspiration (Kundzewicz et al. 2007); as stream flow is projected to decrease in many semi-arid areas, the salinity of rivers and estuaries will increase.

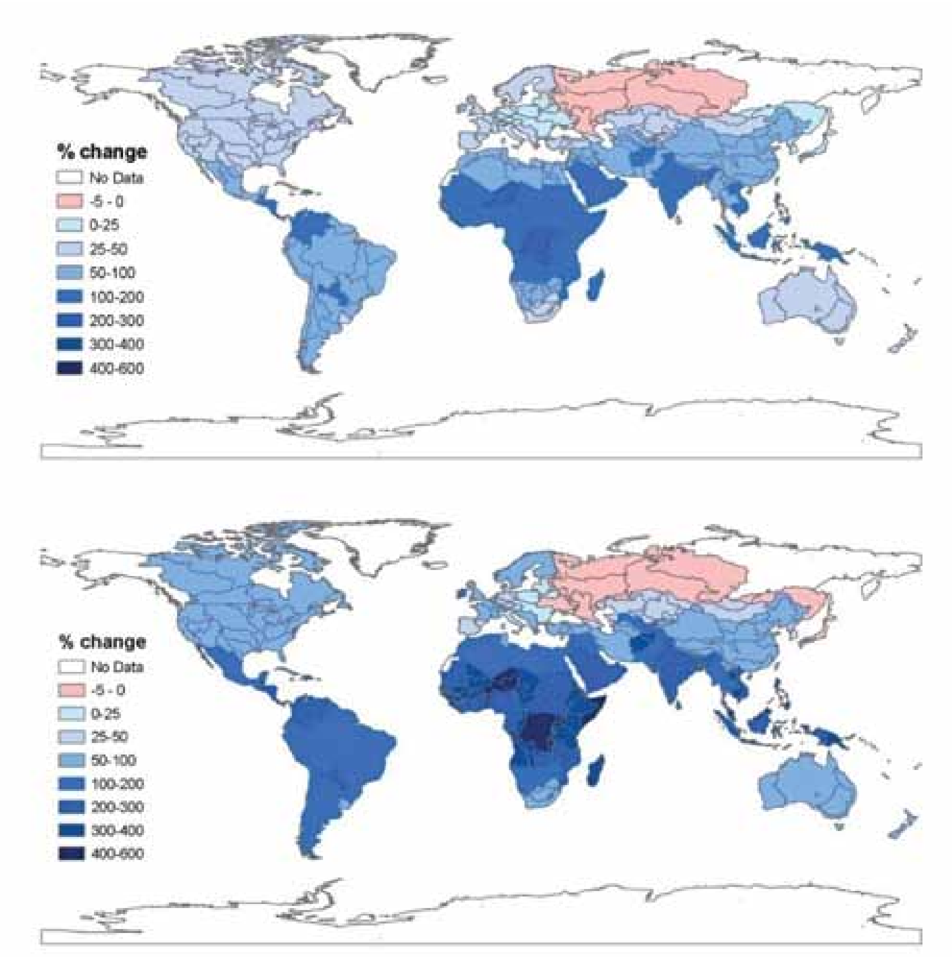
non-climatic drivers also affect the availability of freshwater resources at the global scale (UN 2003). For example, the availability of water is strongly influenced by land-use change (Andréassian 2004; Calder 1993; Iroumé et al. 2005; Mahe et al. 2005; Scott et al. 2005; Ward et al. 2008), but also by the construction of reservoirs and other retaining features (Ward and Robinson 1999; WCD 2000). Moreover, water supply—that is, the water that is supplied to sectoral users to meet their water demands—is not only affected by changes in water availability, but also by changes in water demand.

The IPCC (Bates et al. 2008) states that the increase in household and industrial water demand due to climate change is likely to be rather small, for example less than 5 percent by 2050 at selected locations (Downing et al. 2003; Mote et al. 1999). Nevertheless, large increases in global municipal and industrial water demand are expected as a result of non-climatic drivers, mainly population growth and economic development, and also changing societal views on the value of water (Kundzewicz et al. 2007). There are many plausible scenarios of future domestic and industrial water demand available, but their results can vary strongly (Alcamo et al. 2000; Gleick 2003; Millennium Ecosystem Assessment 2005a,b; Seckler et al. 1998; Vörösmarty et al. 2000). In Figure 2.1, the changes in water demand due to non-climatic drivers between 2005 and 2030, and between 2005 and 2050, are shown for 281 FPUs (Food Producing Units) based on the water-demand scenario used throughout the EACC study. The method used to produce these scenarios is described in the main EACC report. The FPUs of IFPRI (The International Food Policy Research Institute) and IWMI (International Water Management Institute) divide the world into 281 sub-basins, where each sub-basin represents a hybrid between river basins and economic regions, and are discussed in Section 4.1. This scenario shows an increase in water demand in most parts of the world, including OECD countries; this latter finding is contrary to the findings of some projections, for example Gleick (2003), which show a decrease in this region. The maps in Figure 2.1 clearly show that the increase in water demand is expected to be greatest in the developing world. The results of the Millennium Ecosystem Assessment (2005a,b) show a global increase in domestic and industrial water demand of between 14 and 83 percent by 2050.

Agriculture is currently the largest sector in terms of water withdrawal and use: irrigation water withdrawals account for almost 70 percent of global withdrawals, and 90 percent of global consumptive water use (Shiklomanov and Rodda 2003). Research into the non-climate-change-related changes in irrigation water demand in the future show differing results. An FAO study shows an increase in irrigation water withdrawals of 14 percent by 2030 for developing countries (Bruinsma 2003), while the four Millennium Ecosystem Assessment scenarios show much smaller increases at the global scale, ranging between 0–6 percent by 2030, and 0–10 percent by 2050 (Millennium Ecosystem Assessment 2005a,b). These increases are smaller in relative terms than those projected for domestic and industrial water use; this is, based on the idea that the value of water will be much higher for the latter uses (Kundzewicz et al. 2007). According to the IPCC (Kundzewicz et al. 2007), there were no global estimates of the impacts of climate change on irrigated water demand at the time of publication. However, Bates et al. (2008) state that higher temperatures and increased precipitation variability would, in general, lead to increased irrigation water demand, even if the total precipitation in the growing season does not change. Nevertheless, the water demand of the agricultural sector will clearly be affected by changes in irrigation methods and their effectiveness, as well as the price of water.

The differences between water availability and water demand can lead to situations of water stres, which is defined by the IPCC as per capita water availability below 1,000 m^3 per year (Bates et al. 2008). Global assessments of water stress suggest that the current population living in water-stressed basins is between 1.4 to 2.1 billion (Alcamo et al. 2003a,b; Arnell 2004; Oki et al. 2003; Vörösmarty et al. 2000). Most research has found that levels of water stress will increase in the future as a result of both climatic and non-climatic drivers, although there are large differences in estimates across studies. Arnell (2004), who accounted for population growth and the impact of climate change, found that the number of people projected to experience an increase in water stress is between 0.4–1.7 billion in the 2020s, and between 1.0–2.7 billion in the 2050s; this is based on the Special Report on Emission Scenarios (SRES) A2 population scenario for the 2050s (IPCC 2000). When environmental flows—that is, the amount of water required to sustain functioning

FIGURE 2.1. PROJECTED CHANGES (PERCENT) IN MUNICIPAL AND INDUSTRIAL WATER DEMAND PER FOOD PRODUCING UNIT (FPU), 2005 AND 2030 (ABOVE), AND 2005 AND 2050 (BELOW), DUE TO NON-CLIMATIC DRIVERS ACCORDING TO THE SOCIOECONOMIC SCENARIO USED THROUGHOUT THE EACC STUDY.



Note: The FPUs divide the world into 281 sub-basins, where each sub-basin represents a hybrid between river basins and economic regions (see section 4.1).

ecosystems—are incorporated, the degree of water stress may increase further (Smakhtin et al. 2003). Based on these and other studies, the IPCC concluded with high confidence that globally the negative impacts of future climate change on freshwater systems and ecosystems are expected to outweigh the benefits (Kundzewicz et al. 2007). However, it should be noted that these studies do not consider the role of adaptation (planned and autonomous) in reducing water stress. Regional patterns of water stress are discussed further in section 2.2.

Changes in water availability and demand can have serious impacts on the frequency and intensity of droughts. The term drought can refer to: meteorological drought (precipitation well below annual/seasonal average); hydrological drought (low river flows and water levels in rivers, lakes, and groundwater); agricultural drought (low soil moisture with adverse effects on agricultural output); and environmental drought (a combination of the above) (Kundzewicz et al. 2007). Since the 1970s, droughts have become more common, especially in the tropics and subtropics. According to the IPCC, it is *more likely than not* that there is a human contribution to this trend (IPCC 2007). Furthermore, it is *likely* that the area affected by drought will increase in the future, with a tendency for drying of mid-continental areas during summer, leading to an increased risk of droughts in those regions (Bates et al. 2007). A single-model study of global drought frequency suggests that the percentage of land experiencing extreme drought at any one time will increase 10- to 30-fold by the 2090s, under SRES scenario A2 (Burke et al. 2006).

Riverine flooding. The changes in climate and hydrological parameters discussed in section 2.1.1 are expected to lead to changes in the frequency and intensity of riverine floods (Vörösmarty et al. 2000; Wetherald and Manabe 2002). The observed changes in precipitation intensity suggest that climate change may already have had an impact on floods. Globally, the number of great inland flood catastrophes during the period 1996–2005 was twice as many as the decadal average in the period 1950 to 1980 (Kundzewicz et al. 2007). However, there is no clear-cut evidence of a climate-related increasing trend in flood frequency during the last decades of the 20th Century (Kundzewicz et al. 2005; Schiermeier 2006), as the occurrence of flooding is also dependent on many other factors such as land use change (Andréassian 2004; Brown et al. 2005; Calder 1993; EEA 2001; Fahey 1994; Gentry and Parody 1980; Jones 2000; Mahe et al. 2005; Robinson et al. 1991; Ward et al. 2008), river confinement (Kundzewicz and Schellnhuber 2004; Milly et al. 2002), and the presence/absence of other adaptation measures (Bates et al. 2008; Deltacommissie 2008). Nevertheless, many studies show that the projected increases in precipitation totals and intensity in many river basins in the 21st century are expected to lead to an increase in the frequency of flood events (Huntington 2006; Kleinen and Petschel-Held 2007; Milly et al. 2002, 2005; Palmer and Räisänen 2002; Voss et al. 2002). For example, Milly et al. (2002) found that for fifteen out of sixteen large basins that they modeled worldwide, a quadrupling of CO_2 would lead to the much more frequent recurrence of the current 1/100 year peak flow. For some areas, they found that the current 1/100 year peak flow may occur once in every 2 to 5 years by 2100 as a result of climate change.

Traditionally, flood assessments have examined how climatic, hydrological, and socioeconomic changes may affect the probability of flooding, as discussed above. However, there is currently an international shift toward a more integrated system of flood risk assessment (Büchele et al. 2006; Merz et al. 2004), whereby flood risk can be defined as the probability of flooding multiplied by the potential flood damage (Smith 1994). These potential damages can be measured in terms of economic damage and the loss of human lives. Flood risk is therefore not only determined by the factors listed above that control flood probability, but also by the scale and type of developments in flood-prone areas (Kundzewicz and Schellnhuber 2004). The economic value of developments in flood-prone areas, as well as population density, is expected to increase in the future (Bouwer et al. 2007), despite new spatial planning policies and legislation adopted by some countries to minimize developments in flood-prone areas (Pottier et al. 2005). However, while modeling studies of flood damage and risk have been carried out at local to basin scales (Dutta et al. 2003; Hall et al. 2005; IKSR 2001; Lekuthai and Vongvisessomjai 2001; Nascimento et al. 2006), data limitations, scale issues, and current methodologies do not (yet) allow flood damage and risk modeling at the global scale.

2.2 WHO (ACROSS AND WITHIN COUNTRIES) IS LIKELY TO BE MOST AFFECTED?

The impacts of climate change on the water sector will be felt in both developed and developing countries. However, as stated by IPCC (2007), many regions of the developing world are particularly vulnerable. Vulnerability is defined by IPCC as the degree to which geophysical, biological, and socioeconomic systems are susceptible to, or unable to cope with, adverse effects of climate change, including climate variability and extremes. It is a function of, among other things, the character, magnitude, and rate of climate variation and climate change to which a system is exposed, its sensitivity, and its adaptive capacity.

Arnell et al. (2001) identified several factors, both physical and societal, which have been associated with high levels of vulnerability in the water sector. A number of these are summarized below:

Physical Features

- A current hydrological and climatic regime that is marginal for agriculture and livestock
- A highly seasonal hydrological setting
- High rates of sedimentation in reservoirs
- Topography and land-use patterns that promote soil erosion and flash flooding
-
- Lack of variety in climatic conditions across a region, leading to an inability to relocate activities in response to climate change

Societal Characteristics

- Poverty and low incomes, which prevent long-term planning at the household level
- Lack of infrastructure, or poor maintenance of existing infrastructure
- Lack of human capital skills for system planning and management
- Lack of appropriate, empowering institutions
- Absence of appropriate land-use planning
- High population densities and other factors that inhibit population mobility
- Increasing demand for water because of rapid population growth
- Conservative attitudes toward risk
- Lack of formal links among various parties involved in water management

Many of these factors are prevalent in large parts of the developing world, and so the negative impacts of climate change are likely to be greatest there. This is supported by the results of several global estimates of vulnerability, which show medium to high vulnerability in large parts of the developing world (Alcamo and Heinrichs 2002; Raskin et al. 1997; Sullivan 2006); see, for example, Box 2.2.

Water-stressed river basins are mainly located in northern Africa, the Mediterranean, the Middle East, the Near East, southern Asia, the United States, Mexico, north-eastern Brazil, and the west coast of South America (Bates et al. 2008). A number of global-scale (Alcamo and Heinrichs 2002; Arnell 2004), national-scale (Thomson et al. 2005), and basin-scale assessments (Barnett et al. 2004) show that semi-arid and arid basins are the most vulnerable with respect to water stress as a result of climate change.

Africa is one of the regions of the world that is potentially most vulnerable to climate change in terms of water supply, as a large share of the economy of African countries tends to be in climate-sensitive sectors (Smith and Lenhart 1996). Climate change research in Africa suggests that the population at risk of increased water stress will be between 75–250 million by the 2020s, and 350–600 million by the 2050s (for the full range of SRES scenarios). However, the impact of climate change on water supply will not be uniform across the continent; the results of six climate models show that the climatic impact on water stress is a likely increase in the number of people living under water-stressed conditions in northern and southern Africa, with a decrease in eastern and western Africa (Arnell 2004).

Between the 1950s and the 1990s, annual economic losses from large extreme events have increased tenfold. In terms of flood losses, the developing world, and particularly South and East Asia, have been the hardest hit (Kabat et al. 2003). Although these increases in losses are also attributable to a myriad of non-climatic drivers,—including population growth, expansions into flood-prone areas, land use changes, and manipulation of water within channels—climatic factors are partly responsible. According to Kleinen and Petschel-Held (2007), up to 20 percent of the world's population will live in river basins that are likely to be affected by climate-change-related increases in flood hazards by the 2080s.

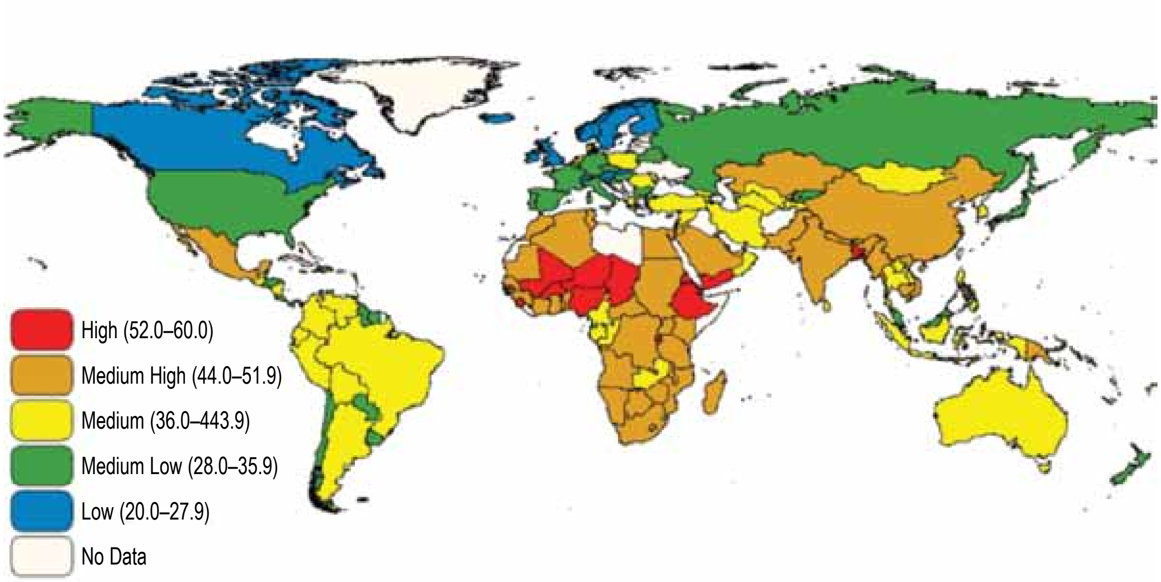
Floodplain areas downstream from glaciers are likely to be particularly vulnerable to increasing flood hazards and flood risks in the coming decades (Bates et al. 2008). The rapid melting of glaciers, due to increased temperatures, can lead to river flooding and to the formation of glacial melt-water lakes, which can lead to a serious threat of outburst floods (Coudrain et al. 2005). Moreover, these areas may face increased water stress in the longer term, since the reduction or disappearance of glacier mass will lead to reductions in glacial melt-water supply.

The impacts of climate change, both in terms of water supply and flooding, may be particularly strongly felt in transboundary river basins. In many developing countries, sharing the water resources of river basins between riparian states, and coordinating flood management, remains challenged by weak institutional

BOX 2.2. CLIMATE VULNERABILITY INDEX

Vulnerability to global changes depends on a combination of factors. For the water resources sector, vulnerability is not only influenced by the quantity of water available, but also by a range of social, economic, and environmental factors that affect the ability to cope with changing conditions. In order to identify the most vulnerable regions, a new approach to this problem has been developed through the application of a Climate Vulnerability Index (CVI). The CVI is a holistic methodology for water resources evaluation in keeping with the sustainable livelihoods approach used by many donor organizations to evaluate development progress. The scores of the index range are on a scale of 0 to 100, with the total score being a weighted average of six major components, namely: resources, access, capacity, use, environment, and geospatial. The map of CVI scores below is an illustrative result only, but it does demonstrate the technique's power.

Estimated CVI scores for 148 countries



Source: http://ocwr.ouce.ox.ac.uk/research/wmpg/cvi/cvi_leaflet.pdf

arrangements and inadequate infrastructure. Regardless of the level of economic development, climate change poses a threat to these basins. Projected changes in water resources and flood frequency due to climate change can impact the water balance and consequently the hydro-political balance (World Bank 2009). Wolf et al. (2003) indicate that historically extreme conflicts over water have been more common in water-scarce regions where extreme conditions characterized by high interannual variability occur.

The extent to which people will be affected by climate change is also strongly related to their adaptive capacity, which is influenced by economic and natural resources, social networks, entitlements, institutions and governance, human resources, and technology (Adger et al. 2007); this is discussed further in section 2.6.

2.3 UNCERTAINTIES IN CLIMATE CHANGE IMPACTS

There are significant uncertainties in projections of the impacts of climate change on water resources. Uncertainties in the impacts of climate change on the hydrological cycle can arise from a myriad of sources, including uncertainties in: the internal variability of the climate system; in the future greenhouse gas and aerosol emission scenarios (and in the scenarios of population, economic development, and technological change that generate them); in the translation of these emissions scenarios into climate change by climate models; in the methods used to downscale climate model data to the lower resolutions required in hydrological impact assessments; and in the hydrological models used to simulate the impacts of climate change on the hydrological cycle. The largest of these uncertainties in climate change impact assessments on water resources are due to the uncertainty in precipitation inputs (Bates et al. 2008).

When assessing the impacts of climate change on water supply, further uncertainties are added with regard to the socioeconomic scenarios used to project future water demand (Bates et al. 2008). When assessing flood hazards, with or without climate change, uncertainties are added through the extrapolation of relatively short observed or simulated time-series of discharge to estimate the return period of rare flood events. Even in basins for which relatively long and reliable observed records exist (e.g., 100 years), the extrapolation of these data to predict events with longer return periods remains problematic for the current climate, let alone under scenarios of future climate change (Box 2.3).

2.4 WHAT EXPERIENCE IS THERE WITH ADAPTATION IN THE SECTOR?

Even if emissions of anthropogenic greenhouse gases were stabilized today, human-induced changes in climate will continue for many centuries (IPCC 2007). Therefore, in addition to mitigation, it is essential to develop adequate adaptation measures to moderate the impacts and realize the opportunities associated with climate change. There are many definitions of what constitutes adaptation to climate change; these are discussed in the main EACC report.

Adaptation to changing conditions in water availability and demand has always been at the core of water management (Adger et al. 2007). Traditionally, water managers and users have relied on historical experience when planning water supplies and distribution (UNFCCC 2007). Water supply management has mainly concentrated on meeting increasing water demand, and flood defense measures have assumed stationary flood recurrence periods. However, under a changing climate, these assumptions are no longer valid (Kundzewicz et al. 2007). Therefore, current water management practices need to be redesigned, and the procedures for designing water-related infrastructure need to be revised. Otherwise, systems may be wrongly conceived, and under- or overdesigned, with either inadequate performance or excessive costs as a result. However, necessary adaptation to climate change in the water sector goes beyond structural measures, but also includes forecasting/warning systems, insurance instruments, and a large variety of means to improve water use efficiency and related behavioral change, economic and fiscal instruments, legislation, and institutional change (Kundzewicz et al. 2008).

Although climate change is not directly addressed in the eight Millennium Development Goals (MDGs), most of them are directly or indirectly related to water (Kundzewicz et al. 2007). Hence, adaptation to climate change in the water sector (as in all sectors) should be carried out in a manner that is synergistic with development priorities in general (Adger et al. 2007; Kundzewicz et al. 2007; Ribot et al. 1996), and climate

BOX 2.3. UNCERTAINTY IN FLOOD RETURN PERIOD ESTIMATES

Traditional flood management practices rely strongly on technical engineering capacity for reducing the probability of a flood, whereby flood defenses are designed to withstand a so-called design discharge; that is, the discharge that occurs, on average, once in a given number of years, or the so-called return period (TAW 2000). In the Netherlands, which has one of the world's most advanced flood management systems, the design discharge for embanked river sections is based on a return period of 1,250 years. For the Meuse River, which enters the Netherlands at Borgharen (flowing from Belgium), the method used to determine the design discharge involves obtaining and analyzing observed annual maximum discharges at Borgharen since 1911. Several theoretical distribution functions are fitted to these observed maxima, and are then used to make an extrapolation to the required exceedance probability. The design discharge is then calculated based on a combination of different extreme-value statistics distribution functions, where the weights are determined by Bayesian analysis. However, the estimation of discharges with return periods of 100–10,000 years via statistical extrapolation based on about 100 years of discharge observations introduces large uncertainties (De Wit and Buishand 2007). Firstly, it is not known how representative the ca. 100-year observed discharge record is. For example, the discharge with a return period of 1,250 years, as estimated in 1996 and 2001, was 3650 m^3s^{-1} and 3800 m^3s^{-1} respectively. This increase is mainly due to the extension of the observed record with a relatively wet period from 1996–2001. This problem is even greater in most basins, since the length of the observed discharge record of the Meuse is relatively long compared to average. Furthermore, the choice of frequency distributions used introduces even more uncertainty.

policy should be embedded in general development policy.

In this section, we provide an overview of a number of available adaptation measures in terms of water supply and riverine flood protection. A few points should be noted. First, in the EACC study, the World Bank differentiates between four categories of adaptation measures: autonomous adaptation, public sector investment, "soft" adaptation, and reactive adaptation. Hence, we have used these categories in this assessment. However, these categories are clearly not mutually exclusive; most forms of adaptation fall into several of these categories. Second, the list of adaptation options is not exhaustive, because the measures available are so diverse, and novel adaptation measures are constantly being developed. Third, as already stated, adaptation to climate change should be carried out in the framework of sustainable development in general. Undertaking interventions that create more stress in the long term does not help to reduce vulnerability to climate change. Fourth, some measures that can be taken to improve the situation in the water sector should be considered regardless of climate change. For example, measures to reduce water transmission losses—for example, reducing pipe leakage—have huge impacts on water supply, but we do not list this as an adaptation to climate change *per se*.

Adaptation options designed to ensure water supply during average and drought conditions require integrated demand-side and supply-side strategies (Bates et al. 2008). Supply-side options generally involve increases in storage capacities or abstraction of (partly) untapped sources, and can therefore have adverse environmental consequences (Bates et al. 2008; Kundzewicz et al. 2007). Some supply-side options may also be inconsistent with climate change mitigation measures because they involve high energy consumption, such as desalination, and to a lesser extent, pumping. Conversely, demand-side options may lack practical effectiveness because they rely on the cumulative actions of individuals (Bates et al. 2008; Kundzewicz et al. 2007). As agriculture is the largest sector in terms of land occupation, a large sector in terms of GDP in developing countries (Kandlikar and Risbey 2000; Nhemachena and Hassan 2007), and irrigation is responsible for 70 percent of global water withdrawals, we include a number of water-related farm-level adaptation measures in this section. An overview of the costs associated with several adaptation measures, both on the supply and demand side, can be found in Box 2.4. Options to counteract increasing flood risk can be divided into two categories: either to modify the probability of flooding, or to modify the flood damage in the event of flooding. Each adaptation measure has advantages and disadvantages, and the choice for one measure or another is site-specific and should be tailor-made: there is no single one-size-fits-all measure (WCD 2000; Bates et al. 2008).

2.4.1 Autonomous adaptation

A distinction is frequently made between autonomous and planned adaptation. Autonomous adaptation measures are those that do not necessarily constitute conscious responses to climate change, but result from changes to meet altered demands, objectives, and expectations that, while not deliberately designed to cope with climate change, may lessen the (likely) consequences of that change (Feenstra et al. 1998). Farm-level adaptation is often referred to as "autonomous," as farmers undertake action without government intervention, such as a decision to change the time of planting or change crop type. However, from a farmer's perspective this is not a spontaneous action, but is likely to have involved some serious consideration and advance planning (Feenstra et al. 1998). Autonomous adaptation is widely interpreted as incorporating actions taken by private actors rather than governments; in fact, autonomous and private adaptation measures are generally one and the same (Smit and Pilifosova 2003). Such adaptations are widespread in the water sector, although with varying degrees of effectiveness in coping with climate change.

In the conventional way of identifying planned adaptation needs, the occurrence of autonomous adaptation is assumed up to a certain level. Policy response and planned adaptations are then only needed for the residual impact of climate change; that is, the impact that appears to remain after autonomous adaptation has taken place (Smit and Pilifosova 2003). The extent to which autonomous, private, or market adaptation can reduce the societal impacts of climate change to an acceptable or non-dangerous level is an issue of great interest (Smit and Pilifosova 2003). Researching this issue automatically leads to the question of adaptive capacities (Adger 2003) (see section 2.6).

BOX 2.4. COSTS OF SEVERAL ADAPTATION MEASURES IN WATER SUPPLY AND DEMAND

Most of the estimates of the costs of both supply and demand adaptation options in the table below are taken from the final report of the World Commission on Dams (WCD) (Sutherland and Fenn 2000), with additional information from Zhou and Tol (2005). The costs in the WCD were originally reported in USD2000, and have been adjusted to USD2005 using the WDI Deflator Index of the World Bank. Of these options, it can be seen that small-scale rainwater harvesting measures tend to provide a cost-effective form of water supply adaptation. Moreover, many of these schemes are easy to implement. The recycling of water is also an economically viable and sustainable option in many municipal and industrial situations. Zhou and Tol (2005) state that while there are large differences depending on the method used, desalination is feasible today at a cost of \$1.00/m^3 for seawater, and \$0.60/m^3 for brackish water; this cost is expected to continue to decline in the future as technology progresses. The latter study also estimates the cost of transporting water at ca. 0.05–0.06m^3 per 100 km in terms of horizontal transport, and ca. 0.05–0.06m^3 per 100 m of vertical lift. Transport makes desalinated water prohibitively expensive in highlands and continental interiors, but not elsewhere.

Option	*Location*	*Cost (USD 2005)*	*Cost basis*	*Source*
Rainwater harvesting				
1-2-1 rainwater project	China	0.10/m^3	30 yrs life; replacement after 15 yr. Rain 4 months/yr	Sutherland and Fenn, 2000
Rainwater jars	Thailand	0.03/m^3	30 yrs life; replacement after 10 & 20 yrs. Rain 4 months/yr	Sutherland and Fenn, 2000
Rooftop to tanks	Sri Lanka	0.25/m^3	30 yrs life; replacement after 10 & 20 yrs. Rain 4 months/yr	Sutherland and Fenn, 2000
Recycling				
Recycling California	USA	0.39/m^3		Sutherland and Fenn, 2000
Recycling Durban	South Africa	0.03/m^3		Sutherland and Fenn, 2000
Discrete private sector distribution; purchase of water from mains at one point	Haiti	0.94/m^3	Based on breakdown of water charge to cover costs	Sutherland and Fenn, 2000
Ultra-low toilet retrofitting	USA	0.18/m^3	USD2000 200/acre foot	Sutherland and Fenn, 2000
Metering	UK	1.13/m^3		Sutherland and Fenn, 2000
Desalination				
Desalination seawater	Global	1.00/m^3		Zhou & Tol, 2005
Desalination brackish water	Global	0.60/m^3		Zhou & Tol, 2005
Water transport	Global	0.05-0.06/100km	Cost per 100 km horizontal transport or 100 m vertical lift	Zhou & Tol, 2005

Some of the main constraints of autonomous adaptation are a private deficiency of information and access to resources, relatively high adaptation costs, and the incurrence of residual damages. Furthermore, autonomous adaptation can lead to a perception of reduced risk to climate change, which is not always correct (Smit and Pilifosova, 2003).

2.4.1.1 Demand-side autonomous adaptation

Improving water efficient technologies. This adaptation measure can be considered as autonomous, since water efficient technologies are developed by private parties, and purchased by private individuals in order to reduce consumption and thus cost. Hence, these measures may perform better where water services are fully priced (see section 2.4.3). Examples of water efficient technologies include ultra-low-flow toilets, low-flow showers, hand basin spray taps, and waterless urinals (Sutherland and Fenn 2000). The market uptake for such technologies can be influenced by policy (section 2.4.3).

Diversifying crop types and varieties, including substitution. This measure has the potential to reduce a farmers' exposure to climate change and to increase the flexibility of farm production. Substitution to more drought-tolerant crops can greatly increase the coping ability during droughts (Gbetibouo 2009; Nhemachena and Hassan 2007; Smit and Skinner 2002).

Diversifying livestock types and varieties, including substitution. This measure is essentially the same as the previous one, but for livestock farmers. It has the potential to reduce a farmers' exposure to climate change and to increase the flexibility of farm production (Smit and Skinner 2002).

Planting trees. Reduces exposure to climate change and increases the flexibility of farm production (Deressa et al. 2009). However, to plant trees and to harvest fruit is a multiple-year investment; if the tree dies, it takes years before a new tree produces fruits or other tangible products. This makes the planting of trees as an adaptive option vulnerable to climatic extremes.

Changing the intensity of production. If precipitation is a limiting factor in crop growth, a change in the amount of precipitation can create chances to plant more or force a farmer to plant less. A decreasing trend in precipitation could be coped with by planting less, so as to ensure that the planted crops at least reach a mature state. This adaptive measure reduces exposure to climate change, and increases flexibility of farm production (Smit and Skinner 2002).

Changing the location of production. A more drastic measure to cope with climate change is to alter land use by changing the location of production to more suitable lands. Moving away from marginal areas has the potential to reduce soil erosion and improve moisture and nutrient retention. However, it may reduce the acreage of land that is available for agricultural production (Smit and Skinner 2002), and there may not be land available to move to, leading to conflicts.

Alternative fallow and tillage practices. This measure has the potential to reduce soil erosion and improve moisture and nutrient retention (Smit and Skinner 2002).

Increasing the efficiency of irrigation. Measures that improve the efficiency of irrigation systems allow for greater flexibility as water consumption reduces while crop yields are maintained (Smith and Lenhart 1996). These measures could be technical—for example, changing sprinkler irrigation to drip-irrigation— but changing the timing of irrigation toward less sunny hours of the day is also beneficial.

Changing the timing of production. By changing the timing of seeding, farmers can maximize farm productivity during the growing season and avoid heat stress and moisture deficiencies. However, for this to work, there needs to be some stability in the seasons, or long-term weather forecasts; otherwise, farmers do not know when they should plant (Smit and Skinner 2002). Farmers can also adapt to changing seasons by spreading their seeding activities over a longer period.

2.4.1.2 Supply-side autonomous adaptation

Rainwater harvesting. Surface runoff can cause erosion, a loss of soil nutrients, and a loss of soil moisture holding capacity. Furthermore, the rapid runoff of water and overextraction of groundwater can lead to decreased groundwater tables. Micro-catchment water harvesting systems help to increase soil moisture retention and groundwater levels by increasing groundwater recharge, and reducing the loss of runoff (Vohland and Barry 2009). However, in some cases the space put aside for these measures cannot be used for growing crops, and can lead to farmer opposition (Smit and Skinner 2002). When implemented as part of a sustainable water management plan at the local level, rainwater harvesting has great potential (Box 2.5). Rainwater harvesting can also be carried out at the household level, for example by capturing rainwater on roofs and collecting this in tanks. This technique is gaining popularity in all parts of the world, developed and developing countries alike (Bates et al. 2008); costs vary geographically, but are generally low (Box 2.4).

Small-scale catchments and storage of precipitation. Small-scale storage of precipitation—for example, in sand dams, tanks, or small storage dams—can increase moisture retention despite decreasing precipitation and increasing evaporation, and has the benefit that the storage constructions usually have a long lifetime (Bates et al. 2008). Sand dams, as one example of small-scale storage, also provide a means to bridge (prolonged) dry periods, as they provide a means to keep crops, livestock, and trees alive (Lasage et al. 2008; Pauw et al. 2008) (Box 2.6).

Prospecting and extraction of groundwater. This measure can be applied both autonomously and as a public sector adaptive measure. However, abstraction of (partly) untapped sources can have adverse environmental consequences (Bates et al. 2008; Kundzewicz et

BOX 2.5. RAINWATER HARVESTING AND LOCAL WATERSHED MANAGEMENT – THE CASE OF LAPORIYA, INDIA

Rainwater harvesting, in combination with good watershed management practices, can be used to address water supply problems. For example, the village of Laporiya in India has adopted such practices, and learned not only how to survive despite low and variable rainfall, but to thrive despite these climatic conditions. The village lies in the state of Rajasthan, about 100 kilometers west of Jaipur. Its climate is semi-arid; it receives an average of 500 mm of rainfall per year, and rainfall is highly variable. The 2001 Census of India states that 93 percent of households own some agricultural land. With no perennial rivers in its vicinity, agriculture in Laporiya is rainfed. However, given the variability in annual precipitation, agriculture is a risky activity. Therefore, in order to achieve the sustainability of its water resources, Laporiya has developed an innovative rainwater harvesting technique, known to many as "Laporiya's Rectangles," that has allowed it to harvest rainfall to provide surface water for irrigation, water to recharge groundwater reservoirs, and to enable grass production on common grazing lands. One of the main elements of the system is a series of shallow, slightly sloped, three-sided embankments (on average 66 meters wide, 132 meters long, and 1.5 meters high), which collect water with a depth of between 2.5–23.0 cm (Laporiya's rectangles, or "chaukas"). This water slowly seeps into the ground to increase the recharge of groundwater. The design also encourages grass production and soil moisture retention. These chaukas are generally built in a series, following the natural slope of the land to eventually reach village ponds. Miniature dams are also built in the system, which help to collect water for irrigation and animal drinking water. Additionally, separate tanks are established to provide irrigation and drinking water, and to serve as a percolation tank. Though no precise figures are available, Laporiya's water harvesting structures are generally low-cost, use mainly local materials, and have been built in part through household labor donations. The village has become self-sufficient in its drinking water needs, despite nine consecutive years of drought, and has experienced increases in agricultural and livestock productivity and per capita incomes. The project was initiated by a local NGO, and is managed at the village level; the importance of stakeholder participation and local knowledge and ownership is a key to the project's success (Narain 2008).

BOX 2.6. LOCAL KNOWLEDGE AND OWNERSHIP IN WATER STORAGE: THE KITUI SAND DAMS IN KENYA

The Kitui sand dams in Kenya are an example of how communities can use their knowledge on water to cope with droughts. It also provides an example of a novel approach to dam building which avoids many of the disadvantages of large dams. Kitui district is a semi-arid region, 135 km east of Nairobi. The area is characterized by highly erratic and unreliable rainfall, with two rainy seasons providing 90 percent of the annual rainfall. Historical analysis of metrological data shows that climate (change) is already an issue in the Kitui district. Since 1990, a local NGO (Sahelian Solution Foundation, SASOL) has been assisting local communities in building over 500 small-scale (3–50 m wide) sand dams to store water in artificially enlarged sandy aquifers. Sand dams are small concrete structures built in ephemeral rivers to store excess rainfall to overcome periods of drought. This old technique differs from traditional dams by storing water within the sand and gravel particles, which are accumulated against the dam wall. Hence, the term "sand" refers to the sand behind the dam that holds the water. The sand prevents high evaporation losses and contamination. Since the start of the project more than 67,500 people in Kitui have better access to safe drinking water, at an average investment of less than $35 per person. Physical restrictions prevent dams from being built everywhere, and this causes disparities within the community. Households with dams now live on average 1700 m closer to their primary water sources and save 100 minutes per day on fetching water. In turn, the increased water availability and the saved time have brought tremendous positive social and economic changes, most of which are agricultural. However, the situation of households without dams has deteriorated due to poor rains in recent years (Pauw et al. 2008). The dams are built by the communities; SASOL only facilitates fundraising for the dam materials and engineering. Hence, communities have ownership and are committed to maintenance and efficient use of the dams. The good practices and experiences in Kitui should be matched with the needs and circumstances in other areas in Kenya and other developing (semi-arid) countries. International organizations could use their networks and resources to scale up this project, which shows that local action can be a cost-effective way of addressing water supply and drought issues on a larger scale (Lasage et al. 2008).

al. 2007). Costs can vary greatly depending on many factors, including: depth of the borehole; bedrock material; and the chance of drilling a successful borehole.

Implementing irrigation practices. Irrigation can lead to increased soil moisture retention in the case of decreasing precipitation and increasing evaporation. Alternatively, more efficient forms of irrigation practice, such as drip irrigation, can be used. However, a clear constraint of these measures is that water needs to be available to implement irrigation practices (Nhemachena and Hassan 2007; Smit and Skinner 2002).

2.4.1.3. *Autonomous adaptation for riverine flood protection*

Miniature protection barriers. Dikes and barriers are usually built on a large scale through public expenditure.

However, small barriers—for example, earthen barriers, wood walls—can be placed around dwellings at low cost in flood-prone areas to offer some protection in the event of flooding (UNFCCC 2006). A drawback is that such adaptation measures may provide little/no protection in the event of major flood events with large flood depths (Marfai and King 2008).

Move valuable things upwards. One way to greatly reduce the damages caused by floods is to move valuable items upwards. For example, granaries can be established in treetops (Patt and Schröter 2008). A simple yet effective way in which people adapt to flooding at the household level is to move valuable items from the ground floor up to higher floors during floods. This method is adopted by many households in coastal cities of Indonesia, although clearly a requirement is that there is a dry level to which valuables can be moved (Marfai and King 2008).

Flood-proofing of buildings. Buildings in flood-prone areas can be built in such a way as to make them less vulnerable to the effects of flooding. Buildings can be modified in several ways to reduce the risk of floodwater penetration, including: waterproofing walls; fitting temporary closure devices; and building boundary walls; or to reduce the effects should water enter the building, such as by routing and locating electrical sockets at higher levels. Indigenous adaptations include building houses on stilts, and sometimes on raised mounds (Green et al. 2000).

Resettlement. An autonomous reaction to flooding can be to move to higher ground or less flood-prone areas. However, floodplains are generally very fertile, and in some cases a scarcity of land may prevent people from moving to less-flood-prone areas. Moreover, people may have cultural or economic bonds with the floodplain area in which they live, and a perception of low risk (Marfai and King 2008). Examples exist in developing countries of communities who temporarily migrate during high-flow events, such as in Bangladesh, where some rural households dismantle their homes and move them by boat to higher ground as river levels rise (Green et al. 2000).

Flood insurance. This measure can help to cover the economic costs of the impacts of climate-related hazards. However, it is hard to organize a good insurance system, especially in rural and developing areas (Bergkamp et al. 2003). Constraints for the insurance industry include a lack of data availability on hazards and exposures in developing countries. Nevertheless, successful schemes against disaster losses in developing countries do exist, such as in Columbia, where microentrepreneurs offer affordable and easy-to-understand life and property microinsurance to the most vulnerable (Bouwer et al. 2007). As a result of climate change, demand for insurance products is expected to increase (ABI 2004; Dlugolecki and Lafeld 2005; Mills et al. 2005; Valverde and Andrews 2006). Recent research shows that homeowners are willing to take measures to reduce their own vulnerability in exchange for lower insurance premiums (Botzen et al. 2009), showing that insurance schemes can help to promote proactive adaptation. A possible constraint is that consumers have low risk awareness, which makes premiums seem expensive (UNFCCC 2007). Also, in general the government will always be the reinsurer of last resort, and it is therefore important to formalize the nature of this public-private partnership.

2.4.2 Public sector investment

Implementing adaptation measures involves many organizations, institutions, and individuals, but in practice the responsibility often falls on the public sector (UNFCCC 2006). Public sector climate change investments are the result of deliberate policy decisions that specifically take climate change into account. In identifying and evaluating which adaptations are most attractive, consideration must be given to how they relate to ongoing decision-making processes, constraints, stimuli and decision criteria (Smit and Skinner 2002). Most of the public sector adaptation options given below are implemented on a larger scale than autonomous adaptation.

2.4.2.1 Demand-side public sector adaptation

Crop development. The agronomical development and provision of new crop varieties—including types, cultivars, and hybrids—has the potential to provide crop choices better suited to different temperature, moisture, and other conditions associated with climate change. Development of new varieties could also have a mitigating function in terms of CO_2 sequestration in the soil (Downing et al. 1997; Patt and Schröter 2008; Smit and Skinner 2002).

Increase the efficiency of irrigation. Measures that improve the efficiency of irrigation systems allow for greater flexibility as water consumption declines while crop yields are maintained (Smith and Lenhart 1996). Public sector investment in the large-scale subsidized supply of efficient irrigation equipment could help private farmers to alter their irrigation systems.

Weather and climate information systems. Seasonal estimates have the potential to aid risk assessment and production decisions over several months, especially during climatological deviations like El Niño and La Niña (Smit and Skinner 2002). Seasonal and longer-term climate projections can inform farmers about the probability of extreme events and likely rainfall patterns and temperatures. However, developing seasonal predictions is difficult as they come with many uncertainties, and their applicability is dependent on a difficult iterative process of gaining credibility, legitimacy, cognition, and timing. Sometimes the projections do not contain enough new information, or the scale of forecasting is not useful (Molua 2002; Patt and Gwata 2002; UNFCCC 2006).

2.4.2.2 Supply-side public sector adaptation

Increasing reservoir storage capacity. Reservoirs are used extensively throughout the world to store surface water, thus providing a buffer during the dry season. For a discussion of the main advantages and disadvantages of this measure, see Box 5.1.

Desalination. This technological measure can be used at all spatial scales, and can potentially lead to an "unlimited" availability of freshwater. However, at present the production of desalinized water is, in general, energy intensive and relatively expensive, about \$1.00/m^3 for sea water and \$0.60 for brackish water (Bates et al. 2008), although the costs are expected to decrease in the future (Zhou and Tol 2005).

Recycling and reuse of (municipal) wastewater. This measure can be cost-effective in the long term as it also reduces demand. However, the installation of distribution systems can initially be expensive compared to other water supply alternatives (Bates et al. 2008).

Inter-basin transfer of water. Where feasible, this may be an effective and flexible response to regional droughts or other problems of water supply, especially for highly valued water uses such as urban supply. However, transferring water from one basin to another can cause large environmental damage (Smith and Lenhart 1996; Kundzewicz et al. 2007). Zhou and Tol (2005) estimate that a 100 m vertical lift in transportation is about as costly as a 100 km horizontal transport (about \$0.0.5–\$0.06/m^3).

Small-scale catchment and storage of precipitation; implementation of irrigation practices; prospecting and extraction of groundwater. These can be carried out as smaller-scale autonomous adaption measures (see section 2.4.1.2), but also on a larger scale via public-sector-driven investments.

2.4.2.3 Public sector adaptation for riverine flood protection

Dams. In the appropriate circumstances, dams can be a highly effective way of reducing downstream flood losses, by providing reservoir storage to retain water during peak flow events (Green et al. 2000). However, there are also numerous disadvantages, and dams are not an appropriate form of adaptation in all cases. These issues are discussed further in section 5.1.1.

Dikes. Large-scale dikes, as opposed to household or small-scale barriers, are usually constructed and maintained by the public sector. They are most likely to be used for floodplains that are already intensively used, such as urban areas and rural areas in non-urbanized regions with a history of flood alleviation. A problem with dikes is that they may be destroyed by erosion as the river dynamically adapts to changing flows, and therefore bank protection and maintenance has to be undertaken regularly (Green et al. 2000).

Polders. Polders are areas of land surrounded by dikes, known as a ring dike. The ring dike protects the area of the floodplain within the dike from riverine flooding, up to a given design discharge. A problem is that they interfere with the natural drainage patterns within the protected area, and therefore while providing protection up to a nominal level from flooding from the main river, they may still be flooded by extreme precipitation events or local tributaries flowing through the area (Green et al. 2000).

Altering river channel morphology. In the past it was common to shorten the length of rivers by cutting off meanders and carrying out channel straightening. However, the trend at present is in the opposite direction, restoring meanders and avoiding straightening. Decreasing river length increases the gradient, thus increasing flow velocities and reducing the storage capacity of the channel, thereby increasing peak flows. Another option is to increase the capacity of the river channel by widening, deepening, or reducing resistance; increasing the discharge capacity of rivers can also be carried out by constructing bypass channels to be used during peak events. The latter approaches may require large investments in dredging to maintain the required depths, and bypass channels can negatively impact on the land they cut through (Green et al. 2000).

Detention basins. Like dams, detention basins help to alleviate flood losses by providing additional water storage capacity during times of high flow (Green et al. 2000). The concept of giving more room to rivers is rapidly assuming a key role in flood hazard management (Aerts and Droogers 2009). Natural wetlands can be excellent forms of detention basins, and artificial wetlands are also increasingly being constructed to store flood waters (Green et al. 2000). In river basins where land is scarce, multi-functional land use planning options can be implemented whereby the land use in risk-prone areas is harmonious with intermittent inundation. For such an approach to be successful, intensive multi-stakeholder participatory approaches must be undertaken in all stages of planning, development, and implementation (Aerts and Droogers 2009). However, this can be problematic when flood waters are polluted, since the pollutants will be deposited in flood retention basins. Hence, this should be considered in combination with water quality alleviation measures.

Increase detention storage in urban areas. In urban areas, buildings and paved impermeable surfaces greatly reduce the rate of infiltration to the soil and groundwater, and increase the rate at which water reaches watercourses (Green et al. 2000). Several options are available to increase the storage area for water in cities, including: infiltration trenches and soakaways; permeable or porous pavements for roads and car parks; and small retention ponds (Green et al. 2000). Excess precipitation can also be stored on roofs of buildings, thus reducing the pressure on the drainage system and the risk of flooding (Bates et al. 2008). An extension to this is the concept of green roofs, which are roofs made of a system of manufactured layers to support the growth of vegetation. Green roofs have been proven to slow the rate of runoff from the roof (Aerts et al. 2009).

Flood forecasting and warning. A flood forecast is a prediction of future flooding; it becomes a flood warning when it is received by those who need it in a usable form. Flood warnings must be disseminated within and between agencies, and need to be delivered to the floodplain occupants, along with advice on what measures are to be taken (Green et al. 2000; UNFCCC 2007). Clearly, the occupants of floodplains must be informed of the actions to be taken prior to the issuing of warnings, since flood warnings are often only available with a limited time span before the flood event (Green et al. 2000).

Emergency planning, evacuation, and disaster relief. In developing a flood hazard management policy, it is essential to consider how all floods will be managed and not just some; that is, not just those up to a nominal design standard. This means that it is necessary to design for failure, and how to respond in the event of disastrous flooding. Emergency planning, evacuation, and flood relief require preparations, including drawing up contingency plans; training emergency planners and managers; rehearsing the emergency response; raising public awareness; educating people on the measures they can take to reduce their vulnerability; and informing people of the location of shelters and evacuation centers, and means of evacuation (Green et al. 2000).

2.4.3 "Soft" adaptation – policies and regulations

To address the broad range of uncertainties involved in climate change projections, anticipatory adaptation policies should be flexible. As such, a policy may be either robust, meaning that it allows the system to continue functioning under a wide range of conditions, or resilient, meaning that it allows the system to quickly adapt to changed conditions (Smith and Lenhart 1996). The adaptation measures described below have not been strictly divided into water supply and flood protection options, since some are relevant in both cases.

Develop integrated water management options. Basinwide management plans integrate water as a resource and ensure the representation of all users. River basin management plans are already developed all over the world, but are not always effectively implemented, especially in large areas where communication is difficult. Another drawback is that the design and investment cycle of an integrated water management plan is framed so that major projects are expected to be operational for several decades (Downing et al. 1997). With the uncertainties that still surround the impacts of climate change, a lack of flexibility could potentially lead to shortcomings in management plans. A key aspect in this regard is that of integrated water resources management, which is discussed in Box 2.7.

Water pricing. The economic incentive of water pricing can reduce the demand for water and promote water reuse (Bates et al. 2008). It could also facilitate a more rapid and efficient response to climate change than is the case under more rigid schemes for water allocation (Smith and Lenhart 1997). However, countries and subnational jurisdictions differ considerably in the extent to which their laws, administrative procedures, and documentation of water rights facilitate market-based water transfers, while protecting other water uses and environmental values (Downing et al. 1997; Kundzewicz et al. 2007). Governments need to facilitate the cost pricing for water services, and appropriate mechanisms must be implemented to protect the poor (Hooper 2006).

Support water-efficient technologies. Many water-efficient technologies exist that can help to reduce municipal water demand (see section 2.4.1.1). Policy measures that can be employed to assist the market penetration of these measures include: appliance exchange programs; subsidies to manufacturers; subsidies to consumers; and encouraging or requiring the use of water-saving technologies in new and/or existing buildings (Sutherland and Fenn 2000).

Establish set-back zones. Relocation of housing and other susceptible types of land use will reduce the losses of climate-related hazards (Bates et al. 2008), in particular flood events. However, relocating people is a difficult process. Patt and Schröter (2008) show that a relocation program in Mozambique failed because the people perceived the risks of flooding differently from policy makers, and they moved back to the areas they were relocated from. Also, in many developing countries, the most vulnerable locations are inhabited by poor communities; in order to promote resettlement to less vulnerable areas, these people must be provided with new houses and economic opportunities in less vulnerable areas. Forced removal is politically unacceptable, and vulnerable people living on floodplains may prefer to stay where they are, since their livelihoods may be based on access to the river and floodplains, and their resources. It must be appreciated that flood risks are not the only risk to life and property for these communities (Green et al. 2000).

BOX 2.7. INTEGRATED WATER RESOURCES MANAGEMENT

A much-heralded approach to water resources planning is the concept of integrated water resources management (IWRM). In 2002, at the Johannesburg World Summit on Sustainable Development, the Technical Advisory Committee of the Global Water Partnership defined IWRM as "… a process, which promotes the coordinated development and management of water, land and related resources in order to maximize the resultant economic and social welfare in an equitable manner without compromising the sustainability of vital ecosystems …", and emphasized that water should be managed in a basin-wide context, under the principles of good governance and public participation (Rahaman and Varis 2005). IWRM strives for the sustainability of all aspects of water resource management, including policy, management, and implementation. It involves applying knowledge from various disciplines as well as the insights from diverse stakeholders to devise and implement efficient, equitable, and sustainable solutions to water and development problems. It is a comprehensive participatory planning and implementation tool for managing and developing water resources in a way that balances social and economic needs, and that ensures the protection of ecosystems for future generations. Successful integrated water management strategies include capturing society's views; reshaping planning processes; coordinating land and water resources management; recognizing water quantity and quality linkages; conjunctive use of surface water and groundwater; protecting and restoring natural systems; and including consideration of climate change. In addition, integrated strategies explicitly address impediments to the flow of information (Moench et al. 2003). IWRM should be an instrument to explore adaptation measures to climate change, but in this respect it is still in its infancy (Bates et al. 2008).

Phase out development in exposed areas. A legal agreement that restricts development is less radical than the establishment of a set-back zone (UNFCCC 2006). However, it is only applicable in areas where there is a longer period of time to react and where there is absolute certainty that the area will be exposed in the future.

Source control / land use planning. Land use change upstream can cause changes in discharge and flood peaks downstream. Hence, policies regarding land use change, particularly those that aim to reduce or eliminate deforestation, can be used to ameliorate flood control at the source (Andréassian 2004; Calder 1993). However, although afforestation normally results in increased evapotranspiration, it is not clear whether it reduces the risk of the most extreme events (Cosandey et al. 2005; Green et al. 2000).

Community involvement and participation. As stated in several of the above examples, community involvement and the participation of all relevant stakeholders greatly improves the chance of developing and implementing sustainable plans in terms of both water supply and flooding (Bates et al. 2008). In this regard, NGOs can play a key role. In addition to raising public awareness, they can act as intermediaries, identifying technologies, facilitating investments, and providing management, technical, and other assistance (UNFCCC 2006). An important part of this process is the incorporation of indigenous knowledge and practices for sustainable water (Bates et al. 2008) (see Boxes 2.5 and 2.6).

Education. Education and information are important elements in a long-term commitment to sustainable development and adaptation in water resources (Green et al. 2000; Sutherland and Fenn 2000).

Information exchange system. The exchange of information, knowledge, and experience on adaptation should be shared at all levels, from local to international. Policies and programs that encourage such exchange can play a key role in adaptation and development in general (Bates et al. 2008).

Help and counseling. Flood hazard plans should account for post-flooding assistance and counseling (Green et al. 2000). There are strong benefits in mobilizing community-based organizations and NGOs to take action in the emergency response and recovery phase of a flood, as demonstrated by projects in Nicaragua and Mozambique (Maskrey 1989).

2.4.4 Reactive adaptation

Adaptation that is triggered by past events is often called reactive. In a sense, reactive adaptation has by definition an anticipatory character, as the adaptive action is taken based on some assessment of likely conditions in the future (Adger et al. 2005). Smit and Pilifosova (2003) argue that autonomous adaptation is mostly reactive. The division between proactive and reactive adaptation is therefore extremely fuzzy. Many of the adaptation measures listed in sections 2.4.1 to 2.4.3 can indeed be taken either reactively or proactively.

2.5 WHAT IS THE NATURE AND EXTENT OF ADAPTATION/DEVELOPMENT DEFICIT IN THIS SECTOR?

Although climate change is not directly addressed in the eight Millennium Development Goals (MDGs), most of them are directly or indirectly related to water (Kundzewicz et al. 2007). Hence, adaptation to climate change in the water sector (as in all sectors) should be carried out in a manner that is synergistic with development priorities in general (Adger et al. 2007; Kundzewicz et al. 2007; Ribot et al. 1996), and climate policy should be embedded in general development policy. Indeed, many believe that the best hope for adaptation to climate change is through development. Development enables an economy to diversify and become less dependent on sectors such as (rainfed) agriculture that are more likely to be affected by climate change. At the same time, adaptation to climate change is seen as essential for development; unless developing countries can adapt to changes in climate, they are unlikely to develop (Narain 2008).

The high vulnerability of many developing countries to water stress, drought, and flooding (see section 2.2) demonstrates that adaptation is needed already to reduce vulnerabilities under current climate and climate variability. Adaptation to projected changes in future climate often has the ancillary benefit of reducing vulnerability with respect to current climate variability

(Fankhauser 2006), and therefore contributes to the goals of sustainable development. Indeed, adaptation policies in water resource management can be designed to explicitly provide ancillary benefits in other sectors, including agriculture, forestry, recreation, and ecosystem services (EEA 2007).

From a temporal perspective, adaptation to climate risks can be viewed at three levels, including responses to (a) current variability (which also reflects learning from past adaptations to historical climates); (b) observed medium- and long-term trends in climate; and (c) anticipatory planning in response to model-based scenarios of long-term climate change. The responses across the three levels are often intertwined (Adger et al. 2007). The level of adaptation that will be carried out in a country essentially depends on an evaluation of the (expected) costs and benefits of adaptation by the relevant stakeholders. Such an evaluation does not have to be in the form of a formal cost-benefit analysis, but some evaluation of gains and losses must be assumed (EEA 2007).

It should also be noted that, if done badly, adaptation can increase the adverse effects of climate change, or have negative effects on sustainable development in general, thus increasing the so-called adaptation deficit. This is called maladaptation, and is defined by the IPCC (2001) as "… any changes in natural or human systems that inadvertently increase vulnerability to climatic stimuli; an adaptation that does not succeed in reducing vulnerability, but increases it instead… ."

2.6 ADAPTIVE CAPACITY

The level of adaptation that will be carried out in a particular country, region, or locality is not only dependent on the kind and magnitude of the change in climatic conditions, but is dependent on adaptive capacity. Adaptive capacity is the ability or potential of a system to respond successfully to climate variability and change, and includes adjustments in both behavior and in resources and technologies (Adger et al. 2007). All societies are fundamentally adaptive (Adger 2003), but the presence of a sufficient level of adaptive capacity is a necessary condition for the design and implementation of effective adaptation strategies to reduce the likelihood and magnitude of the negative impacts of climate change (Brooks and Adger 2005).

Like exposure and vulnerability, adaptive capacity is unevenly distributed between countries, and is highly differentiated within countries. There are individuals and groups within all societies that have insufficient capacity to adapt to climate change (Adger et al. 2007). One early finding in hazard research is that within countries, people's ability to adapt, and their access to adjustments, reflect existing divisions between rich and poor, powerful and powerless, ethnic or gender-favored, and ethnic or gender-denied (Kates 2000). Recent analyses in Africa, Asia, and Latin America show that marginalized, primary resource-dependent livelihood groups are particularly vulnerable to climate change impacts if their natural resource base is severely stressed and degraded, or if their governance systems are in, or near, a state of failure. For example, women in subsistence farming communities in southern Africa are disproportionately burdened with the costs of recovery and coping with drought (Adger et al. 2007).

Adger et al. (2007) and Bates et al. (2008) describe five main limits on adaptive capacity, many of which are specifically relevant to developing countries, namely:

- Physical or ecological. It may not be possible to prevent adverse effects of climate change through either technical means or institutional changes; for example, it may be impossible to adapt where rivers dry up completely.
- Technical, political, or social. For example, it may be difficult to find acceptable sites for new reservoirs, or for water users to consume less.
- Economic. An adaptation strategy may simply be too costly in relation to its benefits.
- Cultural and institutional. Cultural and institutional factors include the institutional context within which water management operates, the low priority given to water management, lack of coordination between agencies, tensions between different scales, ineffective governance, and uncertainty over future climate change, but also the existence of violent conflicts and the spread of infectious disease.
- Cognitive and informational. For example, water managers may not recognize the challenge of climate change, or may give it low priority compared to other challenges. A key informational barrier is the lack of access to methodologies to cope with climate change.

2.7 SUMMARY

There is already much evidence that climate change in recent decades has had many physical impacts on the hydrological cycle. These impacts are expected to continue and intensify over the course of the 21st century. This will affect all water-related sectors, including water supply, flooding, agriculture, health, industry, transport, energy supply, ecosystem services, fisheries, and forestry. There will be positive as well as negative impacts, but overall the negative effects are expected to outweigh the benefits.

The availability of water will increase in some parts of the world, and decrease in others. However, water supply is dependent on both demand and availability. Water demand is expected to increase greatly in most parts of the world, with especially large proportional increases in municipal and industrial demand. Water-stress is expected to increase as a result of both climatic and non-climatic drivers; furthermore, the frequency, magnitude, and geographical extent of droughts are projected to increase.

Due to projected increases in precipitation intensity, increases in the frequency and magnitude of riverine flood events are expected in many parts of the world. Non-climatic drivers such as land-use change, river confinement, and other measures also play a crucial role in flood probability. Flood risk is the product of flood probability and the damages caused by flooding. The damages associated with floods (both economic and loss of life) are expected to increase due to augmented economic values and population density in flood-prone areas.

The impacts of climate change on the water sector will be felt in both developed and developing countries, but the worst impacts are expected in the latter due to a combination of physical and social characteristics. As a result of climate change, water stress is expected to be worst in semi-arid and arid river basins. Africa is especially vulnerable to climate change in terms of water supply. Although many areas of the world are expected to be hit by increased flood risk, the highly populated mega-basins of Asia may be affected worst.

There are, however, considerable uncertainties in assessing the impacts of climate change on water resources. These uncertainties come from a whole range of sources. The largest uncertainty in terms of climate change impact assessments on water resources remains the uncertainty in precipitation inputs.

Despite these uncertainties, the observed trends in water resource change are compelling. Impacts will continue to increase in the 21st century regardless of whether greenhouse gas emission mitigation takes place. Hence, in addition to mitigation, it is essential to develop adequate adaptation measures to moderate the impacts and realize the opportunities associated with climate change.

All adaptation options have their own pros and cons in several aspects, including economic, ethical, technological, social, political, and environmental. The correct measure or combination of measures is always site- and context-specific. Although climate change is not directly addressed in the eight Millennium Development Goals, most of them are directly or indirectly related to water. Hence, adaptation to climate change should be carried out in a manner that is synergistic with development priorities in general, and climate policy should be embedded in general development policy. Adaptation measures should address economic, environmental, and social welfare in an equitable manner, and should address issues in a basinwide context, following the principles of good governance. Furthermore, key facets are public participation and the use of local knowledge in planning, development, and maintenance of adaptation strategies, whether they be structural or policy measures. These issues are addressed in the concept of integrated water resource management, which should be used as an instrument to explore adaptation measures to climate change.

The level of adaptation that will be carried out in a particular country, region, or locality is not only dependent on the kind and magnitude of the change in climatic conditions, but also on the way people are able to prepare or react: their adaptive capacity. Marginalized, natural-resource-dependent livelihood groups are particularly vulnerable to climate-change impacts.

3. LITERATURE REVIEW

In this section, we provide a summary of some of the key works that have been carried out with regard to the economic aspects of climate change and adaptation in the fields of water supply and flood protection. At a regional and global scale, such analyses are currently limited (Adger et al. 2007; EEA 2007; Kuik et al. 2008). One of the reasons for this is that it is first necessary to have a thorough understanding of (a) the expected physical impacts of climate change on the hydrological cycle, and (b) the impacts of those changes on water-related sectors, before it is possible to assess the costs of climate change and adaptation. We first summarize a number of studies that have estimated the possible impacts of climate change on the water sector in economic terms, and then review studies that have specifically examined the costs of adaptation.

3.1 PREVIOUS STUDIES ON THE COSTS OF CLIMATE CHANGE

Between the 1950s and the 1990s, the annual economic losses from large extreme events, including floods and droughts, increased tenfold, with the developing world being hardest hit (Kabat et al. 2003). Currently, flood damage constitutes about a third of the economic losses inflicted by natural hazards worldwide (Munich Re 2005), and the economic losses associated with floods worldwide have increased by a factor of five between the periods 1950–80 and 1996–2005 (Kron and Berz 2007). From 1990 to 1996 alone, there were six major floods throughout the world in which the number of fatalities exceeded 1,000, and 22 floods with losses exceeding $1 billion each (Kabat et al. 2003). Although these increases in loss are also attributable to several non-climatic drivers, climatic factors are also partly responsible (Kundzewicz et al. 2007).

Efforts to quantify the economic impacts of future climate-related changes in water resources are hampered by a lack of data, the uncertainties described in section 2.3, and by the fact that the estimates are highly sensitive to both the cost estimation methods and the different assumptions used with regard to the allocation of changes in water availability across various types of water use (Changnon 2005; Schlenker et al. 2005; Young 2005). In some regions, hydrological changes may have impacts that are positive in some aspects and negative in others; for example, increased annual runoff may produce benefits for a variety of both in-stream and out-of-stream water users by increasing renewable water resources, but may simultaneously increase flood risk. Overall, the IPCC states that it is very likely that the costs of climate change to the water sector will outweigh the benefits globally (Bates et al. 2008).

Most of the studies examining the economic impacts of climate change on the water sector have so far been carried out at the local, national, or river-basin scale, and the global distribution of such studies is skewed toward developed countries (Chen et al. 2001; Choi and Fisher 2003; Dore and Burton 2001; Evans et al. 2004; Hall et al. 2005; Kirshen et al. 2005, 2006; Middelkoop et al. 2001; Schreider et al. 2000). Nevertheless, studies that have assessed the economic impacts of climate variability on floods and droughts in developing countries have found these to be substantial. For example, the cost to Kenya of two extreme events—the floods associated with the 1997/8 El Niño event and the drought associated with the 1998–2000 La Niña event—show a cost to the country of 11 percent of its GDP for the former, and 16 percent of GDP for the latter (World Bank 2006a). According to the same study, floods and droughts are estimated to cost Kenya about 2.4 percent of its GDP annually, and water resources degradation a further 0.5 percent. As these are likely to become more pronounced with climate change, economic costs can be expected to be more substantial in the future, holding all other factors constant. For Ethiopia, economywide models incorporating hydrological variability show a drop in projected GDP growth by up to 38 percent compared to when hydrological variability is not included (Mogaka et al. 2006). However, it is not hydrological variability per se that causes the problem, but rather an extreme vulnerability to it due to a lack of the necessary capacity, infrastructure, and institutions to mitigate the impacts (Grey and Sadoff 2007). Similarly, future flood damages will depend not only on changes in the climate regime, but also on settlement patterns, land-use decisions, flood forecasting quality, warning and response systems, and other adaptive measures (Andréassian 2004; Calder 1993; Changnon 2005; Mileti 1999; Pielke and Downton 2000; Ward and Robinson 1999; Ward et al. 2008; WCD 2000).

At the regional scale, the Association of British Insurers (ABI) estimated the financial costs of climate change through its effects on extreme storms (hurricanes, typhoons, and windstorms) by using insurance catastrophe models. They found that climate change could increase the annual cost of flooding in the U.K. almost 15-fold by the 2080s under high-emission scenarios. If climate change increased European flood losses by a similar magnitude, they estimate that costs could increase by up to \$120–\$150 billion, for the same high-emission scenarios (ABI 2005).

An early global study by Fankhauser (1995) estimated the regional impacts of a temperature increase of 2.5°C in various sectors, converted these to dollars, and then summed them to the global level. For the global water sector, this yielded an estimated loss of about \$47 billion (in 1995 U.S. dollars). Tol (2002a) derived benchmark estimates of the costs of climate change in several sectors based on a review of climate change literature. For the water resources sector, this led to a loss of about \$84 billion (in 2002 U.S. dollars) for the world as a whole for a global temperature increase of 1.0°C. In an accompanying study, Tol (2002b) developed a model of climate change impacts that accounts for the dynamics of climate change and the systems affected by it. For the water resources sector, many simplifying assumptions were made to develop a simple *ad hoc* model of the impacts of climate change on water resources. This model shows a loss to world GDP ranging from 0.5–1.5 percent by 2200 (Tol et al. 2002b). The authors clearly acknowledge and highlight the caveats of these studies, stating that the results are indications of potential pressure points and relative vulnerabilities, and should not be used as predictors or as input to decision analyses.

3.2 PREVIOUS STUDIES ON THE COSTS OF ADAPTATION TO CLIMATE CHANGE

Considering the importance of adapting to climate change in the water sector, the literature on this topic is limited (EEA 2007; Kuik et al. 2008). Estimates of the costs of adaptation to climate change across sectors at the global scale were not available until 2006. Since then, several multisectoral estimates of these costs have become available (Oxfam 2007; Stern 2006; UNDP 2007; UNFCCC 2007; World Bank 2006b). These studies are discussed in the main EACC report, and are therefore not discussed further here.

At the local, national, and river basin level, the geographical distribution of research is skewed toward developed countries, although examples do exist in developing countries. Examples include the costs of adaptation measures to maintain water quality in the Assabet River near Boston, Massachusetts in the U.S. (Kirshen et al. 2006); the costs of adaptation to maintain the availability of drinking water supply and the capacity of treating wastewater in Toronto, Canada (Dore and Burton 2001); water management adaptation costs and benefits for the Berg River in South Africa through the establishment of an efficient water market and an increase in water storage by constructing a new dam (Callaway et al. 2007); the costs of defending the Netherlands against increased river and coastal flooding as a result of climate change (Aerts et al. 2008); the costs of adaptation to reduce flood damage in the Rhine basin in Europe (EEA 2007); and the costs of diverting water and building new water infrastructure at an accelerated pace in order to cope with a reduction in water yields and supply in Quito, Ecuador, as a result of glacier retreat (Vergara et al. 2007).

A regional study of the effects of climate change on water supply is available for Sub-Saharan Africa (Muller 2007). This research estimated the costs of adapting urban water infrastructure in the region to climate change to be \$2–\$5 billion per year. This study assumes that: (a) reliable yields from dams will reduce at the same rate as stream flow (for example, a 30 percent reduction in stream flow will mean a 30 percent reduction in reliable yield); (b) where waste is disposed into streams, a reduction in stream flow by *x* percent will mean that the pollutant load must be reduced by *x* percent; and (c) power generation reduces linearly with stream flow. The costs of adapting existing urban water storage facilities are estimated at \$0.05–\$0.15 billion/year, and the costs of additional new developments are estimated at \$0.015–\$0.05 billion/year. For wastewater treatment, the adaptation costs of existing facilities are estimated at \$0.1–\$0.2 billion/year, and the costs of additional new facilities are estimated at \$0.075–\$0.2 billion/year.

To date, there is only one assessment of the costs of adaptation in water resources at the global level (Kirshen 2007). This study estimates the global costs of adaptation associated with additional water infrastructure needed by 2030 to provide a sufficient water supply, given present and future projected water demands and supplies in more than 200 countries. Costs are estimated for four main water supply utilities: additional surface storage reservoirs; additional groundwater wells; desalination plants; and water reclamation technologies. The study first compares future projected water demands from different sectors to water supplies. Next, the need for additional supply infrastructure is determined, based on an assumed international legislation that would limit water withdrawals in 2050 to 40 percent of total available national water resources. If a country's water withdrawal requirements can be covered by its internal water availability, the additional reservoir storage and wells required (and their costs) are determined. If a country cannot meet the international legislation (that is, withdrawal requirements exceed 40 percent of mean annual flows), it resorts to (in order of priority) desalination for domestic/commercial demand, reclaimed water for irrigation demand, and virtual water. The results suggest that the adaptation costs will amount to about \$531 billion (in 2000 U.S. dollars) in total for the period up to 2030. Of this, 85 percent is estimated to be required in developing countries, mainly Asia and Africa. These costs refer to the adaptation costs associated with both socioeconomic and climatic changes. The assessment of Kirshen (2007) was subsequently modified in UNFCCC (2007). In this study, two further costs were included, namely the increased cost of reservoir construction since the best locations have already been taken, and unmet irrigation demands. This report suggests that the total costs of adaptation worldwide for the period up to 2030 will be \$639 billion under SRES B1 and \$797 billion under SRES A1b. It is assumed that 25 percent of these costs are specifically related to climate change, and hence the cost of adaptation to climate change worldwide in the water supply sector up to 2030 is estimated at \$9–\$11 billion per annum. Of these costs, 85 percent are estimated to be required by developing countries (UNFCCC 2007).

3.3 HOW OUR STUDY COMPLEMENTS EXISTING WORK

In terms of estimating the costs of adaptation to climate change for industrial and municipal water supply, our study builds on the work of Kirshen (2007) in several ways: (a) the method used to estimate the costs of additional reservoir storage requirements is more detailed; (b) the study of Kirshen examined the combined costs of adaptation to socioeconomic development and climate change. This was subsequently updated by UNFCCC (2007), who attempted to delineate the climate-change-related costs, by assuming them to be 25 percent of the total costs. In the present study, we carry out socioeconomic baseline analyses without climate change, and analyses with socioeconomic baseline changes and climate change, and climate change only, in order to derive an improved delineation; and (c) the time-horizon of our study (to 2050) is longer than in the Kirshen study (to 2030). The work of Kirshen does, however, provide more detailed information on the costs of water supply through additional groundwater wells, desalination plants, and water reclamation technologies, as these are lumped into one single category—alternative supply measures—in the present study.

We are not aware of any previous studies on estimating the global costs of adaptation related to riverine flood protection. The results presented in this study should therefore be treated as preliminary indicative costs. Many limitations remain, not least the fact that flood risk (probability x damage) is not assessed. Current methodologies and data, and the time available for this assessment, render a flood-risk-based analysis impossible in this study (see section 6.2). The results do, however, provide a benchmark against which future studies can be compared.

4. METHODOLOGY

In this section, we describe the methods used to address the third and fourth aims of this consultancy, namely:

- Estimate the climate change adaptation costs in the industrial and municipal water supply sector;
- Estimate the climate change adaptation costs for riverine flood protection.

In section 4.1, the geographical and temporal scale of the study is described; in section 4.2, we describe the scenarios used. The model and method used to simulate changes in the hydrological cycle are described in section 4.3. The methods used to estimate the costs of adaptation in terms of industrial and municipal water supply and riverine flood protection are described in sections 4.4 and 4.5 respectively.

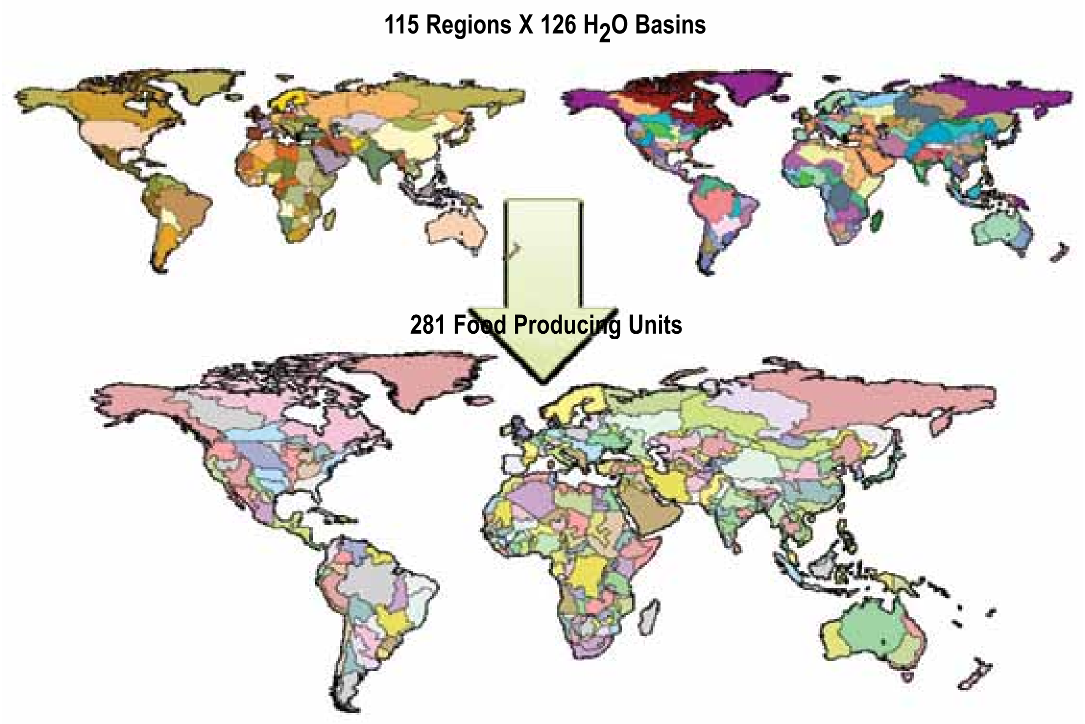
4.1 GEOGRAPHICAL AND TEMPORAL SCALE

All analyses were initially carried out at the geographical scale of the food producing units (FPUs) of IFPRI (The International Food Policy Research Institute) and IWMI (International Water Management Institute). These FPUs divide the world into 281 sub-basins (Figure 4.1), where each sub-basin represents a hybrid between river basins and economic regions. The world is divided into (a) 125 major river basins of various sizes; and (b) 115 economic regions made up mostly of single nations with a few regional groupings of nations; the intersection of these two maps is used to create the FPUs (Cai and Rosegrant 2002; De Fraiture 2007; Rosegrant et al. 2002).

The cost estimates were then aggregated from the FPU level to the country level, and then to the level of the six World Bank regions, namely: East Asia & Pacific (EAP); Europe & Central Asia (ECA); Latin America & Caribbean (LAC); Middle East & North Africa (MENA); South Asia (SA); and Sub-Saharan Africa (SSA). Additionally, we report the results for all countries in these regions together (DC; Developing Countries), and for countries that do not belong to one of the World Bank regions (Non DC; non-developing countries). The results are not presented for individual FPUs or countries, since the aim of this work is to provide an estimate of the costs of adaptation to climate change at the global scale. Moreover, the costs of individual FPUs or countries may be greatly under- or overestimated, as is the case with any study with a focus on the global level. Instead, more detailed and complementary country case studies are being carried out as part of the EACC project.

Throughout the EACC study, the year 2050 is used as the primary time horizon for analysis. This time horizon was chosen for a number of reasons, including: (a) this is a relevant timeframe for current infrastructure planning; and (b) beyond 2050, uncertainties in projections increase dramatically. For some of the EACC analyses, the year 2030 is also used, which allows for some assessment of the temporal evolution of costs between now and 2050. The changes in climate at 2030 and 2050 are relative to the climate in the period 1961–90, as derived from data sets of the Climate Research Unit (CRU), and described in the main EACC report. The years 2030 and 2050 represent decadal averages of monthly climate model output. In other words, when reporting climate in 2030 or 2050, this actually refers to the average climate in the period 2025–35 or 2045–55, respectively.

FIGURE 4.1. MAP SHOWING THE FPUS (FOOD PRODUCING UNITS) USED AS THE BASIC GEOGRAPHICAL UNIT OF STUDY IN THIS PROJECT (AS DEVELOPED BY IFPRI AND IWMI)



Source: IFRPI 2009.

4.2 SCENARIOS

As stated in section 2, climate change adaptation should be carried out in the context of sustainable development in general. Hence, the impacts of climate change, and the costs of adapting to those impacts, should be assessed relative to a baseline socioeconomic situation in the future, rather than relative to current conditions. Using this approach, one should firstly estimate the costs of adapting to some notional level under the future socioeconomic baseline, without climate change. Then, the costs of adapting to the same notional level can be assessed under the future socioeconomic baseline, but including the impacts of climate change. The costs of adapting to climate change are then the residual of the baseline costs with climate change, and the baseline costs without climate change.

In the EACC study, standard scenarios of socioeconomic development and climate change have been used across the sectoral studies; these scenarios are described in the main EACC report. The climate scenario data used in this study were from two GCMs carried out for the Fourth Assessment Report (AR4) of IPCC (IPCC, 2007) using the SRES emissions scenario A2. The GCMs used are NCAR_CCSM3 and CSIRO_MK3, hereinafter referred to as NCAR and CSIRO respectively.

4.3 RAINFALL-RUNOFF SIMULATIONS

The effects of climate change on the water cycle were assessed using the rainfall-runoff model CLIRUN-II, run on a monthly time-step at a spatial resolution of 0.5° x 0.5°. The key parameters simulated by CLIRUN-II and used in the present study were monthly runoff and the magnitude of the 10-year and 50-year maximum monthly runoff (10-year and 50-year monthly floods). A description of the rainfall-runoff model, and the methods used to simulate these runoff parameters, is provided in an accompanying EACC background paper.

4.4 INDUSTRIAL AND MUNICIPAL WATER SUPPLY METHODOLOGY

In this study, the cost of adaptation is defined as the cost of providing enough raw water to meet future industrial and municipal water demand, based on country-level demand projections until 2050. The costs are estimated for the following scenarios:

a. Socioeconomic baseline (**Baseline**): accounts for changes in industrial and municipal water demand between the present and 2030, and between the present and 2050. The demand projection was derived from the socioeconomic scenario described in the main EACC report. The percentage change in industrial and municipal water demand per FPU is shown in Figure 2.1.
b. Baseline and climate change (**Baseline & CC**): assumes the changes in water demand described above, and also accounts for changes in water availability due to climate change, as simulated using the rainfall-runoff model CLIRUN-II.
c. Climate change only (**CC**): difference between baseline and baseline & CC scenario.

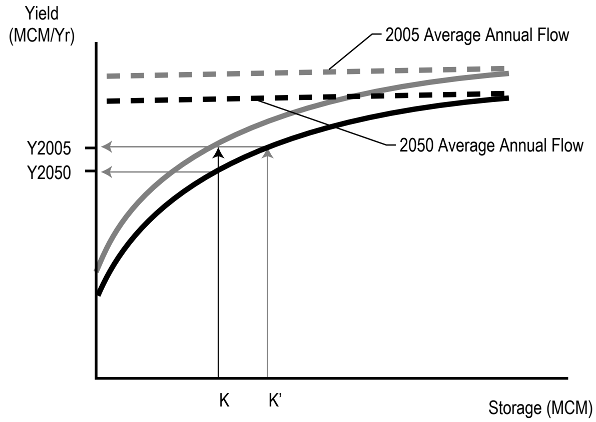
Increased water demand between present and the future scenarios was assumed to be met primarily through reservoir yield by increasing the capacity of surface reservoir storage, except for when:

i. Increasing supply from reservoir yield would increase withdrawals to more than 80 percent of river runoff. If current water withdrawals are already in excess of 80 percent of total runoff, we did not allow the percentage of withdrawals to increase further. There is an extensive literature devoted to determining how much water a river needs to sustain a healthy aquatic ecosystem and ecosystem function (for a review, see Tharme 2003). In reality, assessments must be carried out at the local level, based on local physical, socioeconomic, and political considerations. In a global study of this nature, it is not possible to address such considerations as much more rigorous analyses are required (Vogel et al. 2007), and hence a generalized rule of thumb was applied whereby the percentage of water withdrawals is not allowed to increase above 80 percent of total runoff. The figure of 80 percent was reached through expert judgment during a World Bank consultation. However, this standard is arbitrary, and underscores the need for basin-scale planning when actual water management plans are being developed and implemented, and/or;
ii. The cost of supplying water from reservoir yield is in excess of \$0.30/m^3. In these cases, supply was assumed to be met through a combination of alternative backstop measures—such as recycling, rainwater harvesting, or desalination—at a cost of \$0.30/ m^3. This cost represents an estimate of the average cost of these alternative measures (see Box 2.4).

The required adaptation measures were determined first for the year 2030, and then for the year 2050. It was then assumed that the required measures are implemented linearly between 2010 and 2030, and again between 2030 and 2050. We assume operations and maintenance (O&M) costs of reservoirs of 2 percent of construction costs per annum, as stated in Palmieri et al. (2001), and as the mean of the estimate of 1–3 percent stated in WCD (2000).

Estimating the additional reservoir storage capacity requirement. The additional reservoir storage capacity required (compared to the present) was calculated using storage-yield curves. Storage-yield curves show the storage capacity that is needed to provide a given firm yield and reliability of water supply over the course of a year; that is, basin yield. Basin yield is a better indicator of the reliability of water supply than annual runoff, as annual runoff only provides information on changes in annual water availability, and not on its variability or accessibility for water supply needs (World Bank 2009). In Figure 4.2, typical storage-yield curves are shown for a hypothetical basin. The blue line shows the reservoir storage required to provide different yields, given the mean annual runoff (inflow) indicated by the dotted blue line. Climate change can cause changes in mean basin runoff and in runoff variability, and hence can change the shape of the storage-yield curve. For example, the red line shows the potential effects of reduced annual runoff and/or variability on the storage-yield curve. Given a lower mean annual runoff, more reservoir storage capacity is required to achieve the same yield. The difference between K and K' is the additional

FIGURE 4.2. EXAMPLE OF A TYPICAL STORAGE-YIELD CURVE FOR A HYPOTHETICAL BASIN



Source: World Bank 2009.
Notes: Due to climate change, the discharge in the year 2050 (dotted red line) is lower than in 2005 (dotted blue line), and therefore the storage-yield curve is lower (diminishing returns of yield for the same level of storage). The distance between K and K' shows the additional storage requirement that is needed to compensate for the loss in basin yield between 2005 and 2050 due to climate change.

storage needed to compensate for the loss in basin yield between 2005 and 2050 due to climate change. An increase in demand for water due to changes in the socioeconomic situation of a basin can also affect the yield and storage requirement irrespective of changes in climate. If the demand for water increases in a basin, one moves upward along the storage-yield curve, since an increase in demand requires a higher yield, and hence a higher storage capacity.

For this study, storage-yield curves were developed for each FPU, and for each climate scenario. The curves were established using a modified version (Wiberg and Strzepek 2005) of the sequent peak algorithm approach (Thomas and Fiering 1963), whereby:

$$S_t = \begin{cases} R_t + E_{t-1} - P_{t-1} - Q_t + S_{t-1} & \textit{if positive} \\ O & \textit{otherwise} \end{cases} \quad \text{(Eq. 1)}$$

where S is the reservoir storage capacity, R is the release, E is the evaporation above the reservoir, P is the precipitation above the reservoir, Q is the inflow, and t is the current time period. Equation 1 is applied for each period in the time-series used to construct the storage-yield curve, and the maximum value of S_t from these values is the storage required for the time-series of inflows used. In the present study, monthly values were used to calculate the storage requirement, as using only annual values can lead to an overestimation of each storage level since the storage may not be able to handle the within-year monthly variability of inflow. The monthly time-series of inflow and net evaporation were derived from the CLIRUN-II simulations.

Estimates of current reservoir storage per FPU were previously calculated for IWMI's WATERSIM model, based on data from the World Register of Dams (ICOLD 1998). This version of the ICOLD data base provides the storage capacity of more than 25,000 dams around the world. However, the data are not georeferenced, and are not available as a GIS data base. Therefore, Strzepek (in prep.) carried out an exhaustive analysis to identify and plot the geographical coordinates of the reservoirs accounting for 90 percent of total reservoir storage per country, and then used a GIS to reassign and map these to the FPUs used in this study. ICOLD has a more recent data set (ICOLD 2003), but in terms of the current analysis there is little value-added in repeating this exhaustive and time-intensive exercise, given that the amount of storage added between 1998 and 2003 was small at the global scale, relative to the total stock that already existed in 1998 (ICOLD 2003), and given the time and resources available for this study.

Estimating the cost of reservoir storage construction. Ideally, a global data base showing the construction costs of existing reservoirs would allow us to calculate average construction costs per country. However, such a data base does not exist. Hence, in this study we used and modified a methodology developed jointly by the U.S. Army Corps of Engineers (USACOE) and the U.S. Bureau of Reclamation (USBR) to estimate the construction costs of reservoir storage per FPU. The method was modified by Löf and Hardison (1966), who developed a table of storage-cost relationships for 11 size classes of reservoirs and 10 physiographic zones in the United States. These tables were subsequently updated by Wollman and Bonem (1971) based on 1960s U.S. construction technology. The data used were both

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[1] http://www.iwmi.cgiar.org/Tools_And_Resources/Models_and_Software/WATSIM/index.aspx

geographically comprehensive, since they are based on the physiographic zones of the entire United States, and are very complete. During the period 1940 to 1970, over 60 percent of all U.S. reservoir storage capacity was built, and most of it under the direction of the USACOE and the USBR. Recent work shows that in the period 1970 to the present neither these relative cost relations nor the costs in real terms have changed substantially in the U.S. (Wiberg and Strzepek 2005). Hence, we updated the latter tables to obtain construction costs per cubic meter in 2005 U.S. dollars (Table 4.1).

Given that the spectrum of physiographic zones within the U.S. encompasses many of the physiographic zones that are found elsewhere in the world, it is assumed that these relative cost structures between physiographic zone and reservoir size will be similar around the globe (Wiberg and Strzepek 2005), even though the absolute costs will vary due to differences between countries in heavy civil engineering construction costs. Therefore, these relative cost structures can be transferred to FPUs outside the U.S. by using indices to adjust for the relative difference in heavy civil engineering construction between the U.S. and the FPU in question.

The physiographic zone classifications used by Löf and Hardison (1966) are based on a complex combination of factors that characterize the region in which they are located, namely: slope, geology, landform, soil, vegetation, water, and climate. For many parts of the world, detailed information on all of these parameters are not readily available, which makes it difficult to assign FPUs to a physiographic zone. However, Strzepek (in prep.) found that the most important single factor explaining the differences in reservoir storage construction costs is the slope of the basin in which the reservoir is situated, and derived relationships between mean FPU slope and construction costs per cubic meter for each of the 11 size classes used in the original work. We used these relationships (updated to 2005 U.S. dollars; Table 4.2) to estimate the costs of construction per FPU. The mean slope per FPU was derived from high-resolution digital elevation models: HYDRO1k[2] for most regions; and GTOPO30[3] for Greenland and Australia (since these are not available in the former data set).

Construction index multipliers derived from the work of Compass International Consultants Inc. (2009) were then applied to each FPU to account for cost differences in heavy civil engineering construction. These multipliers are available for 88 countries, and provide a factor by which U.S. construction costs can be multiplied to estimate mean construction costs in those

TABLE 4.1. CONSTRUCTION COSTS OF RESERVOIR STORAGE CAPACITY PER CUBIC METER IN THE UNITED STATES (IN 2005 U.S. DOLLARS)

Size class (million m^3)

Physiographic zone	Class I 0–25	Class II 25–49	Class III 49–74	Class IV 74–123	Class V 123–247	Class VI 247–493	Class VII 493–1233	Class VIII 1233–2467	Class IX 2467–4934	Class X 4934–12,335	Class XI > 12,335
A	1.21	1.00	0.92	0.85	0.76	0.69	0.59	0.53	0.46	0.40	0.32
B	1.05	0.84	0.76	0.69	0.61	0.53	0.45	0.40	0.34	0.29	0.23
C	0.93	0.71	0.63	0.58	0.50	0.42	0.35	0.29	0.26	0.21	0.16
D	0.84	0.63	0.55	0.49	0.41	0.34	0.27	0.22	0.19	0.15	0.09
E	0.82	0.61	0.52	0.45	0.38	0.32	0.25	0.20	0.17	0.13	0.08
F	0.76	0.56	0.48	0.42	0.34	0.29	0.23	0.18	0.15	0.11	0.06
G	0.75	0.54	0.46	0.40	0.32	0.27	0.20	0.16	0.13	0.10	0.05
H	0.65	0.45	0.38	0.33	0.27	0.21	0.16	0.13	0.10	0.08	0.04
I	0.50	0.34	0.29	0.24	0.20	0.16	0.12	0.10	0.08	0.05	0.03
J	0.32	0.23	0.19	0.17	0.13	0.11	0.08	0.06	0.05	0.04	0.02

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[2] http://edc.usgs.gov/products/elevation/gtopo30/hydro/index.html

[3] http://edc.usgs.gov/products/elevation/gtopo30/gtopo30.html

TABLE 4.2. STORAGE-COST RELATIONS BETWEEN MEAN FPU SLOPE, AND AVERAGE RESERVOIR STORAGE COSTS PER CUBIC METER. THE COST IN 2005 U.S. DOLLARS (Y) IS A FUNCTION OF THE MEAN FPU SLOPE IN DEGREES (X).

Reservoir size class	*Storage capacity (million m^3)*	*Storage-cost relation*	*R^2*
I	0–25	$y = 0.0192x^2 + 0.0525x + 0.5677$	0.566
II	25–49	$y = 0.0288x^2 – 0.0043x + 0.4348$	0.607
III	49–74	$y = 0.0332x^2 – 0.0303x + 0.3886$	0.623
IV	74–123	$y = 0.0361x^2 – 0.0508x + 0.3567$	0.614
V	123–247	$y = 0.0363x^2 – 0.0592x + 0.3019$	0.638
VI	247–493	$y = 0.0359x^2 – 0.0655x + 0.2569$	0.653
VII	493–1233	$y = 0.0357x^2 – 0.0750x + 0.2150$	0.663
VIII	1233–2467	$y = 0.0353x^2 – 0.0804x + 0.1849$	0.685
IX	2467–4934	$y = 0.0333x^2 – 0.0807x + 0.1625$	0.684
X	4934–12,335	$y = 0.0326x^2 – 0.0847x + 0.1392$	0.699
XI	> 12,335	$y = 0.0306x^2 – 0.0874x + 0.1084$	0.697

88 countries. For countries for which no construction cost multiplier is available, we used the mean multiplier of all listed countries in the same World Bank region. As the construction cost index is available at the country level, while the spatial unit of analysis in this study is the FPU, we calculated a construction cost multiplier for each FPU as follows. Most FPUs only contain land area of one country; for these FPUs the construction index of the relevant country was used. For those FPUs covered by several countries, the construction index of the FPU was calculated based on the proportion of the FPU covered by each country, such that:

$$CI_{FPU} = \sum_{i}^{n} (CI_{CTRYi} \times A_{CTRYi}) + (CI_{CTRYi+1} \times A_{CTRYi+1}) \ldots (CI_{CTRYn} \times A_{CTRYn}) \qquad \text{(Eq. 2)}$$

where *CI* is the value of the construction index multiplier for a given FPU, and *A* is the proportion of the surface area of that FPU covered by a given country (*CTRY*).

Validation of the reservoir storage cost estimation method. In order to validate this method we used it to estimate the construction costs of 85 existing reservoirs for which we identified the costs and storage capacities from published literature, and compared the actual recorded costs to our cost estimates. The main sources that we used to construct the data base of 85 costed reservoirs were Aylward et al. (2001) and references therein; World Bank (1996); Merrow and Shangraw Jr. (1990); and World Bank project performance assessment reports, implementation completion and results reports, performance audit reports, and project completion reports. From these sources we established, where possible, the total project costs, reservoir construction costs, valuation currency, and year of valuation. In some cases, the year of valuation was unclear, or significantly different cost estimates were given in different sources; these reservoirs were excluded from further analysis. We also excluded reservoir projects that were constructed over a number of phases, and for which it was not possible to separate the costs associated with each project phase. We then established the storage capacity of each of the reservoirs. The primary source for this purpose was the World Register of Dams (ICOLD 2003). However, we also referred to the data base of Chao et al. (2008), which provides corrections to the ICOLD data base for a number of dams, using the latter source where discrepancies existed. In all cases, we checked the value of storage capacity in ICOLD with the capacity stated in the original source; where a large discrepancy existed, we removed these reservoirs from further analyses. For 40 percent of the reservoirs, specific estimates were given of both total costs and construction costs, while for 60 percent of the reservoirs only total costs could be derived. For the reservoirs for which both total costs and construction costs were known, we calculated the ratio of construction costs to total costs, and used this to estimate the construction costs of the remaining reservoirs.

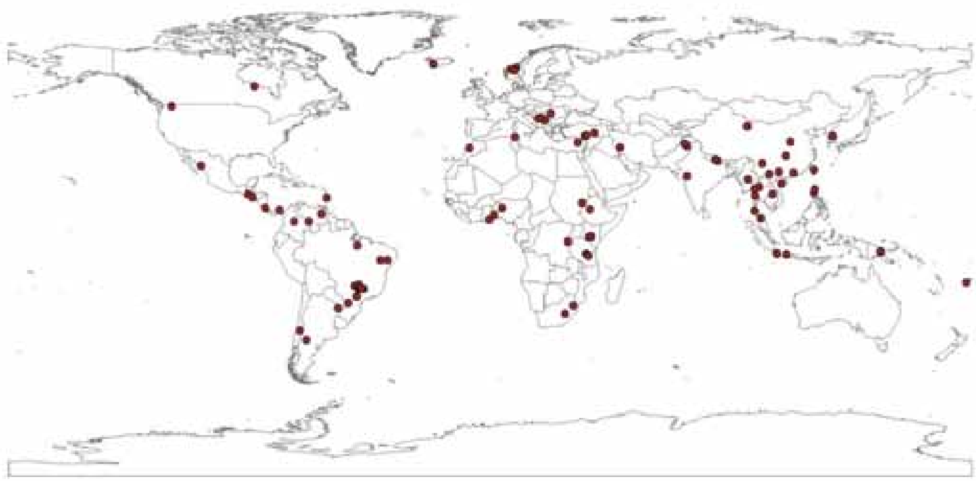
This filtering process resulted in a data base of 85 costed reservoirs (Figure 4.3), with a good geographical coverage over most of the World Bank regions (although relatively few reservoirs in MENA (3) and SA (5)). Summing the total observed and estimated construction costs for all of these reservoirs (about \$58.0 billion and \$65.3 billion, respectively), and dividing these by the total storage capacity (about 498.0 km^3), led to an estimated cost of reservoir storage of \$0.116/m^3 based on the observed costs, compared to \$0.130 based on our estimation method. Hence, the method used provides a good estimate of the costs of reservoir construction globally.

Estimation of future reservoir storage capacity distributions. The cost of reservoir construction depends strongly on the capacity of the reservoir, as shown in Table 4.1. Therefore, in order to estimate the costs of adding reservoirs in the future, information is required on how large those reservoirs will be, in terms of capacity. However, there is no global data base of planned dam or reservoir projects that can be used to assess the future size class distribution of reservoirs per country (or even per region or globally). Therefore, for this study the cost estimates were carried out using three scenarios of future reservoir size distribution: (1) small dams (all future reservoirs have a storage capacity under 25 million m^3); (2) large dams (all future reservoirs have a storage capacity greater than 12,335 million m^3); and (3) best estimate. In the latter scenario, we assume that future reservoir construction will follow the same size distribution as in the 21st Century in the United States, based on the size distribution of industrial and municipal water supply storage reservoirs in the Major Dams of the United States data set (National Atlas of the United States 2006)) (Figure 4.4). The small dams and large dams scenarios do not represent realistic future scenarios; instead they give the maximum and minimum values associated with the method. It would be prudent to use distributions of storage capacity based on analyses of each country separately, but comprehensive georeferenced reservoir data bases for this purpose are not currently available (see section 6.2).

4.5 RIVERINE FLOOD PROTECTION

In this study, the cost of adaptation in terms of riverine flood protection is defined as the cost of providing flood protection against the 50-year monthly flood in urban areas, and the 10-year monthly flood in agricultural

FIGURE 4.3. LOCATION OF THE RESERVOIRS IN OUR DATA BASE OF RESERVOIR CONSTRUCTION COSTS AND STORAGE CAPACITY



areas. The costs were estimated under the following scenarios:

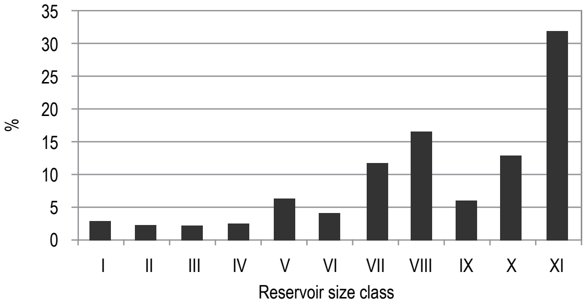
Socioeconomic baseline (**Baseline**): costs of providing riverine flood protection based in 2050, without climate change. Assumes no flood protection is in place at present.

Baseline and climate change (**Baseline & CC**): assumes that the costs of adaptation in the baseline will increase or decrease by the same percentage as the percentage change in magnitude of the 50-year monthly flood (for urban areas) or the 10-year monthly flood (for agricultural areas).

Climate change only (**CC**): difference between baseline and baseline & CC scenario.

The magnitude of the 10-year and 50-year monthly flood was estimated using the rainfall-runoff model CLIRUN-II, using the methodology described in the accompanying EACC background paper. The costs of adaptation were based on providing riverine flood protection to the given nominal standards, via a system of dikes and polders. The costs of providing these standards of flood protection were assumed to be \$50,000 per km^2 for urban areas, and \$8,000 per km^2 for agricultural areas. These cost estimates were derived through a review of World Bank project performance assessment reports, implementation completion and results reports, performance audit reports, and project completion reports. Land use data were taken from the data base of the Center for Sustainability and the Global Environment (SAGE)[4] (Foley et al. 2003; Leff 2003; Ramankutty and Foley 1998).

FIGURE 4.4. RESERVOIR STORAGE OF INDUSTRIAL AND MUNICIPAL WATER SUPPLY RESERVOIRS IN EACH OF THE RESERVOIR SIZE CLASSES SHOWN IN TABLE 4.1, EXPRESSED AS A PERCENTAGE OF THE TOTAL RESERVOIR STORAGE OF INDUSTRIAL AND MUNICIPAL WATER SUPPLY RESERVOIRS



Source: National Atlas of the United States, 2006.
Note: Data are taken for all reservoirs listed in the Major Dams of the United States data set.

The required adaptation measures were calculated for the year 2050, and were then assumed to be implemented linearly in the intervening 40 years. We assume O&M costs of 0.5 percent of construction costs per annum, which is consistent with the maintenance costs of river dikes in coastal areas in the coastal sector work of the EACC study.

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[4] www.sage.wisc.edu

5. RESULTS AND DISCUSSION

In this section we present the main results of the analytical work. The limitations of the study, and accompanying recommendations are given in section 6.2. Maps showing the change in industrial and municipal water demand per FPU in the EACC socioeconomic scenario between 2005 and 2030, and between 2030 and 2050, can be found in Figure 2.1. The changes in the key climatic and hydrological variables that drive our adaptation cost analyses are discussed in an accompanying EACC background paper.

5.1 COSTS OF CLIMATE-CHANGE-RELATED ADAPTATION

Using the methods discussed in section 4, the annual costs of adaptation in relation to water supply and riverine flood protection were estimated. In this report, the climate-change-related adaptation results are calculated using two approaches. In the first approach, the costs (positive and negative) are calculated for each country, and then summed for each 5-year period, before being aggregated to World Bank regions. Thus, the results per region refer to the net total of positive and negative costs, and can therefore be negative (i.e. avoided costs, or benefits) for certain regions. In the second approach, the annual negative costs at the country level are first set to zero, so as only to show the strict costs of adaptation in that year. These results are then summed to 5-year periods, and then aggregated to World Bank regions. In the following discussion we refer to the results of the former approach as net costs, and to the results of the latter approach as gross costs.

5.1.1 Water supply

The estimated costs of adaptation in the industrial and municipal water supply sector per 5- year period in the baseline, baseline & CC, and CC scenarios, for discount rates of 0 percent, 3 percent, 5 percent, and 7 percent, can be found in Appendixes 1 to 8. For the climate change scenarios, both net and gross costs are shown. The overall costs are highly sensitive to the choice of discount rate. In this section, the results are given for a discount rate of 0 percent (consistent with the sectoral results in the main EACC report), and the reader is referred to the appendixes for results relating to other discount rates.

The average annual costs of adaptation in the industrial and municipal water supply sector over the period 2010–50 are shown in Table 5.1. The net and gross adaptation costs differ greatly. The total gross costs for all developing countries are almost twice as large as the total net costs. This is because many countries will benefit from climate change (in relation to the baseline) in terms of water supply. However, as shown by the net cost estimates, globally the total costs outweigh the avoided costs (benefits).

The cost estimates are affected by the choice of scenario of future reservoir storage size. Using the CSIRO model, the total climate-change-related adaptation cost in all developing countries varies by a factor of 2.7 (net), or 2.0 (gross), between the large dams and small dams scenarios. For the NCAR model, these costs only vary by a factor of 1.3. The best estimate scenario suggests costs slightly higher than the large dams scenario (by a factor of 1.3 to 1.5).

The results in Table 5.1 also show large differences between regions and between GCMs; these can be seen

TABLE 5.1. AVERAGE ANNUAL COSTS OVER THE PERIOD 2010–50 OF ADAPTATION IN THE INDUSTRIAL AND MUNICIPAL WATER SUPPLY SECTOR, BASED ON THE BEST ESTIMATE (ABOVE), SMALL DAMS (MIDDLE), AND LARGE DAMS (BELOW) SCENARIOS FOR RESERVOIR CONSTRUCTION

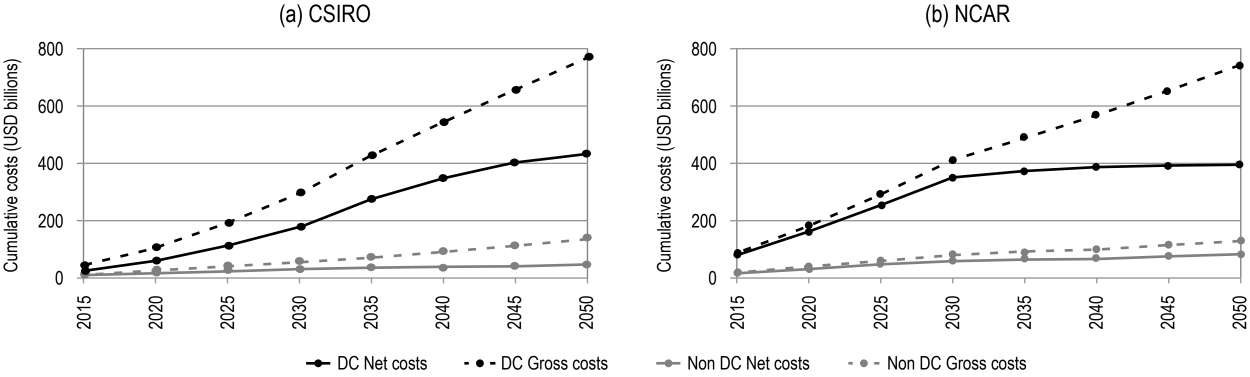
Average annual adaptation costs in the water supply sector (2010–2050) - USD billions

	Baseline	*CC Net costs*		*CC Gross costs*	
		CSIRO	*NCAR*	*CSIRO*	*NCAR*
Best estimate					
EAP	20.79	0.55	0.26	2.14	3.13
ECA	2.15	–0.37	0.86	0.49	1.62
LAC	3.04	1.46	5.20	2.88	5.26
MENA	6.74	–0.39	0.00	0.22	0.55
SA	28.73	2.38	–2.32	5.94	1.82
SSA	5.08	7.31	5.89	7.58	6.16
Total DC	**66.53**	**10.94**	**9.89**	**19.26**	**18.54**
Total Non DC	6.44	1.24	2.06	3.48	3.24
Small dams					
EAP	22.10	0.40	–1.61	2.17	2.34
ECA	3.29	–0.96	0.92	0.45	2.66
LAC	4.57	7.76	5.03	9.96	5.37
MENA	6.89	0.07	0.62	0.69	1.17
SA	28.73	2.28	–2.43	5.90	1.67
SSA	5.32	13.62	8.75	13.90	9.12
Total DC	**70.89**	**23.17**	**11.29**	**33.08**	**22.35**
Total Non DC	7.20	2.12	4.75	5.02	5.95
Large Dams					
EAP	20.79	0.55	0.26	2.14	3.13
ECA	2.15	–0.37	0.86	0.49	1.62
LAC	3.04	1.46	5.20	2.88	5.26
MENA	6.74	–0.39	0.00	0.22	0.55
SA	28.60	1.30	–2.46	4.86	1.67
SSA	5.09	5.95	4.64	6.22	4.92
Total DC	**66.40**	**8.50**	**8.50**	**16.82**	**17.14**
Total Non DC	6.72	0.95	1.78	3.48	3.24

Note: Results are shown for the baseline, and for the CC scenarios. Discount rate = 0%. For the full results per 5-year periods, and for other discount rates (3%, 5%, 7%), please refer to Appendix 1 to Appendix 8.

more clearly in Figure 5.1 and Figure 5.2. For both GCMs, the costs of adaptation are much higher for developing countries than for non-developing countries. Although the total costs across all developing countries are similar for CSIRO and NCAR, they vary greatly at the scale of World Bank regions (Figure 5.2). However, the results forced by both GCMs show the climate-change-related adaptation cost over the entire period 2010–50 (Table 5.1) to be highest for the SSA region. As shown in Figure 5.2 and Table 5.1, there are net avoided costs in some regions. For the best estimate scenario, MENA and ECA show net avoided costs using CSIRO, and SA shows net avoided costs using NCAR. The regional differences between the GCMs clearly highlights the large uncertainties involved in GCM projections of the future.

FIGURE 5.1. CUMULATIVE COSTS (2005 U.S. DOLLARS) OF CLIMATE-CHANGE-RELATED ADAPTATION IN THE WATER SUPPLY SECTOR IN DEVELOPING COUNTRIES (DCS) AND NON-DEVELOPING COUNTRIES (NON-DCS) FOR (A) CSIRO, AND (B) NCAR



Note: Discount rate = 0%.

Besides geographical differences, Figures 5.1 and 5.2 show considerable temporal differences in cost patterns, with clear differences between the first half of the period (2010–30) and the second half of the period (2030–50). The abruptness of these changes derive for a large part from the fact that climate change data in this study were available for 2030 and 2050, with the required adaptation measures assumed to be implemented linearly first between 2010 and 2030 (based on the change in demand and water availability between those periods), and then between 2030 and 2050 (based on the change in demand and water availability between those periods). Nevertheless, both models suggest that (net) costs will be higher in the period 2010–30 than in the period 2030–50. These changes can be explained with reference to Figure 5.3, which shows the individual adaptation costs in all developing countries associated with adding reservoir storage capacity to increase yield, and providing water from alternative supply measures, for both the baseline and baseline & CC scenarios. Most of the baseline water supply adaptation costs pertain to supplying water from alternative supply measures. In both cases, the total baseline costs increase strongly over the entire period 2010–50, due to increasing populations and economic development. However, the net difference between baseline costs and baseline & CC costs becomes smaller after 2030. The costs of water supply from alternative water measures in the baseline & CC scenario fall below those of the baseline scenario by 2050 under both GCMs. These changes are due to the relatively large increase in water availability (runoff) in some basins between 2030 and 2050, which means that a greater yield can be supplied by existing (and new) reservoir storage.

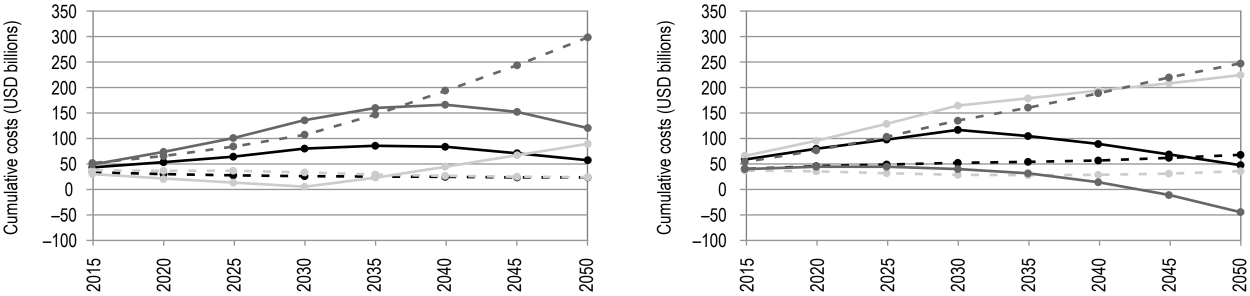
While Figure 5.3 shows that the adaptation costs associated with additional reservoir construction in the future in the baseline and baseline & CC scenarios are much lower than those associated with alternative measures, the projected increase in reservoir capacity is still substantial (Table 5.2). The total differences between the two GCMs are small, although there is more variation between the GCMs when comparing individual World Bank regions. For the sake of comparison, a recent study of current reservoir storage worldwide, based on 29,484 named reservoirs, estimates the current surface storage capacity of the world's reservoirs to be about 8,300 km^3 (Chao et al. 2008).

While the IPPC states that new reservoirs are expected to be built in developing countries in the coming century (Bates et al. 2008), the question of adding new surface water storage, by building new dams, is politically sensitive; many groups and stakeholders have strong feelings either for or against this strategy (WCD 2000). Nevertheless, a global-scale estimate of the direct costs associated with pursuing such a strategy has not previously been carried out, and hence this research

FIGURE 5.2. CUMULATIVE COSTS (2005 U.S. DOLLARS) OF CLIMATE-CHANGE-RELATED ADAPTATION IN THE WATER SUPPLY SECTOR IN THE WORLD BANK REGIONS FOR (A) CSIRO (NET), (B) CSIRO (GROSS), (C) NCAR (NET), AND (D) NCAR (GROSS)

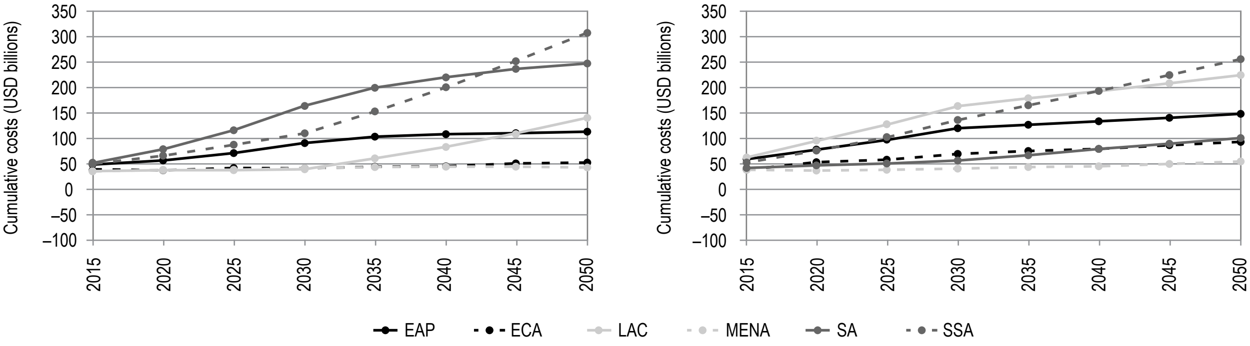
(a) CSIRO (Net costs)

(c) NCAR (Net costs)



(b) CSIRO (Gross costs)

(d) NCAR (Gross costs)

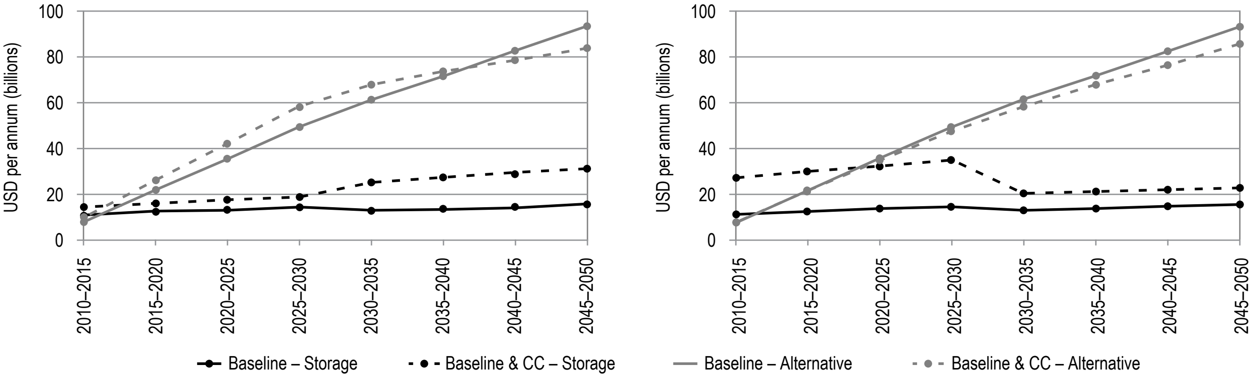


Note: Discount rate = 0%. A downward sloping cost curve signifies net avoided costs.

FIGURE 5.3. ANNUAL COSTS (2005 U.S. DOLLARS) OF ADAPTATION IN THE WATER SUPPLY SECTOR PER 5-YEAR PERIOD FOR THE BASELINE (SOLID LINES) AND BASELINE & CC (DOTTED LINES) SCENARIOS FOR (A) CSIRO, AND (B) NCAR

(a) CSIRO

(b) NCAR



Note: The red lines represent the costs of additional reservoir storage requirements, and the blue lines represent the additional costs of water supply using alternative measures. Discount rate = 0%.

TABLE 5.2. TOTAL INCREASE IN RESERVOIR STORAGE CAPACITY (CUBIC KILOMETERS) BETWEEN PRESENT AND 2050 UNDER THE BASELINE & CC SCENARIO FOR CSIRO AND NCAR GCMS (BEST ESTIMATE)

	Increase in reservoir storage capacity between present and 2050 under baseline & CC scenario (cubic kilometers)	
	CSIRO	*NCAR*
	Best estimate	*Best estimate*
EAP	469	647
ECA	77	95
LAC	701	789
MENA	26	40
SA	298	220
SSA	983	420
Total DC	***2555***	***2212***
Total Non DC	426	591
Total	**2981**	**2803**

adds to the discourse on this topic. Given this significant increase in reservoir storage capacity, a short discussion of some of the pros and cons of reservoirs and dams is presented in Box 5.1. Such a discussion could fill an entire volume, which is beyond the scope of this paper; for a comprehensive overview the reader is referred to specific studies on this issue, such as the report of World Commission on Dams (WCD 2000). There is a clear need to assess the suitability of dams and reservoirs at the project level. The WCD set out 26 guidelines for decision making on the provision of water and energy resources (WCD 2000), which highlights the need to consider a full range of economic, social, and environmental costs and benefits associated with a whole range of measures when assessing water resource development (and adaptation) options. A key element is the need to involve all key stakeholders and policies, including government, civil society, private sector, professional organizations, multilateral and bilateral organizations, international standards, and international agreements. Examples of community-based water projects in developing countries that have included the use of small dam structures to avoid some of the negative impacts of dams are discussed in Boxes 2.5 and 2.6.

Our estimates of climate-change-related adaptation costs in the water supply sector are generally higher

BOX 5.1. PROS AND CONS OF WATER SUPPLY THROUGH RESERVOIR STORAGE

Direct and planned benefits of reservoirs include: the provision of water supply for municipal and industrial water use and irrigation (some 30–40 percent of irrigated land worldwide relies on dams); flood control—globally, 8 percent of dams are reported as having flood alleviation as one of their purposes (Green et al. 2000); hydroelectric power generation—dams generate about 19 percent of the world's electricity (WCD 2000); and navigation (Brown et al. 2009). Indirectly, dams can have the following impacts: increased agricultural yields; local and regional economic diversification; increased fish productivity in reservoirs; local employment and skills development; rural electrification; and the expansion of physical and social infrastructure such as roads and schools. In some cases, reservoir construction has led to the creation of productive fringing wetland ecosystems with fish and waterfowl habitat opportunities, although the ecological impacts of dams have generally been more negative than positive (WCD 2000). Recent research also shows that the impoundment of water on land in artificial reservoirs worldwide may have reduced the magnitude of global sea level rise by about 30 millimeters (Chao et al. 2008).

On the other hand, dams have had many negative impacts, particularly in environmental and social terms (Petts 1984; Poff and Hart 2002; Poff et al. 1987; Ward and Stanford 1979; WCD 2000). Large dams have mainly had negative impacts on the environment, including: loss of forest and wildlife habitat; loss of species populations; environmental degradation of upstream areas due to the inundation of reservoir areas; emissions of greenhouse gases from reservoirs due to decaying vegetation and carbon inflow; loss of aquatic biodiversity and productivity in upstream and downstream fisheries; and loss of ecosystem services in downstream floodplains, wetlands, riverine, and estuarine ecosystems. In addition, it is estimated that 0.5–1.0 percent of the total freshwater storage capacity of existing dams is lost each year to sedimentation (Clarke 2000). Moreover, waterlogging and soil salinity in irrigated systems are becoming serious problems globally; 20 percent of the case-study dams assessed by WCD with an irrigation component reported impacts from waterlogging. Many negative social impacts have been associated with the large-scale use of dams in the 20th century. For example, over 40–80 million people have been displaced worldwide. Many of the displaced were not officially recognized as such, and therefore not resettled or compensated; where compensation was provided, it often proved inadequate. Those who were resettled have rarely had their livelihoods restored, as resettlement programs have focused on physical relocation rather than on the economic or social development of the displaced. In addition, millions of people living downstream from dams have suffered serious harm to their livelihoods and had the future productivity of their resources put at risk. Groups that have suffered disproportionate negative impacts include indigenous and tribal people, vulnerable ethnic minorities, and women (WCD 2000). Dams and reservoirs have also frequently been associated with the loss of cultural resources and heritage (Cernea 1999; Goldsmith and Hildyard 1986).

than those of Kirshen (2007) and UNFCCC (2007). Those studies state that 85 percent of total climate-change-adaptation costs will be required by developing countries, similar to the 80–90 percent estimated in our study. UNFCCC estimate the annual average climate-change-related adaptation costs up to 2030 for developing countries to be about $7.7 billion for the SRES B1 scenario, and $9.6 billion for the A1b scenario. It is difficult to compare these costs directly with those in the present study, since the UNFCCC study projected the combined costs of adaptation due to both climate and socioeconomic change, and then assumed that climate change costs account for 25 percent of this total, whereas we have estimated the climate-change-related costs in relation to a socioeconomic baseline. For the period up to 2030 only, we estimate annual climate-change-related net costs at $9 billion (CSIRO) and $17 billion (NCAR), and annual gross costs at $15 billion (CSIRO) and $21 billion (NCAR).

5.1.2 Riverine flood protection

The estimated costs of adaptation for riverine flood protection per 5- year period in the baseline, baseline & CC, and CC scenarios, for discount rates of 0 percent, 3 percent, 5 percent, and 7 percent, can be found in Appendixes 9 to 16. All of the flood protection cost estimates are made up of an urban and an agricultural component, the costs of which are shown separately in the appendixes. The total costs of urban flood protection are much higher than those of agricultural flood protection. For example, for all developing countries, over the period 2010–50, urban flood protection accounts for 91 percent of the total costs for CSIRO and 94 percent for NCAR. As with water supply, the costs are sensitive to the discount rate used. In this section, the results are given for a discount rate of 0 percent (consistent with the sectoral results in the main EACC report), and the reader is referred to the appendixes for results relating to other discount rates.

The average annual costs of adaptation for riverine flood protection over the period 2010–50 are shown in Table 5.3. These are simply the additional costs of providing flood protection measures against monthly floods with a nominal return period (that is, 50 years and 10 years for urban and agricultural areas, respectively), but do not consider the damages that would be caused by flood events with longer return periods. The differences between the net and gross cost estimates are smaller than in the case of water supply adaptation costs. This is because even in many basins where mean annual runoff is expected to decrease in the future, the occurrence of extreme events (both high and low flows) is expected to increase (Kundzewicz et al. 2007). Hence, fewer basins are projected to encounter "benefits" in terms of flood protection.

TABLE 5.3. AVERAGE ANNUAL COSTS OF ADAPTATION IN TERMS OF RIVERINE FLOOD PROTECTION OVER THE PERIOD 2010–50

Average annual adaptation costs of flood protection (2010–2050) - USD billions

	Baseline	*CC Net costs*		*CC Gross costs*	
		CSIRO	*NCAR*	*CSIRO*	*NCAR*
EAP	8.59	1.57	0.78	1.57	0.94
ECA	13.60	0.67	1.39	0.93	1.66
LAC	10.36	1.74	0.29	2.05	0.96
MENA	5.12	0.46	–0.29	0.55	0.11
SA	6.17	1.64	0.96	1.67	1.09
SSA	4.72	–0.16	0.33	0.25	0.41
Total DC	***48.55***	***5.92***	***3.45***	***7.00***	***5.16***
Total Non DC	49.77	6.18	1.40	7.32	1.99

Note: Results are shown for the baseline, and for the CC scenarios. Discount rate = 0%. For the full results per 5-year period, and for other discount rates (3%, 5%, 7%) please refer to Appendixes 9 to 16.

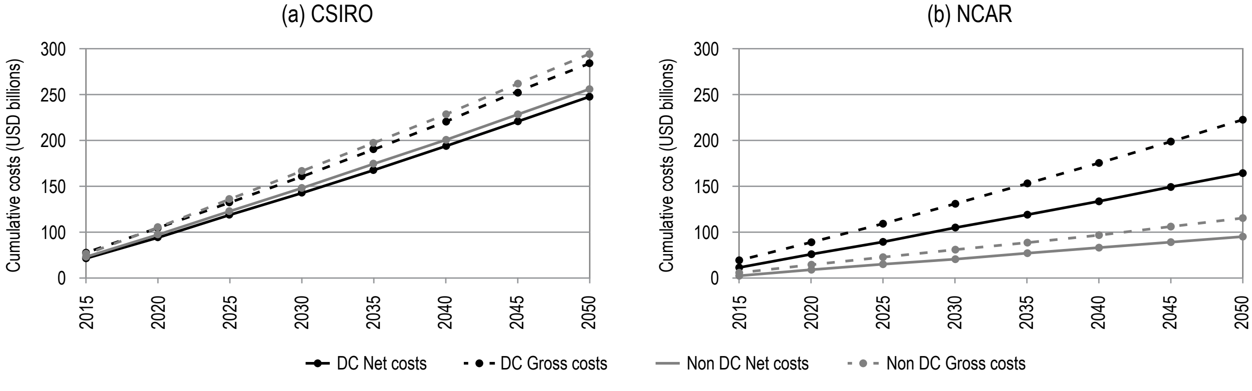
For the CSIRO model, the climate-change-related adaptation costs are of a similar magnitude for developing and non-developing countries (Figure 5.4). For NCAR, the total costs for developing countries are greater than those for non-developing countries by a factor of about 2.5. There are also large differences between the results of the two GCMs at the scale of the World Bank regions (Figure 5.5). In some cases, even the sign of the change is different between the models. This is the case for both MENA (net costs for CSIRO and net avoided costs for NCAR), and SSA (net avoided costs for CSIRO and net costs for NCAR). These differences are associated with the regional differences in the magnitude (and sign) of change of the 50- year and 10- year maximum monthly runoff between the two models, again highlighting the uncertainty involved in the use of GCM results.

5.1.3 Total costs of water resources adaptation

So far, the costs of adaptation have been discussed individually for water supply and riverine flood protection. In Table 5.4, the adaptation costs are shown for water supply and riverine flood protection together, here termed water resources adaptation. In this case, the net costs are obtained by summing the total net costs for water supply and riverine flood protection. However, for gross costs the following method was adopted: (a) net costs for water supply and riverine flood protection were first summed for each country, before (b) setting all net negative costs to zero, and (c) aggregating to the World Bank regions. The average annual net costs for all developing countries are $13.3–$16.9 billion, and average annual gross costs are $20.2–$22.8 billion. The adaptation costs are substantially greater for developing countries than for non-developing countries under both CSIRO and NCAR. There are large geographical differences between the cost estimates derived using the two GCMs, but both suggest that the climate-change-related adaptation costs will be greatest in the SSA region.

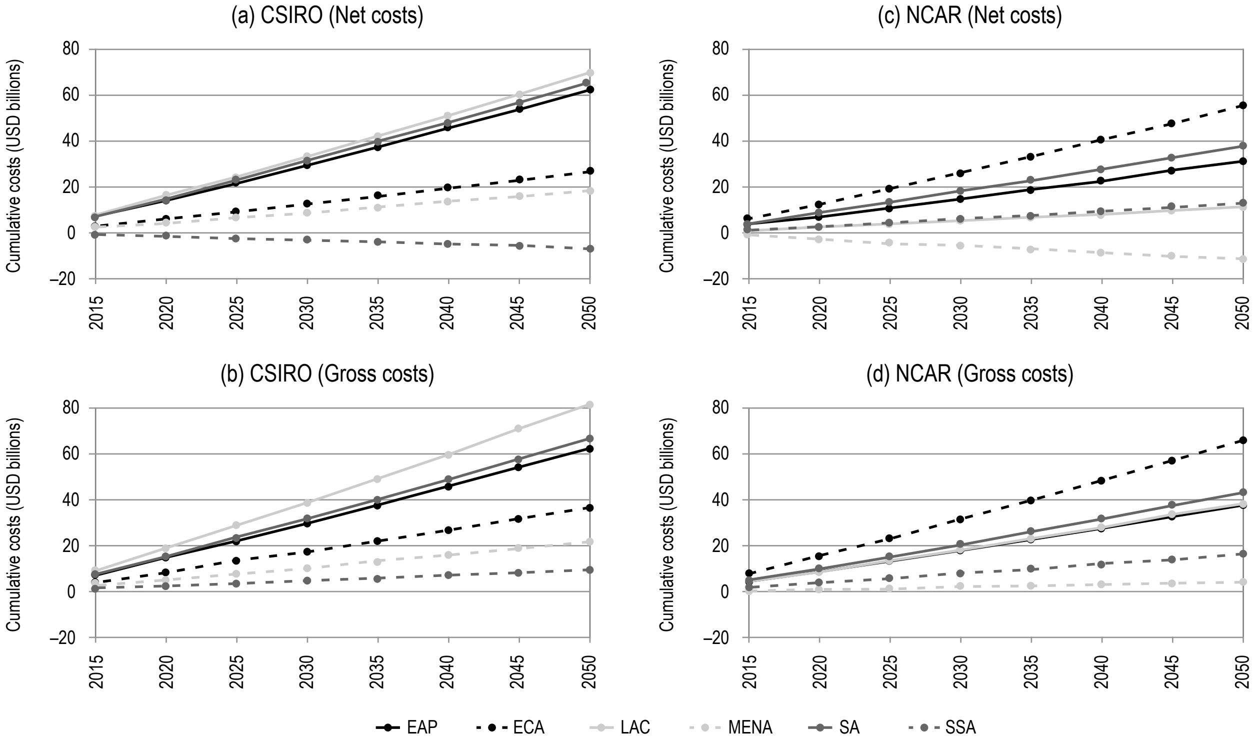
The cost estimates in this study are subject to several limitations (see section 6.2). Nevertheless, they are relatively small in relation to world GDP. In Table 5.5, the baseline and climate-change-related water resources adaptation costs are shown (the water supply costs are based on the best estimate scenario) in relation to world GDP (based on world GDP in 2007 from the World Bank WDI index, in 2005 U.S. dollars; that is, $51,528 billion). The global cost estimates (developing and non-developing countries combined) of climate-change-related adaptation in the water resources sector amount to 0.04–0.06 percent of world GDP. The baseline adaptation costs are significantly higher, but still low (0.33 percent).

FIGURE 5.4. CUMULATIVE COSTS (2005 U.S. DOLLARS) OF CLIMATE-CHANGE-RELATED ADAPTATION FOR RIVERINE FLOOD PROTECTION FOR (A) CSIRO AND (B) NCAR



Note: DC = developing countries; non DC = non-developing countries.

FIGURE 5.5. CUMULATIVE COSTS (2005 U.S. DOLLARS) OF CLIMATE-CHANGE-RELATED ADAPTATION FOR RIVERINE FLOOD PROTECTION IN THE WORLD BANK REGIONS FOR (A) CSIRO (NET), (B) CSIRO (GROSS), (C) NCAR (NET), AND (D) NCAR (GROSS)



Note: Discount rate = 0%.

TABLE 5.4. AVERAGE ANNUAL WATER RESOURCES ADAPTATION COSTS OVER THE PERIOD 2010–50

	Average annual water resources adaptation costs (2010–2050) - USD billions				
	Baseline	*CC Net costs*		*CC Gross costs*	
		CSIRO	*NCAR*	*CSIRO*	*NCAR*
EAP	29.4	2.1	1.0	3.3	3.4
ECA	15.8	0.3	2.3	1.2	2.5
LAC	13.4	3.2	5.5	3.9	5.6
MENA	11.9	0.1	-0.3	0.6	0.4
SA	34.9	4.0	-1.4	6.3	2.0
SSA	9.8	7.2	6.2	7.4	6.4
Total DC	***115.1***	***16.9***	***13.3***	***22.8***	***20.2***
Total Non DC	56.2	7.4	3.5	8.5	4.3

Note: Results are shown for the baseline, and for the CC scenarios. Discount rate = 0%.

TABLE 5.5. AVERAGE ANNUAL ADAPTATION COSTS IN THE WATER RESOURCES SECTOR AS A PERCENTAGE OF WORLD GDP IN 2007

	Annual water resources adaptation costs as a % of world GDP in 2007				
	Baseline	*CC Net costs*		*CC Gross costs*	
		CSIRO	*NCAR*	*CSIRO*	*NCAR*
EAP	0.06	0.00	0.00	0.01	0.01
ECA	0.03	0.00	0.00	0.00	0.00
LAC	0.03	0.01	0.01	0.01	0.01
MENA	0.02	0.00	0.00	0.00	0.00
SA	0.07	0.01	0.00	0.01	0.00
SSA	0.02	0.01	0.01	0.01	0.01
Total DC	***0.22***	***0.03***	***0.03***	***0.04***	***0.04***
Total Non DC	0.11	0.01	0.01	0.02	0.01

6. CONCLUSIONS, LIMITATIONS, AND RECOMMENDATIONS

Even if emissions of anthropogenic greenhouse gases were stabilized today, human-induced changes in climate will continue for many centuries (IPCC 2007). Therefore, in addition to mitigation, it is essential to develop adequate adaptation measures to moderate the impacts and realize the opportunities associated with climate change. However, on a global scale, sectoral and cross-sectoral studies of the economic aspects of climate change and adaptation are very limited (Adger et al. 2007; EEA 2007; Kuik et al. 2008). Hence, the EACC study has been carried out to estimate the costs of adapting to climate change in developing countries over the period 2010–50.

This background paper examines adaptation in terms of the water supply sector and riverine flood protection, and addresses the following research aims:

- Develop a data base of adaptation policies, programs, and projects that can be used in the water supply sector;
- Develop a data base of adaptation policies, programs, and projects that can be used for riverine flood protection;
- Estimate the climate change adaptation costs in the industrial and municipal water supply sector;
- Estimate the climate change adaptation costs for riverine flood protection.

The main conclusions related to these aims are provided in section 6.1. Key limitations of the study, with accompanying recommendations for future research, are summarized in section 6.2.

6.1 MAIN CONCLUSIONS

A myriad of adaptation measures are available in terms of both water supply and riverine flood protection, with new innovative adaptation options continually being developed. A (nonexhaustive) data base of adaptation options is provided in section 2.4.

In the water supply sector, adaptation measures can be divided into supply-side and demand-side measures. Ideally, adaptation options designed to ensure water supply during average and drought conditions should integrate strategies on both sides of this spectrum (Bates et al. 2008). In terms of flood protection, adaptation options can either reduce the probability or magnitude of flood events (i.e., reduce the flood hazard) or can reduce the impacts of floods. Traditionally, flood protection measures in most parts of the world have concentrated on reducing the probability of flooding, often by providing structural measures designed to protect against a flood with a given return period. However, there is currently an international shift toward a more integrated system of flood risk assessment, whereby flood risk can be defined as the probability of flooding multiplied by the potential flood damage. Under this approach, adaptation should consider structural and non-structural measures that address both flood probability and impact.

The costs of adaptation measures vary greatly according to location and type of measure. This is not only true for the direct construction, implementation, and/or O&M costs, but also for the indirect costs, such as environmental and socioeconomic costs. In addition, adaptation measures may provide secondary benefits at all levels from household to international. Again, these benefits vary according to location and type of measure.

The correct measure or combination of measures is always site- and context-specific. Nevertheless, a key factor in adaptation planning is the need to adapt in ways that are synergistic with development, and that do not lead to increases in the adaptation deficit (that is, maladaptation). Although climate change is not directly addressed in the eight Millennium Development Goals (MDGs), most of them are directly or indirectly related to water, and therefore linked to the issue of climate change. Adaptation measures should address economic, environmental, and social welfare in an equitable manner, and should address issues in a basin-wide context, following the principles of good governance. Key facets are public participation and the use of local knowledge in the planning, development, and maintenance of adaptation strategies, whether they be structural or policy measures. These issues are addressed in the concept of integrated water resource management, which should be used as an instrument to explore adaptation measures to climate change.

Our best estimate of the annual costs of climate change adaptation in developing countries in the industrial and municipal raw water supply sector is between $9.9–$10.9 billion (net), and $18.5–$19.3 billion (gross). These costs are much higher than those estimated for non-developing countries. In terms of climate-change-related adaptation costs for riverine flood protection, our annual estimates for developing countries are between $3.5–$5.9 billion (net), and $5.2–$7.0 billion (gross). Most of these costs (>90 percent) are associated with the provision of flood protection in urban areas. There are large differences between the two GCMs used in terms of the regional and temporal distribution of costs, both for water supply and riverine flood protection. This highlights the large uncertainties involved in GCM projections of the future.

The combined annual costs of adaptation in developing countries for water supply and riverine flood protection, here defined as water resources adaptation costs, are between $13.3–$16.9 billion (net), and $20.2–$22.8 billion (gross). These estimates are small in relation to total world GDP, at about 0.03–0.04 percent. The estimated annual cost of adaptation in the baseline scenario (that is, without climate change) in developing countries is significantly higher ($115.1 billion). Nevertheless, this is still small in relation to world GDP (0.22 percent).

The adaptation costs are substantially greater for developing countries than for non-developing countries. While there are large geographical differences between the cost estimates derived using the two GCMs, both suggest that the overall costs will be greatest in the Sub-Saharan Africa region.

The results support the notion that the negative impacts of climate change in the water resources sector will generally be greater in developing countries than in non-developing countries, and that the costs of adaptation will be greatest in Sub-Saharan Africa. They also underline the importance of mainstreaming climate change adaptation into general development practices, since the adaptation costs in the climate change scenarios are small compared to the baseline adaptation costs. Moreover, the costs are relatively small in relation to world GDP, even those associated with adapting to the baseline level.

6.2 LIMITATIONS AND RECOMMENDATIONS

Due to the global nature of this study, the results provide a broad estimate of the possible costs of adaptation to climate change The absolute numbers should be treated with caution, but they give an indication of the magnitude of the problem globally. The relative proportions of the total costs per World Bank region give an indication of the relative scale of the problem among regions. As more information becomes available on the costs of adaptation measures at the global scale, more comprehensive assessments of costs (and benefits) of different approaches can be carried out and compared to the outcomes of this study. In the case of riverine flood protection, the estimates provide, to the best of our knowledge, the first assessment of the costs of climate-change-related adaptation at the global scale. In this section, a number of the main limitations of this study are summarized, as well as recommendations on how future research could address these issues.

- There are significant uncertainties in projections of the impacts of climate change on water resources. Uncertainties about the impacts of climate change on the hydrological cycle include uncertainties in the internal variability of the climate system; in the future greenhouse gas and aerosol emission scenarios (and in the scenarios of population, economic development, and technological change that generate them); in the translation of these emissions scenarios into climate change by climate models; and in the hydrological models used to simulate the impacts of climate change on the hydrological cycle. As with all modeling studies, these uncertainties and model errors permeate through the entire modeling chain. The largest of these uncertainties in climate change impact assessments on water resources are due to the uncertainty in precipitation inputs (Bates et al. 2008). In order to gain a better insight into the size of the uncertainty associated with these factors, future research should assess the impacts under a greater range of GCMs and emissions scenarios. As research continues into improving climate models and model parameterization, and computational power continues to increase, these uncertainties should be reduced.

- As well as the uncertainties in future climate change impact projections described above, uncertainties exist in the projections of baseline changes (that is, without climate change). For this study, we used only one scenario of future socioeconomic change in order to estimate future water demand. In terms of riverine flood protection, the baseline costs are dependent on the protection level to be afforded by flood defense measures. In this study, we estimate the baseline costs as the costs of providing flood protection against a 50-year monthly flood in urban areas, and against a 10- year monthly flood in agricultural areas. In many basins, this protection level is already provided, especially in many non-developing countries, and hence the baseline costs will be overestimated. Nevertheless, the aim of this study is primarily to assess the costs of climate-change-related adaptation.
- We have only examined the direct construction, implementation, and O&M costs associated with the adaptation measures considered. All adaptation measures entail other costs, both direct and indirect. Similarly, we do not consider the possible direct and indirect secondary economic benefits of adaptation measures. As such, the study does not provide an economic cost-benefit analysis, but an assessment of the construction, implementation, and O&M costs of these adaptation strategies.
- The cost of adding reservoir storage capacity varies greatly with reservoir size. No comprehensive data bases of planned future reservoirs exist, and it is therefore not possible to accurately predict the size of reservoirs that will be built in the future. Our best estimate is based on the size distribution of existing water supply reservoirs in the United States. It would be prudent to use distributions of storage capacity based on analyses of each country separately, but comprehensive georeferenced reservoir data bases are currently not available. At present, the most comprehensive is the Global Lakes and Wetlands Database (Lehner and Döll 2004), but this only contains 740 reservoirs. Currently, the Global Reservoir and Dam (GRanD) data base is being developed as part of the Global Water System Project (GWSP) (http://www.gwsp.org/current_activities.html). Once available, this will initially contain about 7,000 reservoirs, and could be used to improve assumptions pertaining to the future distribution of reservoir size classes.
- The relative marginal costs of dam construction may increase in the future because existing dams and reservoirs are likely to have used many of the most cost-effective locations.
- There is an extensive literature devoted to determining how much water a river needs to sustain a healthy aquatic ecosystem and ecosystem function (for a review, see Tharme 2003). When planning adaptation measures in the water sector, assessments must consider how to ensure that a minimum ecological function is maintained. In reality, this must be carried out at the local level, based on local physical, socioeconomic, and political considerations. In a global study of this nature, it is not possible to address such considerations, and hence a generalized rule of thumb was applied whereby the percentage of water withdrawals is not allowed to increase above 80 percent of total runoff. However, this standard is arbitrary, and underscores the need for basin scale planning when actual water management plans are being developed and implemented.
- We did not account for the effects of sedimentation on reservoir storage capacity, since there are no data bases describing regional rates of this phenomenon. This will lead to an underestimation of costs, since either (a) more capacity will need to be added to replace lost capacity; (b) more supply will have to be met through alternative measures; and/or (c) expensive dredging activities will have to be carried out.

- Demand-side adaptations are not explicitly costed in this study, since the demand projections already account for some increase in efficiencies over time, and this could lead to double counting. However, it should be noted that there is substantial scope for economizing on the consumption of water (Zhou and Tol 2005).
- We do not account for water trading between countries; in some cases, this could lead to a more efficient use of water resources. Such arrangements need to be negotiated and formalized in agreements and treaties between riparian states, and cannot be implemented in such a global modeling exercise.
- We do not account for the adaptation costs associated with climate-change-related alterations in water quality. Climate change is expected to worsen many forms of water pollution. Box 2.1 summarizes the main findings of the IPCC on water quality.
- We are not aware of any previous studies estimating the global costs of adaptation related to riverine flood protection. The results presented in this study should therefore be treated as preliminary indicative costs. Many limitations remain, not least the fact that flood risk is not assessed. The costs of adaptation related to climate change in terms of riverine flooding are estimated in terms of the costs of retaining a nominal flood protection standard. The time and resources available for the current study, and existing data sets and methodologies, did not permit us to carry out a flood-risk-based assessment of the costs (and benefits) of adaptation in terms of flood management. Such an assessment would require the combination of a hydrological and hydrodynamic model at the global scale to produce global flood hazard maps, and stage damage relations to relate flood depth to (economic) damage.
- In some areas (especially non-developing countries), the climate-change-related adaptation costs for riverine flood protection will be overestimated since the existing flood management measures already provide protection against floods with a longer return period than 50 years.
- We did not estimate the costs of adapting to localized flash flood events, since the time and resources available did not allow for a global hydrological modeling exercise on a daily time-step. Moreover, the use of GCM data does not lend itself to an assessment of localized events.

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8. APPENDIXES

APPENDIX 1. WATER SUPPLY RESULTS. GCM: CSIRO. DISCOUNT RATE: 0%

		Annual costs (averaged over 5-year periods) in USD billion											
		Baseline			*Baseline & CC*			*CC (net)*			*CC (gross)*		
		Small	*Best*	*Large*	*Small*	*Best*	*Large*	*Small*	*Best*	*Large*	*Small*	*Best*	*Large*
2010–2015	EAP	8.44	8.67	8.67	9.34	9.94	9.94	0.90	1.27	1.27	1.47	2.06	2.06
	ECA	1.06	1.37	1.37	0.61	1.03	1.03	–0.44	–0.34	–0.34	0.06	0.19	0.19
	LAC	1.40	2.00	2.00	0.41	0.41	0.41	–0.99	–1.59	–1.59	0.12	0.12	0.12
	MENA	1.14	1.22	1.22	1.16	1.15	1.15	0.01	–0.07	–0.07	0.17	0.09	0.09
	SA	5.24	5.24	5.53	8.18	8.18	9.75	2.94	2.94	4.22	3.51	3.51	4.79
	SSA	0.91	1.09	1.10	4.45	3.71	3.66	3.55	2.63	2.55	3.70	2.89	2.81
	Non DC	2.56	2.94	3.63	4.30	4.88	4.88	1.74	1.95	1.25	2.18	2.41	2.41
	All DCs	**18.18**	**19.59**	**19.90**	**24.16**	**24.43**	**25.94**	**5.97**	**4.84**	**6.04**	**9.03**	**8.85**	**10.05**
2015–2020	EAP	13.65	13.23	13.23	15.52	15.22	15.22	1.87	1.99	1.99	2.30	2.45	2.45
	ECA	1.93	1.77	1.77	1.22	1.22	1.22	–0.71	–0.56	–0.56	0.09	0.21	0.21
	LAC	2.21	2.26	2.26	0.51	0.51	0.51	–1.70	–1.75	–1.75	0.13	0.13	0.13
	MENA	2.93	2.94	2.94	2.96	2.76	2.76	0.03	–0.18	–0.18	0.44	0.22	0.22
	SA	12.11	12.11	12.34	16.77	16.77	17.74	4.66	4.66	5.40	5.94	5.94	6.68
	SSA	1.96	2.05	2.06	8.41	5.51	5.24	6.45	3.47	3.18	6.69	3.78	3.49
	Non DC	4.03	4.10	4.77	6.24	5.85	5.85	2.21	1.75	1.08	3.17	2.64	2.64
	All DCs	**34.79**	**34.36**	**34.60**	**45.40**	**41.99**	**42.68**	**10.61**	**7.64**	**8.08**	**15.59**	**12.73**	**13.17**
2020–2025	EAP	18.86	17.79	17.79	21.70	20.51	20.51	2.84	2.72	2.72	3.41	3.31	3.31
	ECA	2.81	2.18	2.18	1.83	1.40	1.40	–0.98	–0.78	–0.78	0.16	0.23	0.23
	LAC	3.03	2.52	2.52	0.61	0.61	0.61	–2.41	–1.90	–1.90	0.14	0.14	0.14
	MENA	4.72	4.66	4.66	4.77	4.36	4.36	0.05	–0.30	–0.30	0.71	0.36	0.36
	SA	18.97	18.97	19.14	25.36	25.36	25.72	6.38	6.38	6.58	8.36	8.36	8.56
	SSA	3.02	3.01	3.02	12.37	7.32	6.82	9.36	4.31	3.80	9.69	4.67	4.16
	Non DC	5.50	5.26	5.90	8.17	6.82	6.82	2.67	1.56	0.92	4.25	2.88	2.88
	All DCs	**51.40**	**49.12**	**49.30**	**66.65**	**59.55**	**59.42**	**15.25**	**10.43**	**10.12**	**22.47**	**17.07**	**16.76**
2025–2030	EAP	24.07	22.35	22.35	27.88	25.79	25.79	3.81	3.45	3.45	4.52	4.16	4.16
	ECA	3.68	2.58	2.58	2.44	1.58	1.58	–1.24	–1.00	–1.00	0.23	0.24	0.24
	LAC	3.84	2.77	2.77	0.72	0.72	0.72	–3.12	–2.06	–2.06	0.16	0.16	0.16
	MENA	6.50	6.38	6.38	6.58	5.97	5.97	0.07	–0.41	–0.41	0.98	0.49	0.49
	SA	25.84	25.84	25.94	33.94	33.94	33.71	8.10	8.10	7.77	10.79	10.79	10.45
	SSA	4.07	3.96	3.97	16.34	9.12	8.40	12.26	5.15	4.42	12.68	5.57	4.84
	Non DC	6.98	6.41	7.03	10.11	7.78	7.78	3.13	1.37	0.75	5.41	3.11	3.11
	All DCs	**68.01**	**63.89**	**64.00**	**87.89**	**77.12**	**76.16**	**19.89**	**13.23**	**12.16**	**29.36**	**21.41**	**20.34**
2030–2035	EAP	25.70	22.89	22.89	26.98	23.92	23.92	1.28	1.02	1.02	3.29	2.85	2.85
	ECA	3.77	2.04	2.04	3.29	1.86	1.86	–0.48	–0.18	–0.18	0.66	0.68	0.68
	LAC	5.21	3.29	3.29	10.32	7.37	7.37	5.11	4.09	4.09	6.86	4.88	4.88
	MENA	7.98	7.80	7.80	8.05	7.29	7.29	0.07	–0.51	–0.51	0.97	0.39	0.39
	SA	32.91	32.91	32.38	38.21	38.37	34.41	5.29	5.46	2.02	7.89	7.98	4.55
	SSA	5.48	5.15	5.14	22.83	14.49	13.30	17.35	9.34	8.16	17.60	9.56	8.38
	Non DC	7.95	6.83	6.81	10.02	7.44	7.44	2.08	0.60	0.63	5.76	3.38	3.38
	All DCs	**81.07**	**74.08**	**73.54**	**109.68**	**93.31**	**88.15**	**28.61**	**19.23**	**14.61**	**37.27**	**26.35**	**21.73**

(Continued on next page)

APPENDIX 1. *(continued)*

2035–2040	EAP	27.20	25.01	25.01	26.58	24.52	24.52	–0.61	–0.49	–0.49	1.60	1.53	1.53
	ECA	4.06	2.23	2.23	3.19	2.13	2.13	–0.87	–0.10	–0.10	0.73	0.74	0.74
	LAC	6.08	3.55	3.55	19.49	8.08	8.08	13.41	4.53	4.53	15.47	5.38	5.38
	MENA	9.30	9.05	9.05	9.39	8.52	8.52	0.09	–0.53	–0.53	0.82	0.19	0.19
	SA	38.91	38.91	38.44	40.03	40.22	36.85	1.12	1.30	–1.59	4.53	4.61	1.72
	SSA	7.26	6.81	6.80	25.93	17.08	15.12	18.67	10.27	8.32	18.94	10.47	8.53
	Non DC	9.07	7.74	7.68	10.96	8.49	8.49	1.89	0.74	0.81	6.12	3.93	3.93
	All DCs	**92.81**	**85.57**	**85.09**	**124.62**	**100.54**	**95.22**	**31.81**	**14.97**	**10.13**	**42.10**	**22.93**	**18.09**
2040–2045	EAP	28.69	27.13	27.13	26.18	25.12	25.12	–2.51	–2.00	–2.00	0.39	0.39	0.39
	ECA	4.36	2.42	2.42	3.09	2.39	2.39	–1.26	–0.03	–0.03	0.79	0.80	0.80
	LAC	6.94	3.82	3.82	28.66	8.79	8.79	21.72	4.97	4.97	24.09	5.88	5.88
	MENA	10.62	10.30	10.30	10.73	9.74	9.74	0.11	–0.56	–0.56	0.71	0.02	0.02
	SA	44.91	44.91	44.50	41.86	42.06	39.29	–3.05	–2.85	–5.21	3.58	3.64	1.29
	SSA	9.04	8.48	8.46	29.03	19.66	16.95	20.00	11.19	8.48	20.28	11.39	8.68
	Non DC	10.20	8.65	8.54	11.90	9.53	9.53	1.70	0.88	0.99	6.47	4.47	4.47
	All DCs	**104.55**	**97.06**	**96.63**	**139.56**	**107.77**	**102.28**	**35.01**	**10.71**	**5.65**	**49.84**	**22.12**	**17.06**
2045–2050	EAP	30.19	29.24	29.24	25.78	25.72	25.72	–4.40	–3.52	–3.52	0.38	0.38	0.38
	ECA	4.65	2.61	2.61	2.99	2.65	2.65	–1.65	0.04	0.04	0.86	0.86	0.86
	LAC	7.81	4.09	4.09	37.84	9.49	9.49	30.03	5.40	5.40	32.70	6.37	6.37
	MENA	11.93	11.55	11.55	12.07	10.97	10.97	0.14	–0.58	–0.58	0.77	0.02	0.02
	SA	50.91	50.91	50.56	43.69	43.90	41.73	–7.22	–7.01	–8.83	2.62	2.67	0.86
	SSA	10.81	10.14	10.13	32.13	22.25	18.77	21.32	12.11	8.64	21.64	12.30	8.83
	Non DC	11.33	9.56	9.41	12.85	10.58	10.58	1.52	1.02	1.17	6.82	5.01	5.01
	All DCs	**116.30**	**108.54**	**108.18**	**154.50**	**114.99**	**109.35**	**38.20**	**6.45**	**1.17**	**58.96**	**22.60**	**17.32**

APPENDIX 2. WATER SUPPLY RESULTS. GCM: CSIRO. DISCOUNT RATE: 3%

Annual costs (averaged over 5-year periods) in USD billion

		Baseline			*Baseline & CC*			*CC (net)*			*CC (gross)*		
		Small	*Best*	*Large*	*Small*	*Best*	*Large*	*Small*	*Best*	*Large*	*Small*	*Best*	*Large*
2010–2015	EAP	7.67	7.89	7.89	8.49	9.05	9.05	0.82	1.15	1.15	1.35	1.88	1.88
	ECA	0.96	1.25	1.25	0.56	0.95	0.95	–0.40	–0.31	–0.31	0.05	0.17	0.17
	LAC	1.27	1.83	1.83	0.37	0.37	0.37	–0.90	–1.46	–1.46	0.11	0.11	0.11
	MENA	1.03	1.10	1.10	1.04	1.03	1.03	0.01	–0.06	–0.06	0.15	0.08	0.08
	SA	4.73	4.73	4.99	7.40	7.40	8.85	2.68	2.68	3.85	3.19	3.19	4.36
	SSA	0.82	0.98	1.00	4.04	3.38	3.33	3.22	2.40	2.33	3.36	2.63	2.57
	Non DC	2.32	2.68	3.31	3.92	4.46	4.46	1.59	1.78	1.15	1.98	2.21	2.21
	All DCs	**16.48**	**17.78**	**18.06**	**21.90**	**22.19**	**23.58**	**5.42**	**4.40**	**5.51**	**8.20**	**8.07**	**9.18**
2015–2020	EAP	10.73	10.41	10.41	12.21	11.98	11.98	1.47	1.57	1.57	1.81	1.93	1.93
	ECA	1.52	1.40	1.40	0.96	0.96	0.96	–0.56	–0.44	–0.44	0.07	0.16	0.16
	LAC	1.74	1.78	1.78	0.40	0.40	0.40	–1.34	–1.38	–1.38	0.10	0.10	0.10
	MENA	2.30	2.31	2.31	2.32	2.16	2.16	0.03	–0.14	–0.14	0.34	0.17	0.17
	SA	9.50	9.50	9.68	13.17	13.17	13.94	3.67	3.67	4.26	4.67	4.67	5.26
	SSA	1.54	1.61	1.62	6.61	4.34	4.12	5.07	2.73	2.50	5.26	2.98	2.75
	Non DC	3.17	3.23	3.75	4.91	4.61	4.61	1.74	1.39	0.86	2.50	2.09	2.09
	All DCs	**27.33**	**27.01**	**27.20**	**35.67**	**33.01**	**33.57**	**8.34**	**6.01**	**6.37**	**12.25**	**10.02**	**10.38**
2020–2025	EAP	12.81	12.09	12.09	14.74	13.93	13.93	1.93	1.85	1.85	2.32	2.25	2.25
	ECA	1.91	1.48	1.48	1.24	0.95	0.95	–0.66	–0.53	–0.53	0.11	0.15	0.15
	LAC	2.06	1.71	1.71	0.42	0.42	0.42	–1.64	–1.29	–1.29	0.10	0.10	0.10
	MENA	3.20	3.16	3.16	3.24	2.96	2.96	0.04	–0.20	–0.20	0.48	0.24	0.24
	SA	12.88	12.88	12.99	17.21	17.21	17.47	4.34	4.34	4.48	5.68	5.68	5.82
	SSA	2.05	2.04	2.05	8.40	4.97	4.63	6.35	2.93	2.58	6.58	3.18	2.83
	Non DC	3.74	3.57	4.01	5.55	4.64	4.64	1.81	1.07	0.63	2.89	1.96	1.96
	All DCs	**34.90**	**33.36**	**33.48**	**45.25**	**40.45**	**40.36**	**10.35**	**7.09**	**6.88**	**15.26**	**11.60**	**11.39**
2025–2030	EAP	14.11	13.11	13.11	16.35	15.13	15.13	2.24	2.02	2.02	2.65	2.44	2.44
	ECA	2.16	1.52	1.52	1.43	0.93	0.93	–0.73	–0.59	–0.59	0.14	0.14	0.14
	LAC	2.25	1.63	1.63	0.42	0.42	0.42	–1.83	–1.21	–1.21	0.09	0.09	0.09
	MENA	3.81	3.74	3.74	3.85	3.50	3.50	0.04	–0.24	–0.24	0.57	0.29	0.29
	SA	15.14	15.14	15.21	19.90	19.90	19.76	4.75	4.75	4.56	6.33	6.33	6.13
	SSA	2.39	2.32	2.33	9.58	5.35	4.92	7.19	3.02	2.60	7.43	3.27	2.84
	Non DC	4.09	3.76	4.13	5.93	4.57	4.57	1.84	0.81	0.44	3.17	1.83	1.83
	All DCs	**39.87**	**37.46**	**37.52**	**51.53**	**45.22**	**44.66**	**11.66**	**7.76**	**7.14**	**17.21**	**12.56**	**11.94**
2030–2035	EAP	5.61	5.21	5.21	5.04	4.92	4.92	–0.57	–0.28	–0.28	0.26	0.47	0.47
	ECA	0.60	0.56	0.56	0.79	0.79	0.79	0.19	0.23	0.23	0.37	0.36	0.36
	LAC	1.42	1.55	1.55	3.91	3.62	3.62	2.49	2.07	2.07	2.86	2.48	2.48
	MENA	1.10	1.13	1.13	1.09	1.05	1.05	0.00	–0.08	–0.08	0.10	0.03	0.03
	SA	5.37	5.37	5.23	6.27	6.35	5.47	0.90	0.99	0.24	1.26	1.35	0.60
	SSA	0.94	0.97	0.97	5.38	4.68	4.54	4.44	3.71	3.57	4.50	3.78	3.64
	Non DC	1.86	1.91	2.06	2.46	2.84	2.84	0.60	0.93	0.78	1.51	1.73	1.73
	All DCs	**15.02**	**14.79**	**14.65**	**22.48**	**21.42**	**20.40**	**7.46**	**6.63**	**5.75**	**9.35**	**8.46**	**7.58**

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APPENDIX 2. *(continued)*

2035–2040	EAP	3.20	3.12	3.12	2.24	2.55	2.55	–0.96	–0.57	–0.57	0.17	0.17	0.17
	ECA	0.20	0.39	0.39	0.48	0.69	0.69	0.28	0.30	0.30	0.40	0.35	0.35
	LAC	1.02	1.40	1.40	3.72	3.39	3.39	2.70	1.99	1.99	2.91	2.36	2.36
	MENA	0.27	0.34	0.34	0.26	0.31	0.31	–0.01	–0.02	–0.02	0.04	0.03	0.03
	SA	2.17	2.17	2.07	2.30	2.38	1.86	0.13	0.21	–0.21	0.80	0.88	0.46
	SSA	0.45	0.53	0.53	3.44	3.73	3.69	2.99	3.20	3.16	3.04	3.26	3.21
	Non DC	1.17	1.37	1.54	1.57	2.39	2.39	0.40	1.02	0.85	1.03	1.64	1.64
	All DCs	**7.30**	**7.94**	**7.85**	**12.44**	**13.05**	**12.50**	**5.14**	**5.11**	**4.65**	**7.37**	**7.05**	**6.59**
2040–2045	EAP	2.85	2.76	2.76	1.98	2.24	2.24	–0.87	–0.51	–0.51	0.15	0.14	0.14
	ECA	0.16	0.34	0.34	0.45	0.63	0.63	0.29	0.29	0.29	0.38	0.33	0.33
	LAC	0.91	1.29	1.29	3.25	3.18	3.18	2.33	1.89	1.89	2.52	2.23	2.23
	MENA	0.20	0.26	0.26	0.19	0.24	0.24	–0.01	–0.02	–0.02	0.03	0.03	0.03
	SA	1.79	1.79	1.69	1.98	2.06	1.53	0.20	0.27	–0.16	0.76	0.83	0.40
	SSA	0.36	0.43	0.44	3.09	3.39	3.38	2.73	2.96	2.94	2.78	3.01	2.99
	Non DC	1.04	1.23	1.38	1.40	2.16	2.16	0.36	0.93	0.78	0.94	1.51	1.51
	All DCs	**6.27**	**6.87**	**6.78**	**10.94**	**11.74**	**11.20**	**4.67**	**4.87**	**4.43**	**6.61**	**6.57**	**6.12**
2045–2050	EAP	2.58	2.47	2.47	1.80	2.01	2.01	–0.78	–0.46	–0.46	0.12	0.14	0.14
	ECA	0.14	0.30	0.30	0.42	0.58	0.58	0.28	0.27	0.27	0.35	0.31	0.31
	LAC	0.83	1.18	1.18	2.87	2.96	2.96	2.04	1.77	1.77	2.20	2.09	2.09
	MENA	0.16	0.22	0.22	0.15	0.20	0.20	–0.01	–0.02	–0.02	0.03	0.02	0.02
	SA	1.55	1.55	1.46	1.79	1.86	1.33	0.24	0.31	–0.12	0.71	0.78	0.35
	SSA	0.30	0.37	0.37	2.81	3.10	3.10	2.51	2.73	2.73	2.55	2.77	2.77
	Non DC	0.93	1.11	1.24	1.25	1.95	1.95	0.32	0.85	0.71	0.86	1.39	1.39
	All DCs	**5.55**	**6.09**	**6.00**	**9.83**	**10.70**	**10.18**	**4.28**	**4.60**	**4.17**	**5.97**	**6.11**	**5.68**

APPENDIX 3. WATER SUPPLY RESULTS. GCM: CSIRO. DISCOUNT RATE: 5%

Annual costs (averaged over 5-year periods) in USD billion

		Baseline			*Baseline & CC*			*CC (net)*			*CC (gross)*		
		Small	*Best*	*Large*	*Small*	*Best*	*Large*	*Small*	*Best*	*Large*	*Small*	*Best*	*Large*
2010–2015	EAP	7.22	7.43	7.43	7.98	8.52	8.52	0.77	1.08	1.08	1.27	1.78	1.78
	ECA	0.90	1.18	1.18	0.52	0.89	0.89	–0.38	–0.29	–0.29	0.05	0.16	0.16
	LAC	1.20	1.73	1.73	0.35	0.35	0.35	–0.84	–1.38	–1.38	0.10	0.10	0.10
	MENA	0.96	1.02	1.02	0.97	0.97	0.97	0.01	–0.06	–0.06	0.14	0.07	0.07
	SA	4.42	4.42	4.67	6.94	6.94	8.31	2.52	2.52	3.64	3.00	3.00	4.11
	SSA	0.77	0.92	0.94	3.79	3.19	3.14	3.02	2.26	2.20	3.15	2.48	2.42
	Non DC	2.19	2.52	3.13	3.69	4.21	4.21	1.50	1.69	1.09	1.87	2.08	2.08
	All DCs	**15.47**	**16.71**	**16.98**	**20.56**	**20.86**	**22.18**	**5.09**	**4.14**	**5.20**	**7.72**	**7.60**	**8.66**
2015–2020	EAP	9.19	8.92	8.92	10.45	10.26	10.26	1.26	1.34	1.34	1.55	1.65	1.65
	ECA	1.30	1.20	1.20	0.82	0.82	0.82	–0.48	–0.38	–0.38	0.06	0.14	0.14
	LAC	1.49	1.53	1.53	0.35	0.35	0.35	–1.14	–1.18	–1.18	0.09	0.09	0.09
	MENA	1.96	1.97	1.97	1.99	1.85	1.85	0.02	–0.12	–0.12	0.29	0.15	0.15
	SA	8.12	8.12	8.28	11.26	11.26	11.93	3.14	3.14	3.65	4.00	4.00	4.50
	SSA	1.32	1.38	1.39	5.66	3.72	3.53	4.34	2.34	2.15	4.50	2.55	2.36
	Non DC	2.71	2.76	3.22	4.20	3.96	3.96	1.49	1.19	0.74	2.14	1.79	1.79
	All DCs	**23.39**	**23.11**	**23.28**	**30.52**	**28.26**	**28.74**	**7.14**	**5.14**	**5.46**	**10.49**	**8.58**	**8.89**
2020–2025	EAP	9.97	9.41	9.41	11.47	10.85	10.85	1.50	1.44	1.44	1.80	1.75	1.75
	ECA	1.48	1.15	1.15	0.97	0.74	0.74	–0.52	–0.41	–0.41	0.08	0.12	0.12
	LAC	1.60	1.33	1.33	0.33	0.33	0.33	–1.28	–1.01	–1.01	0.08	0.08	0.08
	MENA	2.49	2.46	2.46	2.52	2.30	2.30	0.03	–0.16	–0.16	0.37	0.19	0.19
	SA	10.01	10.01	10.10	13.39	13.39	13.59	3.38	3.38	3.49	4.42	4.42	4.53
	SSA	1.59	1.59	1.59	6.54	3.87	3.61	4.94	2.28	2.01	5.12	2.48	2.21
	Non DC	2.91	2.78	3.12	4.32	3.61	3.61	1.41	0.83	0.49	2.25	1.53	1.53
	All DCs	**27.15**	**25.96**	**26.05**	**35.21**	**31.48**	**31.41**	**8.06**	**5.52**	**5.36**	**11.87**	**9.03**	**8.87**
2025–2030	EAP	9.98	9.27	9.27	11.56	10.70	10.70	1.58	1.43	1.43	1.87	1.73	1.73
	ECA	1.53	1.07	1.07	1.01	0.66	0.66	–0.52	–0.42	–0.42	0.10	0.10	0.10
	LAC	1.59	1.15	1.15	0.30	0.30	0.30	–1.30	–0.86	–0.86	0.06	0.06	0.06
	MENA	2.69	2.64	2.64	2.72	2.47	2.47	0.03	–0.17	–0.17	0.40	0.20	0.20
	SA	10.71	10.71	10.75	14.07	14.07	13.98	3.36	3.36	3.22	4.47	4.47	4.34
	SSA	1.69	1.64	1.65	6.77	3.78	3.48	5.08	2.14	1.84	5.26	2.31	2.01
	Non DC	2.89	2.66	2.92	4.19	3.23	3.23	1.30	0.57	0.31	2.25	1.29	1.29
	All DCs	**28.19**	**26.49**	**26.54**	**36.44**	**31.98**	**31.59**	**8.25**	**5.49**	**5.05**	**12.17**	**8.88**	**8.44**
2030–2035	EAP	2.93	2.76	2.76	2.47	2.51	2.51	–0.46	–0.25	–0.25	0.13	0.22	0.22
	ECA	0.26	0.32	0.32	0.43	0.49	0.49	0.16	0.17	0.17	0.25	0.24	0.24
	LAC	0.80	0.99	0.99	2.34	2.32	2.32	1.55	1.33	1.33	1.73	1.59	1.59
	MENA	0.43	0.47	0.47	0.43	0.43	0.43	0.00	–0.03	–0.03	0.03	0.00	0.00
	SA	2.39	2.39	2.32	2.84	2.89	2.42	0.44	0.50	0.11	0.69	0.74	0.35
	SSA	0.42	0.47	0.47	2.88	2.76	2.71	2.46	2.29	2.25	2.49	2.33	2.29
	Non DC	1.00	1.09	1.20	1.34	1.74	1.74	0.34	0.66	0.55	0.84	1.11	1.11
	All DCs	**7.24**	**7.39**	**7.31**	**11.38**	**11.40**	**10.89**	**4.14**	**4.02**	**3.58**	**5.33**	**5.13**	**4.69**

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APPENDIX 3. *(continued)*

2035–2040	EAP	1.81	1.75	1.75	1.29	1.45	1.45	–0.52	–0.30	–0.30	0.10	0.10	0.10
	ECA	0.10	0.22	0.22	0.28	0.40	0.40	0.18	0.18	0.18	0.23	0.21	0.21
	LAC	0.57	0.82	0.82	1.96	1.98	1.98	1.39	1.16	1.16	1.50	1.38	1.38
	MENA	0.12	0.16	0.16	0.11	0.14	0.14	–0.01	–0.01	–0.01	0.02	0.01	0.01
	SA	1.08	1.08	1.02	1.25	1.30	0.98	0.17	0.22	–0.04	0.48	0.53	0.27
	SSA	0.21	0.26	0.26	1.92	2.12	2.12	1.71	1.86	1.85	1.74	1.89	1.88
	Non DC	0.65	0.78	0.88	0.89	1.38	1.38	0.24	0.60	0.50	0.59	0.95	0.95
	All DCs	**3.89**	**4.29**	**4.24**	**6.81**	**7.39**	**7.07**	**2.92**	**3.10**	**2.84**	**4.07**	**4.12**	**3.85**
2040–2045	EAP	1.49	1.43	1.43	1.06	1.18	1.18	–0.43	–0.25	–0.25	0.08	0.09	0.09
	ECA	0.08	0.18	0.18	0.24	0.33	0.33	0.16	0.15	0.15	0.20	0.18	0.18
	LAC	0.47	0.68	0.68	1.59	1.68	1.68	1.11	1.00	1.00	1.21	1.18	1.18
	MENA	0.09	0.12	0.12	0.08	0.11	0.11	–0.01	–0.01	–0.01	0.01	0.01	0.01
	SA	0.86	0.86	0.81	1.03	1.07	0.78	0.17	0.21	–0.03	0.41	0.45	0.21
	SSA	0.16	0.20	0.21	1.60	1.77	1.77	1.44	1.56	1.57	1.46	1.59	1.59
	Non DC	0.53	0.64	0.72	0.73	1.13	1.13	0.19	0.50	0.41	0.49	0.80	0.80
	All DCs	**3.15**	**3.48**	**3.43**	**5.60**	**6.15**	**5.86**	**2.44**	**2.67**	**2.43**	**3.37**	**3.50**	**3.26**
2045–2050	EAP	1.23	1.17	1.17	0.87	0.97	0.97	–0.36	–0.21	–0.21	0.06	0.08	0.08
	ECA	0.07	0.14	0.14	0.20	0.28	0.28	0.14	0.13	0.13	0.17	0.15	0.15
	LAC	0.39	0.57	0.57	1.30	1.42	1.42	0.90	0.86	0.86	0.98	1.01	1.01
	MENA	0.06	0.09	0.09	0.06	0.08	0.08	–0.01	–0.01	–0.01	0.01	0.01	0.01
	SA	0.69	0.69	0.64	0.85	0.88	0.62	0.16	0.19	–0.02	0.35	0.38	0.17
	SSA	0.13	0.16	0.16	1.33	1.47	1.48	1.20	1.31	1.32	1.22	1.33	1.34
	Non DC	0.44	0.53	0.59	0.60	0.93	0.93	0.16	0.41	0.34	0.41	0.67	0.67
	All DCs	**2.57**	**2.83**	**2.79**	**4.61**	**5.10**	**4.85**	**2.04**	**2.27**	**2.06**	**2.79**	**2.96**	**2.75**

APPENDIX 4. WATER SUPPLY RESULTS. GCM: CSIRO. DISCOUNT RATE: 7%

Annual costs (averaged over 5-year periods) in USD billion

		Baseline			*Baseline & CC*			*CC (net)*			*CC (gross)*		
		Small	*Best*	*Large*	*Small*	*Best*	*Large*	*Small*	*Best*	*Large*	*Small*	*Best*	*Large*
2010–2015	EAP	6.80	7.01	7.01	7.52	8.03	8.03	0.72	1.02	1.02	1.20	1.68	1.68
	ECA	0.85	1.12	1.12	0.49	0.84	0.84	–0.36	–0.27	–0.27	0.05	0.16	0.16
	LAC	1.13	1.63	1.63	0.33	0.33	0.33	–0.80	–1.30	–1.30	0.10	0.10	0.10
	MENA	0.90	0.96	0.96	0.91	0.91	0.91	0.01	–0.05	–0.05	0.13	0.07	0.07
	SA	4.15	4.15	4.38	6.52	6.52	7.82	2.37	2.37	3.44	2.82	2.82	3.88
	SSA	0.72	0.87	0.88	3.56	3.01	2.96	2.84	2.14	2.08	2.97	2.35	2.29
	Non DC	2.06	2.38	2.95	3.48	3.98	3.98	1.42	1.60	1.03	1.76	1.97	1.97
	All DCs	**14.54**	**15.74**	**15.99**	**19.34**	**19.64**	**20.90**	**4.79**	**3.91**	**4.91**	**7.27**	**7.18**	**8.18**
2015–2020	EAP	7.90	7.66	7.66	8.98	8.82	8.82	1.08	1.15	1.15	1.33	1.42	1.42
	ECA	1.12	1.03	1.03	0.71	0.71	0.71	–0.41	–0.32	–0.32	0.05	0.12	0.12
	LAC	1.28	1.32	1.32	0.30	0.30	0.30	–0.98	–1.02	–1.02	0.08	0.08	0.08
	MENA	1.68	1.69	1.69	1.70	1.59	1.59	0.02	–0.11	–0.11	0.25	0.13	0.13
	SA	6.97	6.97	7.10	9.67	9.67	10.24	2.70	2.70	3.14	3.43	3.43	3.87
	SSA	1.13	1.18	1.19	4.86	3.20	3.04	3.73	2.01	1.85	3.87	2.20	2.03
	Non DC	2.33	2.38	2.77	3.61	3.41	3.41	1.28	1.03	0.64	1.84	1.54	1.54
	All DCs	**20.08**	**19.85**	**20.00**	**26.21**	**24.27**	**24.69**	**6.13**	**4.42**	**4.69**	**9.01**	**7.37**	**7.65**
2020–2025	EAP	7.80	7.36	7.36	8.98	8.49	8.49	1.17	1.13	1.13	1.41	1.37	1.37
	ECA	1.16	0.90	0.90	0.76	0.58	0.58	–0.40	–0.32	–0.32	0.07	0.09	0.09
	LAC	1.25	1.05	1.05	0.25	0.25	0.25	–1.00	–0.79	–0.79	0.06	0.06	0.06
	MENA	1.95	1.92	1.92	1.97	1.80	1.80	0.02	–0.12	–0.12	0.29	0.15	0.15
	SA	7.83	7.83	7.90	10.47	10.47	10.63	2.64	2.64	2.73	3.46	3.46	3.55
	SSA	1.25	1.24	1.25	5.11	3.03	2.82	3.87	1.79	1.58	4.00	1.94	1.73
	Non DC	2.28	2.18	2.45	3.38	2.83	2.83	1.11	0.65	0.38	1.76	1.20	1.20
	All DCs	**21.24**	**20.31**	**20.39**	**27.54**	**24.63**	**24.58**	**6.30**	**4.32**	**4.20**	**9.29**	**7.07**	**6.95**
2025–2030	EAP	7.11	6.60	6.60	8.24	7.62	7.62	1.13	1.02	1.02	1.34	1.23	1.23
	ECA	1.09	0.76	0.76	0.72	0.47	0.47	–0.37	–0.30	–0.30	0.07	0.07	0.07
	LAC	1.14	0.82	0.82	0.21	0.21	0.21	–0.92	–0.61	–0.61	0.05	0.05	0.05
	MENA	1.92	1.88	1.88	1.94	1.76	1.76	0.02	–0.12	–0.12	0.29	0.14	0.14
	SA	7.62	7.62	7.66	10.02	10.02	9.96	2.40	2.40	2.30	3.19	3.19	3.09
	SSA	1.20	1.17	1.17	4.82	2.70	2.48	3.62	1.52	1.31	3.75	1.65	1.43
	Non DC	2.06	1.90	2.08	2.99	2.31	2.31	0.93	0.41	0.22	1.60	0.92	0.92
	All DCs	**20.08**	**18.87**	**18.90**	**25.95**	**22.78**	**22.50**	**5.87**	**3.91**	**3.60**	**8.67**	**6.33**	**6.02**
2030–2035	EAP	1.70	1.62	1.62	1.37	1.44	1.44	–0.33	–0.18	–0.18	0.09	0.12	0.12
	ECA	0.13	0.19	0.19	0.25	0.31	0.31	0.12	0.12	0.12	0.17	0.16	0.16
	LAC	0.48	0.64	0.64	1.47	1.50	1.50	0.98	0.87	0.87	1.09	1.03	1.03
	MENA	0.20	0.22	0.22	0.19	0.21	0.21	0.00	–0.02	–0.02	0.01	0.00	0.00
	SA	1.24	1.24	1.20	1.49	1.53	1.25	0.25	0.29	0.06	0.41	0.44	0.21
	SSA	0.22	0.26	0.26	1.70	1.71	1.70	1.48	1.46	1.44	1.50	1.48	1.47
	Non DC	0.59	0.66	0.74	0.80	1.10	1.10	0.21	0.44	0.37	0.51	0.72	0.72
	All DCs	**3.98**	**4.17**	**4.13**	**6.48**	**6.71**	**6.42**	**2.50**	**2.54**	**2.29**	**3.26**	**3.24**	**2.99**

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APPENDIX 4. *(continued)*

2035–2040	EAP	1.06	1.03	1.03	0.76	0.85	0.85	–0.30	–0.17	–0.17	0.06	0.06	0.06
	ECA	0.06	0.13	0.13	0.17	0.24	0.24	0.11	0.11	0.11	0.14	0.12	0.12
	LAC	0.33	0.48	0.48	1.11	1.17	1.17	0.78	0.69	0.69	0.84	0.81	0.81
	MENA	0.06	0.08	0.08	0.06	0.08	0.08	0.00	–0.01	–0.01	0.01	0.01	0.01
	SA	0.60	0.60	0.57	0.73	0.76	0.57	0.12	0.15	–0.01	0.29	0.31	0.16
	SSA	0.11	0.15	0.15	1.12	1.24	1.24	1.01	1.10	1.10	1.02	1.11	1.11
	Non DC	0.38	0.45	0.51	0.52	0.81	0.81	0.14	0.35	0.29	0.35	0.56	0.56
	All DCs	**2.24**	**2.47**	**2.44**	**3.95**	**4.33**	**4.15**	**1.71**	**1.86**	**1.70**	**2.36**	**2.43**	**2.28**
2040–2045	EAP	0.80	0.77	0.77	0.57	0.63	0.63	–0.23	–0.13	–0.13	0.04	0.05	0.05
	ECA	0.04	0.10	0.10	0.13	0.18	0.18	0.09	0.08	0.08	0.11	0.10	0.10
	LAC	0.25	0.37	0.37	0.83	0.91	0.91	0.57	0.54	0.54	0.62	0.64	0.64
	MENA	0.04	0.06	0.06	0.04	0.05	0.05	0.00	–0.01	–0.01	0.01	0.01	0.01
	SA	0.44	0.44	0.42	0.55	0.57	0.41	0.10	0.13	0.00	0.22	0.24	0.11
	SSA	0.08	0.10	0.11	0.85	0.94	0.95	0.77	0.84	0.84	0.78	0.85	0.86
	Non DC	0.28	0.34	0.39	0.39	0.61	0.61	0.11	0.27	0.22	0.26	0.43	0.43
	All DCs	**1.66**	**1.84**	**1.81**	**2.97**	**3.29**	**3.13**	**1.30**	**1.45**	**1.32**	**1.78**	**1.88**	**1.76**
2045–2050	EAP	0.60	0.57	0.57	0.43	0.47	0.47	–0.17	–0.10	–0.10	0.03	0.04	0.04
	ECA	0.03	0.07	0.07	0.10	0.13	0.13	0.07	0.06	0.06	0.08	0.07	0.07
	LAC	0.19	0.28	0.28	0.62	0.70	0.70	0.43	0.42	0.42	0.46	0.49	0.49
	MENA	0.03	0.04	0.04	0.03	0.04	0.04	0.00	0.00	0.00	0.00	0.00	0.00
	SA	0.33	0.33	0.30	0.41	0.43	0.30	0.08	0.10	–0.01	0.17	0.19	0.08
	SSA	0.06	0.08	0.08	0.65	0.72	0.72	0.59	0.64	0.65	0.60	0.65	0.66
	Non DC	0.21	0.26	0.29	0.29	0.46	0.46	0.08	0.20	0.17	0.20	0.32	0.32
	All DCs	**1.24**	**1.37**	**1.35**	**2.23**	**2.49**	**2.36**	**0.99**	**1.12**	**1.02**	**1.35**	**1.45**	**1.35**

APPENDIX 5. WATER SUPPLY RESULTS. GCM: NCAR. DISCOUNT RATE: 0%

Annual costs (averaged over 5-year periods) in USD billion

		Baseline			*Baseline & CC*			*CC (net)*			*CC (gross)*		
		Small	*Best*	*Large*	*Small*	*Best*	*Large*	*Small*	*Best*	*Large*	*Small*	*Best*	*Large*
2010–2015	EAP	8.44	8.67	8.67	12.54	13.30	13.30	4.11	4.62	4.62	4.20	4.75	4.75
	ECA	1.06	1.37	1.37	1.62	2.01	2.01	0.57	0.64	0.64	1.17	1.48	1.48
	LAC	1.40	2.00	2.00	6.64	8.13	8.13	5.25	6.13	6.13	5.28	6.17	6.17
	MENA	1.14	1.22	1.22	1.13	1.10	1.10	–0.01	–0.12	–0.12	0.17	0.06	0.06
	SA	5.24	5.24	5.53	5.73	6.11	7.07	0.48	0.87	1.54	0.65	1.01	1.68
	SSA	0.91	1.09	1.10	4.96	4.64	4.62	4.05	3.56	3.52	4.15	3.69	3.65
	Non DC	2.56	2.94	3.63	5.70	6.19	6.19	3.15	3.26	2.56	3.53	3.65	3.65
	All DCs	**18.18**	**19.59**	**19.90**	**32.62**	**35.29**	**36.23**	**14.44**	**15.70**	**16.34**	**15.61**	**17.17**	**17.80**
2015–2020	EAP	13.65	13.23	13.23	16.90	17.73	17.73	3.25	4.49	4.49	3.46	4.73	4.73
	ECA	1.93	1.77	1.77	2.40	2.46	2.46	0.47	0.69	0.69	1.61	1.67	1.67
	LAC	2.21	2.26	2.26	8.91	9.02	9.02	6.70	6.76	6.76	6.74	6.80	6.80
	MENA	2.93	2.94	2.94	2.88	2.60	2.60	–0.05	–0.34	–0.34	0.43	0.14	0.14
	SA	12.11	12.11	12.34	12.11	12.53	13.35	0.00	0.42	1.02	0.56	0.93	1.52
	SSA	1.96	2.05	2.06	8.47	6.88	6.80	6.51	4.83	4.74	6.68	5.00	4.91
	Non DC	4.03	4.10	4.77	8.55	7.28	7.28	4.52	3.19	2.52	5.24	3.91	3.91
	All DCs	**34.79**	**34.36**	**34.60**	**51.67**	**51.22**	**51.96**	**16.87**	**16.86**	**17.36**	**19.47**	**19.28**	**19.77**
2020–2025	EAP	18.86	17.79	17.79	21.26	22.15	22.15	2.40	4.37	4.37	2.73	4.72	4.72
	ECA	2.81	2.18	2.18	3.19	2.92	2.92	0.38	0.74	0.74	2.05	1.87	1.87
	LAC	3.03	2.52	2.52	11.18	9.90	9.90	8.15	7.38	7.38	8.19	7.43	7.43
	MENA	4.72	4.66	4.66	4.63	4.11	4.11	–0.09	–0.55	–0.55	0.68	0.22	0.22
	SA	18.97	18.97	19.14	18.49	18.95	19.64	–0.49	–0.02	0.50	0.79	1.16	1.68
	SSA	3.02	3.01	3.02	11.98	9.12	8.97	8.96	6.11	5.95	9.20	6.32	6.16
	Non DC	5.50	5.26	5.90	11.40	8.37	8.37	5.89	3.12	2.48	6.95	4.17	4.17
	All DCs	**51.40**	**49.12**	**49.30**	**70.71**	**67.15**	**67.69**	**19.31**	**18.03**	**18.39**	**23.64**	**21.71**	**22.07**
2025–2030	EAP	24.07	22.35	22.35	25.61	26.58	26.58	1.54	4.24	4.24	2.03	4.70	4.70
	ECA	3.68	2.58	2.58	3.97	3.37	3.37	0.28	0.79	0.79	2.49	2.06	2.06
	LAC	3.84	2.77	2.77	13.44	10.78	10.78	9.60	8.01	8.01	9.75	8.06	8.06
	MENA	6.50	6.38	6.38	6.37	5.61	5.61	–0.13	–0.77	–0.77	0.94	0.30	0.30
	SA	25.84	25.84	25.94	24.87	25.37	25.92	–0.97	–0.47	–0.02	1.02	1.40	1.84
	SSA	4.07	3.96	3.97	15.49	11.36	11.15	11.42	7.39	7.17	11.72	7.63	7.41
	Non DC	6.98	6.41	7.03	14.24	9.46	9.46	7.27	3.05	2.43	8.66	4.44	4.44
	All DCs	**68.01**	**63.89**	**64.00**	**89.75**	**83.07**	**83.42**	**21.74**	**19.19**	**19.41**	**27.95**	**24.15**	**24.38**
2030–2035	EAP	25.70	22.89	22.89	19.87	20.19	20.19	–5.84	–2.70	–2.70	1.43	1.46	1.46
	ECA	3.77	2.04	2.04	3.99	2.77	2.77	0.21	0.73	0.73	2.34	1.30	1.30
	LAC	5.21	3.29	3.29	11.15	6.59	6.59	5.94	3.31	3.31	5.99	3.35	3.35
	MENA	7.98	7.80	7.80	8.27	7.33	7.33	0.29	–0.47	–0.47	1.22	0.46	0.46
	SA	32.91	32.91	32.38	31.04	30.86	29.36	–1.88	–2.06	–3.02	2.59	2.59	1.62
	SSA	5.48	5.15	5.14	15.84	11.12	10.44	10.36	5.98	5.30	10.73	6.24	5.57
	Non DC	7.95	6.83	6.81	13.42	7.25	7.25	5.48	0.42	0.45	6.76	1.69	1.69
	All DCs	**81.07**	**74.08**	**73.54**	**90.15**	**78.86**	**76.68**	**9.08**	**4.78**	**3.14**	**24.30**	**15.40**	**13.76**

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APPENDIX 5. *(continued)*

2035–2040	EAP	27.20	25.01	25.01	21.22	21.50	21.50	–5.98	–3.51	–3.51	1.53	1.51	1.51
	ECA	4.06	2.23	2.23	5.08	3.14	3.14	1.02	0.91	0.91	3.11	1.41	1.41
	LAC	6.08	3.55	3.55	9.82	6.88	6.88	3.74	3.33	3.33	3.80	3.38	3.38
	MENA	9.30	9.05	9.05	10.27	9.19	9.19	0.97	0.14	0.14	1.50	0.67	0.67
	SA	38.91	38.91	38.44	35.21	35.01	33.64	–3.70	–3.91	–4.80	2.59	2.54	1.64
	SSA	7.26	6.81	6.80	17.23	13.00	11.19	9.97	6.19	4.39	10.45	6.52	4.72
	Non DC	9.07	7.74	7.68	13.76	8.53	8.53	4.69	0.79	0.86	6.09	2.18	2.18
	All DCs	**92.81**	**85.57**	**85.09**	**98.84**	**88.72**	**85.54**	**6.02**	**3.15**	**0.46**	**22.98**	**16.03**	**13.34**
2040–2045	EAP	28.69	27.13	27.13	22.57	22.80	22.80	–6.12	–4.32	–4.32	1.63	1.57	1.57
	ECA	4.36	2.42	2.42	6.18	3.51	3.51	1.82	1.09	1.09	3.88	1.52	1.52
	LAC	6.94	3.82	3.82	8.49	7.17	7.17	1.55	3.35	3.35	1.70	3.41	3.41
	MENA	10.62	10.30	10.30	12.27	11.05	11.05	1.66	0.76	0.76	1.86	0.95	0.95
	SA	44.91	44.91	44.50	39.39	39.15	37.93	–5.52	–5.76	–6.58	2.60	2.48	1.67
	SSA	9.04	8.48	8.46	18.62	14.88	11.94	9.58	6.41	3.48	10.16	6.80	3.88
	Non DC	10.20	8.65	8.54	14.10	9.81	9.81	3.90	1.16	1.27	5.44	2.69	2.69
	All DCs	**104.55**	**97.06**	**96.63**	**107.52**	**98.58**	**94.41**	**2.97**	**1.52**	**–2.22**	**21.82**	**16.73**	**12.99**
2045–2050	EAP	30.19	29.24	29.24	23.92	24.11	24.11	–6.27	–5.13	–5.13	1.72	1.63	1.63
	ECA	4.65	2.61	2.61	7.27	3.89	3.89	2.63	1.27	1.27	4.65	1.63	1.63
	LAC	7.81	4.09	4.09	7.16	7.46	7.46	–0.65	3.37	3.37	1.54	3.47	3.47
	MENA	11.93	11.55	11.55	14.28	12.92	12.92	2.34	1.37	1.37	2.59	1.60	1.60
	SA	50.91	50.91	50.56	43.57	43.30	42.21	–7.34	–7.61	–8.35	2.61	2.43	1.69
	SSA	10.81	10.14	10.13	20.01	16.76	12.70	9.20	6.62	2.57	9.87	7.08	3.03
	Non DC	11.33	9.56	9.41	14.44	11.09	11.09	3.11	1.53	1.68	4.93	3.20	3.20
	All DCs	**116.30**	**108.54**	**108.18**	**116.21**	**108.44**	**103.28**	**–0.08**	**–0.11**	**–4.90**	**22.99**	**17.85**	**13.05**

APPENDIX 6. WATER SUPPLY RESULTS. GCM: NCAR. DISCOUNT RATE: 3%

Annual costs (averaged over 5-year periods) in USD billion

		Baseline			*Baseline & CC*			*CC (net)*			*CC (gross)*		
		Small	*Best*	*Large*	*Small*	*Best*	*Large*	*Small*	*Best*	*Large*	*Small*	*Best*	*Large*
2010–2015	EAP	7.67	7.89	7.89	11.44	12.13	12.13	3.77	4.24	4.24	3.85	4.35	4.35
	ECA	0.96	1.25	1.25	1.48	1.84	1.84	0.52	0.59	0.59	1.06	1.35	1.35
	LAC	1.27	1.83	1.83	6.06	7.44	7.44	4.79	5.61	5.61	4.82	5.64	5.64
	MENA	1.03	1.10	1.10	1.02	0.99	0.99	–0.01	–0.11	–0.11	0.15	0.06	0.06
	SA	4.73	4.73	4.99	5.17	5.53	6.41	0.45	0.80	1.42	0.59	0.93	1.55
	SSA	0.82	0.98	1.00	4.50	4.23	4.21	3.69	3.24	3.21	3.78	3.36	3.33
	Non DC	2.32	2.68	3.31	5.19	5.66	5.66	2.87	2.98	2.35	3.22	3.34	3.34
	All DCs	**16.48**	**17.78**	**18.06**	**29.68**	**32.15**	**33.02**	**13.20**	**14.37**	**14.95**	**14.26**	**15.70**	**16.28**
2015–2020	EAP	10.73	10.41	10.41	13.31	13.96	13.96	2.58	3.55	3.55	2.74	3.74	3.74
	ECA	1.52	1.40	1.40	1.89	1.94	1.94	0.37	0.54	0.54	1.27	1.32	1.32
	LAC	1.74	1.78	1.78	7.02	7.12	7.12	5.28	5.33	5.33	5.31	5.36	5.36
	MENA	2.30	2.31	2.31	2.26	2.04	2.04	–0.04	–0.26	–0.26	0.33	0.11	0.11
	SA	9.50	9.50	9.68	9.51	9.84	10.49	0.00	0.34	0.81	0.44	0.73	1.20
	SSA	1.54	1.61	1.62	6.66	5.42	5.35	5.12	3.81	3.73	5.25	3.94	3.86
	Non DC	3.17	3.23	3.75	6.73	5.74	5.74	3.56	2.52	1.99	4.13	3.09	3.09
	All DCs	**27.33**	**27.01**	**27.20**	**40.64**	**40.32**	**40.91**	**13.31**	**13.31**	**13.71**	**15.34**	**15.21**	**15.60**
2020–2025	EAP	12.81	12.09	12.09	14.45	15.06	15.06	1.64	2.98	2.98	1.87	3.22	3.22
	ECA	1.91	1.48	1.48	2.16	1.98	1.98	0.26	0.50	0.50	1.39	1.27	1.27
	LAC	2.06	1.71	1.71	7.60	6.74	6.74	5.54	5.03	5.03	5.57	5.06	5.06
	MENA	3.20	3.16	3.16	3.14	2.79	2.79	–0.06	–0.38	–0.38	0.46	0.15	0.15
	SA	12.88	12.88	12.99	12.55	12.86	13.33	–0.33	–0.01	0.34	0.54	0.79	1.14
	SSA	2.05	2.04	2.05	8.14	6.20	6.10	6.09	4.16	4.05	6.25	4.30	4.19
	Non DC	3.74	3.57	4.01	7.74	5.70	5.70	4.01	2.13	1.69	4.72	2.84	2.84
	All DCs	**34.90**	**33.36**	**33.48**	**48.04**	**45.64**	**46.01**	**13.14**	**12.28**	**12.52**	**16.08**	**14.78**	**15.03**
2025–2030	EAP	14.11	13.11	13.11	15.03	15.60	15.60	0.91	2.49	2.49	1.19	2.76	2.76
	ECA	2.16	1.52	1.52	2.33	1.98	1.98	0.17	0.46	0.46	1.46	1.21	1.21
	LAC	2.25	1.63	1.63	7.89	6.33	6.33	5.63	4.70	4.70	5.72	4.73	4.73
	MENA	3.81	3.74	3.74	3.74	3.29	3.29	–0.08	–0.45	–0.45	0.55	0.17	0.17
	SA	15.14	15.14	15.21	14.58	14.87	15.20	–0.57	–0.27	–0.01	0.60	0.82	1.08
	SSA	2.39	2.32	2.33	9.08	6.66	6.54	6.69	4.34	4.21	6.87	4.48	4.35
	Non DC	4.09	3.76	4.13	8.35	5.56	5.56	4.26	1.79	1.43	5.08	2.61	2.61
	All DCs	**39.87**	**37.46**	**37.52**	**52.63**	**48.73**	**48.93**	**12.77**	**11.27**	**11.41**	**16.40**	**14.18**	**14.31**
2030–2035	EAP	5.61	5.21	5.21	4.70	4.87	4.87	–0.91	–0.33	–0.33	0.69	0.71	0.71
	ECA	0.60	0.56	0.56	0.84	0.93	0.93	0.24	0.37	0.37	0.54	0.56	0.56
	LAC	1.42	1.55	1.55	3.19	3.17	3.17	1.77	1.62	1.62	1.80	1.65	1.65
	MENA	1.10	1.13	1.13	1.21	1.15	1.15	0.11	0.01	0.01	0.18	0.09	0.09
	SA	5.37	5.37	5.23	5.56	5.47	5.05	0.19	0.10	–0.18	1.05	1.01	0.73
	SSA	0.94	0.97	0.97	2.84	2.43	2.35	1.90	1.46	1.38	1.99	1.55	1.47
	Non DC	1.86	1.91	2.06	2.98	2.71	2.71	1.12	0.80	0.65	1.29	0.96	0.96
	All DCs	**15.02**	**14.79**	**14.65**	**18.34**	**18.03**	**17.53**	**3.32**	**3.24**	**2.87**	**6.25**	**5.56**	**5.19**

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APPENDIX 6. *(continued)*

2035–2040	EAP	3.20	3.12	3.12	2.83	2.98	2.98	–0.36	–0.14	–0.14	0.62	0.64	0.64
	ECA	0.20	0.39	0.39	0.49	0.74	0.74	0.29	0.35	0.35	0.36	0.50	0.50
	LAC	1.02	1.40	1.40	2.17	2.82	2.82	1.15	1.42	1.42	1.48	1.44	1.44
	MENA	0.27	0.34	0.34	0.40	0.45	0.45	0.13	0.11	0.11	0.14	0.12	0.12
	SA	2.17	2.17	2.07	2.57	2.48	2.17	0.40	0.31	0.10	0.96	0.90	0.69
	SSA	0.45	0.53	0.53	1.25	1.43	1.37	0.80	0.91	0.84	1.00	0.99	0.94
	Non DC	1.17	1.37	1.54	1.70	2.25	2.25	0.52	0.88	0.71	0.69	0.91	0.91
	All DCs	**7.30**	**7.94**	**7.85**	**9.71**	**10.90**	**10.53**	**2.41**	**2.96**	**2.68**	**4.55**	**4.59**	**4.32**
2040–2045	EAP	2.85	2.76	2.76	2.46	2.59	2.59	–0.39	–0.17	–0.17	0.56	0.58	0.58
	ECA	0.16	0.34	0.34	0.41	0.66	0.66	0.25	0.31	0.31	0.30	0.45	0.45
	LAC	0.91	1.29	1.29	1.99	2.55	2.55	1.07	1.25	1.25	1.34	1.28	1.28
	MENA	0.20	0.26	0.26	0.30	0.35	0.35	0.10	0.09	0.09	0.11	0.10	0.10
	SA	1.79	1.79	1.69	2.21	2.12	1.82	0.43	0.33	0.12	0.89	0.84	0.63
	SSA	0.36	0.43	0.44	1.06	1.23	1.20	0.71	0.80	0.77	0.87	0.87	0.84
	Non DC	1.04	1.23	1.38	1.51	2.00	2.00	0.47	0.77	0.62	0.62	0.80	0.80
	All DCs	**6.27**	**6.87**	**6.78**	**8.43**	**9.49**	**9.16**	**2.16**	**2.62**	**2.38**	**4.07**	**4.11**	**3.87**
2045–2050	EAP	2.58	2.47	2.47	2.16	2.28	2.28	–0.41	–0.20	–0.20	0.51	0.52	0.52
	ECA	0.14	0.30	0.30	0.35	0.59	0.59	0.21	0.28	0.28	0.25	0.40	0.40
	LAC	0.83	1.18	1.18	1.82	2.29	2.29	1.00	1.11	1.11	1.21	1.13	1.13
	MENA	0.16	0.22	0.22	0.24	0.29	0.29	0.08	0.07	0.07	0.09	0.08	0.08
	SA	1.55	1.55	1.46	1.97	1.88	1.58	0.42	0.33	0.13	0.83	0.78	0.57
	SSA	0.30	0.37	0.37	0.94	1.08	1.08	0.64	0.71	0.71	0.77	0.78	0.77
	Non DC	0.93	1.11	1.24	1.36	1.79	1.79	0.43	0.68	0.55	0.55	0.70	0.70
	All DCs	**5.55**	**6.09**	**6.00**	**7.49**	**8.41**	**8.11**	**1.93**	**2.32**	**2.10**	**3.66**	**3.69**	**3.47**

APPENDIX 7. WATER SUPPLY RESULTS. GCM: NCAR. DISCOUNT RATE: 5%

		Annual costs (averaged over 5-year periods) in USD billion											
		Baseline			*Baseline & CC*			*CC (net)*			*CC (gross)*		
		Small	*Best*	*Large*	*Small*	*Best*	*Large*	*Small*	*Best*	*Large*	*Small*	*Best*	*Large*
2010–2015	EAP	7.22	7.43	7.43	10.79	11.44	11.44	3.57	4.01	4.01	3.65	4.11	4.11
	ECA	0.90	1.18	1.18	1.39	1.73	1.73	0.49	0.55	0.55	1.00	1.28	1.28
	LAC	1.20	1.73	1.73	5.71	7.03	7.03	4.52	5.30	5.30	4.55	5.33	5.33
	MENA	0.96	1.02	1.02	0.95	0.92	0.92	–0.01	–0.10	–0.10	0.14	0.05	0.05
	SA	4.42	4.42	4.67	4.85	5.19	6.02	0.43	0.76	1.34	0.56	0.88	1.46
	SSA	0.77	0.92	0.94	4.24	3.98	3.97	3.47	3.06	3.03	3.55	3.17	3.14
	Non DC	2.19	2.52	3.13	4.89	5.34	5.34	2.70	2.82	2.22	3.03	3.15	3.15
	All DCs	**15.47**	**16.71**	**16.98**	**27.93**	**30.29**	**31.11**	**12.46**	**13.58**	**14.13**	**13.46**	**14.83**	**15.38**
2015–2020	EAP	9.19	8.92	8.92	11.41	11.97	11.97	2.22	3.05	3.05	2.36	3.21	3.21
	ECA	1.30	1.20	1.20	1.62	1.67	1.67	0.32	0.47	0.47	1.08	1.13	1.13
	LAC	1.49	1.53	1.53	6.01	6.11	6.11	4.52	4.58	4.58	4.55	4.60	4.60
	MENA	1.96	1.97	1.97	1.93	1.75	1.75	–0.03	–0.23	–0.23	0.29	0.10	0.10
	SA	8.12	8.12	8.28	8.13	8.42	8.98	0.01	0.29	0.70	0.37	0.62	1.03
	SSA	1.32	1.38	1.39	5.70	4.64	4.58	4.38	3.26	3.20	4.50	3.38	3.31
	Non DC	2.71	2.76	3.22	5.76	4.93	4.93	3.05	2.16	1.71	3.53	2.65	2.65
	All DCs	**23.39**	**23.11**	**23.28**	**34.80**	**34.54**	**35.04**	**11.42**	**11.43**	**11.77**	**13.15**	**13.05**	**13.39**
2020–2025	EAP	9.97	9.41	9.41	11.25	11.73	11.73	1.28	2.32	2.32	1.46	2.51	2.51
	ECA	1.48	1.15	1.15	1.69	1.55	1.55	0.20	0.39	0.39	1.09	0.99	0.99
	LAC	1.60	1.33	1.33	5.92	5.25	5.25	4.32	3.92	3.92	4.34	3.94	3.94
	MENA	2.49	2.46	2.46	2.44	2.17	2.17	–0.05	–0.29	–0.29	0.36	0.12	0.12
	SA	10.01	10.01	10.10	9.76	10.01	10.37	–0.25	–0.01	0.27	0.42	0.62	0.89
	SSA	1.59	1.59	1.59	6.33	4.82	4.75	4.74	3.24	3.15	4.86	3.34	3.26
	Non DC	2.91	2.78	3.12	6.03	4.44	4.44	3.12	1.66	1.32	3.68	2.22	2.22
	All DCs	**27.15**	**25.96**	**26.05**	**37.39**	**35.53**	**35.82**	**10.24**	**9.57**	**9.76**	**12.53**	**11.52**	**11.71**
2025–2030	EAP	9.98	9.27	9.27	10.63	11.04	11.04	0.65	1.77	1.77	0.85	1.96	1.96
	ECA	1.53	1.07	1.07	1.65	1.40	1.40	0.12	0.33	0.33	1.03	0.86	0.86
	LAC	1.59	1.15	1.15	5.58	4.48	4.48	3.99	3.33	3.33	4.05	3.35	3.35
	MENA	2.69	2.64	2.64	2.64	2.33	2.33	–0.05	–0.32	–0.32	0.39	0.12	0.12
	SA	10.71	10.71	10.75	10.31	10.51	10.75	–0.40	–0.19	–0.01	0.42	0.58	0.77
	SSA	1.69	1.64	1.65	6.42	4.71	4.62	4.73	3.07	2.98	4.86	3.17	3.08
	Non DC	2.89	2.66	2.92	5.91	3.93	3.93	3.02	1.27	1.01	3.59	1.85	1.85
	All DCs	**28.19**	**26.49**	**26.54**	**37.23**	**34.47**	**34.62**	**9.04**	**7.98**	**8.08**	**11.60**	**10.04**	**10.13**
2030–2035	EAP	2.93	2.76	2.76	2.53	2.64	2.64	–0.40	–0.12	–0.12	0.44	0.45	0.45
	ECA	0.26	0.32	0.32	0.43	0.56	0.56	0.16	0.24	0.24	0.28	0.35	0.35
	LAC	0.80	0.99	0.99	1.84	2.03	2.03	1.04	1.04	1.04	1.06	1.06	1.06
	MENA	0.43	0.47	0.47	0.49	0.49	0.49	0.06	0.03	0.03	0.08	0.04	0.04
	SA	2.39	2.39	2.32	2.63	2.58	2.34	0.24	0.18	0.02	0.65	0.62	0.46
	SSA	0.42	0.47	0.47	1.35	1.26	1.24	0.92	0.80	0.77	0.97	0.85	0.83
	Non DC	1.00	1.09	1.20	1.57	1.65	1.65	0.58	0.57	0.46	0.64	0.63	0.63
	All DCs	**7.24**	**7.39**	**7.31**	**9.27**	**9.56**	**9.30**	**2.04**	**2.17**	**1.98**	**3.48**	**3.38**	**3.19**

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APPENDIX 7. *(continued)*

2035–2040	EAP	1.81	1.75	1.75	1.61	1.69	1.69	–0.20	–0.06	–0.06	0.36	0.37	0.37
	ECA	0.10	0.22	0.22	0.26	0.42	0.42	0.15	0.20	0.20	0.19	0.29	0.29
	LAC	0.57	0.82	0.82	1.29	1.65	1.65	0.72	0.83	0.83	0.87	0.84	0.84
	MENA	0.12	0.16	0.16	0.17	0.21	0.21	0.06	0.05	0.05	0.06	0.06	0.06
	SA	1.08	1.08	1.02	1.37	1.31	1.13	0.29	0.23	0.11	0.56	0.52	0.40
	SSA	0.21	0.26	0.26	0.68	0.78	0.77	0.47	0.52	0.51	0.56	0.57	0.55
	Non DC	0.65	0.78	0.88	0.97	1.28	1.28	0.32	0.51	0.41	0.39	0.52	0.52
	All DCs	**3.89**	**4.29**	**4.24**	**5.37**	**6.06**	**5.87**	**1.48**	**1.77**	**1.64**	**2.60**	**2.65**	**2.51**
2040–2045	EAP	1.49	1.43	1.43	1.29	1.35	1.35	–0.21	–0.08	–0.08	0.30	0.31	0.31
	ECA	0.08	0.18	0.18	0.20	0.34	0.34	0.12	0.16	0.16	0.15	0.23	0.23
	LAC	0.47	0.68	0.68	1.08	1.35	1.35	0.61	0.67	0.67	0.72	0.68	0.68
	MENA	0.09	0.12	0.12	0.13	0.16	0.16	0.04	0.04	0.04	0.05	0.04	0.04
	SA	0.86	0.86	0.81	1.11	1.06	0.90	0.26	0.21	0.09	0.47	0.44	0.33
	SSA	0.16	0.20	0.21	0.54	0.63	0.63	0.38	0.42	0.42	0.45	0.46	0.46
	Non DC	0.53	0.64	0.72	0.80	1.05	1.05	0.26	0.41	0.32	0.32	0.41	0.41
	All DCs	**3.15**	**3.48**	**3.43**	**4.35**	**4.90**	**4.74**	**1.20**	**1.42**	**1.31**	**2.13**	**2.17**	**2.05**
2045–2050	EAP	1.23	1.17	1.17	1.03	1.09	1.09	–0.20	–0.09	–0.09	0.24	0.25	0.25
	ECA	0.07	0.14	0.14	0.16	0.28	0.28	0.09	0.14	0.14	0.11	0.19	0.19
	LAC	0.39	0.57	0.57	0.90	1.11	1.11	0.50	0.54	0.54	0.59	0.55	0.55
	MENA	0.06	0.09	0.09	0.10	0.12	0.12	0.03	0.03	0.03	0.04	0.03	0.03
	SA	0.69	0.69	0.64	0.91	0.87	0.72	0.22	0.18	0.08	0.40	0.38	0.27
	SSA	0.13	0.16	0.16	0.44	0.50	0.51	0.31	0.34	0.35	0.36	0.37	0.38
	Non DC	0.44	0.53	0.59	0.65	0.85	0.85	0.21	0.33	0.26	0.26	0.33	0.33
	All DCs	**2.57**	**2.83**	**2.79**	**3.53**	**3.97**	**3.83**	**0.96**	**1.13**	**1.04**	**1.74**	**1.77**	**1.67**

APPENDIX 8. WATER SUPPLY RESULTS. GCM: NCAR. DISCOUNT RATE: 7%

Annual costs (averaged over 5-year periods) in USD billion

		Baseline			*Baseline & CC*			*CC (net)*			*CC (gross)*		
		Small	*Best*	*Large*	*Small*	*Best*	*Large*	*Small*	*Best*	*Large*	*Small*	*Best*	*Large*
2010–2015	EAP	6.80	7.01	7.01	10.19	10.81	10.81	3.39	3.79	3.79	3.46	3.90	3.90
	ECA	0.85	1.12	1.12	1.31	1.64	1.64	0.47	0.52	0.52	0.95	1.21	1.21
	LAC	1.13	1.63	1.63	5.40	6.65	6.65	4.27	5.01	5.01	4.30	5.04	5.04
	MENA	0.90	0.96	0.96	0.89	0.87	0.87	–0.01	–0.09	–0.09	0.13	0.05	0.05
	SA	4.15	4.15	4.38	4.55	4.87	5.66	0.41	0.72	1.27	0.54	0.84	1.39
	SSA	0.72	0.87	0.88	3.99	3.76	3.74	3.27	2.89	2.86	3.35	3.00	2.97
	Non DC	2.06	2.38	2.95	4.61	5.06	5.06	2.55	2.67	2.10	2.86	2.98	2.98
	All DCs	**14.54**	**15.74**	**15.99**	**26.33**	**28.59**	**29.36**	**11.79**	**12.85**	**13.37**	**12.72**	**14.03**	**14.55**
2015–2020	EAP	7.90	7.66	7.66	9.81	10.29	10.29	1.92	2.63	2.63	2.04	2.77	2.77
	ECA	1.12	1.03	1.03	1.39	1.43	1.43	0.28	0.40	0.40	0.93	0.98	0.98
	LAC	1.28	1.32	1.32	5.17	5.26	5.26	3.89	3.94	3.94	3.92	3.96	3.96
	MENA	1.68	1.69	1.69	1.66	1.50	1.50	–0.03	–0.19	–0.19	0.25	0.08	0.08
	SA	6.97	6.97	7.10	6.98	7.23	7.71	0.01	0.26	0.60	0.32	0.54	0.89
	SSA	1.13	1.18	1.19	4.90	3.99	3.94	3.77	2.81	2.75	3.86	2.90	2.85
	Non DC	2.33	2.38	2.77	4.95	4.24	4.24	2.62	1.86	1.47	3.04	2.28	2.28
	All DCs	**20.08**	**19.85**	**20.00**	**29.91**	**29.70**	**30.13**	**9.83**	**9.84**	**10.13**	**11.32**	**11.23**	**11.52**
2020–2025	EAP	7.80	7.36	7.36	8.81	9.19	9.19	1.01	1.82	1.82	1.15	1.97	1.97
	ECA	1.16	0.90	0.90	1.32	1.21	1.21	0.16	0.31	0.31	0.85	0.78	0.78
	LAC	1.25	1.05	1.05	4.63	4.12	4.12	3.38	3.07	3.07	3.40	3.09	3.09
	MENA	1.95	1.92	1.92	1.91	1.70	1.70	–0.04	–0.23	–0.23	0.28	0.09	0.09
	SA	7.83	7.83	7.90	7.63	7.83	8.12	–0.20	0.00	0.21	0.33	0.48	0.70
	SSA	1.25	1.24	1.25	4.95	3.78	3.72	3.71	2.53	2.47	3.81	2.62	2.55
	Non DC	2.28	2.18	2.45	4.72	3.48	3.48	2.44	1.30	1.03	2.88	1.74	1.74
	All DCs	**21.24**	**20.31**	**20.39**	**29.26**	**27.81**	**28.04**	**8.02**	**7.50**	**7.65**	**9.81**	**9.02**	**9.18**
2025–2030	EAP	7.11	6.60	6.60	7.58	7.87	7.87	0.47	1.26	1.26	0.60	1.40	1.40
	ECA	1.09	0.76	0.76	1.17	1.00	1.00	0.08	0.23	0.23	0.74	0.61	0.61
	LAC	1.14	0.82	0.82	3.98	3.20	3.20	2.84	2.38	2.38	2.88	2.39	2.39
	MENA	1.92	1.88	1.88	1.88	1.66	1.66	–0.04	–0.23	–0.23	0.28	0.09	0.09
	SA	7.62	7.62	7.66	7.34	7.49	7.65	–0.28	–0.14	0.00	0.30	0.41	0.55
	SSA	1.20	1.17	1.17	4.58	3.36	3.30	3.37	2.19	2.12	3.46	2.26	2.19
	Non DC	2.06	1.90	2.08	4.21	2.80	2.80	2.15	0.91	0.72	2.56	1.32	1.32
	All DCs	**20.08**	**18.87**	**18.90**	**26.52**	**24.56**	**24.67**	**6.44**	**5.69**	**5.76**	**8.27**	**7.16**	**7.23**
2030–2035	EAP	1.70	1.62	1.62	1.50	1.57	1.57	–0.20	–0.05	–0.05	0.28	0.29	0.29
	ECA	0.13	0.19	0.19	0.24	0.35	0.35	0.11	0.15	0.15	0.16	0.23	0.23
	LAC	0.48	0.64	0.64	1.13	1.31	1.31	0.65	0.67	0.67	0.68	0.68	0.68
	MENA	0.20	0.22	0.22	0.24	0.25	0.25	0.04	0.02	0.02	0.04	0.03	0.03
	SA	1.24	1.24	1.20	1.43	1.39	1.25	0.19	0.15	0.05	0.42	0.40	0.30
	SSA	0.22	0.26	0.26	0.74	0.73	0.73	0.51	0.48	0.47	0.54	0.51	0.50
	Non DC	0.59	0.66	0.74	0.92	1.04	1.04	0.33	0.38	0.31	0.36	0.41	0.41
	All DCs	**3.98**	**4.17**	**4.13**	**5.28**	**5.61**	**5.45**	**1.30**	**1.44**	**1.33**	**2.13**	**2.14**	**2.03**

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APPENDIX 8. *(continued)*

2035–2040	EAP	1.06	1.03	1.03	0.94	0.99	0.99	–0.12	–0.03	–0.03	0.21	0.22	0.22
	ECA	0.06	0.13	0.13	0.15	0.25	0.25	0.09	0.12	0.12	0.11	0.17	0.17
	LAC	0.33	0.48	0.48	0.77	0.97	0.97	0.44	0.49	0.49	0.52	0.50	0.50
	MENA	0.06	0.08	0.08	0.09	0.11	0.11	0.03	0.03	0.03	0.03	0.03	0.03
	SA	0.60	0.60	0.57	0.78	0.75	0.64	0.18	0.15	0.07	0.33	0.31	0.23
	SSA	0.11	0.15	0.15	0.39	0.45	0.45	0.28	0.31	0.31	0.33	0.33	0.33
	Non DC	0.38	0.45	0.51	0.57	0.75	0.75	0.19	0.30	0.24	0.23	0.30	0.30
	All DCs	**2.24**	**2.47**	**2.44**	**3.13**	**3.53**	**3.42**	**0.89**	**1.06**	**0.98**	**1.52**	**1.56**	**1.48**
2040–2045	EAP	0.80	0.77	0.77	0.69	0.72	0.72	–0.11	–0.04	–0.04	0.16	0.17	0.17
	ECA	0.04	0.10	0.10	0.11	0.18	0.18	0.06	0.09	0.09	0.08	0.13	0.13
	LAC	0.25	0.37	0.37	0.58	0.73	0.73	0.33	0.36	0.36	0.39	0.36	0.36
	MENA	0.04	0.06	0.06	0.06	0.08	0.08	0.02	0.02	0.02	0.02	0.02	0.02
	SA	0.44	0.44	0.42	0.59	0.56	0.47	0.14	0.12	0.06	0.25	0.24	0.18
	SSA	0.08	0.10	0.11	0.29	0.33	0.34	0.21	0.23	0.23	0.24	0.25	0.25
	Non DC	0.28	0.34	0.39	0.43	0.56	0.56	0.14	0.22	0.17	0.17	0.22	0.22
	All DCs	**1.66**	**1.84**	**1.81**	**2.31**	**2.61**	**2.52**	**0.65**	**0.77**	**0.71**	**1.14**	**1.16**	**1.10**
2045–2050	EAP	0.60	0.57	0.57	0.50	0.53	0.53	–0.10	–0.04	–0.04	0.12	0.12	0.12
	ECA	0.03	0.07	0.07	0.08	0.14	0.14	0.04	0.07	0.07	0.05	0.09	0.09
	LAC	0.19	0.28	0.28	0.44	0.54	0.54	0.25	0.26	0.26	0.29	0.27	0.27
	MENA	0.03	0.04	0.04	0.04	0.06	0.06	0.01	0.01	0.01	0.02	0.01	0.01
	SA	0.33	0.33	0.30	0.44	0.42	0.35	0.11	0.09	0.04	0.19	0.18	0.13
	SSA	0.06	0.08	0.08	0.21	0.24	0.25	0.15	0.17	0.17	0.18	0.18	0.19
	Non DC	0.21	0.26	0.29	0.32	0.41	0.41	0.11	0.16	0.13	0.13	0.16	0.16
	All DCs	**1.24**	**1.37**	**1.35**	**1.71**	**1.92**	**1.86**	**0.48**	**0.56**	**0.51**	**0.85**	**0.86**	**0.82**

APPENDIX 9. RIVERINE FLOOD PROTECTION RESULTS. GCM: CSIRO. DISCOUNT RATE: 0%

Annual costs (averaged over 5-year periods) in USD billion

		Baseline			*Baseline & CC*			*CC (net)*			*CC (gross)*
		Urban	*Agric.*	*Total*	*Urban*	*Agric*	*Total*	*Urban*	*Agric*	*Total*	*Total*
2010–2015	EAP	7.4	0.5	7.9	8.7	0.6	9.3	1.3	0.1	1.4	1.4
	ECA	11.7	0.8	12.5	12.3	0.9	13.1	0.6	0.1	0.6	0.9
	LAC	9.2	0.3	9.5	10.7	0.4	11.1	1.5	0.1	1.6	1.9
	MENA	4.6	0.1	4.7	5.1	0.1	5.1	0.4	0.0	0.4	0.5
	SA	5.3	0.4	5.7	6.7	0.5	7.2	1.4	0.1	1.5	1.5
	SSA	4.0	0.3	4.3	3.9	0.3	4.2	–0.2	0.0	–0.1	0.2
	Non DC	44.9	0.9	45.8	50.5	1.0	51.5	5.6	0.1	5.7	6.7
	All DCs	**42.3**	**2.4**	**44.7**	**47.4**	**2.8**	**50.1**	**5.1**	**0.3**	**5.5**	**6.4**
2015–2020	EAP	7.5	0.6	8.1	8.9	0.7	9.6	1.4	0.1	1.5	1.5
	ECA	12.0	0.8	12.8	12.6	0.9	13.5	0.6	0.1	0.6	0.9
	LAC	9.4	0.3	9.8	11.0	0.4	11.4	1.6	0.1	1.6	1.9
	MENA	4.8	0.1	4.8	5.2	0.1	5.3	0.4	0.0	0.4	0.5
	SA	5.4	0.4	5.8	6.9	0.5	7.4	1.4	0.1	1.6	1.6
	SSA	4.1	0.3	4.5	4.0	0.3	4.3	–0.2	0.0	–0.2	0.2
	Non DC	46.1	0.9	46.9	51.8	1.0	52.8	5.7	0.1	5.8	6.9
	All DCs	**43.3**	**2.5**	**45.8**	**48.5**	**2.8**	**51.4**	**5.2**	**0.4**	**5.6**	**6.6**
2020–2025	EAP	7.7	0.6	8.3	9.1	0.7	9.8	1.4	0.1	1.5	1.5
	ECA	12.3	0.8	13.1	12.9	0.9	13.8	0.6	0.1	0.6	0.9
	LAC	9.7	0.3	10.0	11.3	0.4	11.7	1.6	0.1	1.7	2.0
	MENA	4.9	0.1	4.9	5.3	0.1	5.4	0.4	0.0	0.4	0.5
	SA	5.5	0.4	6.0	7.0	0.5	7.5	1.5	0.1	1.6	1.6
	SSA	4.2	0.3	4.6	4.1	0.3	4.4	–0.2	0.0	–0.2	0.2
	Non DC	47.2	0.9	48.1	53.0	1.0	54.0	5.9	0.1	6.0	7.1
	All DCs	**44.3**	**2.6**	**46.9**	**49.7**	**2.9**	**52.6**	**5.4**	**0.4**	**5.7**	**6.8**
2025–2030	EAP	7.9	0.6	8.5	9.3	0.7	10.0	1.4	0.1	1.5	1.6
	ECA	12.6	0.8	13.4	13.2	0.9	14.1	0.6	0.1	0.7	0.9
	LAC	9.9	0.4	10.2	11.5	0.4	12.0	1.7	0.1	1.7	2.0
	MENA	5.0	0.1	5.1	5.4	0.1	5.5	0.5	0.0	0.5	0.5
	SA	5.7	0.4	6.1	7.2	0.5	7.7	1.5	0.1	1.6	1.6
	SSA	4.3	0.3	4.7	4.2	0.3	4.5	–0.2	0.0	–0.2	0.2
	Non DC	48.3	0.9	49.2	54.3	1.0	55.3	6.0	0.1	6.1	7.2
	All DCs	**45.4**	**2.6**	**48.0**	**50.9**	**3.0**	**53.9**	**5.5**	**0.4**	**5.9**	**6.9**
2030–2035	EAP	8.1	0.6	8.7	9.6	0.7	10.3	1.5	0.1	1.6	1.6
	ECA	12.9	0.9	13.8	13.5	0.9	14.4	0.6	0.1	0.7	0.9
	LAC	10.1	0.4	10.5	11.8	0.4	12.2	1.7	0.1	1.8	2.1
	MENA	5.1	0.1	5.2	5.6	0.1	5.7	0.5	0.0	0.5	0.6
	SA	5.8	0.4	6.2	7.4	0.6	7.9	1.5	0.1	1.7	1.7
	SSA	4.4	0.3	4.8	4.3	0.3	4.6	–0.2	0.0	–0.2	0.3
	Non DC	49.4	0.9	50.3	55.5	1.1	56.6	6.1	0.1	6.2	7.4
	All DCs	**46.4**	**2.7**	**49.1**	**52.0**	**3.1**	**55.1**	**5.6**	**0.4**	**6.0**	**7.1**

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APPENDIX 9. *(continued)*

2035–2040	EAP	8.3	0.6	8.9	9.8	0.7	10.5	1.5	0.1	1.6	1.6
	ECA	13.2	0.9	14.1	13.8	1.0	14.8	0.6	0.1	0.7	1.0
	LAC	10.3	0.4	10.7	12.1	0.4	12.5	1.7	0.1	1.8	2.1
	MENA	5.2	0.1	5.3	5.7	0.1	5.8	0.5	0.0	0.5	0.6
	SA	5.9	0.4	6.4	7.5	0.6	8.1	1.6	0.1	1.7	1.7
	SSA	4.5	0.3	4.9	4.4	0.4	4.7	–0.2	0.0	–0.2	0.3
	Non DC	50.5	1.0	51.5	56.8	1.1	57.9	6.3	0.1	6.4	7.6
	All DCs	**47.5**	**2.7**	**50.2**	**53.2**	**3.1**	**56.3**	**5.7**	**0.4**	**6.1**	**7.2**
2040–2045	EAP	8.4	0.6	9.1	10.0	0.7	10.7	1.5	0.1	1.7	1.7
	ECA	13.5	0.9	14.4	14.1	1.0	15.1	0.6	0.1	0.7	1.0
	LAC	10.6	0.4	10.9	12.3	0.5	12.8	1.8	0.1	1.8	2.2
	MENA	5.3	0.1	5.4	5.8	0.1	5.9	0.5	0.0	0.5	0.6
	SA	6.1	0.5	6.5	7.7	0.6	8.3	1.6	0.1	1.7	1.8
	SSA	4.6	0.3	5.0	4.5	0.4	4.8	–0.2	0.0	–0.2	0.3
	Non DC	51.6	1.0	52.6	58.0	1.1	59.1	6.4	0.1	6.5	7.7
	All DCs	**48.5**	**2.8**	**51.3**	**54.4**	**3.2**	**57.6**	**5.9**	**0.4**	**6.3**	**7.4**
2045–2050	EAP	8.6	0.6	9.3	10.2	0.8	11.0	1.6	0.1	1.7	1.7
	ECA	13.8	0.9	14.7	14.4	1.0	15.4	0.6	0.1	0.7	1.0
	LAC	10.8	0.4	11.2	12.6	0.5	13.1	1.8	0.1	1.9	2.2
	MENA	5.5	0.1	5.5	5.9	0.1	6.0	0.5	0.0	0.5	0.6
	SA	6.2	0.5	6.7	7.8	0.6	8.4	1.7	0.1	1.8	1.8
	SSA	4.7	0.4	5.1	4.6	0.4	4.9	–0.2	0.0	–0.2	0.3
	Non DC	52.7	1.0	53.7	59.3	1.1	60.4	6.6	0.1	6.7	7.9
	All DCs	**49.6**	**2.9**	**52.4**	**55.6**	**3.3**	**58.8**	**6.0**	**0.4**	**6.4**	**7.6**

APPENDIX 10. RIVERINE FLOOD PROTECTION RESULTS. GCM: CSIRO. DISCOUNT RATE: 3%

Annual costs (averaged over 5-year periods) in USD billion

		Baseline			*Baseline & CC*			*CC (net)*			*CC (gross)*
		Urban	*Agric.*	*Total*	*Urban*	*Agric*	*Total*	*Urban*	*Agric*	*Total*	*Total*
2010–2015	EAP	6.7	0.5	7.2	8.0	0.6	8.6	1.2	0.1	1.3	1.3
	ECA	10.7	0.7	11.5	11.2	0.8	12.0	0.5	0.1	0.6	0.8
	LAC	8.4	0.3	8.7	9.8	0.4	10.2	1.4	0.1	1.5	1.7
	MENA	4.3	0.1	4.3	4.6	0.1	4.7	0.4	0.0	0.4	0.5
	SA	4.8	0.4	5.2	6.1	0.5	6.6	1.3	0.1	1.4	1.4
	SSA	3.7	0.3	4.0	3.6	0.3	3.8	–0.2	0.0	–0.1	0.2
	Non DC	41.2	0.8	41.9	46.3	0.9	47.1	5.1	0.1	5.2	6.2
	All DCs	**38.7**	**2.2**	**40.9**	**43.4**	**2.5**	**45.9**	**4.7**	**0.3**	**5.0**	**5.9**
2015–2020	EAP	6.0	0.4	6.4	7.0	0.5	7.6	1.1	0.1	1.2	1.2
	ECA	9.5	0.6	10.1	9.9	0.7	10.6	0.4	0.0	0.5	0.7
	LAC	7.4	0.3	7.7	8.7	0.3	9.0	1.2	0.1	1.3	1.5
	MENA	3.8	0.1	3.8	4.1	0.1	4.2	0.3	0.0	0.3	0.4
	SA	4.3	0.3	4.6	5.4	0.4	5.8	1.1	0.1	1.2	1.2
	SSA	3.3	0.2	3.5	3.1	0.3	3.4	–0.1	0.0	–0.1	0.2
	Non DC	36.4	0.7	37.1	40.9	0.8	41.7	4.5	0.1	4.6	5.5
	All DCs	**34.2**	**2.0**	**36.2**	**38.3**	**2.2**	**40.6**	**4.1**	**0.3**	**4.4**	**5.2**
2020–2025	EAP	5.3	0.4	5.7	6.2	0.5	6.7	1.0	0.1	1.0	1.0
	ECA	8.4	0.6	8.9	8.8	0.6	9.4	0.4	0.0	0.4	0.6
	LAC	6.6	0.2	6.8	7.7	0.3	8.0	1.1	0.0	1.1	1.3
	MENA	3.3	0.0	3.4	3.6	0.1	3.7	0.3	0.0	0.3	0.4
	SA	3.8	0.3	4.1	4.8	0.4	5.1	1.0	0.1	1.1	1.1
	SSA	2.9	0.2	3.1	2.8	0.2	3.0	–0.1	0.0	–0.1	0.2
	Non DC	32.1	0.6	32.8	36.1	0.7	36.8	4.0	0.1	4.1	4.8
	All DCs	**30.2**	**1.7**	**32.0**	**33.9**	**2.0**	**35.9**	**3.7**	**0.2**	**3.9**	**4.6**
2025–2030	EAP	4.6	0.3	5.0	5.5	0.4	5.9	0.9	0.1	0.9	0.9
	ECA	7.4	0.5	7.9	7.8	0.5	8.3	0.3	0.0	0.4	0.5
	LAC	5.8	0.2	6.0	6.8	0.2	7.0	1.0	0.0	1.0	1.2
	MENA	2.9	0.0	3.0	3.2	0.0	3.2	0.3	0.0	0.3	0.3
	SA	3.3	0.3	3.6	4.2	0.3	4.5	0.9	0.1	1.0	1.0
	SSA	2.6	0.2	2.7	2.5	0.2	2.7	–0.1	0.0	–0.1	0.1
	Non DC	28.4	0.5	28.9	31.9	0.6	32.5	3.5	0.1	3.6	4.3
	All DCs	**26.7**	**1.5**	**28.2**	**29.9**	**1.8**	**31.7**	**3.2**	**0.2**	**3.4**	**4.1**
2030–2035	EAP	4.1	0.3	4.4	4.8	0.4	5.2	0.8	0.1	0.8	0.8
	ECA	6.5	0.4	7.0	6.8	0.5	7.3	0.3	0.0	0.3	0.5
	LAC	5.1	0.2	5.3	6.0	0.2	6.2	0.9	0.0	0.9	1.0
	MENA	2.6	0.0	2.6	2.8	0.0	2.9	0.2	0.0	0.2	0.3
	SA	2.9	0.2	3.2	3.7	0.3	4.0	0.8	0.1	0.8	0.9
	SSA	2.3	0.2	2.4	2.2	0.2	2.3	–0.1	0.0	–0.1	0.1
	Non DC	25.0	0.5	25.5	28.2	0.5	28.7	3.1	0.1	3.2	3.8
	All DCs	**23.5**	**1.4**	**24.9**	**26.4**	**1.5**	**27.9**	**2.8**	**0.2**	**3.0**	**3.6**

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APPENDIX 10. *(continued)*

2035–2040	EAP	3.6	0.3	3.9	4.3	0.3	4.6	0.7	0.0	0.7	0.7
	ECA	5.8	0.4	6.1	6.0	0.4	6.5	0.3	0.0	0.3	0.4
	LAC	4.5	0.2	4.7	5.3	0.2	5.5	0.8	0.0	0.8	0.9
	MENA	2.3	0.0	2.3	2.5	0.0	2.5	0.2	0.0	0.2	0.2
	SA	2.6	0.2	2.8	3.3	0.2	3.5	0.7	0.1	0.7	0.8
	SSA	2.0	0.1	2.1	1.9	0.2	2.1	–0.1	0.0	–0.1	0.1
	Non DC	22.1	0.4	22.5	24.8	0.5	25.3	2.7	0.0	2.8	3.3
	All DCs	**20.8**	**1.2**	**22.0**	**23.3**	**1.4**	**24.6**	**2.5**	**0.2**	**2.7**	**3.2**
2040–2045	EAP	3.2	0.2	3.4	3.8	0.3	4.0	0.6	0.0	0.6	0.6
	ECA	5.1	0.3	5.4	5.3	0.4	5.7	0.2	0.0	0.3	0.4
	LAC	4.0	0.1	4.1	4.7	0.2	4.8	0.7	0.0	0.7	0.8
	MENA	2.0	0.0	2.0	2.2	0.0	2.2	0.2	0.0	0.2	0.2
	SA	2.3	0.2	2.5	2.9	0.2	3.1	0.6	0.0	0.7	0.7
	SSA	1.8	0.1	1.9	1.7	0.1	1.8	–0.1	0.0	–0.1	0.1
	Non DC	19.5	0.4	19.8	21.9	0.4	22.3	2.4	0.0	2.5	2.9
	All DCs	**18.3**	**1.1**	**19.4**	**20.5**	**1.2**	**21.7**	**2.2**	**0.2**	**2.4**	**2.8**
2045–2050	EAP	2.8	0.2	3.0	3.3	0.2	3.6	0.5	0.0	0.5	0.6
	ECA	4.5	0.3	4.8	4.7	0.3	5.0	0.2	0.0	0.2	0.3
	LAC	3.5	0.1	3.6	4.1	0.2	4.3	0.6	0.0	0.6	0.7
	MENA	1.8	0.0	1.8	1.9	0.0	2.0	0.2	0.0	0.2	0.2
	SA	2.0	0.2	2.2	2.6	0.2	2.7	0.5	0.0	0.6	0.6
	SSA	1.5	0.1	1.7	1.5	0.1	1.6	–0.1	0.0	–0.1	0.1
	Non DC	17.2	0.3	17.5	19.3	0.4	19.7	2.1	0.0	2.2	2.6
	All DCs	**16.1**	**0.9**	**17.1**	**18.1**	**1.1**	**19.1**	**1.9**	**0.1**	**2.1**	**2.5**

APPENDIX 11. RIVERINE FLOOD PROTECTION RESULTS. GCM: CSIRO. DISCOUNT RATE: 5%

Annual costs (averaged over 5-year periods) in USD billion

		Baseline			*Baseline & CC*			*CC (net)*			*CC (gross)*
		Urban	*Agric.*	*Total*	*Urban*	*Agric*	*Total*	*Urban*	*Agric*	*Total*	*Total*
2010–2015	EAP	6.4	0.5	6.8	7.5	0.6	8.1	1.2	0.1	1.2	1.3
	ECA	10.1	0.7	10.8	10.6	0.7	11.4	0.5	0.1	0.5	0.7
	LAC	8.0	0.3	8.2	9.3	0.3	9.6	1.3	0.1	1.4	1.6
	MENA	4.0	0.1	4.1	4.4	0.1	4.5	0.4	0.0	0.4	0.4
	SA	4.6	0.3	4.9	5.8	0.4	6.2	1.2	0.1	1.3	1.3
	SSA	3.5	0.3	3.8	3.4	0.3	3.6	–0.1	0.0	–0.1	0.2
	Non DC	38.9	0.7	39.6	43.7	0.8	44.6	4.8	0.1	4.9	5.8
	All DCs	**36.6**	**2.1**	**38.7**	**41.0**	**2.4**	**43.4**	**4.4**	**0.3**	**4.7**	**5.6**
2015–2020	EAP	5.1	0.4	5.5	6.0	0.4	6.5	0.9	0.1	1.0	1.0
	ECA	8.1	0.5	8.7	8.5	0.6	9.1	0.4	0.0	0.4	0.6
	LAC	6.4	0.2	6.6	7.5	0.3	7.7	1.1	0.0	1.1	1.3
	MENA	3.2	0.0	3.3	3.5	0.1	3.6	0.3	0.0	0.3	0.3
	SA	3.7	0.3	3.9	4.6	0.3	5.0	1.0	0.1	1.1	1.1
	SSA	2.8	0.2	3.0	2.7	0.2	2.9	–0.1	0.0	–0.1	0.2
	Non DC	31.2	0.6	31.8	35.1	0.7	35.8	3.9	0.1	4.0	4.7
	All DCs	**29.4**	**1.7**	**31.1**	**32.9**	**1.9**	**34.8**	**3.5**	**0.2**	**3.8**	**4.5**
2020–2025	EAP	4.1	0.3	4.4	4.9	0.4	5.2	0.8	0.1	0.8	0.8
	ECA	6.5	0.4	7.0	6.8	0.5	7.3	0.3	0.0	0.3	0.5
	LAC	5.1	0.2	5.3	6.0	0.2	6.2	0.9	0.0	0.9	1.0
	MENA	2.6	0.0	2.6	2.8	0.0	2.9	0.2	0.0	0.2	0.3
	SA	2.9	0.2	3.2	3.7	0.3	4.0	0.8	0.1	0.8	0.9
	SSA	2.3	0.2	2.4	2.2	0.2	2.3	–0.1	0.0	–0.1	0.1
	Non DC	25.1	0.5	25.5	28.2	0.5	28.7	3.1	0.1	3.2	3.8
	All DCs	**23.6**	**1.4**	**24.9**	**26.4**	**1.5**	**28.0**	**2.8**	**0.2**	**3.0**	**3.6**
2025–2030	EAP	3.3	0.2	3.5	3.9	0.3	4.2	0.6	0.0	0.6	0.6
	ECA	5.2	0.4	5.6	5.5	0.4	5.9	0.2	0.0	0.3	0.4
	LAC	4.1	0.1	4.3	4.8	0.2	5.0	0.7	0.0	0.7	0.8
	MENA	2.1	0.0	2.1	2.3	0.0	2.3	0.2	0.0	0.2	0.2
	SA	2.4	0.2	2.5	3.0	0.2	3.2	0.6	0.0	0.7	0.7
	SSA	1.8	0.1	1.9	1.7	0.1	1.9	–0.1	0.0	–0.1	0.1
	Non DC	20.1	0.4	20.5	22.6	0.4	23.0	2.5	0.0	2.5	3.0
	All DCs	**18.9**	**1.1**	**20.0**	**21.2**	**1.2**	**22.4**	**2.3**	**0.2**	**2.4**	**2.9**
2030–2035	EAP	2.6	0.2	2.8	3.1	0.2	3.3	0.5	0.0	0.5	0.5
	ECA	4.2	0.3	4.5	4.4	0.3	4.7	0.2	0.0	0.2	0.3
	LAC	3.3	0.1	3.4	3.9	0.1	4.0	0.6	0.0	0.6	0.7
	MENA	1.7	0.0	1.7	1.8	0.0	1.8	0.2	0.0	0.2	0.2
	SA	1.9	0.1	2.0	2.4	0.2	2.6	0.5	0.0	0.5	0.5
	SSA	1.5	0.1	1.6	1.4	0.1	1.5	–0.1	0.0	–0.1	0.1
	Non DC	16.1	0.3	16.4	18.1	0.3	18.5	2.0	0.0	2.0	2.4
	All DCs	**15.1**	**0.9**	**16.0**	**17.0**	**1.0**	**18.0**	**1.8**	**0.1**	**2.0**	**2.3**

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APPENDIX 11. *(continued)*

2035–2040	EAP	2.1	0.2	2.3	2.5	0.2	2.7	0.4	0.0	0.4	0.4
	ECA	3.4	0.2	3.6	3.5	0.2	3.8	0.2	0.0	0.2	0.2
	LAC	2.6	0.1	2.7	3.1	0.1	3.2	0.4	0.0	0.5	0.5
	MENA	1.3	0.0	1.4	1.5	0.0	1.5	0.1	0.0	0.1	0.1
	SA	1.5	0.1	1.6	1.9	0.1	2.1	0.4	0.0	0.4	0.4
	SSA	1.2	0.1	1.2	1.1	0.1	1.2	0.0	0.0	0.0	0.1
	Non DC	12.9	0.2	13.2	14.5	0.3	14.8	1.6	0.0	1.6	1.9
	All DCs	**12.1**	**0.7**	**12.8**	**13.6**	**0.8**	**14.4**	**1.5**	**0.1**	**1.6**	**1.9**
2040–2045	EAP	1.7	0.1	1.8	2.0	0.1	2.1	0.3	0.0	0.3	0.3
	ECA	2.7	0.2	2.9	2.8	0.2	3.0	0.1	0.0	0.1	0.2
	LAC	2.1	0.1	2.2	2.5	0.1	2.6	0.4	0.0	0.4	0.4
	MENA	1.1	0.0	1.1	1.2	0.0	1.2	0.1	0.0	0.1	0.1
	SA	1.2	0.1	1.3	1.5	0.1	1.7	0.3	0.0	0.3	0.4
	SSA	0.9	0.1	1.0	0.9	0.1	1.0	0.0	0.0	0.0	0.1
	Non DC	10.3	0.2	10.5	11.6	0.2	11.8	1.3	0.0	1.3	1.5
	All DCs	**9.7**	**0.6**	**10.3**	**10.9**	**0.6**	**11.5**	**1.2**	**0.1**	**1.3**	**1.5**
2045–2050	EAP	1.4	0.1	1.5	1.6	0.1	1.7	0.2	0.0	0.3	0.3
	ECA	2.2	0.1	2.3	2.3	0.2	2.4	0.1	0.0	0.1	0.2
	LAC	1.7	0.1	1.8	2.0	0.1	2.0	0.3	0.0	0.3	0.3
	MENA	0.9	0.0	0.9	0.9	0.0	0.9	0.1	0.0	0.1	0.1
	SA	1.0	0.1	1.0	1.2	0.1	1.3	0.3	0.0	0.3	0.3
	SSA	0.7	0.1	0.8	0.7	0.1	0.8	0.0	0.0	0.0	0.0
	Non DC	8.3	0.2	8.4	9.3	0.2	9.5	1.0	0.0	1.0	1.2
	All DCs	**7.8**	**0.4**	**8.2**	**8.7**	**0.5**	**9.2**	**0.9**	**0.1**	**1.0**	**1.2**

APPENDIX 12. RIVERINE FLOOD PROTECTION RESULTS. GCM: CSIRO. DISCOUNT RATE: 7%

Annual costs (averaged over 5-year periods) in USD billion

		Baseline			*Baseline & CC*			*CC (net)*			*CC (gross)*
		Urban	*Agric.*	*Total*	*Urban*	*Agric*	*Total*	*Urban*	*Agric*	*Total*	*Total*
2010–2015	EAP	6.0	0.4	6.5	7.1	0.5	7.7	1.1	0.1	1.2	1.2
	ECA	9.6	0.6	10.3	10.1	0.7	10.8	0.5	0.1	0.5	0.7
	LAC	7.5	0.3	7.8	8.8	0.3	9.1	1.3	0.1	1.3	1.5
	MENA	3.8	0.1	3.9	4.2	0.1	4.2	0.3	0.0	0.4	0.4
	SA	4.3	0.3	4.7	5.5	0.4	5.9	1.2	0.1	1.2	1.3
	SSA	3.3	0.2	3.6	3.2	0.3	3.4	–0.1	0.0	–0.1	0.2
	Non DC	36.8	0.7	37.5	41.4	0.8	42.2	4.6	0.1	4.7	5.5
	All DCs	**34.6**	**2.0**	**36.6**	**38.8**	**2.3**	**41.1**	**4.2**	**0.3**	**4.5**	**5.3**
2015–2020	EAP	4.4	0.3	4.7	5.2	0.4	5.6	0.8	0.1	0.9	0.9
	ECA	7.0	0.5	7.5	7.4	0.5	7.9	0.3	0.0	0.4	0.5
	LAC	5.5	0.2	5.7	6.4	0.2	6.7	0.9	0.0	1.0	1.1
	MENA	2.8	0.0	2.8	3.0	0.0	3.1	0.3	0.0	0.3	0.3
	SA	3.2	0.2	3.4	4.0	0.3	4.3	0.8	0.1	0.9	0.9
	SSA	2.4	0.2	2.6	2.3	0.2	2.5	–0.1	0.0	–0.1	0.1
	Non DC	26.9	0.5	27.4	30.3	0.6	30.8	3.3	0.1	3.4	4.0
	All DCs	**25.3**	**1.5**	**26.8**	**28.4**	**1.7**	**30.0**	**3.1**	**0.2**	**3.3**	**3.9**
2020–2025	EAP	3.2	0.2	3.5	3.8	0.3	4.1	0.6	0.0	0.6	0.6
	ECA	5.1	0.3	5.5	5.4	0.4	5.7	0.2	0.0	0.3	0.4
	LAC	4.0	0.1	4.2	4.7	0.2	4.9	0.7	0.0	0.7	0.8
	MENA	2.0	0.0	2.1	2.2	0.0	2.2	0.2	0.0	0.2	0.2
	SA	2.3	0.2	2.5	2.9	0.2	3.1	0.6	0.0	0.7	0.7
	SSA	1.8	0.1	1.9	1.7	0.1	1.8	–0.1	0.0	–0.1	0.1
	Non DC	19.7	0.4	20.0	22.1	0.4	22.5	2.4	0.0	2.5	2.9
	All DCs	**18.5**	**1.1**	**19.5**	**20.7**	**1.2**	**21.9**	**2.2**	**0.2**	**2.4**	**2.8**
2025–2030	EAP	2.3	0.2	2.5	2.8	0.2	3.0	0.4	0.0	0.5	0.5
	ECA	3.7	0.3	4.0	3.9	0.3	4.2	0.2	0.0	0.2	0.3
	LAC	2.9	0.1	3.0	3.4	0.1	3.6	0.5	0.0	0.5	0.6
	MENA	1.5	0.0	1.5	1.6	0.0	1.6	0.1	0.0	0.1	0.2
	SA	1.7	0.1	1.8	2.1	0.2	2.3	0.4	0.0	0.5	0.5
	SSA	1.3	0.1	1.4	1.2	0.1	1.3	–0.1	0.0	0.0	0.1
	Non DC	14.3	0.3	14.6	16.1	0.3	16.4	1.8	0.0	1.8	2.1
	All DCs	**13.5**	**0.8**	**14.3**	**15.1**	**0.9**	**16.0**	**1.6**	**0.1**	**1.7**	**2.1**
2030–2035	EAP	1.7	0.1	1.8	2.0	0.1	2.2	0.3	0.0	0.3	0.3
	ECA	2.7	0.2	2.9	2.9	0.2	3.1	0.1	0.0	0.1	0.2
	LAC	2.1	0.1	2.2	2.5	0.1	2.6	0.4	0.0	0.4	0.4
	MENA	1.1	0.0	1.1	1.2	0.0	1.2	0.1	0.0	0.1	0.1
	SA	1.2	0.1	1.3	1.6	0.1	1.7	0.3	0.0	0.4	0.4
	SSA	0.9	0.1	1.0	0.9	0.1	1.0	0.0	0.0	0.0	0.1
	Non DC	10.5	0.2	10.7	11.8	0.2	12.0	1.3	0.0	1.3	1.6
	All DCs	**9.8**	**0.6**	**10.4**	**11.0**	**0.6**	**11.7**	**1.2**	**0.1**	**1.3**	**1.5**

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APPENDIX 12. *(continued)*

2035–2040	EAP	1.2	0.1	1.3	1.5	0.1	1.6	0.2	0.0	0.2	0.2
	ECA	2.0	0.1	2.1	2.1	0.1	2.2	0.1	0.0	0.1	0.1
	LAC	1.6	0.1	1.6	1.8	0.1	1.9	0.3	0.0	0.3	0.3
	MENA	0.8	0.0	0.8	0.9	0.0	0.9	0.1	0.0	0.1	0.1
	SA	0.9	0.1	1.0	1.1	0.1	1.2	0.2	0.0	0.3	0.3
	SSA	0.7	0.1	0.7	0.7	0.1	0.7	0.0	0.0	0.0	0.0
	Non DC	7.6	0.1	7.8	8.6	0.2	8.7	0.9	0.0	1.0	1.1
	All DCs	**7.2**	**0.4**	**7.6**	**8.0**	**0.5**	**8.5**	**0.9**	**0.1**	**0.9**	**1.1**
2040–2045	EAP	0.9	0.1	1.0	1.1	0.1	1.2	0.2	0.0	0.2	0.2
	ECA	1.4	0.1	1.5	1.5	0.1	1.6	0.1	0.0	0.1	0.1
	LAC	1.1	0.0	1.2	1.3	0.0	1.4	0.2	0.0	0.2	0.2
	MENA	0.6	0.0	0.6	0.6	0.0	0.6	0.1	0.0	0.1	0.1
	SA	0.7	0.0	0.7	0.8	0.1	0.9	0.2	0.0	0.2	0.2
	SSA	0.5	0.0	0.5	0.5	0.0	0.5	0.0	0.0	0.0	0.0
	Non DC	5.6	0.1	5.7	6.2	0.1	6.4	0.7	0.0	0.7	0.8
	All DCs	**5.2**	**0.3**	**5.5**	**5.9**	**0.3**	**6.2**	**0.6**	**0.0**	**0.7**	**0.8**
2045–2050	EAP	0.7	0.0	0.7	0.8	0.1	0.8	0.1	0.0	0.1	0.1
	ECA	1.1	0.1	1.1	1.1	0.1	1.2	0.0	0.0	0.1	0.1
	LAC	0.8	0.0	0.9	1.0	0.0	1.0	0.1	0.0	0.1	0.2
	MENA	0.4	0.0	0.4	0.5	0.0	0.5	0.0	0.0	0.0	0.0
	SA	0.5	0.0	0.5	0.6	0.0	0.6	0.1	0.0	0.1	0.1
	SSA	0.4	0.0	0.4	0.3	0.0	0.4	0.0	0.0	0.0	0.0
	Non DC	4.0	0.1	4.1	4.6	0.1	4.6	0.5	0.0	0.5	0.6
	All DCs	**3.8**	**0.2**	**4.0**	**4.3**	**0.3**	**4.5**	**0.5**	**0.0**	**0.5**	**0.6**

APPENDIX 13. RIVERINE FLOOD PROTECTION RESULTS. GCM: NCAR. DISCOUNT RATE: 0%

Annual costs (averaged over 5-year periods) in USD billion

		Baseline			*Baseline & CC*			*CC (net)*			*CC (gross)*
		Urban	*Agric.*	*Total*	*Urban*	*Agric*	*Total*	*Urban*	*Agric*	*Total*	*Total*
2010–2015	EAP	7.4	0.5	7.9	8.0	0.6	8.6	0.7	0.1	0.7	0.9
	ECA	11.7	0.8	12.5	12.9	0.9	13.8	1.2	0.1	1.3	1.5
	LAC	9.2	0.3	9.5	9.4	0.4	9.8	0.2	0.0	0.3	0.9
	MENA	4.6	0.1	4.7	4.4	0.1	4.4	–0.3	0.0	–0.3	0.1
	SA	5.3	0.4	5.7	6.1	0.5	6.6	0.8	0.1	0.9	1.0
	SSA	4.0	0.3	4.3	4.3	0.3	4.6	0.3	0.0	0.3	0.4
	Non DC	44.9	0.9	45.8	46.2	0.9	47.1	1.3	0.0	1.3	1.8
	All DCs	**42.3**	**2.4**	**44.7**	**45.2**	**2.7**	**47.9**	**2.9**	**0.3**	**3.2**	**4.7**
2015–2020	EAP	7.5	0.6	8.1	8.2	0.6	8.8	0.7	0.1	0.7	0.9
	ECA	12.0	0.8	12.8	13.2	0.9	14.1	1.2	0.1	1.3	1.6
	LAC	9.4	0.3	9.8	9.7	0.4	10.0	0.2	0.0	0.3	0.9
	MENA	4.8	0.1	4.8	4.5	0.1	4.6	–0.3	0.0	–0.3	0.1
	SA	5.4	0.4	5.8	6.2	0.5	6.7	0.8	0.1	0.9	1.0
	SSA	4.1	0.3	4.5	4.4	0.3	4.8	0.3	0.0	0.3	0.4
	Non DC	46.1	0.9	46.9	47.4	0.9	48.3	1.3	0.0	1.3	1.9
	All DCs	**43.3**	**2.5**	**45.8**	**46.3**	**2.8**	**49.0**	**3.0**	**0.3**	**3.3**	**4.9**
2020–2025	EAP	7.7	0.6	8.3	8.4	0.6	9.1	0.7	0.1	0.8	0.9
	ECA	12.3	0.8	13.1	13.6	0.9	14.5	1.3	0.1	1.3	1.6
	LAC	9.7	0.3	10.0	9.9	0.4	10.3	0.3	0.0	0.3	0.9
	MENA	4.9	0.1	4.9	4.6	0.1	4.7	–0.3	0.0	–0.3	0.1
	SA	5.5	0.4	6.0	6.4	0.5	6.9	0.9	0.1	0.9	1.0
	SSA	4.2	0.3	4.6	4.5	0.4	4.9	0.3	0.0	0.3	0.4
	Non DC	47.2	0.9	48.1	48.5	0.9	49.4	1.4	0.0	1.4	1.9
	All DCs	**44.3**	**2.6**	**46.9**	**47.4**	**2.8**	**50.2**	**3.0**	**0.3**	**3.3**	**5.0**
2025–2030	EAP	7.9	0.6	8.5	8.6	0.7	9.3	0.7	0.1	0.8	0.9
	ECA	12.6	0.8	13.4	13.9	0.9	14.8	1.3	0.1	1.4	1.6
	LAC	9.9	0.4	10.2	10.1	0.4	10.5	0.3	0.0	0.3	0.9
	MENA	5.0	0.1	5.1	4.7	0.1	4.8	–0.3	0.0	–0.3	0.1
	SA	5.7	0.4	6.1	6.5	0.5	7.0	0.9	0.1	0.9	1.1
	SSA	4.3	0.3	4.7	4.6	0.4	5.0	0.3	0.0	0.3	0.4
	Non DC	48.3	0.9	49.2	49.7	0.9	50.6	1.4	0.0	1.4	2.0
	All DCs	**45.4**	**2.6**	**48.0**	**48.5**	**2.9**	**51.4**	**3.1**	**0.3**	**3.4**	**5.1**
2030–2035	EAP	8.1	0.6	8.7	8.8	0.7	9.5	0.7	0.1	0.8	0.9
	ECA	12.9	0.9	13.8	14.2	1.0	15.2	1.3	0.1	1.4	1.7
	LAC	10.1	0.4	10.5	10.4	0.4	10.8	0.3	0.0	0.3	1.0
	MENA	5.1	0.1	5.2	4.8	0.1	4.9	–0.3	0.0	–0.3	0.1
	SA	5.8	0.4	6.2	6.7	0.5	7.2	0.9	0.1	1.0	1.1
	SSA	4.4	0.3	4.8	4.7	0.4	5.1	0.3	0.0	0.3	0.4
	Non DC	49.4	0.9	50.3	50.8	0.9	51.8	1.4	0.0	1.4	2.0
	All DCs	**46.4**	**2.7**	**49.1**	**49.6**	**3.0**	**52.6**	**3.2**	**0.3**	**3.5**	**5.2**

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APPENDIX 13. *(continued)*

2035–2040	EAP	8.3	0.6	8.9	9.0	0.7	9.7	0.7	0.1	0.8	1.0
	ECA	13.2	0.9	14.1	14.5	1.0	15.5	1.3	0.1	1.4	1.7
	LAC	10.3	0.4	10.7	10.6	0.4	11.0	0.3	0.0	0.3	1.0
	MENA	5.2	0.1	5.3	4.9	0.1	5.0	–0.3	0.0	–0.3	0.1
	SA	5.9	0.4	6.4	6.8	0.5	7.4	0.9	0.1	1.0	1.1
	SSA	4.5	0.3	4.9	4.8	0.4	5.2	0.3	0.0	0.3	0.4
	Non DC	50.5	1.0	51.5	52.0	1.0	52.9	1.5	0.0	1.4	2.1
	All DCs	**47.5**	**2.7**	**50.2**	**50.7**	**3.0**	**53.8**	**3.3**	**0.3**	**3.6**	**5.3**
2040–2045	EAP	8.4	0.6	9.1	9.2	0.7	9.9	0.8	0.1	0.8	1.0
	ECA	13.5	0.9	14.4	14.8	1.0	15.8	1.4	0.1	1.5	1.7
	LAC	10.6	0.4	10.9	10.8	0.4	11.3	0.3	0.0	0.3	1.0
	MENA	5.3	0.1	5.4	5.0	0.1	5.1	–0.3	0.0	–0.3	0.1
	SA	6.1	0.5	6.5	7.0	0.5	7.5	0.9	0.1	1.0	1.1
	SSA	4.6	0.3	5.0	5.0	0.4	5.3	0.3	0.0	0.3	0.4
	Non DC	51.6	1.0	52.6	53.1	1.0	54.1	1.5	0.0	1.5	2.1
	All DCs	**48.5**	**2.8**	**51.3**	**51.9**	**3.1**	**55.0**	**3.3**	**0.3**	**3.7**	**5.5**
2045–2050	EAP	8.6	0.6	9.3	9.4	0.7	10.1	0.8	0.1	0.8	1.0
	ECA	13.8	0.9	14.7	15.2	1.0	16.2	1.4	0.1	1.5	1.8
	LAC	10.8	0.4	11.2	11.1	0.4	11.5	0.3	0.0	0.3	1.0
	MENA	5.5	0.1	5.5	5.1	0.1	5.2	–0.3	0.0	–0.3	0.1
	SA	6.2	0.5	6.7	7.2	0.5	7.7	1.0	0.1	1.0	1.2
	SSA	4.7	0.4	5.1	5.1	0.4	5.5	0.3	0.0	0.4	0.4
	Non DC	52.7	1.0	53.7	54.3	1.0	55.3	1.5	0.0	1.5	2.1
	All DCs	**49.6**	**2.9**	**52.4**	**53.0**	**3.2**	**56.2**	**3.4**	**0.3**	**3.7**	**5.6**

APPENDIX 14. RIVERINE FLOOD PROTECTION RESULTS. GCM: NCAR. DISCOUNT RATE: 3%

Annual costs (averaged over 5-year periods) in USD billion

		Baseline			*Baseline & CC*			*CC (net)*			*CC (gross)*
		Urban	*Agric.*	*Total*	*Urban*	*Agric*	*Total*	*Urban*	*Agric*	*Total*	*Total*
2010–2015	EAP	6.7	0.5	7.2	7.3	0.6	7.9	0.6	0.1	0.7	0.8
	ECA	10.7	0.7	11.5	11.8	0.8	12.6	1.1	0.1	1.2	1.4
	LAC	8.4	0.3	8.7	8.6	0.3	9.0	0.2	0.0	0.2	0.8
	MENA	4.3	0.1	4.3	4.0	0.1	4.1	–0.2	0.0	–0.2	0.1
	SA	4.8	0.4	5.2	5.6	0.4	6.0	0.7	0.1	0.8	0.9
	SSA	3.7	0.3	4.0	3.9	0.3	4.3	0.2	0.0	0.3	0.3
	Non DC	41.2	0.8	41.9	42.3	0.8	43.1	1.2	0.0	1.2	1.7
	All DCs	**38.7**	**2.2**	**40.9**	**41.4**	**2.5**	**43.8**	**2.7**	**0.3**	**2.9**	**4.3**
2015–2020	EAP	6.0	0.4	6.4	6.5	0.5	7.0	0.5	0.1	0.6	0.7
	ECA	9.5	0.6	10.1	10.5	0.7	11.2	1.0	0.1	1.0	1.2
	LAC	7.4	0.3	7.7	7.6	0.3	7.9	0.2	0.0	0.2	0.7
	MENA	3.8	0.1	3.8	3.5	0.1	3.6	–0.2	0.0	–0.2	0.1
	SA	4.3	0.3	4.6	4.9	0.4	5.3	0.7	0.1	0.7	0.8
	SSA	3.3	0.2	3.5	3.5	0.3	3.8	0.2	0.0	0.2	0.3
	Non DC	36.4	0.7	37.1	37.4	0.7	38.1	1.1	0.0	1.0	1.5
	All DCs	**34.2**	**2.0**	**36.2**	**36.6**	**2.2**	**38.7**	**2.4**	**0.2**	**2.6**	**3.8**
2020–2025	EAP	5.3	0.4	5.7	5.7	0.4	6.2	0.5	0.0	0.5	0.6
	ECA	8.4	0.6	8.9	9.2	0.6	9.9	0.9	0.1	0.9	1.1
	LAC	6.6	0.2	6.8	6.8	0.3	7.0	0.2	0.0	0.2	0.6
	MENA	3.3	0.0	3.4	3.1	0.0	3.2	–0.2	0.0	–0.2	0.1
	SA	3.8	0.3	4.1	4.4	0.3	4.7	0.6	0.0	0.6	0.7
	SSA	2.9	0.2	3.1	3.1	0.2	3.3	0.2	0.0	0.2	0.3
	Non DC	32.1	0.6	32.8	33.1	0.6	33.7	0.9	0.0	0.9	1.3
	All DCs	**30.2**	**1.7**	**32.0**	**32.3**	**1.9**	**34.2**	**2.1**	**0.2**	**2.3**	**3.4**
2025–2030	EAP	4.6	0.3	5.0	5.1	0.4	5.4	0.4	0.0	0.5	0.5
	ECA	7.4	0.5	7.9	8.2	0.6	8.7	0.8	0.1	0.8	1.0
	LAC	5.8	0.2	6.0	6.0	0.2	6.2	0.2	0.0	0.2	0.6
	MENA	2.9	0.0	3.0	2.8	0.0	2.8	–0.2	0.0	–0.2	0.1
	SA	3.3	0.3	3.6	3.8	0.3	4.1	0.5	0.0	0.6	0.6
	SSA	2.6	0.2	2.7	2.7	0.2	2.9	0.2	0.0	0.2	0.2
	Non DC	28.4	0.5	28.9	29.2	0.5	29.7	0.8	0.0	0.8	1.2
	All DCs	**26.7**	**1.5**	**28.2**	**28.5**	**1.7**	**30.2**	**1.8**	**0.2**	**2.0**	**3.0**
2030–2035	EAP	4.1	0.3	4.4	4.5	0.3	4.8	0.4	0.0	0.4	0.5
	ECA	6.5	0.4	7.0	7.2	0.5	7.7	0.7	0.0	0.7	0.8
	LAC	5.1	0.2	5.3	5.3	0.2	5.5	0.1	0.0	0.1	0.5
	MENA	2.6	0.0	2.6	2.4	0.0	2.5	–0.1	0.0	–0.1	0.1
	SA	2.9	0.2	3.2	3.4	0.3	3.7	0.5	0.0	0.5	0.6
	SSA	2.3	0.2	2.4	2.4	0.2	2.6	0.1	0.0	0.2	0.2
	Non DC	25.0	0.5	25.5	25.8	0.5	26.2	0.7	0.0	0.7	1.0
	All DCs	**23.5**	**1.4**	**24.9**	**25.2**	**1.5**	**26.7**	**1.6**	**0.2**	**1.8**	**2.6**

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APPENDIX 14. *(continued)*

2035–2040	EAP	3.6	0.3	3.9	3.9	0.3	4.2	0.3	0.0	0.4	0.4
	ECA	5.8	0.4	6.1	6.3	0.4	6.8	0.6	0.0	0.6	0.7
	LAC	4.5	0.2	4.7	4.6	0.2	4.8	0.1	0.0	0.1	0.4
	MENA	2.3	0.0	2.3	2.2	0.0	2.2	–0.1	0.0	–0.1	0.0
	SA	2.6	0.2	2.8	3.0	0.2	3.2	0.4	0.0	0.4	0.5
	SSA	2.0	0.1	2.1	2.1	0.2	2.3	0.1	0.0	0.1	0.2
	Non DC	22.1	0.4	22.5	22.7	0.4	23.1	0.6	0.0	0.6	0.9
	All DCs	**20.8**	**1.2**	**22.0**	**22.2**	**1.3**	**23.5**	**1.4**	**0.1**	**1.6**	**2.3**
2040–2045	EAP	3.2	0.2	3.4	3.5	0.3	3.7	0.3	0.0	0.3	0.4
	ECA	5.1	0.3	5.4	5.6	0.4	6.0	0.5	0.0	0.6	0.7
	LAC	4.0	0.1	4.1	4.1	0.2	4.2	0.1	0.0	0.1	0.4
	MENA	2.0	0.0	2.0	1.9	0.0	1.9	–0.1	0.0	–0.1	0.0
	SA	2.3	0.2	2.5	2.6	0.2	2.8	0.4	0.0	0.4	0.4
	SSA	1.8	0.1	1.9	1.9	0.1	2.0	0.1	0.0	0.1	0.2
	Non DC	19.5	0.4	19.8	20.0	0.4	20.4	0.6	0.0	0.6	0.8
	All DCs	**18.3**	**1.1**	**19.4**	**19.6**	**1.2**	**20.7**	**1.3**	**0.1**	**1.4**	**2.1**
2045–2050	EAP	2.8	0.2	3.0	3.1	0.2	3.3	0.3	0.0	0.3	0.3
	ECA	4.5	0.3	4.8	4.9	0.3	5.3	0.5	0.0	0.5	0.6
	LAC	3.5	0.1	3.6	3.6	0.1	3.7	0.1	0.0	0.1	0.3
	MENA	1.8	0.0	1.8	1.7	0.0	1.7	–0.1	0.0	–0.1	0.0
	SA	2.0	0.2	2.2	2.3	0.2	2.5	0.3	0.0	0.3	0.4
	SSA	1.5	0.1	1.7	1.6	0.1	1.8	0.1	0.0	0.1	0.1
	Non DC	17.2	0.3	17.5	17.7	0.3	18.0	0.5	0.0	0.5	0.7
	All DCs	**16.1**	**0.9**	**17.1**	**17.2**	**1.0**	**18.3**	**1.1**	**0.1**	**1.2**	**1.8**

APPENDIX 15. RIVERINE FLOOD PROTECTION RESULTS. GCM: NCAR. DISCOUNT RATE: 5%

Annual costs (averaged over 5-year periods) in USD billion

		Baseline			*Baseline & CC*			*CC (net)*			*CC (gross)*
		Urban	*Agric.*	*Total*	*Urban*	*Agric*	*Total*	*Urban*	*Agric*	*Total*	*Total*
2010–2015	EAP	6.4	0.5	6.8	6.9	0.5	7.5	0.6	0.1	0.6	0.7
	ECA	10.1	0.7	10.8	11.2	0.8	11.9	1.0	0.1	1.1	1.3
	LAC	8.0	0.3	8.2	8.2	0.3	8.5	0.2	0.0	0.2	0.8
	MENA	4.0	0.1	4.1	3.8	0.1	3.8	–0.2	0.0	–0.2	0.1
	SA	4.6	0.3	4.9	5.3	0.4	5.7	0.7	0.1	0.8	0.9
	SSA	3.5	0.3	3.8	3.7	0.3	4.0	0.2	0.0	0.3	0.3
	Non DC	38.9	0.7	39.6	40.0	0.7	40.8	1.1	0.0	1.1	1.6
	All DCs	**36.6**	**2.1**	**38.7**	**39.1**	**2.3**	**41.4**	**2.5**	**0.2**	**2.8**	**4.1**
2015–2020	EAP	5.1	0.4	5.5	5.6	0.4	6.0	0.5	0.0	0.5	0.6
	ECA	8.1	0.5	8.7	9.0	0.6	9.6	0.8	0.1	0.9	1.1
	LAC	6.4	0.2	6.6	6.6	0.2	6.8	0.2	0.0	0.2	0.6
	MENA	3.2	0.0	3.3	3.0	0.0	3.1	–0.2	0.0	–0.2	0.1
	SA	3.7	0.3	3.9	4.2	0.3	4.6	0.6	0.0	0.6	0.7
	SSA	2.8	0.2	3.0	3.0	0.2	3.2	0.2	0.0	0.2	0.3
	Non DC	31.2	0.6	31.8	32.1	0.6	32.7	0.9	0.0	0.9	1.3
	All DCs	**29.4**	**1.7**	**31.1**	**31.4**	**1.9**	**33.3**	**2.0**	**0.2**	**2.2**	**3.3**
2020–2025	EAP	4.1	0.3	4.4	4.5	0.3	4.8	0.4	0.0	0.4	0.5
	ECA	6.5	0.4	7.0	7.2	0.5	7.7	0.7	0.0	0.7	0.8
	LAC	5.1	0.2	5.3	5.3	0.2	5.5	0.1	0.0	0.1	0.5
	MENA	2.6	0.0	2.6	2.4	0.0	2.5	–0.1	0.0	–0.1	0.1
	SA	2.9	0.2	3.2	3.4	0.3	3.7	0.5	0.0	0.5	0.6
	SSA	2.3	0.2	2.4	2.4	0.2	2.6	0.1	0.0	0.2	0.2
	Non DC	25.1	0.5	25.5	25.8	0.5	26.3	0.7	0.0	0.7	1.0
	All DCs	**23.6**	**1.4**	**24.9**	**25.2**	**1.5**	**26.7**	**1.6**	**0.2**	**1.8**	**2.6**
2025–2030	EAP	3.3	0.2	3.5	3.6	0.3	3.9	0.3	0.0	0.3	0.4
	ECA	5.2	0.4	5.6	5.8	0.4	6.2	0.5	0.0	0.6	0.7
	LAC	4.1	0.1	4.3	4.2	0.2	4.4	0.1	0.0	0.1	0.4
	MENA	2.1	0.0	2.1	2.0	0.0	2.0	–0.1	0.0	–0.1	0.0
	SA	2.4	0.2	2.5	2.7	0.2	2.9	0.4	0.0	0.4	0.4
	SSA	1.8	0.1	1.9	1.9	0.1	2.1	0.1	0.0	0.1	0.2
	Non DC	20.1	0.4	20.5	20.7	0.4	21.1	0.6	0.0	0.6	0.8
	All DCs	**18.9**	**1.1**	**20.0**	**20.2**	**1.2**	**21.4**	**1.3**	**0.1**	**1.4**	**2.1**
2030–2035	EAP	2.6	0.2	2.8	2.9	0.2	3.1	0.2	0.0	0.3	0.3
	ECA	4.2	0.3	4.5	4.6	0.3	4.9	0.4	0.0	0.5	0.5
	LAC	3.3	0.1	3.4	3.4	0.1	3.5	0.1	0.0	0.1	0.3
	MENA	1.7	0.0	1.7	1.6	0.0	1.6	–0.1	0.0	–0.1	0.0
	SA	1.9	0.1	2.0	2.2	0.2	2.4	0.3	0.0	0.3	0.4
	SSA	1.5	0.1	1.6	1.5	0.1	1.7	0.1	0.0	0.1	0.1
	Non DC	16.1	0.3	16.4	16.6	0.3	16.9	0.5	0.0	0.5	0.7
	All DCs	**15.1**	**0.9**	**16.0**	**16.2**	**1.0**	**17.2**	**1.0**	**0.1**	**1.1**	**1.7**

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APPENDIX 15. *(continued)*

2035–2040	EAP	2.1	0.2	2.3	2.3	0.2	2.5	0.2	0.0	0.2	0.2
	ECA	3.4	0.2	3.6	3.7	0.3	4.0	0.3	0.0	0.4	0.4
	LAC	2.6	0.1	2.7	2.7	0.1	2.8	0.1	0.0	0.1	0.3
	MENA	1.3	0.0	1.4	1.3	0.0	1.3	–0.1	0.0	–0.1	0.0
	SA	1.5	0.1	1.6	1.8	0.1	1.9	0.2	0.0	0.3	0.3
	SSA	1.2	0.1	1.2	1.2	0.1	1.3	0.1	0.0	0.1	0.1
	Non DC	12.9	0.2	13.2	13.3	0.2	13.5	0.4	0.0	0.4	0.5
	All DCs	**12.1**	**0.7**	**12.8**	**13.0**	**0.8**	**13.7**	**0.8**	**0.1**	**0.9**	**1.4**
2040–2045	EAP	1.7	0.1	1.8	1.8	0.1	2.0	0.2	0.0	0.2	0.2
	ECA	2.7	0.2	2.9	3.0	0.2	3.2	0.3	0.0	0.3	0.4
	LAC	2.1	0.1	2.2	2.2	0.1	2.3	0.1	0.0	0.1	0.2
	MENA	1.1	0.0	1.1	1.0	0.0	1.0	–0.1	0.0	–0.1	0.0
	SA	1.2	0.1	1.3	1.4	0.1	1.5	0.2	0.0	0.2	0.2
	SSA	0.9	0.1	1.0	1.0	0.1	1.1	0.1	0.0	0.1	0.1
	Non DC	10.3	0.2	10.5	10.6	0.2	10.8	0.3	0.0	0.3	0.4
	All DCs	**9.7**	**0.6**	**10.3**	**10.4**	**0.6**	**11.0**	**0.7**	**0.1**	**0.7**	**1.1**
2045–2050	EAP	1.4	0.1	1.5	1.5	0.1	1.6	0.1	0.0	0.1	0.2
	ECA	2.2	0.1	2.3	2.4	0.2	2.5	0.2	0.0	0.2	0.3
	LAC	1.7	0.1	1.8	1.7	0.1	1.8	0.0	0.0	0.0	0.2
	MENA	0.9	0.0	0.9	0.8	0.0	0.8	0.0	0.0	0.0	0.0
	SA	1.0	0.1	1.0	1.1	0.1	1.2	0.1	0.0	0.2	0.2
	SSA	0.7	0.1	0.8	0.8	0.1	0.9	0.0	0.0	0.1	0.1
	Non DC	8.3	0.2	8.4	8.5	0.2	8.7	0.2	0.0	0.2	0.3
	All DCs	**7.8**	**0.4**	**8.2**	**8.3**	**0.5**	**8.8**	**0.5**	**0.1**	**0.6**	**0.9**

APPENDIX 16. RIVERINE FLOOD PROTECTION RESULTS. GCM: NCAR. DISCOUNT RATE: 7%

Annual costs (averaged over 5-year periods) in USD billion

		Baseline			*Baseline & CC*			*CC (net)*			*CC (gross)*
		Urban	*Agric.*	*Total*	*Urban*	*Agric*	*Total*	*Urban*	*Agric*	*Total*	*Total*
2010–2015	EAP	6.0	0.4	6.5	6.6	0.5	7.1	0.5	0.1	0.6	0.7
	ECA	9.6	0.6	10.3	10.6	0.7	11.3	1.0	0.1	1.0	1.2
	LAC	7.5	0.3	7.8	7.7	0.3	8.0	0.2	0.0	0.2	0.7
	MENA	3.8	0.1	3.9	3.6	0.1	3.6	–0.2	0.0	–0.2	0.1
	SA	4.3	0.3	4.7	5.0	0.4	5.4	0.7	0.1	0.7	0.8
	SSA	3.3	0.2	3.6	3.5	0.3	3.8	0.2	0.0	0.2	0.3
	Non DC	36.8	0.7	37.5	37.9	0.7	38.6	1.1	0.0	1.1	1.5
	All DCs	**34.6**	**2.0**	**36.6**	**37.0**	**2.2**	**39.2**	**2.4**	**0.2**	**2.6**	**3.9**
2015–2020	EAP	4.4	0.3	4.7	4.8	0.4	5.2	0.4	0.0	0.4	0.5
	ECA	7.0	0.5	7.5	7.7	0.5	8.3	0.7	0.0	0.8	0.9
	LAC	5.5	0.2	5.7	5.7	0.2	5.9	0.1	0.0	0.2	0.5
	MENA	2.8	0.0	2.8	2.6	0.0	2.7	–0.2	0.0	–0.2	0.1
	SA	3.2	0.2	3.4	3.6	0.3	3.9	0.5	0.0	0.5	0.6
	SSA	2.4	0.2	2.6	2.6	0.2	2.8	0.2	0.0	0.2	0.2
	Non DC	26.9	0.5	27.4	27.7	0.5	28.2	0.8	0.0	0.8	1.1
	All DCs	**25.3**	**1.5**	**26.8**	**27.0**	**1.6**	**28.7**	**1.7**	**0.2**	**1.9**	**2.8**
2020–2025	EAP	3.2	0.2	3.5	3.5	0.3	3.8	0.3	0.0	0.3	0.4
	ECA	5.1	0.3	5.5	5.6	0.4	6.0	0.5	0.0	0.6	0.7
	LAC	4.0	0.1	4.2	4.1	0.2	4.3	0.1	0.0	0.1	0.4
	MENA	2.0	0.0	2.1	1.9	0.0	1.9	–0.1	0.0	–0.1	0.0
	SA	2.3	0.2	2.5	2.7	0.2	2.9	0.4	0.0	0.4	0.4
	SSA	1.8	0.1	1.9	1.9	0.1	2.0	0.1	0.0	0.1	0.2
	Non DC	19.7	0.4	20.0	20.2	0.4	20.6	0.6	0.0	0.6	0.8
	All DCs	**18.5**	**1.1**	**19.5**	**19.7**	**1.2**	**20.9**	**1.3**	**0.1**	**1.4**	**2.1**
2025–2030	EAP	2.3	0.2	2.5	2.6	0.2	2.8	0.2	0.0	0.2	0.3
	ECA	3.7	0.3	4.0	4.1	0.3	4.4	0.4	0.0	0.4	0.5
	LAC	2.9	0.1	3.0	3.0	0.1	3.1	0.1	0.0	0.1	0.3
	MENA	1.5	0.0	1.5	1.4	0.0	1.4	–0.1	0.0	–0.1	0.0
	SA	1.7	0.1	1.8	1.9	0.1	2.1	0.3	0.0	0.3	0.3
	SSA	1.3	0.1	1.4	1.4	0.1	1.5	0.1	0.0	0.1	0.1
	Non DC	14.3	0.3	14.6	14.8	0.3	15.0	0.4	0.0	0.4	0.6
	All DCs	**13.5**	**0.8**	**14.3**	**14.4**	**0.9**	**15.3**	**0.9**	**0.1**	**1.0**	**1.5**
2030–2035	EAP	1.7	0.1	1.8	1.9	0.1	2.0	0.2	0.0	0.2	0.2
	ECA	2.7	0.2	2.9	3.0	0.2	3.2	0.3	0.0	0.3	0.4
	LAC	2.1	0.1	2.2	2.2	0.1	2.3	0.1	0.0	0.1	0.2
	MENA	1.1	0.0	1.1	1.0	0.0	1.0	–0.1	0.0	–0.1	0.0
	SA	1.2	0.1	1.3	1.4	0.1	1.5	0.2	0.0	0.2	0.2
	SSA	0.9	0.1	1.0	1.0	0.1	1.1	0.1	0.0	0.1	0.1
	Non DC	10.5	0.2	10.7	10.8	0.2	11.0	0.3	0.0	0.3	0.4
	All DCs	**9.8**	**0.6**	**10.4**	**10.5**	**0.6**	**11.1**	**0.7**	**0.1**	**0.7**	**1.1**

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APPENDIX 16. *(continued)*

2035–2040	EAP	1.2	0.1	1.3	1.4	0.1	1.5	0.1	0.0	0.1	0.1
	ECA	2.0	0.1	2.1	2.2	0.1	2.3	0.2	0.0	0.2	0.3
	LAC	1.6	0.1	1.6	1.6	0.1	1.7	0.0	0.0	0.0	0.1
	MENA	0.8	0.0	0.8	0.7	0.0	0.8	0.0	0.0	0.0	0.0
	SA	0.9	0.1	1.0	1.0	0.1	1.1	0.1	0.0	0.1	0.2
	SSA	0.7	0.1	0.7	0.7	0.1	0.8	0.0	0.0	0.1	0.1
	Non DC	7.6	0.1	7.8	7.8	0.1	8.0	0.2	0.0	0.2	0.3
	All DCs	**7.2**	**0.4**	**7.6**	**7.7**	**0.5**	**8.1**	**0.5**	**0.0**	**0.5**	**0.8**
2040–2045	EAP	0.9	0.1	1.0	1.0	0.1	1.1	0.1	0.0	0.1	0.1
	ECA	1.4	0.1	1.5	1.6	0.1	1.7	0.1	0.0	0.2	0.2
	LAC	1.1	0.0	1.2	1.2	0.0	1.2	0.0	0.0	0.0	0.1
	MENA	0.6	0.0	0.6	0.5	0.0	0.5	0.0	0.0	0.0	0.0
	SA	0.7	0.0	0.7	0.8	0.1	0.8	0.1	0.0	0.1	0.1
	SSA	0.5	0.0	0.5	0.5	0.0	0.6	0.0	0.0	0.0	0.0
	Non DC	5.6	0.1	5.7	5.7	0.1	5.8	0.2	0.0	0.2	0.2
	All DCs	**5.2**	**0.3**	**5.5**	**5.6**	**0.3**	**5.9**	**0.4**	**0.0**	**0.4**	**0.6**
2045–2050	EAP	0.7	0.0	0.7	0.7	0.1	0.8	0.1	0.0	0.1	0.1
	ECA	1.1	0.1	1.1	1.2	0.1	1.2	0.1	0.0	0.1	0.1
	LAC	0.8	0.0	0.9	0.9	0.0	0.9	0.0	0.0	0.0	0.1
	MENA	0.4	0.0	0.4	0.4	0.0	0.4	0.0	0.0	0.0	0.0
	SA	0.5	0.0	0.5	0.5	0.0	0.6	0.1	0.0	0.1	0.1
	SSA	0.4	0.0	0.4	0.4	0.0	0.4	0.0	0.0	0.0	0.0
	Non DC	4.0	0.1	4.1	4.2	0.1	4.2	0.1	0.0	0.1	0.2
	All DCs	**3.8**	**0.2**	**4.0**	**4.1**	**0.2**	**4.3**	**0.3**	**0.0**	**0.3**	**0.4**

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