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Water Working Notes

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CLIMATE CHANGE AND URBAN WATER UTILITIES: CHALLENGES & OPPORTUNITIES

Alexander Danilenko
Eric Dickson
Michael Jacobsen

wsp water and sanitation program

WATER PARTNERSHIP PROGRAM

BNWP

MINISTERIO DE ECONOMÍA Y HACIENDA

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TABLE OF CONTENTS

Boxes

Figures

Tables

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Approving Manager: Julia Bucknall, ETWWA

CONTACT INFORMATION

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ABBREVIATIONS AND ACRONYMS

AWWA	American Water Works Association
CAN	Central Areas of Namibia
CSIRO	Commonwealth Scientific and Industrial Research Organisation
DAF	Dissolved Air Flotation
DMA	Dhaka Metropolitan Area
DRWH	Domestic Roofwater Harvesting
DSPM	Decision Support Planning Methods
DWASA	Dhaka Water Supply and Sewage Authority
EIB	European Investment Bank
EMASESA	Empresa Metropolitana de Abastecimiento y Saneamiento de Aguas de Sevilla
GCM	Global Circulation Models
GWRP	Goreangab Water Reclamation Plant
HA	Hectares
IDF	Intensity-Duration-Frequency
IPART	Independent Pricing and Regulatory Tribunal
IPCC	Intergovernmental Panel on Climate Change
ISKI	Istanbul Water and Sewerage Administration
IUWM	Integrated Urban Water Management
KFW	German Development Bank
LPCD	Liters Per Capita Per Day
ML	Megalitres
MLD	Million Liters Per Day
NCCS	National Climate Change Strategy
NRW	Non-Revenue Water
NWC	Nairobi Water Company
NYC	New York City
NYCDEP	New York City Department of Environmental Protection
ONEA	Office National de l'Eau et de l'Assainissement
PUB	Public Utilities Board
SEDAPAL	Servicio de Agua Potable y Alcantarillado de Lima
SPU	Seattle Public Utilities
STP	Sewage Treatment Plant
TDS	Total Dissolved Solids
UARL	Unavoidable Annual Real Loss
USD	United States Dollar
UWSS	Urban Water Supply and Sanitation
WCT	Water Conservation Tax
WRMA	Water Resources Management Authority
WSAA	Water Supply Association of Australia
WUCA	Water Utility Climate Alliance

EXECUTIVE SUMMARY

The impact of climate change is increasingly important to the design of infrastructure investment programs. Growing evidence indicates that the water sector will not only be affected by climate change, but that it will deliver many of its impacts through floods, droughts, or extreme rainfall events. Water resources will change in both quantity and quality, and water, storm water and wastewater facilities' infrastructure will face greater risk of damage caused by storms, floods and droughts. The effect of the climate change will manifest from difficulties in operations to disrupted services and increased cost of the water and wastewater services. Governments, urban planners, and water managers are therefore re-examining development processes for municipal water and wastewater services and are adapting strategies to incorporate climate change into infrastructure design, capital investment projects, service provision planning, and operation and maintenance.

Variability and uncertainty challenge water utilities in their daily operations and long term planning. Yet many utilities are only now beginning to assess the impact that climate change will have on their water sources and what the technical, financial, operational and institutional implications will be. The challenge is compounded by the fact that there are pressing needs, such as expanding coverage and high levels of non-revenue water, that compete with developing appropriate climate change adaptation strategies, especially in low and middle-income countries. Indeed weak and financially challenged water utilities are still struggling with old and persistent problems of water management, coverage and efficiency issues in the delivery of services.

An important difference between financially viable utilities and those that are struggling is well performing utilities are now beginning to identify strategic options to address climate change concerns based on monitoring, analysis and the use of climate models. Leading utilities from a number of nations are adopting a mixture of scientific approaches in conjunction with institutional reforms to assist in defining responses to climate associated risks. Assisting such processes are entities such as the Water Utility Climate Alliance (WUCA) of the United States and the Water Supply Association of Australia (WSAA), which are respectively funding research that identifies approaches to develop decision support systems for utilities.

Adaptation actions taken by utilities are often of an ad hoc nature, despite the risk of climate change. While certain actions being taken by urban water utilities may help to reduce their exposure to climate change, there is an evident need to address climate vulnerability more systematically. Some of the measures currently being implemented primarily address short-term concerns. For many utilities longer term actions may often appear to be unaffordable or unfeasible given perceived complexity, a lack of scientific information relevant to the urban environment, or a lack of coordination with other authorities related to issues such as watershed protection, resource protection and flooding.

Approaches implemented by utilities that are already addressing climate change can assist others formulate their own strategic options. Climate change intensifies existing challenges currently faced by utilities, and increases economic pressure to improve existing operational procedures. This will require that utilities begin to consider the wider implications of climate change on water resources and its influence on service delivery. Traditional approaches to urban water operations and investment planning have in many cases not yet taken the interdependent nature of water resources and urban delivery systems into account. Climate change requires addressing this interdependency so that utilities give greater attention to water resources and source protection, in addition to improving operational performance of existing infrastructure. Utilities are likely to benefit from broadening their traditional perspective of operations, and incorporate principles of integrated urban water management (IUWM).

By adopting IUWM utilities are able to consider the interaction between water resources, infrastructure, operations and planning. This comprehensive perspective on operations places a utility in an improved position to consider how factors outside of their traditional operations such as spatial development, pollution control, and solid waste and storm water management undertake may influence service delivery. It also serves as a strategic entry point for preparing climate vulnerability assessments of a utility's systems.

Such assessments allow for estimating the scope and intensity of potential impacts on performance as a result of climate change. On the basis of vulnerability assessments, utilities are better able to analyze the extent to which system components are exposed to climate change against their operation and value, and identify adaptation measures that reduce potential exposure and improve resilience. Undertaking this form of analysis can be used as an important input to an analytical framework that supports prioritizing and quantifying costs associated with each identified adaptation option that considers technical complexity, associated cost, institutional complexity, and operational implementation.

Each adaptation option should be screened for a financial viability using the utility's established evaluation processes for investment planning. 'No-regret' investments are worth doing anyway, no matter what the eventual climate change stress may be on a particular system. Such actions consider climate change but do not make it the primary factor in decision making. 'Climate justified' investments are beneficial only if climate change impacts actually do occur and the overall benefits of taking a specific action exceed the marginal cost following a cost-benefit analysis. Undertaking such analyses can serve as a major input into the formulation of climate action plans for short and medium terms.

Climate action plans can be complemented through targeted communication with consumers and improved coordination among municipal authorities regarding the potential impact of climate change on water resources and services. This may include regular publications of brochures and booklets, announcing precipitation and river levels, or storage volume of reservoirs. In the short to medium term, cities with similar climatic risks may benefit from intensified knowledge exchange of institutional and managerial experience on addressing climate change, recording and disseminating impacts, and analyzing the cost efficiency and operational effectiveness of adopted adaptation measures.

The World Bank, as a multilateral institution with convening power, stands to play a role. The implications of climate change may strongly affect the development impact of World Bank projects in the urban water supply and sanitation sector and similarly reduce a nation's capacity to recuperate economic and financial losses incurred from related impacts. In the short term the Bank is well positioned to facilitate knowledge exchange and disseminate emerging best practices with the objective of strengthening urban water utilities' capacity to undertake climate vulnerability assessments, improve monitoring of technical and financial performance, and the preparation of climate action plans. As the body of knowledge grows in its client countries, the Bank is well positioned to support utilities addressing climate change through North-South and South-South partnerships.

This report is part of a larger World Bank effort that seeks to provide analytical and strategic assistance to Bank staff and utilities in client countries as they begin to consider the implications of climate change on water resources. The key objectives of this document are to:

- Improve understanding and awareness of the operational implications of climate change on the provision of water and wastewater services by urban utilities;
- Present adaptation actions conducted at the utility level for inspiration;
- Establish an analytical framework to assist Bank staff and client countries' utility managers to identify and prioritize potential climate change adaptation measures;
- Assess the feasibility of implementing adaptation measures based on a set of criteria

This report is structured as follows: Chapter 1 provides an overview of the role that climate change will have on urban water utilities and highlights the often competing priorities that water managers are faced with in developing countries; Chapter 2 describes the relationship between climate change and water resources as they influence water service provision; Chapter 3 presents a framework for analysis of vulnerability and adaptive capacity of water providers; Chapters 4 presents a framework for adaptation actions. Annexes contain detailed graphs and statistics taken from the international workshop held in Madrid, Spain in January of 2009 and utility specific case studies which are highlighted throughout the report.

1. CLIMATE CHANGE AND WATER RESOURCES

Climate change will affect the water resource base for many water utilities. Higher temperatures and reduced precipitation levels will cause shortages in available supply due to slower replenishment rates of underground water resources and/or reduced availability of surface water. Rising seawater levels and inland flooding will cause land inundation and blockages in natural drainage structures. These effects will be even more difficult to manage for those water utilities that are unprepared and/or financially weak.

General agreement among various climate change models suggests that surface water runoff will decrease by 10 percent to 30 percent in the Mediterranean, southern Africa, the western USA, and northern Mexico. The impact of climate change will lead to variations in the seasonality of river flows especially where winter precipitation comes as snow; rapid melting of glaciers and snow will lead to an *increase* in winter flow and thus a *decrease* in summer flow. The European Alps, Himalayas, North America, Andes in Latin America, Russia, Scandinavia and Baltic regions will face this phenomenon [IPCC, 2007]. Due to melting glaciers in the Himalaya-Hindu-Kush region nearly one billion people in India, Bangladesh, Pakistan and China will be affected. Glaciers in the Andes have shrunk by 20 percent since 1970, which creates serious implications for water resources *and* hydro-power generation in countries like Colombia, Ecuador, Peru, Bolivia, Chile and Argentina [Vergara, 2007].

Wetlands in major river basins will suffer from large scale sedimentation, land-use conversion, logging and human intervention. Coastal and estuarine wetland habitats may be destroyed if sea-level rise exceeds the rate of vertical sediment accretion and inland migration is not possible. Organic wetlands are highly vulnerable to even small changes in ground water level. Drying, decrease in wetland size, and conversion to uplands can be expected for most freshwater wetlands where precipitation decreases or remains steady while temperatures are increased because these wetlands are very sensitive to subtle changes in precipitation and groundwater level. [IPCC, 2007].

Lakes and Man-Made Reservoirs. A number of locations have become considerably drier in the last decades. This has impacted cities as diverse as Examples and Seville, Spain, Windhoek, Namibia and Melbourne, Australia (see details in Annex 2) as well as Ankara, Turkey, Mumbai, India and a large number of other cities. Climate change is threatening unique biota, as well their sustainability as the sources of water for municipalities. In India, for example, where most lakes those supply water to Indian cities are heavily dependent on monsoon rainfall this has been shown large fluctuations in recent years, even by historical standards. On 7 July 2009, it was reported that authorities in Mumbai had been forced to reduce water supplies by 30% as the city experienced one of the worst water shortages in its history. The cuts affect supplies to hundreds of thousands of households as well as hospitals and hotels. The city corporation urged citizens to save water and use it sparingly as reserves from three lakes are estimated to only contain approximately two and a half months of supply.

Ecosystems in arid and semi-arid regions. The disruption of local hydrological patterns places ecosystems in arid and semi-arid regions at risk. Consequently, subsistence agriculture and rural livelihoods are highly vulnerable. Coastal areas and deltas are vulnerable to an increase in sea levels, flooding, storm surges, and stronger winds, displacing the population in those areas. Of the world's 27 megacities, which have populations of 10 million and greater), 18 are thought to be vulnerable to these effects [UN-Water, 2009].

Increased precipitation. More frequent and intense rain events will contribute to flash floods, accumulation of rainwater in poorly-drained environments, decreased storage due to siltation, and coastal floods caused by extreme tidal and wave events. Over the next 100 years, flooding is likely to become more common or more intense in many areas, especially in low-lying coastal sites or in zones that currently experience high rainfall. Flood risk dynamics have various social, environmental and technical drivers and have multiple impacts in terms of services disruption, health and damage to infrastructure. For example, on 26 July 2005, Mumbai received 94 cm of rain in a single day, breaking a 100 year record. The rainfall caused an unprecedented flood which affected 20 million people, caused some 1,000 deaths and a financial loss of an estimated USD 1 billion. One of the principal reasons for the disaster was that the rainfall was accompanied by high tides and waves, which blocked storm water drainage systems [ActionAid 2005]. A detailed case of increased precipitation in Seattle is presented in Annex 2.

Groundwater. In arid and semi-arid regions, with poor access to surface water, groundwater plays a major role in meeting domestic as well as irrigation demands. It is also essential for providing informal and private access to populations not served by municipal water utilities. It is estimated by the United Nations suggests that 2 billion people depend on groundwater. Since the 1970s groundwater use has helped in achieving food sufficiency and drinking water security in many Asian and Middle Eastern countries. But a lack of proper planning, ineffective legislation and poor governance has jeopardized many groundwater aquifers [CA, 2007]. Climate change is expected to reduce surface water supplies and result in a greater reliance on groundwater particularly in semi-arid and arid regions. At the same time, replenishment of groundwater may be hindered due to hydro-climatic changes and demographic, socio-economic and institutional factors that will bring in more challenges for sustainable groundwater management.

Reduced precipitation and continued abstraction will affect replenishment rates of groundwater resulting in declining water tables if the net recharge rate is exceeded. Table 1 below presents a list of countries with the lowest groundwater replenishment rates. Often over-exploitation of groundwater magnifies inherent salts such as total dissolved solids (TDS), fluorides and chlorides. The problem of groundwater over-exploitation is self-limiting owing to higher pumping cost, deteriorating quality and treatment cost, and subsequent reduction of the resource.

The use of 'fossil water' is also prevalent in countries including China, Egypt, Libya, Jordan, Saudi Arabia, Turkmenistan, Mexico and the United States. Fossil water, also known as paleowater, refers to underground water reservoirs that have been geologically sealed and cannot be replenished due to their origin. In the United States eight states in the mid-West extract sizeable quantities of fossil water from the Ogallala Aquifer (see Figure 1.1). This aquifer supplies 82% of the drinking water for these states and approximately 30% of the water for crop irrigation. It is estimated that this aquifer will be empty in 25 years.

Similarly, in Rawalpindi, Pakistan considerable groundwater depletion has been observed which is primarily due to diminishing recharge rates. Intense rainfall and quick runoff are causal factors coupled with increased extraction that have resulted in groundwater tables depleting by approximately 2–3 meters per year (see the Figure 1.2).

The discussion above demonstrates how climate change affects the water sources that are critical for supplying urban water service providers and highlights the challenges that utilities must respond to. Given that the effects of climate change will be felt over the long-term, utilities should consider phased and coordinated adaptation measures appropriate to their own technical, financial and institu-

Box 1.1: Groundwater Pollution in Hanoi, Vietnam

Groundwater is the main source of supply for the city of Hanoi. Presently, approximately 500,000 m^3 of groundwater is being withdrawn daily and that amount could reach 1 million m^3 per day by 2010 if extraction rates continue unchecked. The pumping of large volumes of groundwater negatively impacts the water table, enlarges the cone of depression, and contributes to land subsidence. The quality of groundwater supplies is also affected by the city's poor sewerage and drainage systems.

With less than half the population of the city connected to formal sewerage system, rivers and lakes in the Hanoi area are severely polluted by domestic and industrial wastewater which infiltrate the city's aquifers. The pollutants include nitrogen compounds, biological and organic matter and toxic elements such as arsenic and mercury. Wastewater management, as in many other cities around the globe, remains one of the most significant challenges for Hanoi in the face of the city's rapid demographic and economic growth.

Source: Van Dan and Thi Dzung 2003

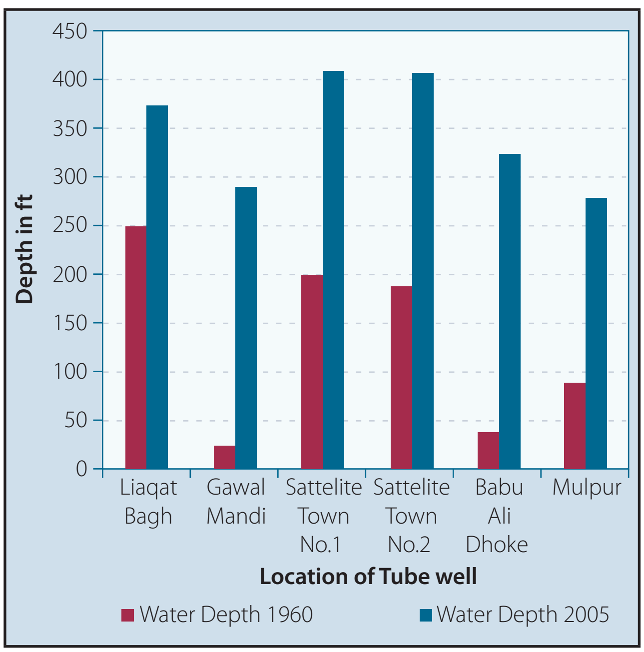
tional capacity. The following chapter presents an analytical framework that seeks to provide guidance to utilities on assessing their own climate vulnerabilities and suggests adaptation actions through an integrated urban water management lens.

Table 1.1: Low Natural Renewable Water Resources in the Middle East & North Africa

	Resource M³/ capita/year	Withdrawal M³/ capita/year
Kuwait	9.9	306.0
UAE	55.5	896.0
Libya	108.5	870.0
Saudi Arabia	110.6	1056.0
Jordan	169.4	255.0
Yemen	205.9	253.0
Israel	265.0	287.0
Oman	363.6	658.0
Algeria	460.0	181.0
Tunisia	576.5	312.0

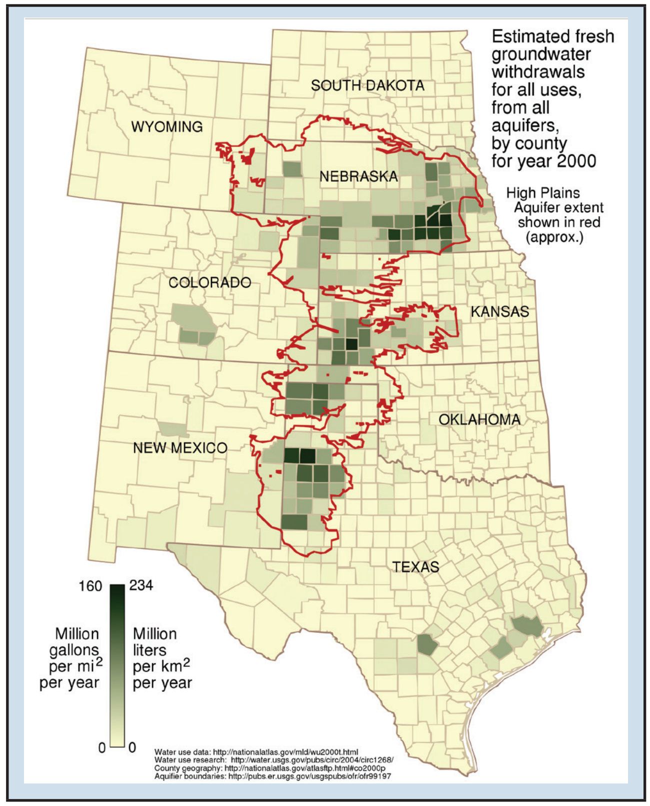
Source: GWI, Desalination Markets: A Global Industry Forecast, 2007

Figure 1.2: Groundwater Depletion: Rawalpindi, Pakistan



Source: Water and Sanitation Agency Rawalpindi

Figure 1.1: Estimated Groundwater Withdrawal of Ogallala Aquifer



Source: National Atlas of the United States, 2005

Box 1.2: Groundwater overexploitation in Jakarta, Indonesia

Overexploitation of Jakarta's groundwater is resulting in land subsidence that often causes increased bursting of water pipes. This also contributes to increased flood risk, with the most affected being areas inhabited by low-income households. In addition to increasing salt water intrusion, the infiltration of chemical and microbiological pollutants has resulted in 65% of the city's groundwater being unsuitable for human use according to the Indonesian Ministry of Environment. The Jakarta Mining Department has committed to controlling further exploitation of groundwater in order to abate continued land subsidence.

Source: Asian Development Bank, 2007

2. CLIMATE CHANGE AND WATER UTILITIES

Even without climate change, urban water utilities are faced with challenges to ensuring sustainable service delivery in many cities. In addition accurate forecasting of supply and demand levels, some of the more fundamental challenges on water utilities include growing urban populations, aging infrastructure, and increasing competition for water resources.

2.1 Fundamental Challenges on Water Utilities

Urbanization Pressure. A demographic shift is taking place at a remarkable pace across the developing world that will likely see another two billion residents added to urban areas in the next twenty years, with the urban populations of South Asia and Africa doubling during that time. As a city's population grows there is a need to expand the capacity of existing water sources to meet the increasing demand. In many cases cities have to access supplemental sources of supply (ground water, desalination, conveyance from distant areas) in order to sustain residential, industrial and agricultural consumption levels.

Increased urban water demand generates pressure on existing infrastructure and demands substantial investments for expansion. The problem is even more severe in developing countries where limited financial resources, often stemming from low efficiency and subsidized tariffs, reduce the ability of water utilities to address priorities to improve service delivery. An example of this is Rawalpindi, Pakistan where at present 70 percent of the current population is served either through the piped network or tanker delivery. However only 35 percent of the service area is covered by a sewerage system and none of the collected sewage is treated. The city is witnessing a population growth of 4.29 percent per annum. Connecting 100 percent of the population with water supply and sewage would need significant investments, which is currently beyond the financial capacity of the water utility as well as additional technical expertise [Pintz and Johnson, 2006]. A similar case of Dhaka, Bangladesh is presented in Box 2.1.

Outdated Infrastructure. Water utilities' networks and infrastructure require proper maintenance and rehabilitation. If these measures are not effectively and routinely implemented, the operational life of water infrastructure and networks may be exceeded and result in disproportionate and perpetually increasing maintenance costs. Given that utilities often lack the financial capacity to invest in substantial infrastructure replacement programs, the result is that utilities continue to operate fully depreciated assets for 20–50 years after the point when replacement should have

Box 2.1: Extreme Vulnerability of Dhaka, Bangladesh

The Dhaka Metropolitan Area (DMA) is one of the fastest growing megacities in the world with a total population estimated at over 12 million. Of this, about 8.6 million people live in the formal city and about 4 million in slums. The elevation in Dhaka ranges between 2 and 13 meters above sea level implying that even a slight rise in sea level would likely engulf large parts of the city. High urban growth rates and urban population densities make Dhaka susceptible to human-induced and environmental disasters.

Inland flooding due to extreme rainfall events and coastal flooding caused by sea level rise are expected to be more frequent as a result of climate change. The problems associated with recurrent flooding are compounded by poor quality housing and overcrowding as nearly 60 percent of the city's slums have poor or no drainage. Water supplies also become contaminated during floods, as pipes in slum areas are likely to be damaged or to leak. The situation worsens when floodwater in slums mixes with raw sewage and breeds water-borne diseases.

Source: UN-Habitat, 2008

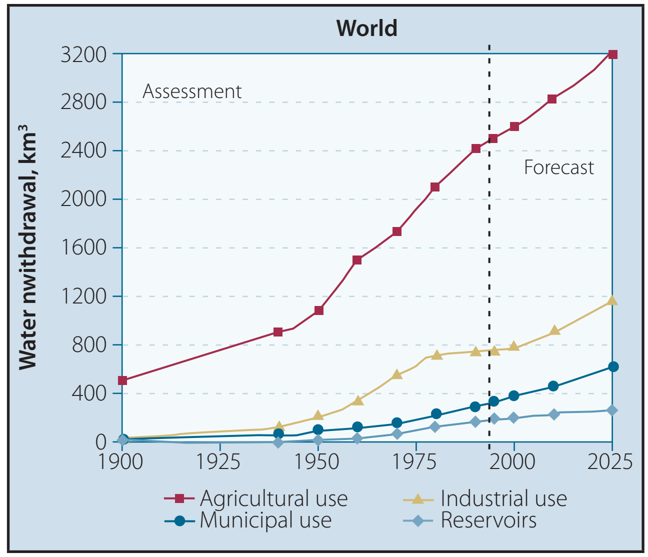
occurred (multiple cases of Russia, Ukraine and countries of the former USSR). An additional complication arises from growing rates of urbanization and a lack of coordination and planning across government bodies that leads to new construction reliant on already outdated networks that cannot and should not support expansion of demand for water and wastewater services (see Box 4.1).

The Nairobi Water Company faces challenges with the city's system that was originally built in 1913 with a system capacity of 13.5 million m^3 per year intended to supply about 200,000 people. With the city's growth to its current population, estimated at 4 million people, the system's current capacity of 88.9 million m^3 per year is proving to be overstretched. In addition, nearly ten years of stagnant tariffs between 1999 and 2009 have prevented the utility from allocating needed financial resources to emerging priorities. The recent (2009) food crisis Kenya is experiencing and the global financial crises is placing additional financing constraints on the Government and limiting its capacity to support the water company.

Nairobi Water finds its capacity to begin addressing climate change highly limited amidst decreasing surface water supplies, increasing competition from farming, increasing water demand from a rising population, the need to improve services to an estimated 1.6 million people living in slums, poor infrastructure, stagnant tariffs, floods and droughts. However since many of the measures to address its current problems, such as improved demand management, integration of water resource considerations for Nairobi with that of upstream population and agriculture as well as improved drainage may also increase the resilience of Nairobi water to climate change, the utility may consider to consider climate change systematically as part of its program of measures..

Competition for water resources. Over the last century the world's agriculture water use grew fivefold in order to satisfy rising food demand. Global water withdrawal in 2025 (see Figure 2.1) is projected to grow by 22 percent above 1995 withdrawal to 5,240 km^3. Notably in developing countries it will be 27 percent, while in developed countries it will be 11 percent [Rosegrant *et. al.*, 2002]. In some cases cities are given priority over agriculture and other users when

Figure 2.1: Dynamics of Water Use 1900–2025



Source: Igor A. Shiklomanov, State Hydrological Institute, Russia for UNESCO International Hydrological Programme (IHP), 1999

water resources become scarce. In response to the decade long drought in the Murray Darling Basin of Australia, for example, farmers have had their water allocations drastically cut in part to reallocate necessary resources to the city of Adelaide which relies on the Murray River for up to 90 percent of its water supply during periods of low rainfall. In other cases such as Nairobi mentioned above, the issue has yet to be comprehensively addressed and resolved. In all cases, the increased competition for water resources between urban water utilities and agricultural stakeholders will result in service providers and local government authorities facing greater scrutiny insofar as their operations and policy measures being implemented to improve water management under climate change.

2.2 The Climate Change Challenge

The Intergovernmental Panel on Climate Change (IPCC) has projected that average global temperatures could rise in the range of 1.1 to 6.4°C by the end of the 21st century, which would be 1.8 to 4.0°C higher than 1980–2000 average temperature. The most likely impacts of temperature increase are a rise in sea levels, and more frequent and intense extreme weather events including droughts and floods [IPCC, 2007]. These forecasted changes will affect water availability and both short and long term operations of urban water supply and sanitation systems. In the case of water and wastewater utilities, higher temperatures and reduced precipitation levels will cause shortages in available supply due to slower replenishment rates of underground water resources and/or reduced availability of surface water. Please see Annex 1 that presents experience of the utilities and their perception and exposure to climatic events.

Water service providers currently face a number of challenges from the external environment. Global water consumption increased six-fold in the 20th century, more than twice the rate of population growth. It is expected that consumption levels will continue to grow as a result of expanding industrialization and urbanization processes, particularly in developing nations and specifically in peri-urban areas. Consumption levels are likely to grow also as a result as higher incomes. Pollution is a growing threat to urban water supplies in many part of the world. Demands for sanitation are increasing, etc. In addition, current climate variability and the resulting floods and drought represent a recurring challenge. Water service providers will be faced with the challenges of having to adapt their operational systems and institutional arrangements to account for increasing climatic variations.

Urban water utilities will likely be able to cope with the effects of climate change on their operations in the short to medium term based on existing design parameters and availability of water resources which are largely based on fluctuations in demand and long-term development projections. However, the long run impact of climate change will exceed the current design margins which allow utilities to continue daily operations.

Many utilities in different parts of the world already face the challenges of increased climatic variability which exceed projections made under historical records and hydrologic modeling, and some have started to address them through their planning processes. However, in the majority of cases these efforts are still in the most preliminary stages and frequently ad-hoc in nature. This is in part because management practices continue to be based on historic climate data which is largely accepted to be no longer sufficient to project changing precipitation and run-off patterns, and their impact on the quality and quantity of water resources. Annex 1 presents the analysis of an internationally distributed questionnaire to 20 utilities. Each reported experiencing climatic events that have prompted the utility to begin discussions and analysis of the influence that climate change will have on their operations. It also describes the actions taken by the utilities to address climate change challenges.

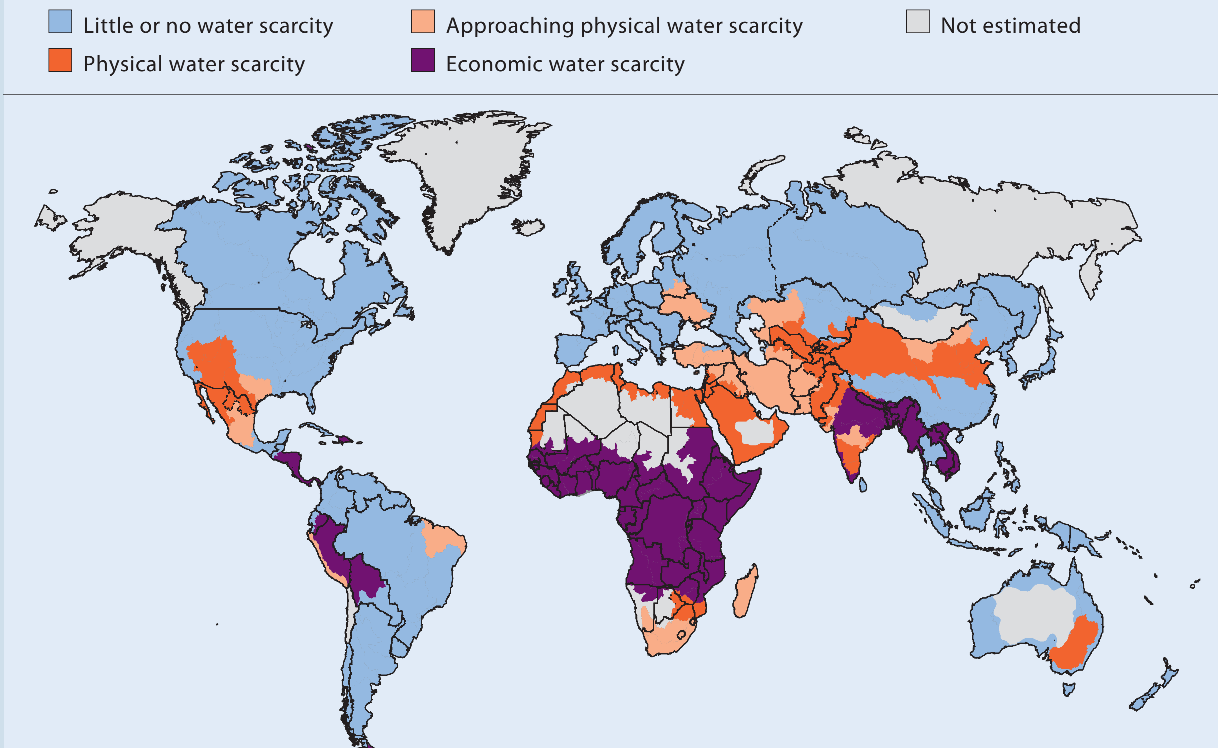
Climate change related extreme events may result in short-run reductions in water supply, and if unplanned for cause utilities to implement water conservation measures and possibly make use of unpopular demand management actions such as water rationing and intermittent supply. This type of operational approach is costly to a utility; intermittent supply and associated hydraulic shocks cause long-term damage to existing water systems, networks, pumps and gates and shorten the functional life of water infrastructure.

Wastewater systems built on historical design parameters, such as minimum flow levels or storm water capacity, will become obsolete and reconstruction rather than rehabilitation may become necessary. With reduced flow in receiving water meeting ambient water standards after dilution of wastewater treatment plants' effluent may become increasingly difficult and result in a need for increased treatment standards.

More generally the effects of climate change will require that water and wastewater service providers perform more frequent technical maintenance, undertake unscheduled rehabilitation and in some cases scale down operations at their facilities, and by extension reduce service to their clients. All of this implies additional cost for the utility. The utility may reduce the additional expenditures through implementation of improved planning, monitoring and maintenance systems (see Section 3.3 on adaptation below), it may pass on the cost to consumers, it may let parts of the system deteriorate, it may provide lower service levels or a combination of all of the above.

The challenge is compounded by the fact that there 'are still political, institutional and financial constraints on the

Figure 2.2: Areas of Physical and Economic Water Scarcity



Definitions and indicators

- *Little or no water scarcity*. Abundant water resources relative to use, with less than 25% of water from rivers withdrawn for human purposes.
- *Physical water scarcity (water resources development is approaching or has exceeded sustainable limits)*. More than 75% of river flows are withdrawn for agriculture, industry, and domestic purposes (accounting for recycling of return flows). This definition—relating water availability to water demand—implies that dry areas are not necessarily water scarce.
- *Approaching physical water scarcity.* More than 60% of river flows are withdrawn. These basins will experience physical water scarcity in the near future.
- *Economic water scarcity (human, institutional, and financial capital limit access to water even though water in nature is available locally to meet human demands)*. Water resources are abundant relative to water use, with less than 25% of water from rivers withdrawn for human purposes, but malnutrition exists.

Source: International Water Management Institute analysis done for the Comprehensive Assessment of Water Management in Agriculture using the Watersim model; chapter 2.

Source: UNEP/GRID, 2008.

ability of local governments to develop appropriate climate change adaptation policies, especially in low and middle-income countries' [ICLEI, 2009]. Indeed water utilities in the developing world are still struggling with old and persistent problems of water management and sustainable delivery of services. Conversely, utilities in the developed world are increasingly challenged with aging infrastructure and capital intensive rehabilitation needs. An important difference is that water utilities in developed and middle income nations are now beginning to identify strategic policy directions based on monitoring, analysis and the global circulation models (GCM) of possible climate change scenarios. Ironically, as illustrated in Section 3.1, the importance of forward looking approaches to the climate challenge is greater for the institutionally and financially weak utilities.

Frameworks for climate change adaptation that are currently being put to use in countries such as the United States, Australia, and South Africa reflect calculated policy design that could be used to inspire other utilities around the world. Assisting such processes are entities such as the Water Utility Climate Alliance (WUCA) of the United States and the Water Supply Association of Australia (WSAA), which are respectively funding research to identify approaches to develop decision support systems for utilities.

Specific utilities such as the Public Utilities Board (Singapore), Melbourne Water (Australia) and Seattle Public Utilities (USA) have adopted a mixture of scientific approaches in conjunction with institutional reforms to assist in defining responses to climate associated risks. The norm, however, is that many utilities such as the Water and Sanitation Agency (Rawalpindi, Pakistan), Hyderabad Metropolitan Water Supply and Sewerage Board (India), Istanbul Water and Sewerage Administration (Turkey) and the Nairobi Water Company (Kenya) are concurrently coping with a range of existing problems that more often than not overshadow concerns of addressing climate change. Nonetheless many utilities, municipalities, and even national governments are taking action to improve water use efficiency, conserve water, and reduce system leakages on the demand side, without explicitly identifying these activities as being in response to concerns about climate change. These efforts are important and will likely yield real benefits, regardless if they are designed and implemented specifically to address climate change.

While certain actions being taken within such utilities may help to reduce their vulnerability due to climate change, there is a need for undertaking vulnerability assessments and related climate action plans for urban water utilities in general.

Coping with factors associated with climate change will require concerted efforts of many stakeholders in the water sector and should compel increased development and implementation of:

- Monitoring and research on climate variability and change and related impacts on water utilities including the regulatory changes required to ease operational and financial burdens;
- Changes in traditional water and wastewater services operation and delivery reflecting variations of available water and costs of its provision;
- Technological changes that take the growing costs of water and its management into account;
- Acceptance of these changes and the cost burden borne by utilities and by the public they serve.

3. FRAMEWORK FOR ANALYSIS

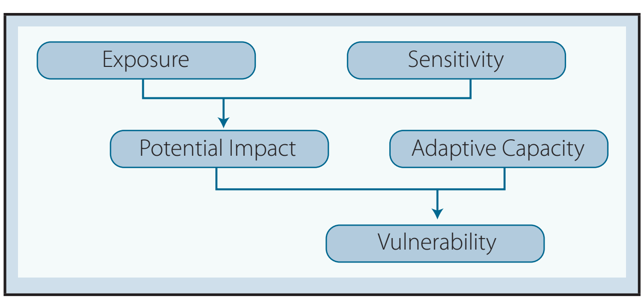
3.1 Vulnerability and Adaptive Capacity Assessment

Vulnerability is defined as the degree to which a system is susceptible to, and unable to cope with, the adverse effects of climate change, including climate variability and extremes. Vulnerability is a function of the character, magnitude, and rate of climate change and variability to which a system is exposed, its sensitivity, and its adaptive capacity [IPPC (2007)]. Assessing the vulnerability of water utilities to climate change is complex given that the associated challenges vary in particular according to geographic location and thus in terms of possible impacts as well as in relation to the capacity of utilities to respond. Generally, financially strong and technically well functioning utilities will find it easier to adapt.

Vulnerability identification. To identify the vulnerability of water supply system utilities can consider adopting '*top-down*' and '*bottom-up*' approaches [Cromwell *et. al.*, 2007]. Both these approaches provide an analytical assessment of possible disruptions to water supply systems arising from the impacts of climate change.

The top-down approach. This methodology is characterized by the use of GCMs (General Circulation Models) at the regional level which are then used to assess implications on water systems [AWWARF, 2006]. Some utilities in developed countries are collaborating with universities and research facilities to use GCMs to evaluate both exposure and potential impact on utilities, and then use these for medium and long-term planning. One of the existing problems with this approach is the downscaling of global climate models from their current level of analytical resolution to a level that is useful for utility planning purposes. The trouble lies in the mismatch of scale between global climate models (whose data is generally provided on a monthly time step at a spatial resolution of several tens of thousands of square kilometers) and catchment hydrological models (which require data on at least daily scales and at a resolution of perhaps a few square kilometers) [Bates *et. al.*, 2008]. Further ambiguity lies in estimating runoff from un-gauged rivers/channels. In many parts of the world, especially in less developed countries and remote areas, either there is no data available or only a very short period of hydrological data is available. Estimating runoff in such regions by computing generalized catchment responses in quantitative ways might be highly imprecise.

Figure 3.1: Definition of Vulnerability (Graphical)



Source: Adapted from D. Schroter and the ATEAM consortium 2004

The bottom-up approach. In applying the bottom-up approach utilities employ their own water resource planning models to assess critical vulnerabilities of their 20–50 year supply plans due to the impacts of climate change. Extrapolating from the general findings of climate change research, utilities can identify the likely effects that could prove troublesome such as decreasing groundwater recharge, surface water quality, or potential floods. Thresholds, or tipping points, of risk for utility planning are identified and adaptive measures put forward that seek to address the assessed vulnerabilities [Cromwell *et. al.*, 2007]. Utilities in developing countries are therefore likely to find that adopting a bottom-up approach to be a more practical first step to undertaking climate vulnerability assessments as they begin to analyze their own adaptive capacity.

It is important to point out that traditional approaches to urban water operations and investment planning have in many cases not taken yet the interdependent nature of water resources and urban delivery systems into account.

Climate change requires addressing this interdependency so that utilities give greater attention to water resources and source protection, in addition to improving operational performance of existing infrastructure. Utilities are likely to benefit from broadening their traditional perspective of operations, and incorporate principles of integrated urban water management (IUWM). By adopting IUWM utilities are better able to consider the interaction between watersheds and the provision of services based on factors outside of their traditional operations such as spatial development, pollution control, and solid waste and storm water management.

3.2 Mapping Utility Vulnerability

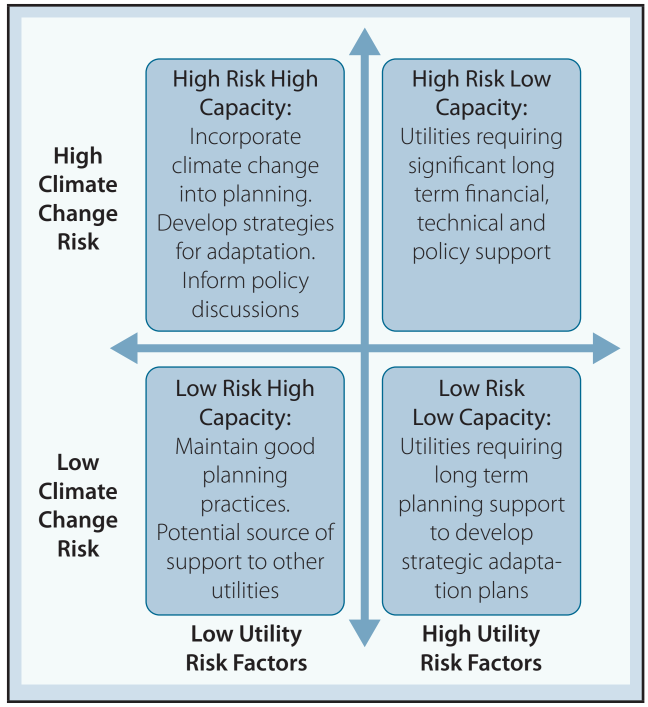
Utilities are likely to fall into four broad categories based on an analysis of utility exposure to the potential impacts of climate change and their capacity to adapt (see Figure 3.2).

The bottom left set of utilities is characterized by low climate exposure risk and possesses the institutional and financial capacity to respond. These utilities have strong planning practices and most likely represent a potential pool of support to more vulnerable utilities. This is probably a rather small set of utilities likely to be concentrated in a few countries.

The top left set of utilities face higher climate change risks but also has good institutional and financial capacity to adapt. For this group the potential impact of climate change impacts is a priority that should be mainstreamed in the utility's short term and long term planning processes. In some cases these utilities may provide useful insights into appropriate policy responses which may guide weaker utilities facing similar climatic threats.

The bottom right set of utilities face low climate change risks but are challenged by weak capacity. Although the potential impacts of climate change are small they may still have an effect at the margin of their operations. These utilities already require significant support to maintain adequate operational and investment performance and climate change risks should be built into strategies for capacity building and enhanced planning.

Figure 3.2: Mapping Utility Vulnerability



Source: Evans and Webster (2008).

The top right set of utilities is faced with multiple risks from climate change and possesses a weak capacity to respond. Significant financial, technical and policy support is likely needed to equip these utilities with the necessary tools and knowledge to face the challenges of both regular operation as well as operations under changed climate conditions. Climate change planning and adaptation must urgently be built into all plans for system rehabilitation, improvement and extension and an analysis is needed to identify those instances where climate change is likely to result in the need for major new measures, whether investments, major operational changes or institutional changes. This group is cause for greatest concern and identifying these utilities is a pressing task. It is the customers (actual and potential) of these utilities which will feel the greatest difference between systematic climate change planning and adaptation and the lack of it.

3.3 Preparing for Adaptation

Climate change intensifies existing challenges currently faced by utilities. As argued in Section 2.2 it also increases the pressure to improve existing operational procedures. Given that climate change is expected to affect a utility's intake, conveyance, storage, treatment, supply and sewerage networks, wastewater treatment, disposal systems and drainage an improved asset management system will be increasingly important. This may start with, an inventory of assets and a monitoring system based on existing information. In view of the simultaneous impact of climate change on the water resource, the infrastructure etc. both that which is inside the immediate area of control of the utility and that which is outside this area of control, an integrated urban water management system (IUWM) approach will be necessary.

Adaptation options need to be developed on the basis of vulnerability assessments. Having established an improved system for monitoring and managing current assets and operations, utilities and relevant authorities will be better positioned to assess how water resources, infrastructure, operations and planning are exposed to climatic risks through a climate vulnerability assessment. Such assessments allow for estimating the scope and intensity of potential impacts on performance as a result of climate change. Utilities will be able to analyze the extent to which system components are exposed to climate change in terms of their operation and value, and to identify adaptation measures that reduce vulnerability and improve resilience. Undertaking this form of analysis can be an important input to an analytical framework that supports prioritizing measures associated with each identified adaptation option considering its technical complexity, associated cost, institutional complexity, and operational implementation. In this way climate action plans for short and medium terms can be integrated with the regular planning process for measures to improve operations and financial viability.

3.4 Regrets Analyses for Climate Change Adaptation

There are inherent uncertainties associated with forecasting future water demand in urban areas that must also adapt to changes in urbanization rates, employment, technology, population, irrigation and industrial demands, consumer behavior, and overall economic development. Management of future risks is an integrated part of all medium and long term planning. *Inter alia*, this applies to the introduction of new technologies, whether for water intake, distribution networks, household use, or wastewater treatment etc. A good understanding of the future and its likely outcomes is essential in providing strategic direction and allowing for prioritization for future actions whether it be on resource expansion or demand management.

Along with medium and long-term resource planning, utilities now need to establish their own understanding of the costs and benefits associated with implementing climate change adaptation measures. One of the challenges that utilities face is that decisions must be made in an environment of limited information as climatic forecasts and predictions of likely impacts that are not only imprecise, but may be inherently uncertain. Historical levels and variations in hydrologic data, traditionally an important source of information for forecasting, may no longer be a good predictor of the future.[1] The emission scenarios that drive the results of the General Circulation Models are highly uncertain (although the impact hereof will show only in the long run). In addition the downscaling of General Circulation Models (GCM), which provides information for areas of several thousand square kilometers, may in itself introduce unknown uncertainties.

The key difference between forecasting with and without climate change is that the later introduces fundamental uncertainty into the forecast. To help manage this uncertainty, planners may benefit from the adoption of the distinction between no-regrets and climate justified measures to aid in decision-making.

According to IPCC no-regrets policy/strategy/measure is defined as; "A policy/strategy/measure that would generate net social and/or economic benefits irrespective of whether or not anthropogenic climate change occurs". Many of the options to reduce vulnerability to climate variability are no different in a world with climate change than they are in a world without. In many cases it is not a question of whether or not to implement a policy (or a measure), but the degree

[1] Milly, P.C. et. al (2008).

to which this should be implemented. E.g. a small reduction of non-revenue water may yield net benefits in all cases, but a larger reduction of non-revenue water may only yield net benefits under future climate conditions, where water supply becomes scarcer and water demand increases. While in many cases it a question of degree whether a strategy is a no-regrets strategy or a climate-justified strategy it may be helpful to provide a rough categorization of which strategies will tend to be no-regrets strategies and which will tend to be climate justified strategies. This is done in the two sections below.

3.4.1 No-regrets strategies

Many no-regrets strategies focus on identifying non-structural and operational modifications before considering solutions that involve major capital investments and neither disregards climate change nor makes it the primary factor in decision making. They are worth doing anyway, no matter what the eventual climate change stress may be on a particular system and can be implemented to address concerns of resource supply, consumer demand or utility operations.

On the supply side, collaboration across stakeholders for improved watershed management or the preservation of riparian wetlands upstream of cities supports improved water quality and provides valuable flood protection. Similarly, measures to augment supply through wastewater recycling or the encouragement of water markets that move water to high-valued uses may provide benefits regardless of future climate change related impacts.

On the demand side, strengthening water conservation programs that seek to improve water use efficiency through education and awareness campaigns (see Annex 2; Seville, Spain), or the introduction of incentives for consumer can provide benefits regardless of additional climate change stress. This may reduce the need for water restrictions during drought and delay the need for developing new water supplies as a city's population grows, potentially saving the utility and its clients from incurring associated costs of rehabilitation, additional maintenance and expansion.

Operational measures that a utility can take include reducing energy consumption through efficiency audits of the utility, minimizing non-revenue water in the supply system and reducing household consumption levels by making low use equipment available, or enhancing the flexibility and capacity of assets by, for example, altering refill and draw down practices on existing reservoirs to maximize yield (see Annex 2; Seattle Public Utility). Many such options carry 'no regrets' in that they confront the climate change challenge, yet are also often justifiable under existing conditions of variability.

3.4.2 Climate justified strategies

'Climate justified' actions may include, for example, constructing new infrastructure (dams, water conveyance systems, building retaining walls, overhauling combined-sewer overflow systems or various systems to prevent intrusion of salty or polluted water into the water resource), retro-fitting existing infrastructure (the introduction of new and more expensive technologies), tapping new sources of water (e.g., desalinization), water transfers, or conjunctive use of surface and groundwater.

A utility planning storm water system upgrades, for example, may opt to expand the capacity of its collection system in anticipation of more extreme precipitation events. Similarly, a city concerned about sea level rise may increase setback requirements for coastal development as part of its master plan. The City of Boston took such a decision and moved a planned wastewater treatment plant to a higher elevation in response to concerns of flooding [Legeti, 2007].

3.4.3 Robust Decision Making

It is in the realm of the 'climate-justified' that water managers will have to make difficult decisions about how to balance the political, economic, social and environmental costs of action versus of non-action, given an uncertain future. The strategies designed must be 'intelligent' and robust in the sense that they are able to deliver (near) optimal levels of service over a wide range of conditions. A number of tools that will assist decision makers to choose such strategies exist. They are typically presented under the heading "Robust Decision Making".

Robust strategies may differ in a number of ways. However, they typically have some common features. They are flexible, that is, they have the ability to react to a wider range of future (climatic) conditions. This sometime entails a more step-wise decision process starting with relatively modest re-design, retrofitting or re-operation measures. However, since these have to be prepared with the long term outcomes in mind, in these cases, the decision making process of policy makers and utility managers is more complicated.

3.4.4 Communication with Stakeholders

Since adapting to climate change is likely to place additional burdens on utilities and their customers as described above, climate action plans need to be complemented through targeted communication with consumers and improved coordination among municipal authorities. This may include regular publications of brochures and booklets, announcing precipitation and river levels, or storage volume of reservoirs. In the short to medium term, cities with similar climatic risks may benefit from intensified knowledge exchange of institutional and managerial experience on addressing climate change, recording and disseminating impacts, and analyzing the cost efficiency and operational effectiveness of adopted adaptation measures. The example below describes the development of decision support planning methods in the United States that bring together top-down and bottom-up approaches.

Box 3.1: Water Utility Climate Alliance, USA

To complement the application of top-down and bottom-up approaches, the Water Utility Climate Alliance (WUCA), which consists of eight well developed utilities in the United States, is developing decision-support tools for planning, decision-making and policy-making that can accommodate uncertainty under climate change.

Decision support planning methods (DSPMs) provide an analytical framework for water utilities through the integration of 'broader planning assumptions such as watershed development and land use changes, water quality and quantity changes, and demand changes in planning for future water supplies' (WUCA, 2009). While recognizing that utility risks are context specific, the DSPMs being introduced by WUCA as useful frameworks for strategic planning of adaptation actions include: i) decision analysis (a probability-based method), ii) traditional scenario planning and robust decision-making (scenario-based methods), iii) portfolio planning and real options (financial-based methods), and iv) catastrophe model (insurance-based methods).

4. FRAMEWORK FOR ADAPTATION

Climate adaptation measures for urban water supply will be driven by the geographic context of a given utility and respond to their own unique set of risks. The specific approaches adopted, and the related processes of implementation will therefore vary from utility to utility. A framework for adaptation may therefore be useful for utilities to consider during their initial planning. This could be accomplished through a two phased approach: i) identifying specific risk factors which will hamper efforts to adapt to climate change (macroeconomic environment, utility infrastructure endowment, utility operational conditions, resource baseline),[2] and ii) assessing the technical, financial and institutional complexity of selected adaptation measures.

The framework and adaptation measures presented here are not intended to be used as a scorecard, a roadmap to their implementation, or an assessment of how far reaching their impacts will be. Rather the purpose is to provide a contribution to the establishment of an analytical framework that may assist Bank staff and client countries' utility managers to identify and screen climate change adaptation measures.

Adaptation measures have been classified to respond to the following five areas: (i) Climate Monitoring, (ii) Water Availability, (iii) Water Quality, Water Distribution, (iv) Wastewater Collection, (v) Wastewater Treatment and Effluent Discharge.

To screen adaptation measures for potential effectiveness and feasibility, a number of criteria should be considered; (i) Is the no-regrets categorization applicable? (ii) Is the measure controlled by the utility? (iii) Is the level of technical complexity realistic for the utility? (iv) Is the measure financially feasible? (v) What are the institutional complexities of implementing each action?

In the following sections a sample of measures included in the table are discussed in greater detail. The discussion is based on responses to the internationally distributed questionnaire and the experience presented by utilities in the consultative workshop. One of the important findings of the chapter is that key measures such as protection of water resources, aquifer recharge and enhancing storage capacity are not part of the operational mandate and thus controlled by the utility itself. Furthermore, the roles and responsibilities for water resource management and water services provision are most often separated. This may pose potential conflicts of interest between water resource management and water utilities. This highlights the need for integrated urban water resources management in order to consider the trade-offs between competing uses in one integrated policy framework.

4.1 Climate Monitoring

The monitoring of water resources, precipitation and water utility performance is an important tool for any utility. One of the few government bodies to include precipitation in its water utilities performance assessment system is the National Water Commission of the Australian Government. It established a utility performance benchmarking system linked to water resources and precipitation to analyze the effects of climate change and provide assistance based on the robust evidence. Utilities contributing to the study (see Annex 1) suggested a number of system elements (see Box 4.1) necessary for effective monitoring that are within the scope of water utility operations.

Monitoring not only assists utilities but at the same time facilitates decision making that avoids over-investments.

A similar approach has been implemented in the United Kingdom where Ofwat, the national regulatory body, insists on transparent analyses of the possible effects of climate change on water utilities' investment programs (see Box 4.2).

[2] See Evans and Webster (2008) for a full discussion of mapping utility risk factors.

Box 4.1: Monitoring for Climate Change

Water resources and hydrologic patterns: precipitation, glacier melting, water table levels, surface water flow, ambient water quality and saline "tongue" intrusions into estuarine water supply intake schemes;

Water systems sustainability: Measuring the degree to which water use meets current needs; this could include the ratio of water withdrawn to renewable supply or days of available fresh water supply for a specific city

Demand for water services: and effects of demand management;

Water utilities operation: cost of water production, transmission, treatment and distribution; leakage, commercial and technical NRW; brakes in the system, wastewater flow

Wastewater operations monitoring: changes in volumes and composition of wastewater, brakes and clogs in wastewater collection network, adequacy of existing technology to composition of wastewater and wastewater treatment effluent and sludge;

Monitoring of adequacy of adaptation actions: With system vulnerabilities defined and a baseline established, adaptation actions/strategies can be tracked over a period of time to assess progress towards predetermined targets

Box 4.2: Ofwat, United Kingdom

"Several companies are planning significant investment in AMP5 [5 year price setting schedule for 2010–2015] in order to address the perceived effects of climate change on the supply/demand balance. Climate change is an important issue, and it is vital that companies plan carefully to mitigate and adapt to its impact. However, this will be a long-term challenge, requiring a response appropriate for the long-term. As set out in the guidance for water resource planning, it is equally important to make sure that there is a robust evidence base for significant investment decisions that companies cannot reverse and that will have a permanent impact on customers' bills.

Companies will need to provide robust evidence for any step changes to the estimates of existing supply capacity (for example, deployable output) and demand that they use in their investment planning for the 2010–15 period, whether those changes are related to new information on climate change or to other factors".

Source: Ofwat, Water Supply and Demand Policy Price review, 2008

4.2 Water Availability

4.2.1 Demand Management and adjustment of operations to below capacity

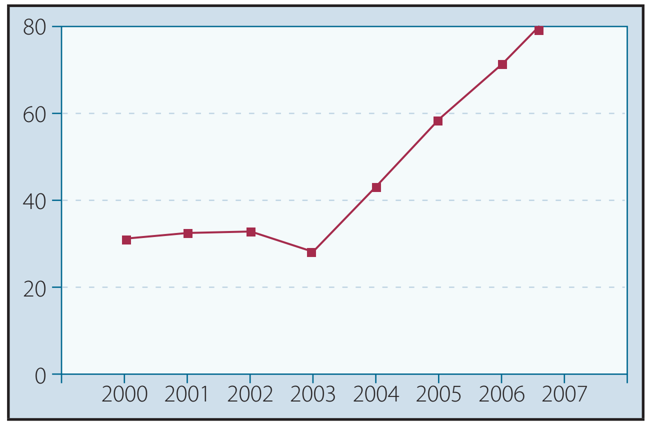
Since 1990 demand management has been increasingly promoted in the planning and management of freshwater resources. Consequently legislative mandates began to emerge whereby water institutions implemented conservation programs and individual consumers adopted water saving measures [Dziegielewski, 1999]. Demand management is now widely promoted in many countries and is recognized as an important adaptation measure to both current climate variation and climate change.

Reducing demand, however, largely depends on current consumption levels and patterns of water use. At present, domestic use of water in the United Kingdom is about 150 liters per capita per day (lpcd) as compared to 250 lpcd in Saudi Arabia and 300 lpcd in the United States. While significant gains can be made early on in consumer behavior change campaigns to reduce water consumption, diminishing returns may set in as per capita consumption reaches a floor. Singapore Public Utility Board's (PUB) target to reduce water consumption by a mere 3 lpcd, for example, from 158 lpcd to 155 lpcd has been planned over 6 years [Government of Singapore, 2007]. In the United Kingdom the target for the water industry is to reduce water consumption to approximately 130 lpcd over a period of 20 years [Defra, 2008]. The city of Copenhagen has had a water demand management program in place for two decades and has reduced water consumption from 174 lpcd to 121 lpcd in that period.[3]

The proper balance of demand management and technical designs need to be carefully considered as poorly planned conservation efforts can be counter-productive to a utility's financial and operational stability. Running existing infrastructure, primarily pumping equipment and networks, below designed capacity can lead to operational difficulties and prove financially risky. For example, it may be costly and difficult to maintain pressure within oversized networks that are designed for specific levels of consumption. Gravity fed sewerage can also be affected as minimum flow levels may not be met and result in the clogging of pipes. Wastewater treatment plants may also face operational challenges due to low wastewater flow and contaminant levels in the wastewater that do not correspond to a system's existing technology.

Since 1997 the city of Astana, Kazakhstan, has experienced rapid urbanization rates (10% annually) and concurrent drought that caused the depletion of the Viacheslavskoye Reservoir, the major water source for the city. To respond to the resulting water shortages the municipality implemented demand management measures including water metering and the increased water tariffs to promote responsible use. Within the first two years of these reforms a significant drop in domestic consumption from 370 lpcd to 100 lpcd occurred. This reduction in consumption resulted in an unanticipated outcome for the wastewater collection system that was designed for substantially higher wastewater flow rates. Currently the municipal utility Astana Su has up to 300 clogs on its wastewater network a day (see Figure 4.1).

Figure 4.1: Astana, Kazakhstan: State Communal Enterprise Astana Su Arnasy Sewer System Blockages (blockages/km/yr)



Source: IBNET, 2009.

4.2.2 Reduction of Non Revenue Water

Non-revenue water (NRW) affects the financial viability of water utilities through lost revenues and increased operational costs. If a utility has limited water resources, high levels of NRW can result in water shortages during peak demand periods, reducing the level of service provided to customers and/or causing intermittent supply. A utility's level of NRW depends on many factors; network density, age and design, pressure in the system, maintenance efforts and most importantly, approaches in the utility's technical and financial operations. In well developed utilities NRW varies from 5–15 percent, as in compact systems like Singapore or Hong Kong, but may reach 80 percent in water utilities in developing countries (See IBNET database at www.ib-net.org). It is generally considered that 20–25 percent is an acceptable or "tolerable" level of NRW for a utility.[4] Climate change, however, will inevitably reduce this "tolerable" level as it becomes more affordable for a utility to address NRW given increased marginal cost of water and associated revenues which will meet the marginal cost of increased NRW reduction efforts (please see figure 4.2).

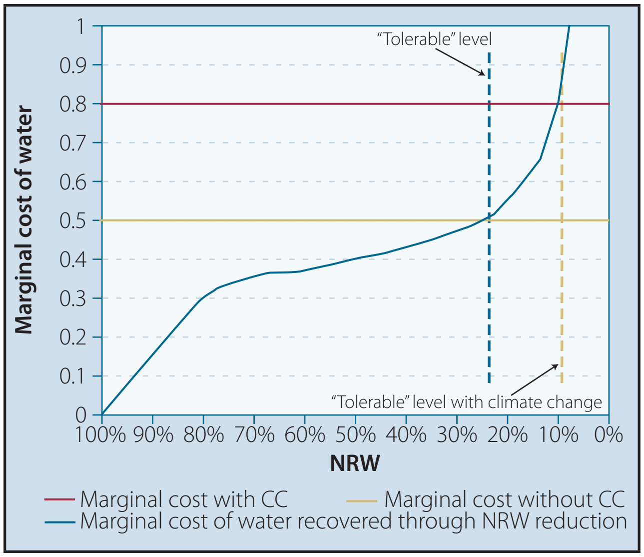
4.2.3 Water metering

Water metering is the most efficient tool for reducing domestic water consumption. Metering allows for greater accountability to both a consumer who pays for water according to actual use, and to utilities that are paid according to the volume of services they provide. Coupled with an

[3] See https://www.ke.dk/portal/page/portal/Erhverv/Vand/Vand_forbrug?page=152

[4] The authors recognize that measuring NRW in percentages is a very crude measure. Better alternatives include m^3/km/day or even better comparing total losses in m^3/year with the so-called unavoidable annual real loss (UARL) for the system. However, here we follow the tradition of using percentages as the measure.

Figure 4.2: Influence of Climate Change on NRW



Source: Authors. Values are indicative.

appropriate tariff policy, this can result in a significant drop in water demand. Evidence shows that utilities that switch from a fixed fee (flat rate) billing system to universal metering experience a reduction of water use among customers in the order of 30 percent, with an upper limit being as high as 50 percent [AWWA, 2008]. As a result of water shortages in Moldova in the mid 1990s, Chisinau Water faced pressure from its consumers to implement a new billing system based on actual consumption to replace the flat monthly tariff structure. The introduction of individual apartment meters resulted in a marked reduction in consumption levels and assisted to alleviate concerns over water availability (See Figure 4.3). It must be noted that the introduction of metering can at times result in unanticipated outcomes. In a number of cases, consumers may react if reductions in consumption are followed by increases in the tariff (to keep revenues). On the other hand in many cases, lower consumption may also reduce costs (for example pumping costs) and this has to be fed back into tariffs.

In New York City a completed metering program and incentives for installation of water efficient equipment by consumers resulted in the total water saving of nearly 17% (see Box 4.3 below) for the city.

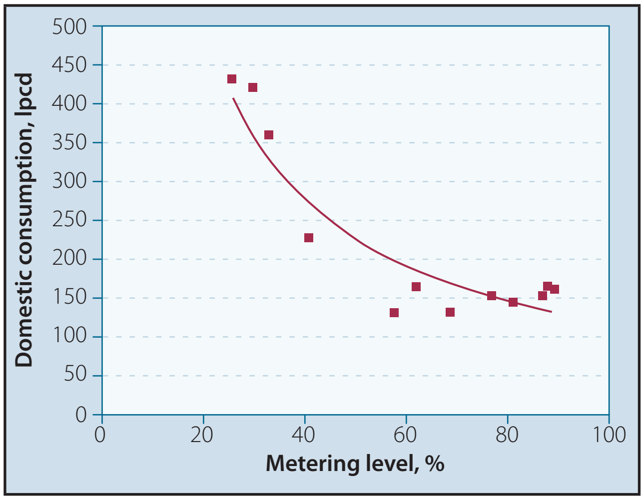
It is also important to note that metering programs are expensive given that meters require regular calibration and replacement. In the case of England and Wales, Ofwat calculated that metering would cost an additional $48 per year per connection compared to an average bill of water $174 per year and $308 for water and sewerage combined. Therefore, many utilities in OECD countries have decided against metering in cases where the decision to install me-

Table 4.1: Non Revenue Water of Participating Utilities (%)

City, Country	NRW %	City, Country	NRW %
Sao Paulo, Brazil	38	Singapore	5
Istanbul, Turkey	30	Senegal	20
Dhaka, Bangladesh	40	Melbourne, Australia	3
Lima, Peru	37	Nairobi, Kenya	34
Bogota, Colombia	41	Burkina Faso	22
ROSVODOKANAL, Russia	29	Hanoi City, Vietnam	20
Hyderabad, India	50	Rawalpindi, Pakistan	46
Manila, Philippines	48	Windhoek, Namibia	14

Source: The International Benchmarking Network for Water and Sanitation Utilities (IBNET). Base year 2005 except Manila and Bogota 2004

Figure 4.3: Effects of Water Metering on Residential Consumption in Chisinau, Moldova (1996–2008)



Source: IBNET

ters cannot be justified by the marginal cost of water and a potential reduction of investment costs as a result of a reduction in demand. However, metering has indirect benefits, such as increasing consumer awareness and helping to detect and estimate leakages.

4.2.4 Water Tariffs: Key to Demand Management

'Climate change led' water policy interventions are likely to see the use of tariffs as an effective tool to reduce demand and increase rational water use behavior among users. Tariff is a key instrument in demand management, yet it is widely known that tariff adjustments can be politically challenging and difficult to implement. As a result, most urban water utilities in developing countries often are unable to cover

Box 4.3: New York City Water Conservation Program

New York City implemented a water conservation program during the 1990s and early 2000s. With a consumer base estimated at 8 million, the city administration took the following steps:

- Installed more than 500,000 meters and converted most customers from flat-rate to metered billing
- Designed and commissioned a new billing system and assumed responsibility for billing from the Department of Finance
- Conducted a toilet replacement program involving more than 1.3 million fixtures and 120,000 properties

The program resulted in significant savings in water as well as raising the revenue base.

- Consumption reduced by 15–17% after completion of universal water metering
- Implementation of water conservation actions at the consumer level: toilet replacements, water consumption audits, education programs
- Customer complaints regarding their high bills were taken as an opportunity to educate consumers on the role of water metering

There were also regulatory measures which enhanced the overall efficacy of the program.

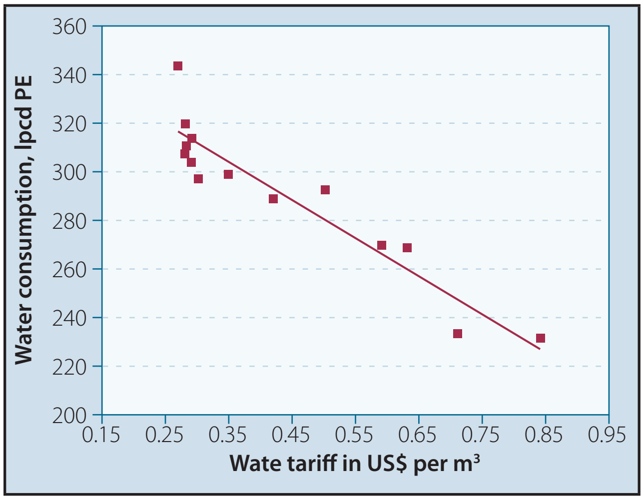
- City Council prohibited the sale of high-flow showerheads and faucets (1989) and toilets (1992)
- Federal law strengthened city/state laws (1994)
- Toilet replacements undertaken in public housing (1992–2005)
- State Energy Authority provided incentives for Energy Star clothes washers which contributed to increasing sales of high efficiency clothes washers (2000-Present)
- Building Code revised to require 20% water/energy reduction (Mayoral Proposal 2008)

Overall program benefits were,

- Per unit cost of the "saved" water was 45–68% less than new supply and treatment
- Net present value of savings amounted to of USD196 million which allowed deferring supply expansion for ten years
- Impact evaluation found that participating apartment buildings reduced consumption by 29%
- Citywide savings of about 350,000 m^3 a day
- Mean daily demand 4.12 million m^3 a day in 2006, compared with 5.58 million m^3 a day in 1990.

Source: Liebold, 2008

Figure 4.4: Water Tariffs and Consumption in Budapest



the recurrent costs of operation and maintenance, leaving little or no funds to recover capital costs, invest in modernization and/or system expansion [UN-Water, 2009].

Countries facing water scarcity are increasingly beginning to address tariff reform in attempts to improve water services. In those utilities where cost recovery has been made possible through setting appropriate tariffs and improving bill collection, water usage patterns have been shown to change markedly. For example, the Walvis Bay municipality in Namibia doubled its tariffs between 1998 and 2003. This contributed to a 50 percent reduction in demand for groundwater abstraction [Windhoek presentation at Madrid Workshop, 2009].

Water tariffs as a tool for improving demand management in Budapest resulted in a reduction in water consumption from 345 lpcd in 1995 to approximately 230 lpcd in 2007.

4.2.5 Consumer behavior and low water use appliances

While much of the discussion has focused on actions that can be taken by a utility itself, there is also a role for consumer behavior change in adapting household use of water in the use of appliances. Behavior change can be accomplished through *direct* actions, such as increasing tariff rates, promoting retrofitting programs, imposing legal restrictions, in combination with more *indirect* mechanisms including educational campaigns, corporate social responsibility initiatives, or customer recognition programs.

Public campaigns in Singapore which made 'do-it-yourself' water-saving kits available coupled with mobile exhibitions to give advice on proper installation and demonstration of water efficient appliances proved to be effective in harnessing public attention and interest [Rouse, 2007]. In the case of Singapore demand management has been given equal importance to supply management. Reducing water consumption from users is one of the major objectives for the Public Utilities Board (PUB) to be achieved under demand management through public education, regulations and pricing. Moreover, the installation of low capacity flushing cisterns and constant flow regulators have been made compulsory, and this has significantly reduced domestic water consumption from 176 lpcd in 1994 to 158 lpcd in 2007. The PUB is now aiming to further reduce consumption to 155 lpcd by 2012.

In 2006, PUB launched the '10 Liter Challenge' to encourage customers to reduce their daily water consumption by 10 liters. This was followed up in 2008 by two complementary initiatives; (i) the 'Water Efficient Homes Program' where PUB officers visit households in Singapore to install free-of-charge water saving devices such as thimbles and cistern water saving bags, and (ii) the '10% Challenge' which focuses on the non-domestic sector, such as hotels and industries, to reduce their total water consumption by 10 percent. Another mechanism adopted to reduce water consumption is the enforcement of the Water Conservation Tax (WCT) on domestic as well as non-domestic consumers. This tiered tax is applied to a customer's monthly tariff charge at a rate of 30% for households consuming less than 40 cubic meters of water per month, and 45% for those above.

Annex 2 presents a range of other actions taken in Seattle, Seville, Melbourne, Singapore and Namibia to engage consumers into the water conservation. Table 4.2 indicates the relative percentages for the water consumption of household appliances and is useful for identifying where advanced water-saving technologies may emerge.

Table 4.2: Indoor Residential End Uses of Water

End Use	Percentage of Indoor Water Use
Toilets	27
Clothes washers	22
Showers	17
Faucets	16
Leakage	14
Other domestic	2
Baths	2
Dishwashers	1
Total Indoor*	100

Source: Mayer et. al., 1999 in AWWA 2008.
* Total sums to 101 due to rounding.

With greater awareness of water conservation in addition to rising costs of water, demand for water saving equipment and household appliances may rise in the short and medium term. Many technologies exist, including, but not limited to: low-flow toilets (single/double flush), shower fixtures, tank-less or on-demand water heaters, motion activated taps, and dishwashers and laundry equipment that reduces the waste of increasingly costly water. However, barriers for widespread use could include the convenience factor and financing (many of these appliances require (additional) expenditure and many households do not have easy access to finance.

Various studies presented by the American Water Works Association [2008] show that potential for water savings in urban systems from such appliances are in the magnitude of 15–25 percent over one to two decades. In Singapore, Australia and Germany programs to guide consumers in purchasing water efficient appliances are now common. However, regulatory and government support were crucial making these programs operational.

Utilities can also play an important role in educating their consumer of such products. SEDAPAL, the water utility of Lima, Peru, has patented the Product Seal for Water Saving Appliances, which supports and certifies products that generate a minimum of 30 percent water saving. Elsewhere the municipality of Sydney, Australia, encouraged water conservation devices in addition to implementing demand management measures and water metering programs (see Box 4.4).

4.2.6 Integrated Water Resource Management

Land use planning and management for agricultural land, forest, fallow and pasture land affects watershed soils and vegetation. Factors such as urbanization, shifting cultivation, mining and industrialization within watersheds have a direct influence on the quality of water from surface runoff. In order to manage their water effectively, municipalities and water utilities will have to extend their operational reach to include watershed vegetation and ecology. To facilitate this, better communication and coordination within water utilities and between government departments dealing with water, storm water, sewage and land use planning will be necessary, but not sufficient.

For instance, the Nairobi Water Company has initiated a new approach towards watershed management by developing a partnership between the Ministry of Environment and private companies that may have direct or indirect interests in the protection of watersheds. Over the last three years actions have been taken under this joint initiative in the upper catchments of Motoine-Ngong River to increase forest cover, reduce source pollution and increase groundwater recharge rate. The Nairobi Water Company has also increased its cooperation with the Water Resources Management Authority (WRMA) and is benefitting from WRMA's activities in its catchment area including sediment monitoring, tracing study to identify the catchment area of Kikuyu Springs which is one of Nairobi's water sources, and the support WRMA is providing to develop sib-catchment management plans.

Watershed dynamics determine the overall levels of available water supplies through a complex interaction between evaporation, precipitation, infiltration, storage, soil moisture and runoff. For example, to reduce potential contamination of its water supply catchments

Box 4.4: Sydney Water Conservation Program

Sydney water serves some 1.7 million homes and businesses of which more than 97% are metered. The utility receives about 80 percent of supplies from the Warragamba Dam over the Hawkesbury Nepean River. Facing severe water shortages, Sydney water plans to reduce water intake by 25% by 2000–2001 to the level of 1990–1991, and will achieve 35% reduction by 2010–2011. These reduction targets were set by the local regulator – Independent Pricing and Regulatory Tribunal (IPART) as the part of Sydney Water operating license. The utility carried out Least Cost Planning and cost-benefit analysis of individual demand management options from an end-use perspective.

The End Use-Least Cost Planning model provided a flexible framework to compare a diverse range of options,

- Rebates: washing machine, rainwater tanks
- Regulation: appliance and building standards
- Pricing: multi-tier prices, fixed/ variable price ratio
- Recycled water options: discrete and whole community projects
- Education / behavior change initiatives
- Non-cash incentives

Program	Utility cost estimate (USD/kL)	Total Resource cost estimate (USD /kL)	Utility cost/benefit estimate (USD /kL)	Customer cost/ benefit estimate (USD /kL)
EDC Business[1]	$0.13	$0.24	$0.13	–$1.95
Waterfix	$0.40	$0.45	$0.21	–$0.11
Active Leak reduction	$0.19	$0.19	–$0.11	N/A
Rainwater tank rebates	$0.61	$3.27	$0.61	$1.37

Under a major public campaign the city administration encouraged households to save water through various measures, which best suit them. The program resulted in:-

- Rainwater tank rebates: 45,500 / ~ $11.82M
- Waterfix visits: 458,300 / ~ $44.57M, 9.58 billion liters /year saved
- Washing machine rebates: 98,500 / $11.51M, 1.974 billion liters / year saved
- EDC Business program: 388 participant organizations @ 2,069 sites, 13.406 billion liters/year saved.

Source: Boerema, 2008
Note: 2006 values have been taken, Conversion rate, $1 AUD=$0.778 USD
[1] Water conservation in commercial office buildings and shopping centers

the Melbourne authorities have regulated public access to catchment areas. The mountain ranges in the east of the city are marked as 'open' and 'closed'. Public access to closed catchments is usually not permitted and only specifically authorized activities can be carried out in those areas. Open catchments are accessible to the public in designated areas, but with careful management and restrictions on camping and other activities. Similarly, every year the catchments of only one of the four Yarra Tributaries are harvested and other water supply systems are 'turned out' during the timber harvesting months (December to April, inclusive) to protect water quality. This coincides with the lowest water yielding period and water is not often harvested during this time to maintain minimum environmental flows required downstream [Government of Victoria, 2009].

4.2.7 Diversification of water sources

Diversifying sources of water supply is likely to become increasingly important for water utilities. Whether this is through the construction of new storage facilities, the appropriate and sustainable extraction of groundwater, water trading or conservation, or the use of recycled or desalinated water, utilities must begin to think about ways in which they can affordably use alternative sources.

Given the expected impacts that climate change will have on water resources, reliance on a single source of supply may become an increasing risk for many urban water utilities. Existing water intake systems may not be adequate under climate change and the foreseeable increasing cost of water available for treatment and distribution may force utilities to assess alternative options. It may include building new reservoirs or expanding their existing capacity, tapping groundwater aquifers, inter-basin water transfer, capturing unharnessed resources such as rainwater harvesting, desalination, or employing water reuse technologies.

It will be particularly important to assess a utility's flexibility to switch between different water sources. Intake from each of these sources has different implications for required equipment, inputs (chemicals, electricity) and the technical capacity of a utility's staff.

Since 1970s, Singapore has added three main sources to the existing water mains to ensure reliability of supply in addition to water imported from Malaysia: collection of rain-water, reclamation of wastewater, and water desalination. The four sources together are known as 'Four National Taps', and are expected to serve as principal supplies to meet Singapore's water requirements in a future affected by climate change. In addition to these steps, Singapore is also expanding its water catchment area to two-thirds of its land area by 2009 with the completion of three new reservoirs.

4.2.8 Enhancing storage capacity

Most water utilities opt to develop renewable resources and enhance storage capacity when possible. This might involve

Box 4.5: Roofwater Harvesting

Domestic Roofwater Harvesting (DRWH) provides an additional source from which to meet local water needs. In recent years, DRWH systems have become cheaper and more predictable in performance. There is a better understanding of the way to mix DRWH with other water supply options, in which DRWH is usually used to provide full coverage in the wet season and partial coverage during the dry season as well as providing short-term

security against the failure of other sources. Interest in DRWH technology is reflected in the water policies of many developing countries, where it is now cited as a possible source of household water.

There has been much recent activity concerning domestic roofwater harvesting in countries as far apart as Kenya, China, Brazil and Germany. Many countries now have Rainwater (Harvesting) Associations. The technique is approaching maturity and has found its major applications where

(i) rival water technologies are facing difficulties (for example due to deterioration in groundwater sources), and
(ii) water collection drudgery is particularly severe (for example hilly areas of Africa).

In some locations, such as India, DRWH has been strongly linked with aquifer replenishment programs. Elsewhere it is seen as an attractive technique, in part because it fits with the decentralization of rural water supply and is suitable for household management.

While water availability has been decreasing all over the world, rainwater usage has been suggested to promote potable water savings and ease water availability problems. A study undertaken in Brazil shows a potential for potable water savings for the residential sector. It demonstrated that average water availability in Brazil amounts to about 33,000 m^3 per capita per year. In two of the five geographic regions of Brazil, however, this availability is lower than 5,000 m^3 per capita per year. By using rainwater the potential for potable water savings is shown to vary from 48% to 100% depending on the geographic region.

Source: Thomas, T.H. & Martinson, D.B, 2007; Ghisi, 2006

Box 4.6: Nairobi Water Company

Nairobi's water utility is strongly advocating its need to increase its water availability vis a vis concerned ministries and departments of the Government of Kenya. Together with the Athi Water Services Board is therefore currently embarking on a comprehensive study to identify additional water sources for Nairobi. The study will look at all options including additional dams, use of shallow and deep groundwater, roof catchment, reclaiming wastewater, inter-catchment water transfer, usage of existing public and private wells during emergency situations etc.

tapping lower quality raw water sources such as water from the lower reaches of a river, new dams and reservoirs, or long-distance water conveyance. Construction of additional reservoirs to alleviate variability in seasonal, monthly, daily and hourly water availability is one consideration for utilities that face water stress.

Enhancing seasonal reservoir capacity is also an option for utilities facing increased precipitation variability so that water reservoirs filled during the rainy/winter seasons are used to bridge any shortfalls that may be encountered during dry periods. This approach is already in use in places such as USA (New York City, Michigan, Colorado), Sri Lanka (Kirindi Oya), and Senegal (Lake Guiers). The key difficulty reported for this option is in maintaining/securing agreements for pollution protected zones to ensure acceptable levels of water quality. Another consideration with this approach is that such reservoirs may affect property rights, land acquisition and resettlement of affected communities. If properly designed, these reservoirs have the capacity to bring substantial environmental benefits. In addition to increased stability in water supply, seasonal reservoirs can capture storm water runoff, and contribute to increased aquifer recharge.

While the construction of new dams and reservoirs may be feasible for some utilities, they can only be built where suitable sites are available. In the case of EMASESA (Seville, Spain) the utility has been prohibited from constructing a new reservoir as part of its supply management. As a result, the utility was forced to change its strategy and focus heavily on demand management through public campaigns to reduce water consumption and placing increased emphasis on operational efficiency by minimizing distribution losses. Annexes 2 and 3 present details on water management in Seville (Spain), Nairobi (Kenya) and Ningbo (China).

4.2.9 Water reuse and desalination

Where existing water resources are constrained from meeting rising demands, water utilities tend to explore alternatives such as water reuse and desalination. There are multiple international examples where wastewater reuse is factoring heavily into supply strategies for urban use and consumption. This approach is not widely applied however, due to factors such as costs of necessary treatment and difficulty in gaining social acceptance. Two noteworthy examples are the city of Windhoek, Namibia where direct potable reuse is an important supplementary source of water (see Box 4.7), and Singapore where high quality treated wastewater (NEWater) is being sold as a potable product (see Annex 2).

A major consideration in the viability of a reuse project is the proximity of the treatment plant to the application site as a separate distribution system is required to transport the reclaimed water to where it can be used. Given that a large proportion of investment costs in the water industry are in the distribution network, a new water source which requires its own network is potentially not competitive on cost grounds. At present the cost of water reuse with different combinations of treatment and supply ranges USD 0.02 to 2.50 per cubic meter [Yuan Zhou Richard S.J. Tol, 2004]. However, it is important to note that cost varies drastically from one region to another. For instance, the cost of recycled water to PUB is USD 0.30 per cubic meter [PUB, 2008]; while for Windhoek it is USD 0.76 per cubic meter [IBNET, 2005]. An additional consideration of wastewater reuse by suburban agriculture is that it can dramatically reduce competition for fresh water which has been documented in reports from Egypt, India, and Pakistan [Ensink, J., et al, 2002]

Box 4.7: Water reclamation, Windhoek, Namibia

The City of Windhoek started its two water reclamation plans in the early 1960s. After a number of years of experimental work, and the achievement of favourable results, the municipality established the Goreangab Water Reclamation Plant (GWRP) in 1969, with an initial capacity of 4,300 m^3 per day, which was approximately 25% of the daily demand at the time. Between 1969 and 1992 GWRP was upgraded four times and the capacity increased to 7,500m^3 per day (15% of total demand). The reclaimed water is blended before distribution to the city.

During the drought of 1996, the supply dam serving Windhoek dropped below 6% of its capacity. Feasibility studies indicated that increased reclamation was the only readily available option and in 1999 construction on a new reclamation plant of 21Mm^3 per day was started. The New Goreangab reclamation plant was put into operation in 2002 and forms one of the pillars in the supply chain to the City, supplying up to 35% of the daily demand of the City.

Over the decades citizens of Windhoek have accepted drinking a blend of water that contains reclaimed water. The city has embraced the value of recycling to its water supply to the extent that the annual water resource planning relies on the contribution from recycling.

While desalination is another possible response to water scarcity, it presently amounts to only 0.4 percent of the world's freshwater needs. [Yuan Zhou, Richard S.J. Tol, 2004]. However, it may be considered in a number of circumstances including where there is a sufficient and convenient source of water whose salinity renders it non-potable, where there is the ability to finance large capital projects which have higher operating costs than traditional water utility assets, or where the alternative sources of potable water are either more expensive to develop or less reliable. Whether desalination is the solution for a particular utility is dependent on the relative cost of alternatives. Currently, desalination is a relatively high-cost alternative in the range of USD 0.50–1.00/m^3 [Yuan Zhou, Richard S.J. Tol, 2004.] Many advocates of desalination believe that this will change, as technology makes the process cheaper, and the alternatives become more expensive [GWI, 2006].

Wastewater treatment and desalination are also proving to be important in making Singapore self-reliant in for its water demands. Approximately 15 percent of Singapore's total water demand is met by the use of high grade wastewater treatment processes, which employs a multi-barrier treatment including a micro/ultra-filtration, reverse osmosis and finally, ultraviolet disinfection. The resultant water quality meets the standards set by the United States Environmental Protection Agency and World Health Organization for drinking water. With a fifth water treatment plant expected to be operating by 2010, Singapore will be able to meet 30% of its water requirements from reclaimed water after

Box 4.8: Desalination and Wastewater Treatment in Melbourne

Desalination and wastewater treatment are set to gain importance in Melbourne's water supply management in the future. A major desalination plant will supply 150 billion liters of water a year to Melbourne by the end of 2011. This will be equivalent to about one third of Melbourne's annual water supply, independent of the variations in rainfall.

Another strategy being implemented by Melbourne to secure high quality recycled water is the upgrading of its water treatment plants. At present about half of the city's wastewater is treated and being used for agricultural, residential parks and gardens and industrial recycling schemes. Upgrading the treatment plants to tertiary level will open avenues to progressively expand the scope of using recycled water, including replacing supplies currently used from the Latrobe Valley river water in power system cooling.

Source: Melbourne Water (2007)

treatment. The desalination plant started in 2003 supplies 30 million gallons of water per day. Please also refer to Annex 1 for details on water management in Windhoek and Singapore. Detailed cases of water reuse are presented in Annex 2.

4.2.10 Market-based mechanisms for reallocation of water resources and integrated water management

Market-based mechanisms whereby cities can buy water rights from other users to meet urban water demand have been put to use in Australia, the western United States, Chile and Mexico. This is possible in formal water markets, where water rights and legislation are established. Melbourne participates in the water market of the Murray-Darling Basin in Australia along with the agricultural community. This allows for the efficient sharing and the optimization of water resources between irrigators and urban users. In Tucson, United Sates, it was found that the purchase of water rights from agricultural users was a cheaper alternative than long-distance water conveyance [Schiffler, 1998]. Under climate change, water utilities may find trading water rights more economically attractive than undertaking investment heavy infrastructure projects. In the longer-term this could feasibly be an adaptation measure that encourages farmers to use water more efficiently and in turn on-sell surpluses while using revenues to reinvest in additional water efficient technologies for agriculture [Godden, 2008]. Please refer to Annex 2 for details on water markets in Australia.

4.3 Actions to Protect Water Quality

4.3.1 Protection of the water resource

Quality of water resources and land use are intrinsically linked. Land type and use, plus human intervention (along with natural and climatic factors) will have a strong influence on receiving waters. Land use management helps utilities protect water quality from soil erosion, land salinity, and agrochemicals from farmlands, industrial pollutants or runoff with high levels of silt.

Surface water quality is similarly affected by increased water temperature, extreme variability in rainfall, and catchment contamination due to severe floods or droughts leading to increased costs of treatment for utilities.

In addition to the need for improved protection of water quality at point of source, dilution of wastewater treatment plants' effluent is becoming increasingly complex given the need for increased treatment standards as a result of existing environmental regulations and reduced flows of receiving waters, in. It is therefore probable that advanced wastewater treatment will become more common as advanced technologies are introduced that conform to increasingly stringent environmental standards and regulations.

The Nairobi Water Company is bearing high water treatment costs due to longer dry spells prior to the onset of the annual monsoons, which cause high turbidity in its surface water sources. Similarly in Pakistan, the Water and Sanitation Authority of Rawalpindi has observed higher bacterial contamination of the sources filling Lake Rawal during the dry season. In both cases the utilities have been required to take considerations in account that go beyond traditional operations and approach the respective environmental and water resource authorities to collectively establish policies governing water source protection.

Prior to the February 2009 fires that struck southern Australia, Melbourne Water identified that the utility faced increased risk of bushfires in catchment areas and associated impacts on water quality as a result of extended drought. This perceived risk was proven accurate. The fires damaged approximately 30% of the utility's catchments and affected an estimated 940km of waterways. Rivers and creeks in the catchments were impacted through loss of surrounding vegetation, fallen and burnt vegetation in the water and increased sediment and reduced water quality. Detrimental effects on drinking water quality for Melbourne were avoided, however, given that the utility is able to transfer water between its nine storage reservoirs and rely on those for necessary supply while affected catchments recover from such types of shocks. To minimize prolonged risk to water quality the utility is undertaking rehabilitation work to stabilize soils and thereby reduce erosion and sediment runoff coupled with heightened monitoring. Some rain since the fires has helped some of Melbourne's waterways and catchments start their gradual recovery. It has encouraged vegetation to grow and this natural barrier has reduced the amount of ash and sediment entering rivers and creeks. Case studies from Melbourne and Nairobi are presented in Annex 2

Table 4.3: Technical, Financial & Institutional Complexities

	Technical Complexity	Financial Complexity	Institutional Complexity
Low	The available solutions are present on the market	The proposed action is within the utility's operational mandate and can be financed from the operation and maintenance budget	The proposed solution does not require approval by its consumers, governing bodies or owner and can be done within the operational mandate
Medium	The technical solution requires additional research modification to a specific utility operating under special conditions	The investment program associated with the proposed solution can be implemented only through external borrowing by the local government authority	The investment program will require substantial communication and consensus from consumers and governing bodies
High	A new, technically challenging, solution must be developed	The investment program can only be implemented through substantial financial assistance from the central government or international donors.	The involvement of the central government is required for the resolution of institutional gridlock or establishment of new operational policies.

Climate Monitoring	Technical Complexity	Financial Complexity	Institutional Complexity	Regret	Measure Controlled By	Reference To Text
Establishing Monitoring System for Climatic Effects	Low	Low	Low	No-regret	National authorities / utility	Chapter 4.1.
Downscaling of the GCM	Medium	Medium	Low	Climate justified	utility	

Water Availability	Technical Complexity	Financial Complexity	Institutional Complexity	Regret	Measure Controlled By	Reference To Text
Demand Management	Low	Low	Medium	No-regret	Utility	Chapter 4.2.1
NRW Reduction	Medium	Medium	Low	No-regret	Utility	Chapter 4.2.2
Water Metering	Low	Low	Medium	No-regret	Utility	Chapter 4.2.3
Water Tariffs	Low	Low	High	No-regret	Utility	Chapter 4.2.4
Consumer Behavior and Low Water Use Appliances	Medium	Medium	Low	No-regret	Consumer / Utility	Chapter 4.2.5
Integrated Water Resources Management	Medium	Medium	High	No-regret	External stakeholders	Chapter 4.2.6
Diversification of Water Resources	Medium	High	High	Climate justified	Authorities, utility and external stakeholders	Chapter 4.2.7
Enhancing Storage Capacity	Medium	High	Medium	Climate justified	Authorities, utility and external stakeholders	Chapter 4.2.8
Water Reuse and Desalination	Medium	High	Low	Climate justified	Utility	Chapter 4.2.9
Adjustment to Operation Below Design Capacity	Medium	High	Low	Climate justified	Utility	Chapter 4.2.1

(*continued on next page*)

Water Availability	Technical Complexity	Financial Complexity	Institutional Complexity	Regret	Measure Controlled By	Reference To Text
Aquifer Recharge Using Recycled Water	High	High	High	Climate justified	Utility / External stakeholders	Annex 1 – Namibia
Relocation of Flooded Infrastructure	Medium	High	Medium	Climate justified	Utility	
Market Based Instruments	Medium	Medium	High	No regret	Authorities, utility and external stakeholders	Chapter 4.2.10
Water Quality	**Technical Complexity**	**Financial Complexity**	**Institutional Complexity**	**Regret**	**Measure Controlled By**	**Reference To Text**
Protection of the Water Resource	Low	Low	Low	No-regret	Authorities, utility and external stakeholders	Chapter 4.3.1
Integrated Water Resource Management	Medium	Medium	High	No-regret	Authorities, utility and external stakeholders	4.2.6
Water Distribution	**Technical Complexity**	**Financial Complexity**	**Institutional Complexity**	**Regret**	**Measure Controlled By**	**Reference To Text**
Reduce Effects of Weakened Surface Crust on the Network	Medium	High	Low	Climate justified	Utility	
Adjustment to Operation Below Design Capacity	Medium	High	Low	Climate justified	Utility	Chapter 4.2.1.
Wastewater Collection	**Technical Complexity**	**Financial Complexity**	**Institutional Complexity**	**Regret**	**Measure Controlled By**	**Reference To Text**
Protection of Sewers from Overflow	Medium	Medium	Medium	Climate justified	Utility	Annex 1 – Seattle
Adjustment of Hydraulic Systems to Floods	Medium	High	Medium	Climate justified	Utility	

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(continued)

Wastewater Collection	Technical Complexity	Financial Complexity	Institutional Complexity	Regret	Measure Controlled By	Reference To Text
Reduce Effects of the Weakened Surface Crust on the Network	Medium	High	Low	Climate justified	Utility	
Adjustment to Operation Below Design Capacity	Medium	High	Low	Climate justified	Utility	Chapter 4.2.1
Relocation of Flooded Sewers	Medium	High	Medium	Climate justified	Utility	

Wastewater Treatment & Effluent Discharge	Technical Complexity	Financial Complexity	Institutional Complexity	Regret	Measure Controlled By	Reference To Text
Adjust Treatment Technology to New Effluent Composition	Medium	Medium	Medium	Climate justified	Utility	
Adjust Treatment Level to Dilution Capacity of Discharge Point	Medium	High	Low	Climate justified	Utility	
Relocation of Flooded Wastewater Treatment Facilities	Medium	High	Medium	Climate justified	Utility	Chapter 3.4.2

5. CONCLUSIONS

For many water utilities climate change intensifies existing challenges, risks of demand and supply functions over the medium to long term for water and wastewater services, and adds additional complexities in day-to-day operations. Effective adaptive responses to potential impacts of climate change often compete with other priorities, poor public understanding of risks and a lack of available financial resources. This is particularly true if required adaptation measures call for significant infrastructure investments.

This study demonstrates how water utilities around the world are beginning to consider the potential impacts of climate change and are gradually developing strategies for adaptation. Much of this knowledge remains poorly documented and is largely unavailable to other utilities. There is a need to overcome this knowledge gap through the design and implementation of simple, dynamic and flexible approaches that allow utilities to learn from others.

Urban water managers may wish to consider the following as practical responses to emerging climatic threats: (i) undertake climate vulnerability assessments and identify perceived climatic risks, their likely impacts on water infrastructure, operations and planning; (ii) prepare climate action plans which identify, quantify and prioritize a range of adaptation options, their associated cost and regrets analyses; (iii) strengthen communication and coordination with their consumers and concerned municipal authorities on the potential impacts of climate change; (iv) intensify knowledge exchange between utilities of institutional and managerial experience on addressing climate change, recording and disseminating impacts, and analyzing the cost efficiency and operational effectiveness of adopted adaptation measures.

Undertaking vulnerability assessments will require, among other preparations, the completion of an inventory of assets and the implementation of monitoring systems that consider intake, conveyance, storage, treatment, supply and sewerage networks, wastewater treatment and disposal systems and drainage. Such assessments will benefit from the inclusion of factors that are typically considered to be outside the traditional scope of operations in terms of their influence on a utility's assets. These could include considerations such as spatial development, pollution control, and solid waste and storm water management. An additional consideration for undertaking a vulnerability assessment is the identification of gaps in utility monitoring instruments related to its technical performance and operational costs which will be impacted by climate change.

Building on the vulnerability assessments utilities can apply an analytical framework to select appropriate adaptation. In the short and medium terms climate action plans should establish criteria by which their success can be measured. These might include reduced water loss, increased supply, improved water quality or reduction in structural damage through rehabilitation efforts. As a final step, the action plan should provide timelines against which selected adaptation measures can be reassessed for appropriateness and for making necessary adjustments to the action plan itself.

Successful adaptation to climate change for urban water utilities will require a high level of cooperation and communication between sector stakeholders. Climate change presents an opportunity to improve water consumers and users understanding of the potential impacts on water and wastewater operations, and how there is likely to be an increased cost burden. Certain utilities have begun taking steps to increase public awareness and engage municipal stakeholders on the issues of water and climate change. These measures include fact sheets, websites, and public meetings. Dedicated leadership from both within a utility and also from municipal officials is a critical input to this process, as is the ongoing engagement of city managers.

Effective communication and coordination with sector stakeholders can be facilitated through the dissemination and explanation of the climate vulnerability assessments and action plans to create awareness and understanding of associated risks and proposed responses. Presently, water utilities are largely absent from many national level planning discussions on climate change despite being at the forefront of its impact, and conversely governments are often not involved in public campaigns on water conservation or tariff policy for water services. In addition to improving the participation of utility representatives in climate change dialogue, national governments should facilitate flows of emerging climate related information to utilities, and equally assess the degree to which environmental funds could support possible adaptation measures.

5.1 The Role of the World Bank

One of the objectives of the World Bank is to support development activities by addressing climate change issues in the urban water supply and sanitation (UWSS) sector. The Bank's current portfolio of water related projects—USD 8.7 billion between financial year 2006–2008, is planned to increase to USD 10.6 billion for the year 2009–2010. Nearly half of this budget is allocated to urban water supply and sanitation services.

The implications of climate change may affect the development impact of World Bank projects in the urban water supply and sanitation sector and similarly reduce a nation's capacity to recuperate economic and financial losses incurred from related impacts. The challenges require heightened cooperation at global scale and financial resources necessary to meet the costs of adaptation and mitigation while providing sustainable services.

Yet there is a need to strategically target resources at undertaking climate exposure assessments and utility specific climate action plans to begin streamlining strategic responses. Care must also be taken when considering climate change and its impact on urban water services, that it does not become a justification for overdesigning capital projects and seeking unwarranted financing in the name of adaptation. Clearly, no-regret options will be on the priority list. Critical review of urban water utilities suggests that there is a scope to improve urban water services and suggested priority areas with respect to climate change adaptation could include:

- **Infrastructure –** intelligent and flexible design and operation; cross-sectoral projects; climate smart rehabilitation; and early warning systems
- **Technology –** monitoring and assessment, efficiency improvement and demand management
- **Economics and tradeoff** – decision making under increased uncertainty and risk-based project economic analysis
- **Financing of adaptation** – risk insurance (for systems and for customers, notably the poor)

Funding from the Bank alone will not suffice and resources from elsewhere will have to be generated. The Bank has to encourage local and national governments to take ownership of the issues and leverage additional resources from other stakeholders including private-sector investments. The Bank is well positioned to strategically support urban utilities interested in undertaking climate vulnerability assessments and climate action plans, assisting in the roll-out of decision-making support tools, and the development and delivery of training programs related to adaptation for urban water utilities.

ANNEX 1: ANALYSIS OF QUESTIONNAIRE

The project team conducted interviews with 20 large utilities around the globe. The following Annex presents the analysis of the replies and comments from the utilities.

One of the reasons for selecting these particular utilities was to strengthen the ongoing efforts of the World Bank water programs by documenting the current trends and identifying future requirements to deal with the challenges of climate change. Other criteria for selection were (a) intensity of climate risk, (b) climate change affected region, (c) size of city, (d) availability of information on the current status of water infrastructure including that of non-revenue water loss, coverage of water supply, and condition of reservoirs and treatment plants; and (e) availability of indicator sets such as water consumption, operational cost, tariff collection ratio.

Nineteen water utilities from across the globe were selected using these criteria (see table A.1.1). Collectively these utilities serve more than 100 million people and supply approximately 5.4 km^3 of water per year. Figure A.1.1 describes the location of the selected utilities on a world map.

Water supply for residential use was reported as the primary responsibility of the water utilities covered under study. More than 90 percent of them were also engaged in water treatment and water supply for industrial purposes. Other major responsibilities mentioned by the utilities were wastewater treatment and wholesale treated water supply.

The data suggests that many cities and their utilities have already begun to face extreme climatic variability and its effects on water resources. 80 percent of responding utilities have faced extreme droughts and more than 50 percent have gone through severe rain events (Figure A.1.3). Nairobi Water Company had to apply water rationing due to prolonged droughts and reduced rainfall between

Figure A.1.1: Location of Participating Water Utilities

2000–01 and 2008–09. This reduced the life of its water infrastructure as it ran below the designed optimum capacity. On the other hand, the problem of greater intensity in precipitation patterns was not anticipated when the drainage system of Seattle, USA was designed. The historic hydrologic pattern on which the system was based has significantly altered following the intense rain events of recent years.

Table A.1.1: Participating Water Utilities

Utilities	City/Country	Population served (000)	Volume of water sold, million m^3/year
SABESP	Sao Paulo, Brazil	22,700	1,806
Istanbul Water and Sewerage Administration	Istanbul, Turkey	10,000	365
Dhaka Water Supply and Sewage Authority	Dhaka, Bangladesh	9,100	302
SEDAPAL	Lima, Peru	7,311	395
Empresa de Acueducto y Alcantarillado de Bogotá	Bogotá, Columbia	7,000	270
ROSVODOKANAL	Russia	6,000	438
Hyderabad Metropolitan Water Supply and Sewerage Board	Hyderabad, India	5,875	200
Ningbo Water Supply Company	Ningbo, China	5,646	303
Manila Water Company Inc.	Manila, Philippines	5,000	263
Public Utilities Board	Singapore	4,840	177
Sénégalaise des Eaux	Senegal	4,597	104
Melbourne Water	Melbourne, Australia	3,400	310
Nairobi Water	Nairobi, Kenya	3,000	168
Office National de l'Eau et de l'Assainissement	Burkina Faso	2,180	31
Hanoi Water Works	Hanoi, Vietnam	1,800	106
Seattle Public Utilities	Seattle, USA	594	173
Rawalpindi Water and Sanitation Agency	Rawalpindi, Pakistan	590	32
Dept Infrastructure, Water and Waste Management	Windhoek, Namibia	219	17.5
Empresa Metropolitana de Abastecimiento y Saneamiento de Aguas de Sevilla	Seville, Spain	704	94.7

Figure A.1.2: Services Provided by Water Utilities

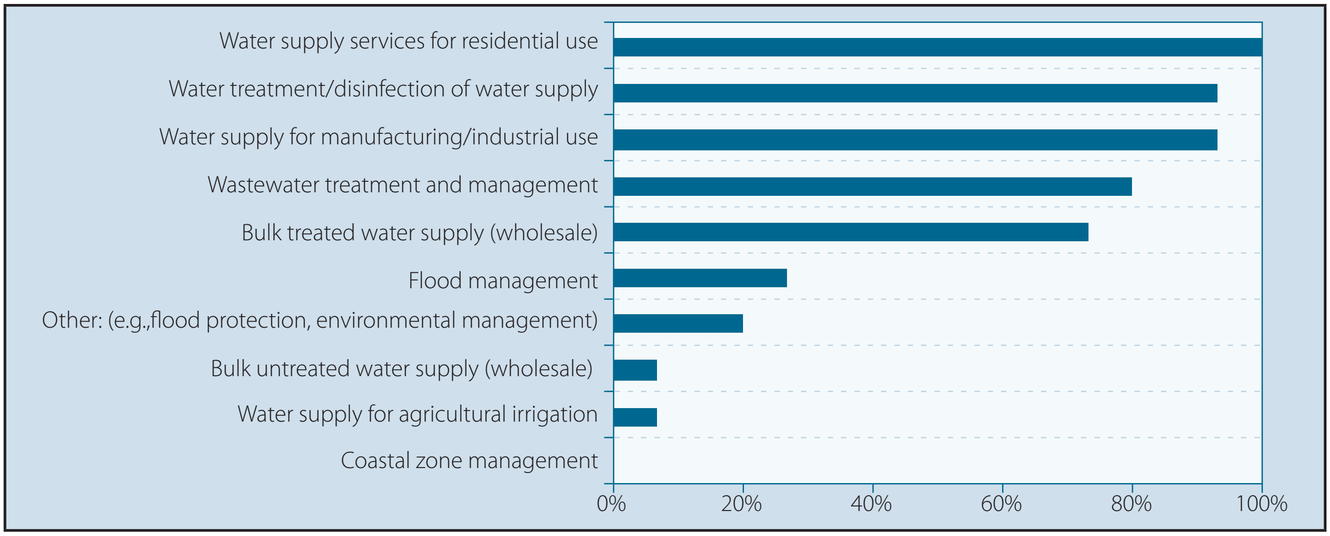
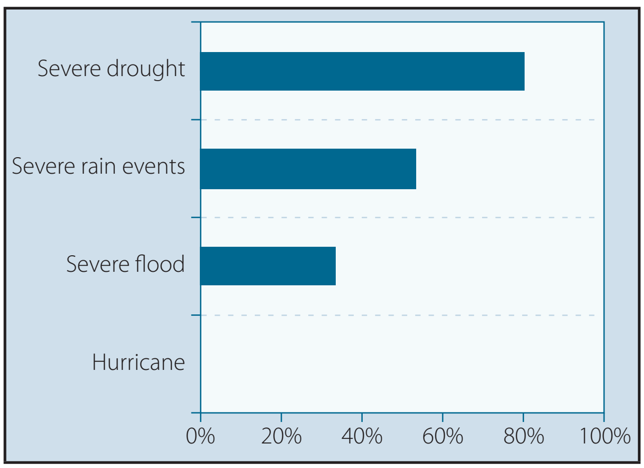


Figure A.1.3: Cities Witnessing Climatic Events



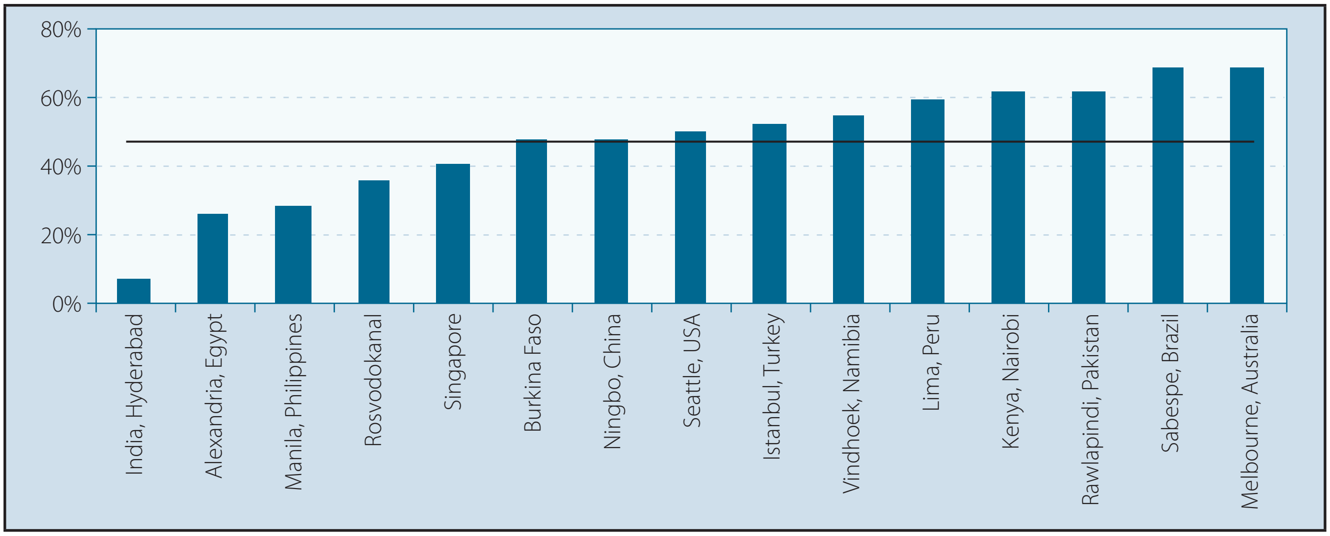
Perception of Vulnerability

The questionnaire sent to the water utilities attempted to capture qualitative and quantitative data on the following aspects of climate change and adaptation measures:

- Recent extreme weather events affecting the ability of the utilities to provide normal services
- Utilities plans to deal with the impacts of climate change and stakeholder involvement
- Assessment of vulnerability
- Adaptation measures being implemented by the utilities as a response to potential climatic and operational impacts on their performance capacities, and
- The limiting factors on further actions.

Each utility identified the potential risk areas and weighted them with a score from one to three (one is low, three is high) (Figure A.1.4). More than 50 percent of the utilities identified decreased surface water as the highest risk to their business. This means that surface structures are the main sources of water to many utilities and they are more susceptible to the negative impacts of climate change due to reduced run-off or heavy rate of siltation during extreme rain events and reduced vegetation in catchments, high rate of evaporation etc. Utilities like ONEA in Burkina Faso, whose 70 percent of total water supply comes from dam reservoirs face this challenge more severely. Other major concerns raised were increased urban demand for water (45 percent) and decreased surface water quality (42 percent). Notably more than 30 percent of the utilities have raised concerns about the difficulties faced in incorporating climate change risks into planning processes due to limitations of climate models in predicting risks with accuracy. In fact, the changes in weather conditions across the world are so recent that it might prove to be too early to claim something based on the current trends. Furthermore, climatic events remain volatile and render historic weather

Figure A.1.4: Perception of Exposure to Climate Change



data unreliable in planning for the future. That is why even though they have been experiencing variability in rainfall, utilities such as Seattle are not in a position to say that that climate was *directly* impacting their ability to manage their functions. Similarly, currently ROSVODOKANAL in Russia does not make allowance for climate change factors in its investment activities, because the utility judges it is too early to conclude the estimates of the impact of climate change on its performance.

In a response to a question asking the utilities about which resources they use to estimate potential climate change impacts, around 60 percent mentioned that they have commissioned research studies to measure future impacts on their business. The outcomes of one such study commissioned by ISKI serving Istanbul in Turkey has projected that the water potential of the city might decrease as much as 14 percent in the next two decades. These studies played a vital role in revising ISKI's financial plans and identifying the need to develop effective strategies and adaptation plans. Other sources for more information on potential risks is the research done by other institutes, national governments, IPCC reports and climate change scenarios developed to meet the requirements of the utilities (Figure A.1.5).

A wide variety of actions have been implemented to meet the challenges, however 80 percent of the utilities put the highest emphasis on reducing water consumption, improving watershed management, and reducing non-revenue water losses due to leakages (Figure A.1.6). These measures have a direct impact on the quality and efficiency of water supplied, and so have a positive impact on the performance of the utilities. Other significant actions taken by the utilities include increasing water augmentation from ground and surface sources, waste water treatment, better coordination and management of infrastructure and incorporating climate change considerations into planning processes. However, not all these actions are taken explicitly to deal with climate change. For example, Windhoek in Namibia is located in the most arid region of sub-Saharan Africa and so the city's water utility has adapted water efficiency and use of recycled water for many decades. Cities like Rawalpindi in Pakistan and Hyderabad in India are constantly searching for new sources of water due to increasing population pressures in these cities. Even though these actions generate positive impact on the efficiency of the utilities, incorporating climate change risks in their planning will strengthen the utilities' resistance to deal with them.

Some cities and their utilities are taking steps to increase public awareness and engage municipal stakeholders on the issue of water and climate change. These actions include fact sheets, websites, and public meetings. The results show a mixed response from stakeholders to the issue of

Figure A.1.5: Exposure to Potential Climate Change Impacts

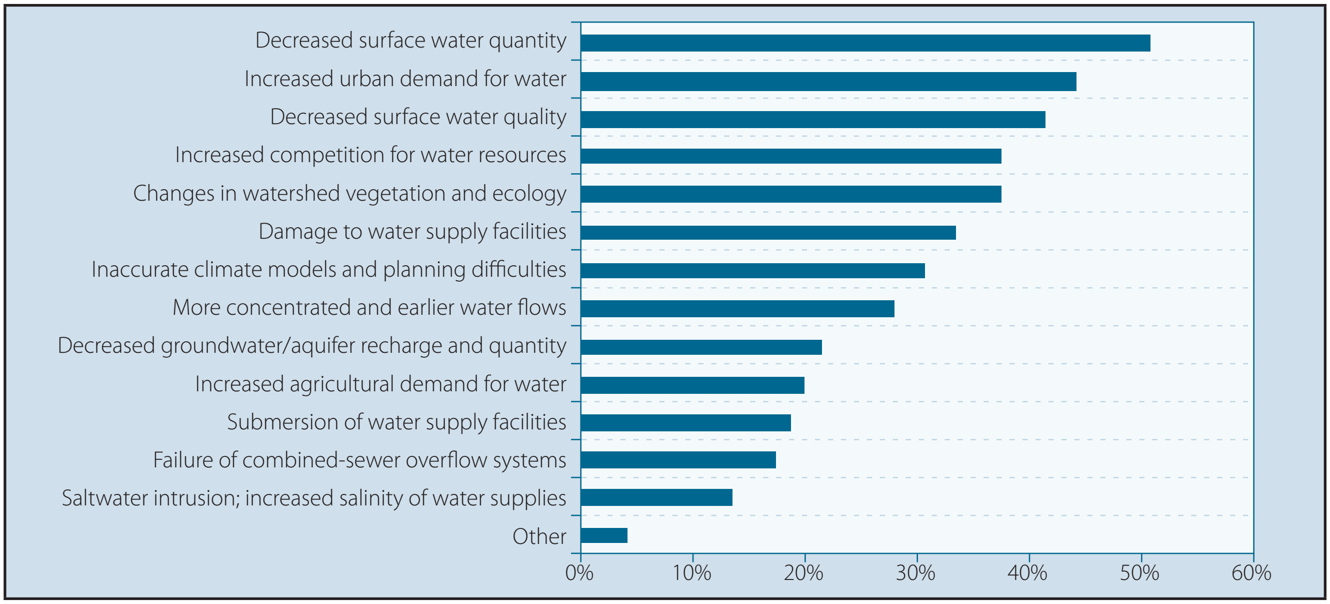
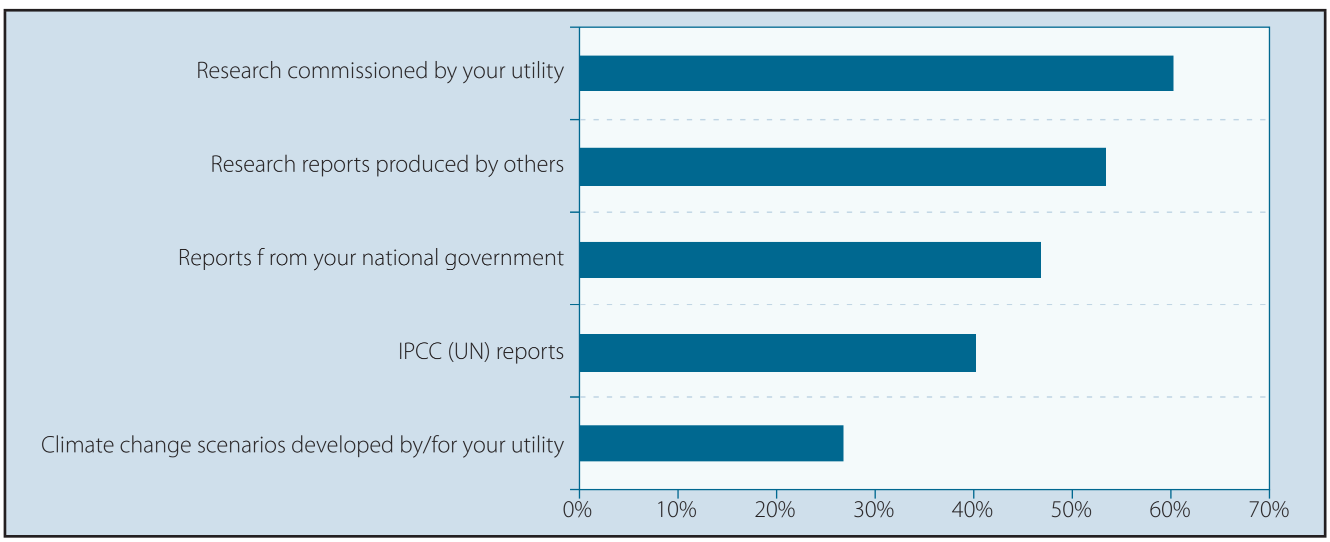


Figure A.1.6: Resources Used to Estimate Climate Change Impacts



climate change. Universities and government agencies have been actively involved in the discussions on the impact of climate change, but participation from household and industrial customers is as low as 15 percent. This clearly indicates that the urgency and concerns felt by the utilities towards climate change risks are not echoed by their customers in the same way. The analysis reveals that 67 percent of the total utilities studied are deeply concerned about the challenges, but according to them only 13 percent of their customers are sharing their concerns with the same intensity.

Currently, it is a difficult task for most water utilities to take definite actions to curb the impacts of climate change on water delivery. *The major limiting factor is the lack of sufficient and accurate information on how the potential impacts of climate change may affect the functioning of a particular utility. Even now, most of the climate change models are unable to predict climate change impacts at city level.* On the operational front, climate change adaptations need huge investments in building new/ upgrading existing infrastructure, developing new sources and other such initiatives. Frequently, such huge investments are beyond the capacity of an urban water utility. To give an example: the water distribution network in Nairobi, Kenya first built in the early 1920s, now suffers heavy water loss. Nairobi Water Company is lobbying the concerned government departments to get financial support for replacing it. Close coordination and dedicated leadership from both within a utility and also from municipal officials are seen as critical inputs to this process, as is ongoing engagement of city managers.

Figure A.1.7: Actions Taken by Utilities to Address Climate Change

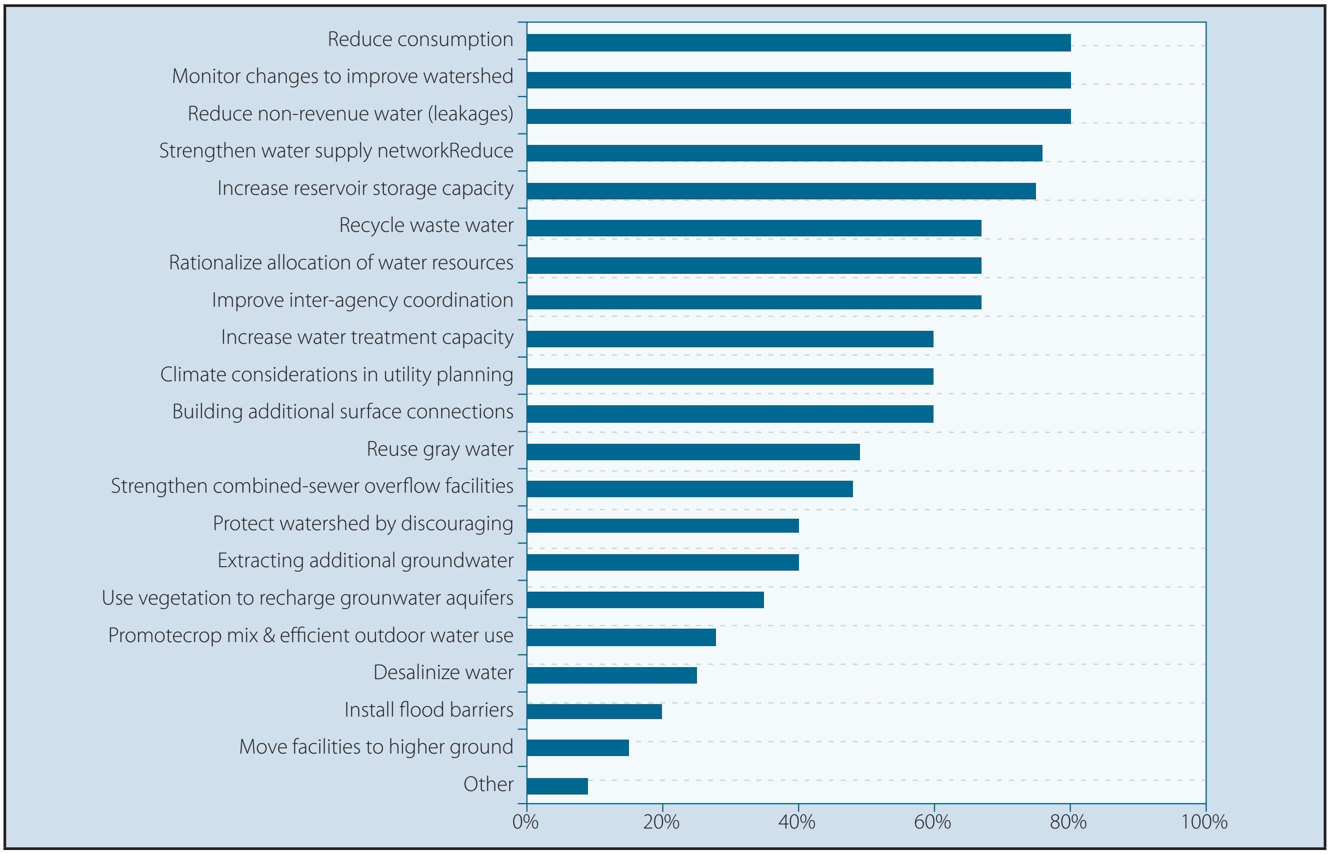


Figure A.1.8: Stakeholders Involvement in Climate Change Discussions

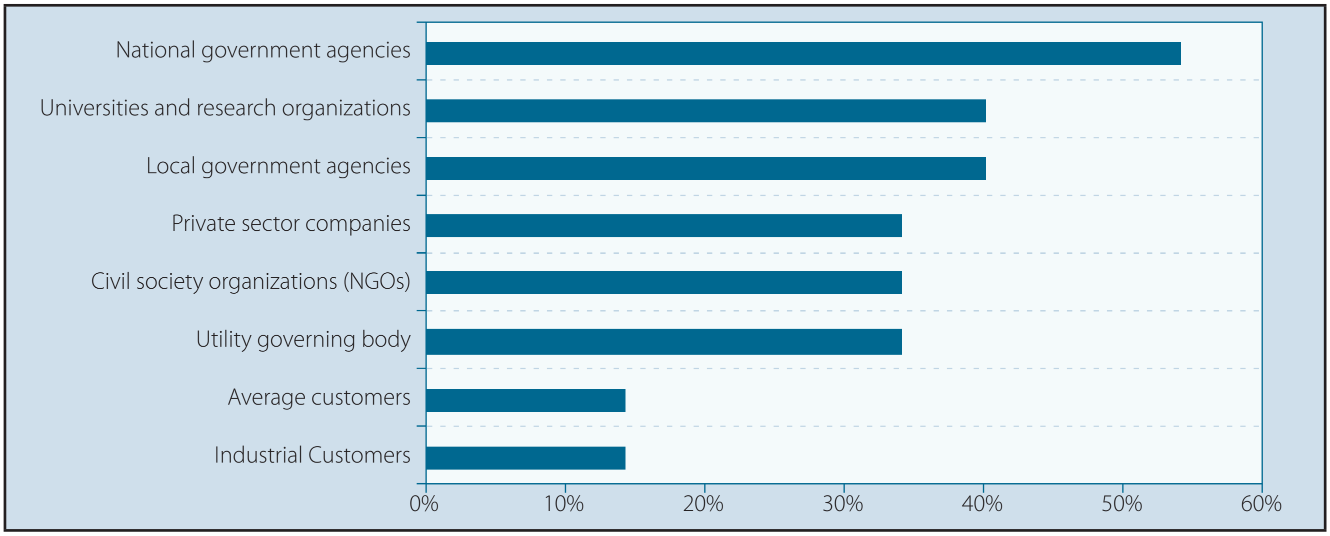
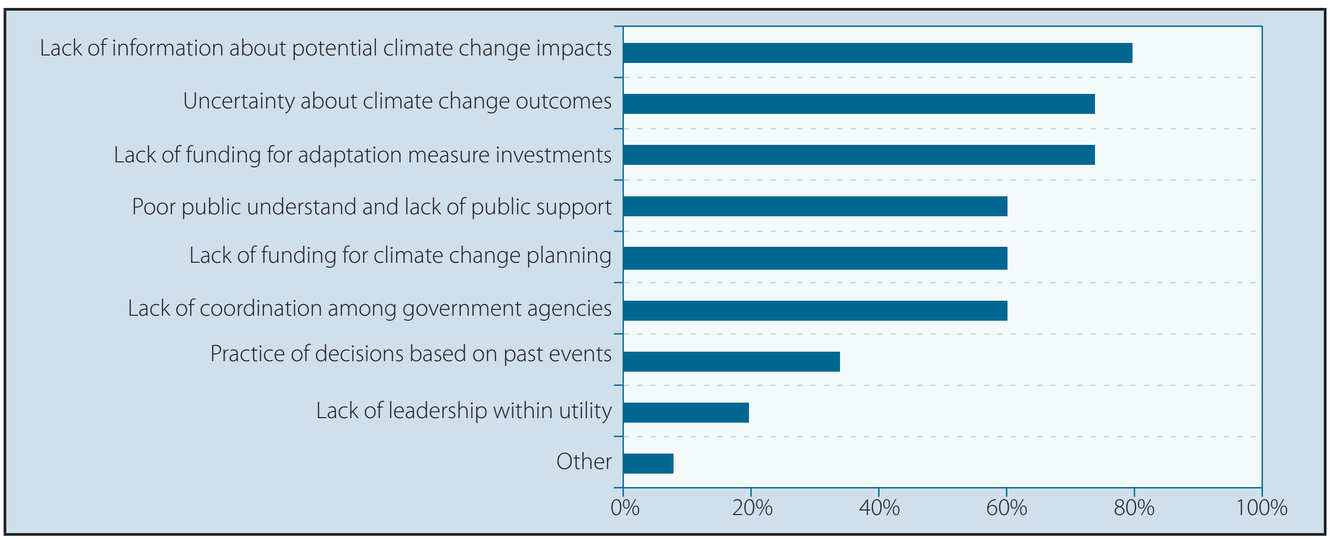


Figure A.1.9: Barriers to Action



ANNEX 2: UTILITIES TAKING ACTION

The findings presented in this section are based on a desk review of relevant cases and an experience-sharing workshop that took place in Madrid, Spain in January 2009. Twenty large water utilities from around the globe participated at the workshop with many providing background papers and completing an internationally distributed questionnaire regarding climate change adaptation.

A.2.1 Public Utilities Board, Singapore

Urban region	Singapore
Population served, million	4.84
Total Water supply (ml/day), 2005	1.20
Total Water supply (ml/day), 2008	1.26
% Water resources, SW	80%
% Water resources, GW	20%
Climate threats	Sea rise

PUB, the National Water Authority of Singapore has implemented a holistic approach in designing, implementing and analyzing its climate change adaptation strategy. PUB is conducting monitoring and streamlining the outcomes and predictions of various research studies in planning for self-sustainability in water supply augmentation. The agency has also adopted a multi-facetted approach for demand management which is a combination of strategies for consumer behavior change, reducing unaccounted water losses to less than five percent, introducing a water conservation tax in addition to water pricing, and enforcing mandatory and voluntary measures for water conservation. Precautions have also been taken against unprecedented weather conditions such as intense rain, flooding and high tides.

Major investments have been made to rehabilitate and separate the drainage system for storm water and wastewater. This has contributed to reducing flood-prone areas from 3,200 hectares (ha) in the 1970s to 124 ha today; the intention is to further reduce at risk areas to only 64 ha by 2011. PUB is taking part in a vulnerability study to understand the impact and implications of climate change on the drainage system. This includes the review of drainage design criteria (IDF curve), new flood maps taking into account climate change impacts and the review of minimum platform areas for developments and land reclamation.

Development regulations have also been put in place for any land reclamation projects to ensure that the impacts of sea level rise can be avoided. Since 1991, all land reclamation projects had to be built at least 125 cm above the highest recorded tide level. With hindsight, this requirement has put Singapore in a stronger position to deal with any future increases in sea levels arising from climate change as the requirement exceeds the IPCC's AR4 projection of the highest sea level rise in the region, 59 cm, by the end of the twenty-first century.

Proactive planning, judicious land use, vigilant surveillance, strict enforcement and public participation are some of the main reasons for the successful implementation of PUB's strategies.

PUB's efforts have been strongly supported by other Singapore Government agencies. The Government has developed a National Climate Change Strategy (NCCS), which documents Singapore's past and ongoing efforts on climate change and sets out future plans to address climate change in the areas of (i) vulnerability and adaptation; (ii) mitigation, (iii) competency-building and (iv) international participation. To better understand the detailed effects and resulting impacts of climate change on Singapore, the Singapore government has commissioned a study of Singapore's vulnerability to climate change. This study will project the changes in temperature, sea level and rainfall patterns in Singapore over this century, and their results such as increased flooding and impacts on water resources.

A.2.2 Empresa Metropolitana de Abastecimiento y Saneamiento de Aguas de Sevilla (EMASESA): Seville, Spain

Utility Name	EMASESA
Urban region	Seville, Spain
Population served, million	NA
Total Water supply (ml/day), 2005	260
Total Water supply (ml/day), 2008	253
% Water resources, SW	100
% Water resources, GW	0
Climate threats	Decreased surface water quantity and quality

With the onset of severe drought in the mid 1990s (see figure A.2.1), and the strategic reserves dipping to a three month 'red alert' level, the water utility of Seville, Spain (EMASESA) was forced to consider a number of extreme measures. These included the seeding of clouds to produce artificial rain, the importing of an iceberg, importing water by boat, and even the possible evacuation of the city. Despite these drastic options, and to overcome the unprecedented drought, the utility employed a number of crucial preventative measures which focused on the optimization of internal facilities and the widespread promotion of responsible use of water.

In Seville, consumers were reached through advertisements on buses, in schools and at the workplace. 'Save Today the Water of Tomorrow' reads EMASESA's slogan.

Photo courtesy of EMASESA.

This experience was central to the utility recognizing that long-term sustainability of water services could not be achieved by boosting supplies alone. With the construction of new reservoirs prohibited, the utility began an aggressive public campaign called 'Save 55' (liters per person per day). The campaign aimed to educate and inform consumers of potential water savings in daily use and provide information on water saving appliances. The results were very encouraging with water consumption decreasing from 179 lpcd in 1991 to 129 lpcd in 2008.

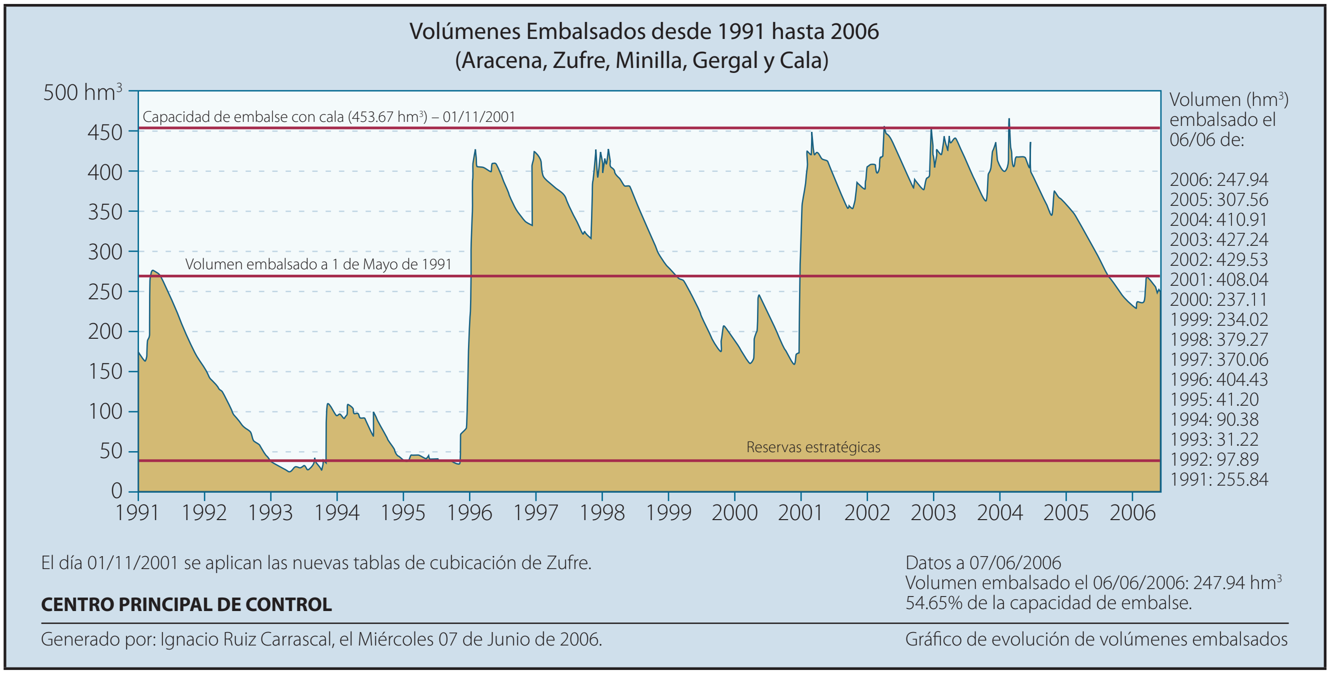
A.2.3 Seattle Public Utility: Seattle, USA

Utility Name	Seattle Public Utilities
Urban region	Seattle, WA, USA
Population served, million	1.27
Total Water supply (ml/day), 2005	577
Total Water supply (ml/day), 2008	560
% Water resources, SW	99
% Water resources, GW	< 1
Climate threats	Failure of combined-sewer overflow systems; Other: changes to hydrologic patterns in the urban environment affecting drainage and wastewater infrastructure

The abundant mountain water and river resources that characterize greater Seattle provides some assurance to local government and the Seattle Public Utility (SPU) that there is sufficient resource capacity to meet current and forecasted water demand. Given the uncertainties in water demand forecasting, however, a proactive planning process that reduces long-term risks and incorporates potential climate change impacts is being pursued.

Currently, SPU serves approximately 1.3 million customers in the King County metropolitan area of Washington State. The Cedar River and the South Fork Tolt River watersheds pro-

Figure A.2.1: Reservoir Volume, Seville: 1991–2006



vide much of the water for King County, but the estimated 40–50 percent reduction in snowpack melt over recent years threatens reservoir recharge rates and ultimately long-term water supply reliability and management of these watershed systems.

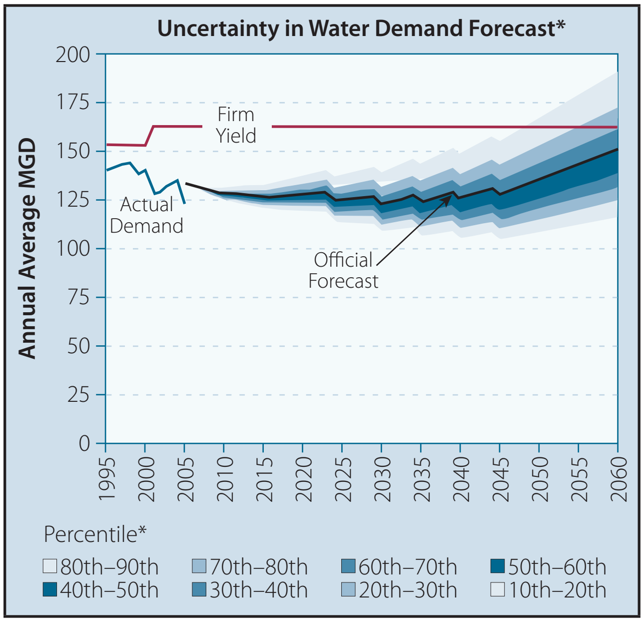
SPU's challenges in planning include: preparing for possible large shifts in demand from customers; changes in legal requirements such as those resulting from new in-stream flow requirements under consideration in the region; potential environmental conservation issues; or an unforeseen severe drought [Kersnar, 2006].

King County and SPU have engaged stakeholders and prepared adaptation plans to address adverse impacts of climate change. SPU has engaged experts and technical institutions to help it better understand and characterize climate impacts and projections. In 2002, SPU partnered with the University of Washington Climate Impacts Group to conduct a study on the potential impact of climate change on its water supply, and to develop methods to better incorporate future climate change into its planning processes. The results of this study included better developed methodologies for translating information from global circulation models to the local watershed (also known as downscaling techniques).

The study team used four loosely linked global climate models, applied statistical downscaling to the Cedar and Tolt watershed levels, and integrated the process with watershed hydrology modeling and systems simulation modeling. These methods helped to reduce uncertainties and project possible future climate impacts. The results included projections of 1.4°F to 2.3°F temperature increases by 2040; more frequent low snow-pack years; and an average decline of 3.4 percent per decade in water supply.

In partnership with the Cascade Water Alliance, Washington State Department of Ecology, and King County, SPU sponsored additional research to identify possible improvements to operational flexibility in its systems. In its recent 5-year plan, SPU identified several research and knowledge gaps. These included flood frequency, precipitation intensity and timing, water demand, and the need to develop scenarios for conditions not yet experienced on record. Modeling to address the effects of these changes on operations was also needed. A key strategy for SPU is to address demand side stresses on the water systems by promoting and

Figure A.2.2: Water Demand and Supply Options, Seattle Public Utilities



Note: Percentiles represent the probability that actual demand will be less than the value shown. Ranges reflect uncertainty in projected household, employment, price and income growth, price elasticity, income elasticity, and conservation. Note that the Official Forecast is at about the 57th percentile.

implementing water conservation programs. These initiatives are driven primarily by a desire to be proper stewards of the region's natural resources, to stretch current water resources as far as possible, and to reduce costs, rather than climate change [Kersnar, 2006].

More broadly, in 2005, King County established a Global Warming Action Team, comprising representatives from a variety of county offices, including the budget office, water planning, solid waste, and other relevant departments. In February 2007, the group produced the 2007 Climate Plan, which laid out goals and actions across various sectors to address climate change impacts.

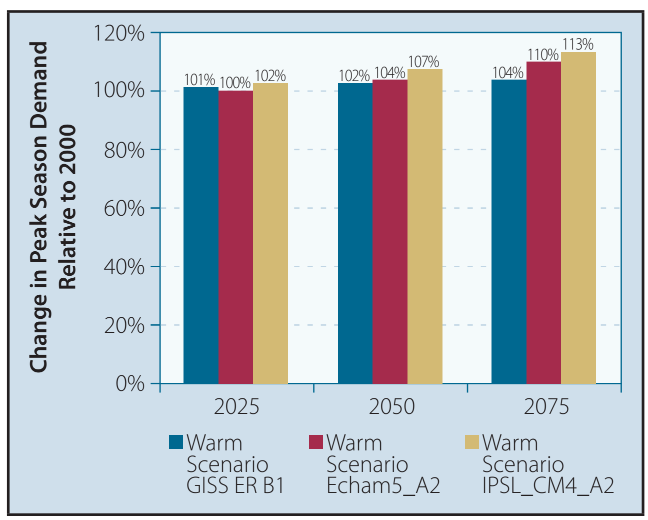
In September 2007, King County, in partnership with the University of Washington and others, released a comprehensive manual for municipal governments entitled Preparing for Climate Change: A Guidebook for Local, Regional, and State Governments. Among the sectors examined in this guidebook were water resources. Steps to assess vulnerabilities to climate change and methods to develop adaptation plans were developed.

Between 2004 and 2006, the University of Washington ran four different global circulation models using the IPCC Special Report Emissions Scenarios, and downscaled them to better characterize local impacts at the Cedar and Tolt watershed levels. SPU created scenarios for 2020 and 2040 to examine potential impacts on decisions about future supply using the results from this study. The results included:

- In 2020, the study projected reduction in water supply by 50,000 m^3/day to 600,000 m^3/day. Under this scenario, there would be no impact on SPU's ability to meet its projected demands in 2020.
- In 2040, the study projected a reduction in yield of approximately 100,000 m^3/day to 556,000m^3/day. Existing sources should still be able to meet the demand forecast through to 2053, assuming no further decreases in yield after 2040.

SPU plans to continually analyze and refine its data gathering and information processing procedures in an effort to

Figure A.2.3: Change in Peak Season Consumption with Climate Change Scenarios



Peak season is May through September. Percent changes consider only climate change and do not include changes in the demand forecast.

Figure A.2.4: Change in Water Supply with Climate Change Scenarios Plus Tier 1 Response

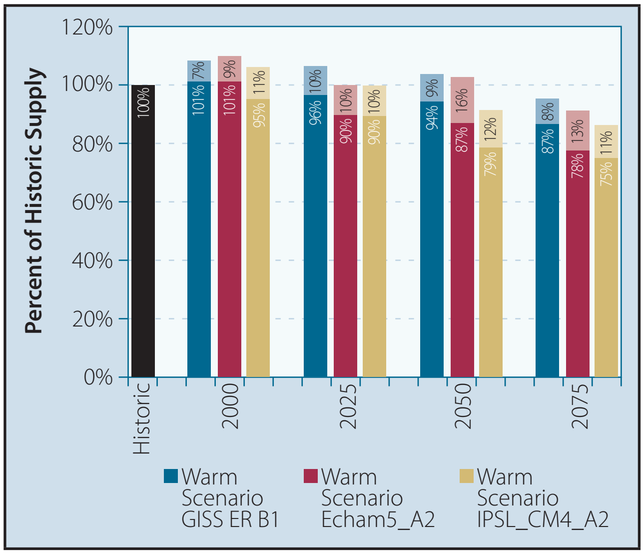
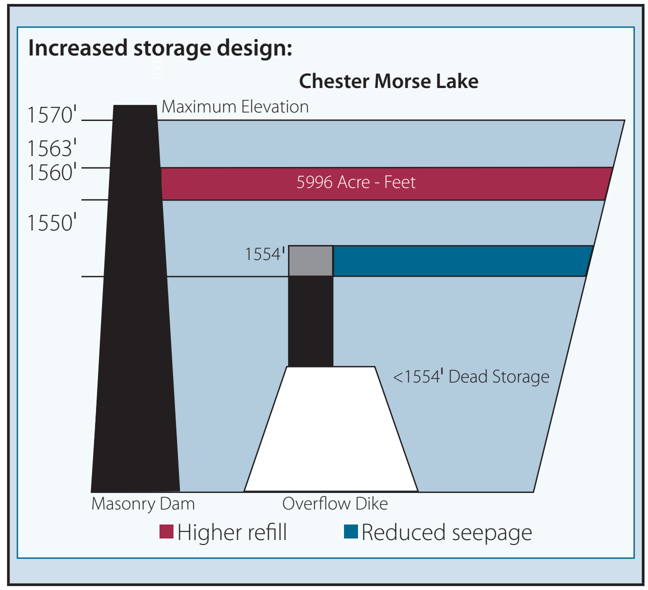


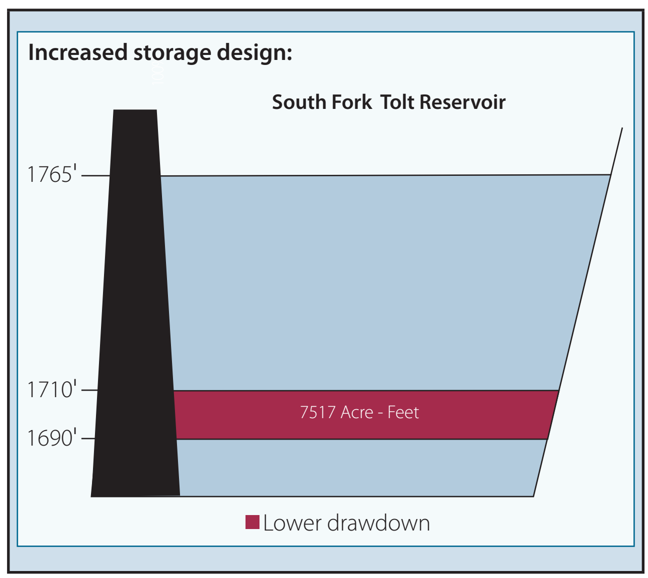
Figure A.2.5: Increased Storage at Chester Morse Lake



improve decision-making processes and better accommodate climate change factors. In addition, the utility has identified a series of adaptation strategies to enhance its water supply system and reduce the impacts of climate change, including operational changes such as managing flood storage capacity and reservoir refill, and investing in infrastructure development and retrofits. SPU's climate adaptation strategies, based on as much reliable data, projections, and scenario simulations as possible, are aimed at ensuring that decisions do not result in unnecessary costs. In attempts to further manage the cost burden associated with climate change, SPU is encouraging improved system management and operational flexibility to allow for variability. In 2005 low snow pack reduced the probability of floods from snow melt. In response SPU captured more water in storage earlier than normal which facilitated returning to normal supply conditions by early summer, despite the lowest snowpack on record. It also demonstrated the flexibility in the water system to adjust operations for changing weather conditions, whether they are low snowpack or abnormal levels of precipitation.

SPU's programs also help to mitigate demand side impacts and serve as insurance for managing future climate change. The utility is aiming to conserve roughly 15% of current demand by 2030 through behavioral modification, pricing strategies, technical assistance and incentives, promotion of devices that reduce water use to residents and commercial customers.

Figure A.2.6: Lowered Drawdown at South Fork Tolt Reservoir



In addition, the utility has identified some alternative capital investments for water supply. These alternatives were illustrated in detail in the SPU 2007 Planning document and include alternatives such as construction of a pumping station at Chester Morse Lake (USD$26.2 million); a river diversion project at North Fork Tolt (USD$179 million); and the development of the Snoqualmie Aquifer, with a new filtration plant, pump station and associated pipelines (USD$114.9 million). [Kersnar, 2006]

A.2.4 Melbourne Water: Melbourne, Australia

Utility Name	Melbourne Water
Urban region	Melbourne, Australia
Population served, million	3.8
Total Water supply (ml/day), 2005	261
Total Water supply (ml/day), 2008	286
% Water resources, SW	100
% Water resources, GW	0
Climate threats	Decreased surface water quantity; Increased urban demand for water; Increased agricultural demand for water; Changes in watershed vegetation and ecology; Inaccurate climate models and planning difficulties; Increased competition for water resources

Climate change is recognized as presenting significant risks and challenges to the water industry and Melbourne Water works collaboratively with the Victorian Government, particularly the Department of Sustainability and Environment, in areas related to climate change and the assessment and management of associated impacts on the water sector.

The Melbourne water supply system supplies a population of around 3.8 million people and has developed since the late 1800s. It is a surface water supply system relying on large surface storages to provide reliable supplies during drought periods. Total system storage capacity is 1,773,000 megalitres (ML). The largest reservoir in the system is Thomson Reservoir, which has a capacity of 1,068,000 ML, which is equivalent to around four times the mean annual streamflow. Storage volumes are heavily influenced by climate variability and change.

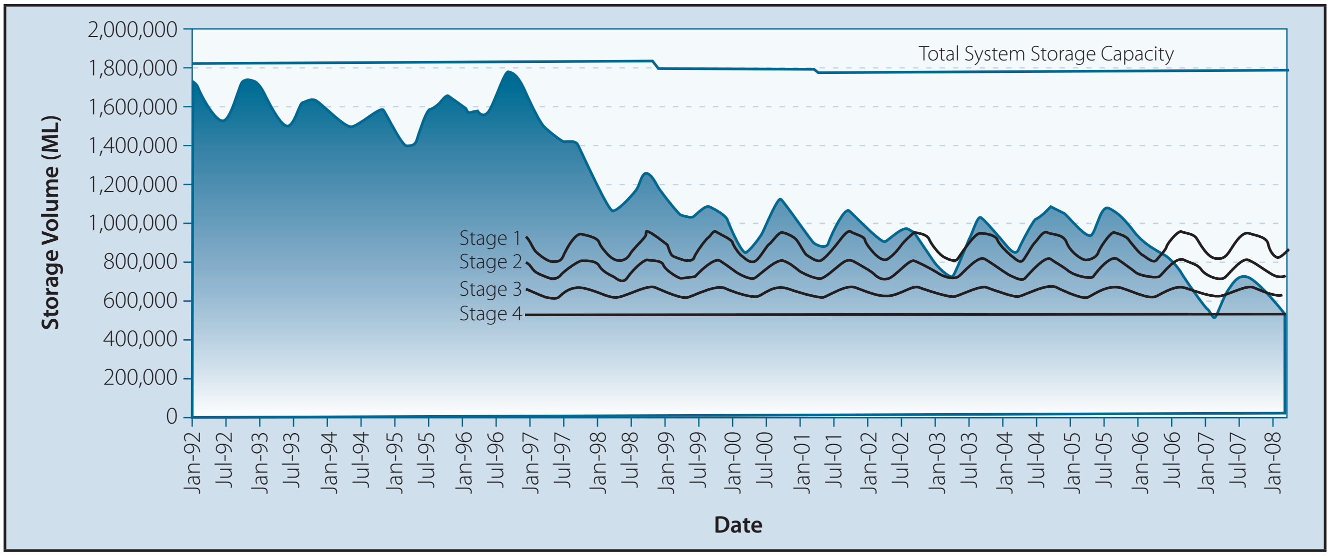
Since 1997, south eastern Australia has had an extended period of below average rainfall and higher temperatures. This has resulted in streamflows into Melbourne's main water storages being around 39% below the long term average recorded to 1996 (see Figure A.2.7) and storage volumes falling from full capacity levels in 1996 to levels (December 2008) of around 34%. The reduction in streamflow since 1996 has exceeded the projected severe climate change reductions for 2050.

In 2005 Australia's Commonwealth Scientific and Industrial Research Organisation (CSIRO) and Melbourne Water completed a major collaborative study to assess the implications of climate change for Melbourne's water supply system. This study identified over 150 risk areas for Melbourne's water, sewerage and drainage systems and included detailed case studies on long term water supply/demand, urban flooding and sewer overflows from the trunk sewer system (see Box A.2.1). The study projected changes in temperature, evaporation, rainfall, streamflow and yield in 2020 and 2050 (see Table A.2.1).

Melbourne Water's impact analyses and climate change adaptation process have included stakeholder engagement, starting with internal company meetings and extending to public workshops. This outreach was aimed at better understanding stakeholder perspectives on climate change impact on its water systems, and including these in methodologies and techniques for impact assessments. The following three major risk areas related to climate change impacts were identified:

- Water supply systems where the primary risks are reduced water quantity, deterioration of water quality, and increased wildfire incidents due to decreased precipitation and stream flows. Wildfire poses extreme risks to water quality.

Figure A.2.7: Melbourne Water Storage Since 1992



Box A.2.1: Potential Climate Change Related Impacts, Melbourne

- Water supply:
  - Reductions in rainfall and changes to rainfall-runoff processes leading to reduced water supply yield and availability
  - Changes in drought frequency and variability of seasonal rainfall and streamflow patterns with associated implications for water supply yield, system operations, water quality and in stream environmental health.
  - Increased risk of bushfires in catchment areas and associated risk of water quality issues and long term reductions in streamflow due to the re-growth characteristics of Melbourne's forested catchments
  - Reduced environmental conditions with associated implications for water harvesting in regulated and unregulated streams
  - Changes to water demands due to higher temperatures and changes in water use patterns
  - Changes to estimates of probable maximum rainfall with implications for the design of major spillways
- Sewerage Systems
  - Increased potential for corrosion and odours in the sewerage network as a result of increased sewage concentrations associated with water conservation, increasing ambient and seasonal temperatures, and longer travel times within the sewer network
  - Increased incidence of sewer overflows due to increased rainfall intensity during storms
  - Changes to infiltration rates in sewer systems
  - Increased risk of pipe failure and collapse due to changed soil moisture levels and associated subsidence
  - Increased salinity levels in recycled water due to rising sea levels resulting in increased infiltration to sewerage network and at wastewater treatment plants
- Drainage
  - Increased flooding risk and property damage due to increased rainfall intensity during storms
  - Increased risk of damage to stormwater infrastructure and facilities (e.g. underground drains, levee banks, pump stations etc) due to higher peak flows
- Receiving waters
- Reduced health of waterways due to changes in base flows
  - Potential for negative water quality impacts in Port Phillip Bay due to increased concentration of pollutants entering the Bay (as a result of longer periods between runoff events and then high intensity events leading to concentrated pollutant runoff), and higher ambient Bay water temperatures.

Table A.2.1: Melbourne Water Projected Climate Change Impacts

	2020	2050
Temperature	0.3˚C to 1.0˚C (mid range 0.5˚C)	0.6˚C to 2.5˚C (mid range 1.4˚C)
Evaporation	1% to 7% (mid range 3%)	3% to 18% (mid 8%)
Rainfall	–5 % to –0% (mid range –2%)	–13 % to 1 % (mid range –4%)
Streamflow	**–3 % to –11% (mid range–7%)**	**–7 % to –35 % (mid range –18%)**
Yield	–4 % to –15% (mid range –8%)	–10 % to –40% (mid range –20%)

- Sewerage systems, where there are four primary risks: increased siltation in sewerage systems due to water conservation, increasing temperatures, and subsequent corrosion of piping systems; increased incidence of sewer overflows from more intense rainfalls; increased risk of pipe failure and collapse due to dry soil conditions; and increased salinity levels in recycled water from rising sea levels.
- Drainage, where there is a risk of increased flooding and property damage from more intense storms, and an increased risk of damage to storm water infrastructure and facilities due to higher peak flows.

Potential adaptation measures were identified for each of the above components of the Melbourne Water service areas. Regarding the water supply component, the following adaptation measures were proposed:

- Improve sensitivity and risk assessments by looking at cumulative factors and impacts, examining more case studies of high-risk and worst case scenarios for lessons learned, and identifying best practices to reduce uncertainties and risks in climate and hydrological projections
- Consider climate change impacts carefully in the design, planning and operation of major resource management systems
- Promote no-regrets policy options
- Explore potential adaptation measures such as desalination, recycling, markets and pricing
- Prioritize planned activities to maximize resilience against climate change
- Review engineering design criteria adopted for planning purposes

Figure A.2.8: Melbourne's Communication Campaign

Photos courtesy of Melbourne Water

Melbourne Water pursues an aggressive public awareness campaign in response to the extended drought that the region has been experiencing for more than a decade. This includes regularly publishing brochures and booklets, announcing rainfall quantities, river levels and storage volume of their reservoirs, providing weekly water updates and restrictions information, and advertising through various media channels and in city taxis.

No financial subsidies are provided by Federal or State Government for climate change adaptation, mitigation or drought response activities for Melbourne's water supplies. The metropolitan water sector funds all capital and operational activities through charges on water customers which comprise a service charge, a pay for use component consisting of a rising block tariff and a sewerage disposal change. Melbourne Water recovers its costs through charges to the retail water companies. The water prices are expected to double by 2012/13 to recover the costs for supply augmentations and other activities.

A.2.5 City of Windhoek, Namibia

Utility Name	Water and Waste Management
Urban region	Windhoek, Namibia
Population served, million	3
Total Water supply (ml/day), 2005	55
Total Water supply (ml/day), 2008	60
% Water resources, SW	65–80
% Water resources, GW	5–20
% Water resource, Reclaimed	15–35
Climate threats	Decreased surface water quantity and quality; Decreased groundwater / aquifer recharge and quantity

The City of Windhoek has not specifically embraced the possible effects of climate change in its long term planning for water supply. It is a fact that everything the city administration plans, hinges on the availability of water as Windhoek has been living the effects of climate change for many years and variable weather patterns are the norm for its area. Since the early seventies, Windhoek has relied heavily on surface water collected from a random rainfall pattern, leading to a situation where the conjunctive use of groundwater, surface water and purified wastewater has become an integral part of water supply. Wastewater is fully recognized as a resource and potable water could contain up to 35% reclaimed water.

Water resources

The City of Windhoek is situated in the central highlands of the country. The country's only perennial rivers are located in the very south, and the very north roughly 900 and 750 km from Windhoek. In the interior, there are only ephemeral rivers. These normally run for 1 to 4 days after a rainfall event.

With an annual rainfall of 360 mm, and an annual evaporation of 3400mm, water supply to a growing Windhoek, remained very difficult. Between 1973 and 1987, Government built three dams, combined capacity of 154 Mm^3 (95% assured yield of 17 Mm^3 and 98% assured yield of 6 Mm^3 p/a) on ephemeral rivers between 70 and 200 km from Windhoek. These dams were totally dependent on seasonal rainfall and extremely susceptible to evaporation.

The supply to Windhoek is also improved by bringing water from the Tsumeb and Grootfontein Karst areas, which is some 525 kilometres from Windhoek. This water is transported in an open canal over a distance of 300 kilometres to the first of the three dams, from where it is pumped to the main storage dam, where water from all three dams is treated before being pumped over 70 kilometres to Windhoek.

The long term defined augmentation option for Windhoek, is to pump water from the Okavango River over a distance of 350 kilometres and an elevation of 800 metres to Grootfontein. From there the water gravitate via open canal to the Omatako Dam, from where it will be pumped via existing pipeline to the Von Bach Dam, where water from all three dams is treated before it is pumped to Windhoek.

The Goreangab Water Reclamation Plant

The continued stressed water supply situation and unavailability of alternative sources, led the City to use sewage effluent as a water resource. Experimental work started in the early 1960's with a pilot plant at Windhoek's Gammams Sewage Plant (Gammams) and another pilot plant in Pretoria. After a number of years of experimental work at the two pilot plants, and upon the achievement of favorable results, the Municipal Council of Windhoek, resolved to implement potable reclamation in Windhoek. The Goreangab water treatment plant was converted to treat water from the Goreangab Dam as well as treated sewage effluent from Gammams.

The final product water is blended with borehole water before distribution to the City. This was the start of direct potable reclamation at Goreangab Water Reclamation Plant (GWRP). The Goreangab plant had an initial capacity of 4300 m^3 per day, and could supply up to 25% of the daily demand at the time.

The GWRP was upgraded four times between 1969 and 1992. By 1992 the capacity of the GWRP was 7500m^3 per day, meaning that 15% of demand could be satisfied from reclamation. During the drought of 1996, the main supply dam serving the City went below 6% and water had to be taken from an emergency storage. Feasibility studies indicated that increased reclamation of sewage was the only readily available option and in 1999 construction on a new reclamation plant of 21Mm^3 per day was started. The New Goreangab reclamation plant was put into operation in 2002 and forms one of the pillars in the supply chain to the City, supplying up to 35% of the daily demand of the City.

Water demand management

Measures implemented included rising block tariffs providing for a lifeline support of 6m^3 per household per month at a subsidized tariff, a middle block up to 36m^3 per month at cost recovery tariff and a penal block above 36 m^3, calculated at long run marginal cost, currently roughly double cost recovery.

Due to the extreme evaporation rate, it is mandatory for all private swimming pools to be covered when not in use. All new water installations are to be fitted with low flush cisterns and water saving shower heads and taps. Public facilities are not allowed to have self flushing urinals.

The City promotes the establishment of drought resistant gardens and during times of short supply, hose pipe bans and restricted hours of garden irrigation is enforced. This has led to a marked reduction in sizes of cultivated gardens and people in the City being water aware. In cases of excessive use, the City would install flow limiting devices to supply points.

Water demand management has slowed the growth in demand and reduced the per capita water demand from 252 lpcd in 1996 to 198 lpcd in 2008

Semi purified irrigation

During 1993, Windhoek introduced a dual pipe system to supply all parks and sports fields with semi purified irrigation water. Due to high evaporation rates, irrigation requirements for sports fields are high and equates to roughly 1000 mm per year. Due to the unavailability of fresh water, secondary treated waste water is put through the Old Goreangab Reclamation plant where it is treated via dissolved air floatation (DAF), sand filters and light chlorination, before being distributed through the dual pipe system and three reservoirs. This water is made available at a subsidized tariff and makes it possible to have City gardens and sports fields of fair quality. The current capacity for the supply of irrigation water is 5mm^3 per day, and includes one golf course, which is fully irrigated with semi purified waste water.

Artificial aquifer recharge

The City is built on a substantial aquifer. The limiting factor however, is that the natural recharge of the aquifer on average, is calculated as 1.73 Mm^3 per annum. This means that in the time it has been exploited, the aquifer has been over-exploited by some 22 Mm^3, which is equivalent to the current annual demand of Windhoek. Due to the variable inflow into the three dams serving Windhoek (83%) and other consumers (17%) in the Central Areas of Namibia (CAN), an operational regime has been introduced where, after each rainy season, the available water is allocated such that the water will last until after two subsequent rainy seasons, if no additional inflow is received. This requires the dams to be operated at the highest possible levels, which makes it extremely susceptible to evaporation.

Windhoek started in 1997 to investigate the feasibility of artificially recharging the Windhoek aquifer, which is a highly fractured hard rock aquifer. This feasibility study, as well as a study commissioned by Bulk Water Supplier, NamWater in 2004, confirmed that the project was indeed the best option for augmentation of water supply to Windhoek. Agreement was reached that at all times when the main storage dam was above 40%, all surplus water would be treated to potable standard and stored in the Windhoek Aquifer. During drought periods, the aquifer would then be able to meet the City's needs for up to two years. As soon as the dams receive inflow, the water bank in the aquifer can then again be recharged. This project does not add additional sources of supply, but optimizes the currently available sources and secures the supply situation to acceptable level.

Aquifer protection measures

During 1999/2000, the City undertook an aquifer vulnerability study, followed by an environmental structure plan for the Southern Windhoek bowl. From these studies, it became evident that, due to open geological structures in a highly fractured aquifer zone, development in the southern part of the bowl should be limited. In order to protect the aquifer, the City resolved to reduce the available number of developable residential plots in this area, from 17 000 to 7000 plots. The loss of these plots in an area already short on developable land, as well as the loss of potential revenue from the sale of these plots, is a clear indication of the City's commitment towards planning for water security. The Windhoek aquifer was similarly accepted as a strategic resource which has to be protected at all cost.

Water system financing

New infrastructure is financed from loans, either from own resources or commercial sources. During 1997 / 1998 the City concluded loans from the German Development Bank (KfW), and the European Investment Bank (EIB), for the construction of the New Goreangab Reclamation Plant and other water and waste water infrastructure. These loans have 20 yr periods and were obtained at interest rates of 7% and 11% respectively. The City has been attempting to find €20 million in donor funding for the artificial recharge project, but has been unsuccessful. Financing of the water operations comes from a two tier tariff: "availability charge" and a "consumption charge". The availability charge is aimed at recovering the capital cost and the consumption charge is aimed at recovering operational cost.

A.2.6 New York City: New York, USA

Utility Name	New York City Department of Environmental Protection
Urban region	New York City, NY, USA
Population served, million	
Total Water supply (ml/day), 2005	5.00
Total Water supply (ml/day), 2008	5.12
% Water resources, SW	90%
% Water resources, GW	10%
Climate threats	Water quality impairment from extreme events and temperature rise, Flood damage from sea level rise and extreme events

The watershed of New York City's 19 reservoirs and three lakes includes parts of eight counties. Its water supply system includes two surface water supply systems with a total of 580 billion gallon capacity (Catskill/Delaware Watershed and Croton Watershed); one groundwater system (Brooklyn/Queens Aquifer); and 23 total lakes and reservoirs. The New York City Department of Environmental Protection

(NYCDEP) is responsible for operating and protecting New York's water supply system, which serves nine million residents. The system delivers about 1.35 billion gallons of water per day [Lloyd, 2005].

The city's location on the bank of a river and proximity to the coast make it particularly vulnerable to climate change impacts such as sea level rise and flooding. The size and importance of the city's at-risk assets make planning for climate change an imperative.

Public awareness and partnerships with a range of public and private institutions are cornerstones of NYC's approach to addressing urban environmental sustainability and particularly climate change impacts. Partners in the city's climate change efforts have included a number of universities (Columbia University, Hunter College, the State University of New York), federal agencies such as the National Aeronautic and Space Administration and the Environmental Protection Agency, private companies, and non-governmental organizations. The city and its partners prepared a comprehensive climate change impact assessment in 2000, publishing Climate Change and a Global City: An Assessment of the Metropolitan East Coast Region.

The report reviews the conditions and stressors on six urban systems: coasts, wetlands, water, energy, infrastructure and health. The report assessed the vulnerabilities of these systems to climate change, and developed climate trend scenarios using historical climate information and projections generated from global climate models that have been downscaled to the New York metropolitan area. These climate change scenarios helped to better identify areas of special vulnerability to flooding, hot weather, and other climate change impacts.

NYCDEP established a Climate Change Task Force in collaboration with Columbia University in 2004. In 2006, the city established an Office of Long-term Planning and Sustainability, tasked with helping to integrate adaptation into long-term sustainability planning for the city. Climate change was part of Mayor Bloomberg's challenge to the city on Earth Day 2007, where he announced "PlaNYC 2030," which aims to improve the city's urban environment by focusing on six key elements of the city's environment: air, land, water, energy, transportation and climate change. An advisory board comprised of a variety of public and private sector stakeholders has been tasked with helping the city develop a risk-based cost benefit assessment process and to assess strategies to protect against flooding and storm surges.

The NYCDEP and its partners have examined in detail a variety of the potential impacts of climate change on the various water systems and services for local utilities. Impacts were examined on water supply services, water distributions and sewer systems, and wastewater treatment systems. The city has also proposed a range of adaptation options which are at various stages of planning and implementation. Some of the recently identified impact assessments and adaptation measures by the NYCDEP include:

- *Water quality impairment from extreme events and temperature rise.* Heavy rains can increase pathogen levels and turbidity and increase the need for filtration, which could be prohibitively expensive. The city estimates that filtering the Catskill/Delaware water supply would cost USD$5–USD$10 billion for a plant, plus USD$300–USD$500 million for annual operation and maintenance. Possible adaptation measures include acquiring more watershed land and more intensive management of forests.
- *Flood damage from extreme events.* Communities residing within NYC's watershed will likely experience more flooding as a result of climate change. One significant challenge for NYC's reservoirs, however, is that they are not designed for rapid releases. This would be needed for typical flood control reservoirs, where billions of gallons of water may need to be released from the NYC reservoirs once they reach a certain capacity level. Releasing water from the reservoirs as a flood control measure might reduce the water supply for NYC; thus the authorities have to find a balance between flood control needs and water supply needs. Using current water supply reservoirs as flood control reservoirs is being considered as a possible adaptation measure.
- *Flood damage from sea level rise and extreme events.* High sea levels and heavy rains can cause sewer backup and extensive flooding of streets and basements. Adaptation options include expanding urban greening

programs, such as the increasingly popular and effective "green roofs" initiatives, expansion of other urban green spaces, and soil erosion and sediment control programs to mitigate the impact of storm-water runoff. Construction or reinforcement of flood walls is also an adaptation option to protect water utilities from potential flood damage due to sea level rise.

New York City views adaptation from the perspective of all critical urban infrastructure, including water supply, wastewater treatment, and sewerage systems. Going forward, a citywide strategic planning process for climate change adaptation is underway. Through this process, site-specific strategies will be developed for vulnerable neighborhoods. The city will continue to work with scientific research institutions to reduce uncertainties in climate impact projections and to support decision making. NYCDEP and local utilities will also aim to reduce vulnerabilities to the water supply by addressing demand side pressures, such as promoting water conservation and water efficiency measures, retrofits, and re-designs of existing infrastructure to promote system flexibility.

A.2.7 Manila Water Company: Manila, Philippines

Utility Name	Manila Water Company Inc
Urban region	Metro Manila, Philippines
Population served, million	5.6
Total Water supply (ml/day), 2005	864
Total Water supply (ml/day), 2008	1,060
% Water resources, SW	99
% Water resources, GW	1
Climate threats	Decreased surface water quantity and quality; Increased urban demand for water; Damage to water supply facilities; Changes in watershed vegetation and ecology; Increased competition for water resources

The Philippines' water sector is one of the sectors most affected by climate change. In November 2007, Manila Water launched its climate change policy which places a strong emphasis on *mitigation* of climate change. The policy highlights four commitments that the company will undertake.

Development and implementation of a carbon management plan: Manila Water is currently developing its carbon management plan and finalizing its 2007 and 2008 carbon footprint. Once the figures have been finalized, Manila Water will report them to key stakeholders along with the carbon reduction targets. The company has also started its awareness campaign on Climate change aimed at employees as initial audience, and eventually all other stakeholders including business partners and customers.

Improvement in energy consumption and utilization of renewable energy:

- *Reducing Water Losses:* For the past 10 years, Manila Water's pipe replacement programs have contributed to the massive decrease in systems losses, from 63% in 1997 to 20% as of October 2008, giving a 482 million liter per day (mld) water saving. In turn, the reduction of non-revenue water resulted in more water supply for customers and lessened the need to develop new water sources.
- *Energy Efficiency:* With the goal of conserving resources, Manila Water's new service improvement plan ensures that all new facilities will be operated at a minimal cost by considering power efficiencies in the design stage, therefore ensuring reduction in power consumption despite expansion programs. The company's power efficiency initiatives include systems modeling and investigation of optimal setting, pump refurbishment, power factor correction and use of power monitoring equipment for larger facilities.
- *Waste-to-energy:* In response to global warming, Manila Water also started the construction of its first-ever waste to-energy project within the Ayala South Wastewater Treatment Plant located in Makati City, the central business district of the Philippines. Said project hopes to recover energy from wastewater sludge

and use it to run the plant, thereby rendering it self-sufficient and helping reduce the company's carbon footprint at the same time.

- *Biosolids Management:* Manila Water recognized the key role of biosolids in response to global warming. Thus, the company is currently studying the means to recycle biosolids to enhance yields of biodiesel producing Jathropa curcas, and initiating steps towards producing electricity from biogas generated from digesting biosolids. Manila Water is also aiming to start an ecofarm that will intertwine biosolids processing and recycling with carbon-reducing initiatives.

Integration of Climate change in medium- and long-term operations:

- *Recycling Water:* Consistent with its aim of preserving the natural environment, Manila Water is continuously finding ways to make optimal use of available resources. In 2007, the company signed an agreement to provide recycled water to the technological park in Quezon City, marking the first ever wastewater effluent reuse in Metro Manila. Manila Water will deliver at least 4mld of recycled water to the park by mid-2009.
- *Combined-Sewer Drainage System:* The Pineda-Kapitolyo Sewage Treatment Plant (STP) will be the first sewage-drainage system in the Philippines, which will treat sewage and storm flows of up to 4,000 cubic meters per day before discharging to one of the major rivers in Metro Manila, the Pasig River. With a World Bank-assisted loan, the STP is expected to benefit 18,000 residents. This project is one of the three initiatives under the Riverbanks Sewerage System component of the Manila Third Sewerage Project which aims to rehabilitate the Pasig river system, restore water quality, promote urban renewal along the riverbanks, and control wastewater discharges.
- *Groundwater Protection:* In response to water depletion caused by excessive use of groundwater, Manila Water has fast tracked and successfully completed numerous service improvement projects to supply surface water to the rest of its service area. Manila Water is currently sourcing 99% of its water supply from surface water, and only 1% from groundwater. The company's service expansion plans include elimination of all deep wells, providing the entire service area with 100% renewable surface water supply.
- *New Water Resources:* To mitigate the risk of supply deficiency caused by unreliable water supply due to Climate change, Manila Water has continuously been developing new water resources. Presently, a number of potential water resources such as Laiban Dam and Rizal Province Water Supply Improvement Project are being developed to ensure reliability of supply.
    - *Laiban Dam Project:* To meet the growing demand in the next 10 years, the Laiban Dam Project, in coordination with the Metropolitan Waterworks and Sewerage System (MWSS) is planned to be developed by 2014 to utilize surface water from the Kaliwa River in Tanay, Rizal (which is located 57 km east of Metro Manila). Other components of the project include raw water conveyance pipes, hydropower plant, water treatment plant, treated water conveyance, pumping station and reservoir. Total project cost is P25.002 million for phase 1 to be shared equally with Maynilad Water, the West Zone concessionaire, and target capacity volume is 1,900 mld by 2014.
    - *Rizal Province Water Supply Improvement Project (RPWSIP):* The RPWSIP is a new water resource project located along the peripherals of the largest lake in the Philippines, Laguna Lake. The project is expected to deliver a total of 100 mld of additional water supply by 2009 to 2012 to meet the demand of Rizal province which is just 20 km east of Metro Manila.
- *Protection of watersheds:* Manila Water supplies 99% of its water from surface water that is sourced from the watersheds of Angat, Ipo and La Mesa. Unfortunately, due to the activities around the watersheds, only 30% of the total 665 sq. km watershed area is forest-covered. Given this, Manila Water has been aggressive in pursuing the rehabilitation of the watersheds through the Adopt-a-Watershed program in partnership with various stakeholders.

A.2.8 Istanbul Water and Sewerage Administration (ISKI): Istanbul, Turkey

Utility Name	Istanbul Water And Sewerage Administration (ISKI)
Urban region	Istanbul, Turkey
Population served, million	12.6
Total Water supply (ml/day), 2005	1,912
Total Water supply (ml/day), 2008	1,850
% Water resources, SW	95
% Water resources, GW	5
Climate threats	Decreased surface water quantity and quality; Damage to water supply facilities; Inaccurate climate models and planning difficulties

In recent years, Istanbul has suffered from a period of serious drought which recorded the lowest rainfall of last 50 years. In 2006 the measured rainfall of 66.7 mm was a record low, the average being 257.2 mm per year. In late 2007, many of the city's drinking water reservoirs which provide water for 12 million residents had decreased to a record low 8.96 percent of capacity. ISKI is becoming increasingly concerned over the potential long term impacts of climate change as recent calculations suggest that the water supplies for the city may decrease by as much as 14% in the following two decades. The combination of the drought being currently experienced and the long term climate change projections has placed ISKI under great pressure to ensure the sustainability of Istanbul's water supply services.

The first response to the crisis imposed by the drought was to revise investment plans in order to manage the risks imposed on the sustainability of water recourses. The utility recognized the need to develop effective strategies and adaptation plans, which prompted the consideration of alternatives including water saving campaigns, and water transfer projects from adjacent basins situated up to 150 km away.

ISKI put a number of structural and non-structural adaptation plans into action:

- A successful water saving campaign to encourage consumers to use water more efficiently to avoid possible rationing. Water savings campaigns are now recognized as an important measure in raising awareness of climate change and appropriate utilization of limited freshwater resources.
- Istanbul has established a specific target to reduce the amount of water losses to support and implement the climate change adaptation plans.
- An integration system was put in place across the city's reservoirs to prevent any reservoir from running dry. The integration system allows for water to be pumped from one reservoir to another to prevent the possibility of water cuts in some areas of the city.
- The Melen Project Phase I became operational in late 2007 which transfers an additional 268 million m^3 of water per year from an adjacent basin for treatment and distribution.
- Through the Melen River Project, which was initiated in 1997, pipelines were laid under the Bosporus. It is projected that as much as 300,000 m^3 of water will be carried through the pipeline daily to meet the water needs of 4 million people in Istanbul.
- ISKI initiated the construction of new wells to increase conjunctive use of groundwater to provide greater flexibility in supply of water resources. Through the development of 197 wells, the city is provided with 20–25 million m^3 of water per year.
- Approximately 2 million m^3 of wastewater is treated daily in Istanbul and is recognized as an important resource needed to meet increasing water demands. Through reclamation projects, treated water shall be used in watering of parks and gardens, sport facilities and recreational areas as well as industrial use and fire fighting.

ISKI is placing increased emphasis on monitoring and research on climate change and the related impacts on water resources. Importantly, this includes consideration of regulatory changes that will be required to ease operational and financial burdens associated with implementing climate adaptation measures. The utility has commissioned a research study, *Affects of Climate Change on Water Resources*, which applies a number of global circulation models to Istanbul with the objective of estimating hydrological extremes including the frequency and intensity of droughts and floods.

ANNEX 3: SEARCHING FOR SOLUTIONS

A.3.1 Water and Sanitation Agency: Rawalpindi, Pakistan

Utility Name	Water and Sanitation Agency
Urban region	Rawalpindi, Punjab, Pakistan
Population served, million	1.1
Total Water supply (ml/day), 2005	232
Total Water supply (ml/day), 2008	250
% Water resources, SW	55
% Water resources, GW	45
Climate threats	Decreased surface water quantity and quality; Decreased groundwater / aquifer recharge and quantity; Increased urban demand for water; Changes in watershed vegetation and ecology; Increased competition for water resources

Rawalpindi is situated in north Pakistan with rocky plateaus and alluvium patches beneath it. The Rawalpindi water utility serves some 1.1 million people, and is supplied by 45% groundwater and 55% surface water. The utility experienced high commercial and technical water losses. In extracting an estimated 10 times more than the volume needed for its customers, it was depleting groundwater resources and incurring high energy costs for pumping.

As a part of its climate change adaption measures the utility is planning to expand the capacity of the both groundwater and surface water sources and to increase storage capacity. The utility faces a multitude of challenges, however, in undertaking the proposed actions. Groundwater in the region is an unreliable source of sustainable supply as the water tables are sharply declining, and it is reported to be polluted with e-coli, feacal coliforms and other bacteriological contamination as a result of poor sanitation and lack of proper wastewater treatment facility (Government of Punjab and Asian Development Bank, 2004).

The utility is attempting to address many of these pre-existing and interconnected water quality issues. However, there are risks to the financial sustainability of the utility, as during periods of low stream flow balancing permitted discharge volumes and effluent quality will be critical as it may require additional investments in wastewater treatment.

A.3.2 Office National de l'Eau et de l'Assainissement (ONEA): Burkina Faso

Utility Name	ONEA: Office National de l'Eau et de l'Assainissement
Urban region	Ouagadougou, BURKINA FASO
Population served, million	2.33
Total Water supply (ml/day), 2005	93
Total Water supply (ml/day), 2008	118
% Water resources, SW	Yes (NA)
% Water resources, GW	Yes (NA)
Climate threats	Decreased surface water quantity and quality; Decreased groundwater / aquifer recharge and quantity; Increased competition for water resources

The national water utility of Burkina Faso, ONEA, relies on surface water from dam reservoirs for 70% its supply. This heavy dependency on a single source has been identified as a significant risk to the utility as its supply is vulnerable to reduced precipitation levels and higher evaporation losses as a result of rising temperatures.

Improving ONEA's flexibility in supply, however, is hampered by the geology of Burkina Faso; 80% of the country is underlain by fractured bedrock making use of groundwater unreliable. It is reported that the majority of the 220 wells have little capacity beyond 10–15 m^3/h and the water table becomes further exacerbated by reduced precipitation levels. Hydrological variability is also affecting the utility, as monitoring of isolines of average rainfall indicated a shift of approximately 100 kilometers from north to south over 50 years resulting in greater frequency of droughts.

Given that ONEA's challenges are predominately supply drive, the utility is undertaking careful monitoring of its resource and taking steps to improve demand management through rationalization of consumption with meters for all connections, the implementation of progressive tariff blocks, sensitizing consumers to avoid water wasting.

A Council within the Ministry of Environment has been created to begin addressing national concerns related to climate changes and a national action plan has been adopted. Of twelve projects identified as being of importance, one specifically focuses on sedimentation in reservoirs and rivers. To date, no specific climate change response activities have been planned for urban water supply reservoirs or the utility.

A.3.3 Nairobi Water Company: Nairobi, Kenya

Utility Name	Nairobi Water Company
Urban region	Nairobi City, Kenya
Population served, million	3 million, Plus 2 million floating
Total Water supply (ml/day), 2005	261
Total Water supply (ml/day), 2008	286
% Water resources, SW	100
% Water resources, GW	0
Climate threats	Decreased surface water quantity; Increased urban demand for water; Damage to water supply facilities; Changes in watershed vegetation and ecology; Inaccurate climate models and planning difficulties; Increased competition for water resources

Nairobi Water Company (NWC) reports that the influences of climate change are having notable affects on water availability and service provision. Reduced levels of rainfall have diminished groundwater recharge and available surface water in the utility's major water catchments. This has resulted in less river yield and base flows in rivers that supply the utility which is negatively influencing storage levels in the main reservoir. Water quality has also been affected through rising turbidity in the raw treatment plants resulting in increasing costs for required chemicals during treatment.

The low storage volumes have on several occasions resulted in the company resorting to water rationing in order to manage the limited supply. This has caused system infrastructure to operate below its designed optimum capacity. Low pressure in the distribution system pipes, for example, increases air intake in the place of water and causes increased corrosion and asset depreciation.

While NWC has yet to adopt a formal plan to begin addressing the affects of climate change, the utility is taking measures to enhance it supply resources and better manage consumer demand including:

- Reduction of Non Revenue water (NRW. The utility has taken steps to reduce the NRW from about 49% in 2004 to 40% in 2008.
- The utility together with Athi Water Services Board is carrying out a comprehensive study for additional water resources to meet the increased demand.
- NWC is already using some public boreholes (from the railway company) to increase water supply during drought conditions and together with other stakeholders is working on a more comprehensive program to use private and public wells during drought emergencies.
- The utility has partnered with other stakeholders including the Ministry of Environment, and private companies such as UAP Insurance and Kenya Breweries to improve watershed management and source protection. Since 2006, 100,000 seedlings have been planted in the upper catchments to increase forest cover, reduce source pollution and ultimately increase ground and surface water recharge.
- The utility embarked on an ambitious metering initiative in which 220,000 meters were examined and faulty ones replaced.
- The utility started preparing for a rationing program to ensure that under drought stress every customer gets at least a minimum amount of water. As a first measure the company installed 600 water tanks in underserved areas to improve the water supply and to avoid that water vendors increase the water costs too much in poor areas.
- The company and the Athi Water Service Board cooperate with the City Council to make roof catchment mandatory for all new constructions.

NWC recognizes that the impacts of climate changes will be dynamic and that the need for information is central to assessing feasible adaptation strategies. However the utility possesses very little documented information or data on climate change necessary for formulating appropriate action plans or making informed decisions.

A.3.4 Servicio de Agua Potable y Alcantarillado (SEDAPAL): Lima, Peru

Utility Name	Servicio de Agua Potable y Alcantarillado de Lima (SEDAPAL)
Urban region	Lima, Perú
Population served, million	8.4
Total Water supply (ml/day), 2005	232
Total Water supply (ml/day), 2008	250
% Water resources, SW	80
% Water resources, GW	20
Climate threats	Decreased surface water quantity and quality; Damage to water supply facilities; More concentrated and earlier water flows

SEDAPAL recognizes its vulnerability to climate change and one of its principle concerns is the melting of key glaciers in the Andes. Glacial melt will have significant implications on the utility's ability to use Atlantic/Amazon watershed which provides 98% of the country's water. It has recently been reported that the melting of glaciers has already reduced the water supply to Peru's coastline by 12 percent which is where 60 percent of the country's population resides.

In response to the recognition of these long term risks, the utility has begun implementing measures to increase the capacity of its reservoirs and water treatment plants, in addition to considering desalination as a 'highly viable alternative' and optimization of groundwater resources through artificial aquifer recharge. Steps are similarly being taken to reduce water losses through network rehabilitation, macro and micro metering, and pressure zoning of the distribution network. Treated wastewater is now also being increasingly used for the watering of parks and city gardens.

To address demand management, the utility has conducted consumer awareness campaigns for school and community organizations which have involved presentations and site visits to treatment plants. In an effort to promote the use of water saving technologies, SEDAPAL patented the Product Seal for Water Saving Appliances which supports and certifies products that generate a minimum 30% of savings.

SEDAPAL recognizes that the utility will not be able to address climate change through traditional operations, and that solutions must be formulated through strong collaboration and coordination with the agricultural, mining, housing, industry and education sectors.

A.3.5 Dhaka Water Supply & Sewerage Authority (DWASA): Dhaka, Bangladesh

Utility Name	Dhaka Water Supply and Sewerage Authority (DWASA)
Urban region	Dhaka, Bangladesh
Population served, million	12
Total Water supply (ml/day), 2005	1,100
Total Water supply (ml/day), 2008	1,250
% Water resources, SW	15
% Water resources, GW	85
Climate threats	Decreased surface water quantity and quality; Decreased groundwater/aquifer recharge and quantity; Increased urban demand for water; More concentrated and earlier water flows; Submersion of water supply facilities; Increased competition for water resources

With an urban growth rate of more than 4 percent annually, Dhaka, which already hosts more than 13 million people, is one of the fastest growing metropolitan regions in the world, and is projected to accommodate more than 20 million by 2025. Approximately 80 percent of the population in Dhaka lives in dense slums with densities of between 500 and 1,500 persons per acre. Experts believe that glacial and snow melt in the Himalayas, in addition to increasing rainfall attributable to climate change will lead to more frequent and intense flooding across Bangladesh. It is expected that such flooding will also affect cities located near the coast and those that are in the delta region, including Dhaka. Plans for flood protection are already underway in greater Dhaka; as result of frequent flooding in the 1980s the government, has already completed the construction of embankments, concrete reinforced walls and pumping stations in the densest parts of the city. While such technically oriented solutions may alleviate some of the risks posed by climate change, unresolved development problems, such as the city's growing slum population which has doubled in the last decade, must be taken into consideration [UN HABITAT, 2008].

A.3.6 ROSVODOKANAL: Russia/Ukraine

Utility Name	ROSVODOKANAL
Urban region	Moscow, Russia
Population served, million	5.4
Total Water supply (ml/day), 2005	NA
Total Water supply (ml/day), 2008	NA
% Water resources, SW	70
% Water resources, GW	30
Climate threats	None as very severe

The ROSVODOKANAL Group is a private water operator in Russia. It has operations in seven territories across the Russian Federation and one territory in the Ukraine. Climate change poses a significant threat in three of eight territories in which the company is active arising from severe water shortages. As a result of reoccurring droughts and overuse of Severski Donets River by upstream communities, the majority of towns in the Lugansk Oblast district of Ukraine are supplied with water 5–10 hours per day. At present the Group is also facing severe problems due to reduced water levels in rivers, non-revenue water losses up to 50 percent in some of its operators, relatively high per capita water consumption (up to 350 lpcd), and the comparatively low tariffs throughout Russia and Ukraine. The Group has emphasized the need for large scale investments in water supply infrastructure. To deal with this situation the respective national governments are considering public-private partnerships for NRW programs, increased operator efficiency and to establish financial tools to bring new capital into the sector.

A.3.7 Tianjin Water Company: Tianjin, China

Utility Name	Tianjin Water Company
Urban region	Tianjin City and vicinity
Population served, million	5.5
Total Water supply (ml/day), 2005	1.20
Total Water supply (ml/day), 2008	1.35
% Water resources, SW	95%
% Water resources, GW	5%
Climate threats	Sea rise, depletion of surface water

A recent study examined climate adaptation potential for the City of Tianjin [Zhou, 2004]. Currently, Tianjin's key risk in terms of water supply stems from the demand side, where urbanization, population growth, agricultural use, and industrial development continue to place much stress on the water resources and utilities in the province. Future climate change impacts, including reduced precipitation levels or increasing droughts and flooding, will only add more pressure to an already stressed system.

Tianjin's water supply is dependent on local water resources, inflow from upstream, and water transferred from the Luan River. While the total surface water inflow into Tianjin is 2.61 billion m^3 in an average year, in a typical drought year, however, this flow is reduced to only 527 million m^3, based on 1990–99 hydraulic data. Thus, water from the Luan River has been introduced to Tianjin through a water diversion project which since 1983 has averaged 792 million m^3/year. Urban water supply in Tianjin has relied heavily on this project.

Rural areas and agricultural uses continue to utilize local surface water and groundwater. Tianjin has three large reservoirs and eleven medium sized reservoirs with a total storage capacity of 2.66 billion m^3. Its current water supply capacity is 0.86 billion m^3. With water transfers and groundwater, there is less than 3 billion m^3 per year to meet the basic needs of the city. Tianjin would benefit from a planned South-North Water Transfer Plan, which is projected to increase the water supply to 3.74 billion m^3 in 2010, and 4.14 billion m^3 in 2020. This project is aimed at addressing Tianjin's perceived unsustainable use of the Hai River Basin by planners and government authorities [Zhou, 2004].

The South-North Water Transfer, a concept that has been under consideration since the 1950s but has only recently begun to receive full commitment from the government, refers to three sets of water diversions (dam projects) from the Yangtze River; the Eastern, Central and Western routes, each serving separate areas of China. Tianjin will receive water from both the Eastern and Central routes, which will pass under the Yellow River. Driven in part by a perceived need to relieve unsustainable water use in the Hai River basin, especially in Beijing and Tianjin, construction has begun on key components of the Eastern route, and on the source of the Central route (the Danjiangkou Reservoir) to diversify water sources for the utility. Construction of the Eastern and Middle Routes is targeted for completion in 2020 [Nickum, 2006].

There is currently low stakeholder awareness and engagement in addressing climate change impacts on the water sector in Tianjin, although public and utility planners are aware of and have been dealing with extreme hydrological and climatic variability for some time. These efforts are aimed at addressing rapid urbanization and growth in water consumption, as well as periodic droughts and floods.

Future opportunities for adaptation in Tianjin's water sector range from reactive measures such as NRW reduction, to proactive measures such as improving water infrastructure, upgrading wastewater treatment systems and promoting water conservation programs. National attention and proactive adaptation planning and implementation however, have yet to materialize. This is likely because of other competing priorities for time and resources, the uncertainties in climate change projections, and emphasis placed on addressing pressing water demand issues from regional urbanization and water use, where major efforts are being placed on the large-scale water transfer/diversion projects.

GLOSSARY OF TERMS

[Source: Bates *et al*, 2008, except where noted]

Adaptation

Initiatives and measures to reduce the vulnerability of natural and human systems against actual or expected climate change effects. Various types of adaptation exist, e.g. anticipatory and reactive, private and public, and autonomous and planned. Examples are raising river or coastal dikes, the substitution of more temperature-shock resistant plants for sensitive ones, etc.

Adaptive Capacity

The whole of capabilities, resources and institutions of a country or region to implement effective adaptation measures.

Climate

Climate in a narrow sense is usually defined as the average weather, or more rigorously, as the statistical description in terms of the mean and variability of relevant quantities over a period of time ranging from months to thousands or millions of years. The classical period for averaging these variables is 30 years, as defined by the World Meteorological Organization. The relevant quantities are most often surface variables such as temperature, precipitation and wind. Climate in a wider sense is the state, including a statistical description of the climate system.

Climate Change

Climate change refers to a change in the state of the climate that can be identified (e.g. by using statistical tests) by changes in the mean and/or the variability of its properties, and that persists for an extended period, typically decades or longer. Climate change may be due to natural internal processes or external forces, or to persistent anthropogenic changes in the composition of the atmosphere or in land use. Note that the United Nations Framework Convention on Climate Change (UNFCCC), in Article 1, defines climate change as: "A change of climate which is attributed directly or indirectly to human activity that alters the composition of the global atmosphere and which is in addition to natural climate variability observed over comparable time periods". The UNFCCC thus makes a distinction between climate change attributable to human activities altering the atmospheric composition, and climate variability attributable to natural causes.

Climate Projection

A projection of the response of the climate system to emissions or concentration scenarios of greenhouse gases and aerosols, or radiactive forcing scenarios, often based upon simulations by climate models. Climate projections are distinguished from climate predictions in order to emphasize that climate projections depend upon the emission/concentration/radioactive forcing scenario used, which are based on assumptions concerning, for example, future socioeconomic and technological developments that may or may not be realized and are therefore subject to substantial uncertainty.

Climate System

The climate system is the highly complex system consisting of five major components: the atmosphere, the hydrosphere, the cryosphere, the land surface and the biosphere, and the interactions between them. The climate system evolves in time under the influence of its own internal dynamics and because of external forces such as volcanic eruptions, solar variabilities and anthropogenic forces such as the changing composition of the atmosphere and land-use change.

Climate Variability

Climate variability refers to variabilities in the mean state and other statistics (such as standard deviations, the occurrence of extremes, etc.) of the climate on all spatial and temporal scales beyond that of individual weather events. Variability may be due to natural internal processes within the climate system (internal variability), or to variabilities in natural or anthropogenic external forcing (external variability).

Exposure

In the context of this report, exposure refers to Bank projects and/or regional investments being subjected to negative changes in annual runoff (from present day values) in the year 2030 or 2050. The Climate Change Exposure Index was defined, as follows, for all projects except flood control projects:

Exposure Index	Description
Water systems (non-flood control)	
Low	% reduction in annual runoff…. Less than 5%
Medium	% reduction in annual runoff…. Between 5 and 15%
High	% reduction in annual runoff…. More than 15%
Flood control system	
Low	% reduction in annual runoff…. More than 15%
Middle	% reduction in annual runoff…. Between 5 and 15%
High	% reduction in annual runoff…. Less than 5%

Flexibility

The flexibility of a system refers to its ability to adapt to a wide range of operating conditions through relatively modest and inexpensive levels of redesign, refitting or reoperation [Hashimoto, T. et al., 1982a].

Greenhouse Effect

Greenhouse gases effectively absorb thermal infrared radiation emitted by the Earth's surface by the atmosphere itself due to the same gases, and by clouds. Atmospheric radiation is emitted on all sides, including downward to the Earth's surface. Thus, greenhouse gases trap heat within the surface troposphere system. This is called the greenhouse effect. Thermal infrared radiation in the troposphere is strongly coupled to the temperature of the atmosphere at the altitude at which it is emitted. In the troposphere, the temperature generally decreases with height. Effectively, infrared radiation emitted to space originates from an altitude with a temperature of, on average, –19°C, in balance with the net incoming solar radiation, whereas the Earth's surface is kept at a much higher temperature of, on average, +14°C. An increase in the concentration of greenhouse gases leads to an increased infrared opacity of the atmosphere, and therefore to an effective radiation into space from a higher altitude at a lower temperature. This causes a radiative forcing that leads to an enhancement of the greenhouse effect, the so-called "enhanced greenhouse effect".

Greenhouse Gas (GHG)

Greenhouse gases are those gaseous constituents of the atmosphere, both natural and anthropogenic, that absorb and emit radiation at specific wavelengths within the spectrum of thermal infrared radiation emitted by the Earth's surface, the atmosphere itself, and by clouds. This property causes the greenhouse effect. Water vapor (H_2O), carbon dioxide (CO_2), nitrous oxide (N_2O), methane (CH_4) and ozone (O_3) are the primary greenhouse gases in the Earth's atmosphere. Moreover, there are a number of entirely human-made greenhouse gases in the atmosphere, such as the halocarbons and other chlorine and bromine containing substances, dealt with under the Montreal Protocol. Beside CO_2, N_2O and CH_4, the Kyoto Protocol deals with the greenhouse gases sulphur hexafluoride (SF_6), hydrofluorocarbons (HFCs) and perfluorocarbons (PFCs).

(Climate Change) Impacts

The effects of climate change on natural and human systems. Depending on the consideration of adaptation, one can distinguish between potential impacts and residual impacts:

Potential impacts: all impacts that may occur given a projected change in climate, without considering adaptation.

Residual impacts: the impacts of climate change that would occur after adaptation.

Mitigation

Technological change and substitution that reduce resource inputs and emissions per unit of output. Although several social, economic and technological policies would produce an emission reduction, with respect to climate change, mitigation means implementing policies to reduce greenhouse gas emissions and enhance sinks.

No-Regrets Policy

A policy that would generate net social and/or economic benefits irrespective of whether or not anthropogenic climate change occurs.

Projection

A potential future evolution of a quantity or set of quantities, often computed with the aid of a model. Projections are distinguished from predictions in order to emphasize that projections involve assumptions concerning, for example, future socioeconomic and technological developments that may or may not be realized, and are therefore subject to substantial uncertainty.

Reliability

Reliability is defined as the likelihood that services are delivered (no failure) within a given period, expressed as a probability. High probabilities indicate high reliability [Hashimoto, T. et al., 1982b].

Resilience

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

B. Resiliency is the speed at which the system recovers from a failure, on average. Shorter recovery periods indicate higher resiliency [Hashimoto, T. et al., 1982b].

Risk

The potential for realization of unwanted, adverse consequences; usually based on the expected result of the conditional probability of the occurrence of the event multiplied by the consequence of the event, given that it has occurred. What makes a situation risky rather than uncertain is the availability of objective estimates of the probability distribution [USACE, 1992].

Scenario

A plausible and often simplified description of how the future may develop based on a coherent and internally consistent set of assumptions about driving forces and key relationships. Scenarios may be derived from projections, but are often based on additional information from other sources, sometimes combined with a narrative storyline.

Sensitivity

Sensitivity is the degree to which a system is affected, either adversely or beneficially, by climate variability or climate change. The effect may be direct (e.g. a change in crop yield in response to a change in the mean, range, or variability of temperature) or indirect (e.g. damages caused by an increase in the frequency of coastal flooding due to sea level rise).

Uncertainty

A. An expression of the degree to which a value (e.g. the future state of the *climate system*) is unknown. Uncertainty can result from lack of information or from disagreement about what is known or even knowable. It may have many types of sources, from quantifiable errors in the data to ambiguously defined concepts or terminology, or uncertain *projections* of human behavior. Uncertainty can therefore be represented by quantitative measures, for example, a range of values calculated by various models, or by qualitative statements, for example, reflecting the judgment of a team of experts.

B. Uncertain situations are those in which the probability of potential outcomes and their results cannot be described by objectively known probability distributions, or the outcomes themselves, or the results of those outcomes are indeterminate [USACE, 1992]

United Nations Framework Convention on Climate Change (UNFCCC)

The Convention was adopted on 9 May 1992 in New York and signed at the 1992 Earth Summit in Rio de Janeiro by more than 150 countries and the European Community. Its ultimate objective is the "stabilization of greenhouse gas concentrations in the atmosphere at a level that would prevent dangerous anthropogenic interference with the climate system". It contains commitments for all Parties. Under the Convention, Parties included in Annex I (all OECD member countries in the year 1990 and countries with economies in transition) aim to return greenhouse gas emissions not controlled by the Montreal Protocol to 1990 levels by the year 2000. The Convention entered in force in March 1994.

Vulnerability

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

B. Vulnerability refers to the severity of the likely or expected consequences of failure [Hashimoto, T. et al., 1982b].

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