14

Urban Water Systems

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Sustaining Water Security

In regard to climate change, water is both a resource and a hazard. As a resource, good-quality water is basic to the well-being of the ever-increasing number of people living in cities. Water is also critical for many economic activities, including peri-urban agriculture, food and beverage production, and industry. However, excess precipitation or drought can lead to hazards ranging from increased concentrations of pollutants (with negative health consequences), a lack of adequate water flow for sewerage, and flood-related damage to physical assets.

Projected deficits in the future of urban water supplies will likely have a major impact on both water availability and costs. Decisions taken now will have an important influence on future water supply for industry, domestic use, and agriculture.

Major Findings

- The impacts of climate change put additional pressure on existing urban water systems (UWS) and can lead to negative impacts for human health and well-being, economies, and the environment. Such impacts include increased frequency of extreme weather events leading to large volumes of stormwater runoff, rising sea levels, and changes in surface water and groundwater.

- A lack of urban water security, particularly in lower income countries, is an ongoing challenge. Many cities struggle to deliver even basic services to their residents, especially those living in informal settlements. As cities grow, demand and competition for limited water resources will increase, and climate changes are very likely to make these pressures worse in many urban areas.

- Water security challenges extend to peri-urban areas as well, where pressure on resources is acute and where there are often overlapping governance and administrative regimes.

- Governance systems have largely failed to adequately address the challenges that climate change poses to urban water security. Failure is often driven by a lack of coherent and responsive policy, limited technical capacity to plan for adaptation, limited resources to invest in projects, lack of coordination, and low levels of political will and public interest.

Key Messages

Adaptation strategies for urban water resources will be unique to each city since they depend heavily on local conditions. Understanding the local context is essential to adapting water systems in ways that address both current and future climate risks.

Acting now can minimize negative impacts in the long term. Master planning should anticipate projected changes over a time frame of more than 50 years. Yet, in the context of an uncertain future, finance and investment should focus on low-regret options that promote both water security and economic development, and policies should be flexible and responsive to changes and new information that come to light over time.

Many different public and private stakeholders influence the management of water, wastewater, stormwater, and sanitation. For example, land-use decisions have long-lasting consequences for drainage, infrastructure planning, and energy costs related to water supply and treatment. Therefore, adapting to the changing climate requires effective governance and coordination and collaboration among a variety of stakeholders and communities.

Cities should capture co-benefits in water management whenever possible. Cities might benefit from low-carbon energy production and improved health with wastewater treatment. Investment strategies should include the application of life cycle analysis to water supply, treatment, and drainage; use of anaerobic reactors to improve the balance between energy conservation and wastewater treatment; elimination of high-energy options, such as interbasin transfers of water, wherever alternative sources are available; and the recovery of biogas produced by wastewater.

14.1 Introduction

According to the Intergovernmental Panel on Climate Change (IPCC) (2013), much of the impact of climate change will be felt in the water sector. Given the critical role of water resources for health, well-being, and economic activities, the impact on both people and economies has the potential to disrupt development significantly. The impacts of climate change on the urban water sector can be categorized in two ways: water as a resource and water as a hazard. As a resource, the availability of good-quality water is the basis for the well-being of the ever-increasing number of people living inside cities. It is also critical for many economic activities in and around cities, including peri-urban agriculture, food and beverage industries, and other industrial activities. Meanwhile, excess precipitation or drought can lead to hazards ranging from an increased concentration of pollutants (with negative health consequences), lack of adequate water flow for sewerage, and flood-related damage to physical assets. Huge expected deficits in urban water supply will likely have a major impact on the future availability and cost of water. Decisions taken now by cities will have an important influence on future water supply for industry, domestic use, and agriculture.

In 2011, the First Assessment Report of the Urban Climate Change Research (UCCRN) Network (ARC3.1) published a chapter on "Climate Change, Water and Wastewater" (Major et al., 2011). The chapter offered one of the earlier overviews of climate change impacts on cities, rightly arguing that, as of 2011, the IPCC Assessment Reports and the wider research community had not paid specific attention to cities, water, and climate change. The chapter was an overview of the range of challenges faced by cities in the context of environmental change. Since then, three major trends and milestones have emerged that the present chapter reflects: (1) the growing body of research, particularly in developing countries, on urbanizing watersheds; (2) the increasing numbers of available case studies in smaller and medium-sized cities; and (3) the launch of the IPCC's Working Group II Fifth Assessment Report (AR5) in 2014, with a substantive section on climate change and cities, which concludes that water scarcity is already affecting cities and that reducing the basic service deficit is essential for longer term resilience.

This chapter updates the range of issues faced by cities in the context of climate change initially presented in the first ARC3 report (Rosenzweig et al., 2011). In particular, it focuses on water security – essentially the sustainable availability of water for different uses and the avoidance of water-related disasters – and how expected climate change will complicate the ability of water resource managers to secure water for future urban uses. It also emphasizes improvements in frameworks for adaptation in the water sector, which, to date, have been challenging to communicate and difficult to implement. The chapter starts off by defining water security and outlining the main components of a "water secure" city (Section 14.1.2). This section includes an overview of stormwater and drainage, an issue only touched on in ARC3.1. The range of stakeholders that must be engaged to support adaptive water management is then presented (Section 14.2), followed by an analysis of the main climate risks faced by urban water systems (UWS) (Section 14.3). The subsequent Section (14.4) integrates the IPCC perspective on adaptation in cities, with specificity added by the authors of this chapter through examples of available adaptation options for improved water management. The main argument made is that cities at different scales of development face different climate impacts and will need to determine their own context-specific adaptation pathways because there is no common solution available to all cities. Finally, while the chapter emphasizes adaptation, a section on mitigation (Section 14.5) discusses how to integrate water management with greenhouse gas (GHG) reductions. Throughout the chapter, case studies from a range of cities, both developed and developing, help to connect the "real-world" challenge with the concepts presented.

14.1.1 Water Security as a Framing Concept

Achieving water security in the context of a changing climate remains a central challenge for cities. UN Water defines water security as:

> The capacity of a population to safeguard sustainable access to adequate quantities of acceptable quality water for sustaining livelihoods, human well-being, and socio-economic development, for ensuring protection against water-borne pollution and water-related disasters, and for preserving ecosystems in a climate of peace and political stability. (UN Water, 2013: vi)

In the urban context, water security emphasizes the importance of mediating conflicts between competing options and sequencing of infrastructure investments, acknowledging the complex interplay among industry, human health, and well-being (Braga, 2001; World Bank, 2014).

Considerable progress has been made in recent years in securing water for cities. For example, between 1990 and 2012, a remarkable 2 billion people across Latin America, India, and China were able to improve their access to water and sanitation, largely due to economic growth and improved service delivery. Despite this, 700 million people worldwide remain underserved in regard to water, with half of this number in Sub-Saharan Africa (WHO-UNICEF, 2014). One typical problem is the lack of access to water services (e.g., supply, wastewater collection, and sanitation), which hinders the productive development of cities. In African cities, 40% of the population is still not able to access a safe source of drinking water (UN-Habitat, 2014). Consequently, informal systems often proliferate, particularly in developing countries, as a response to water needs. In the case of water quality (both supply and treatment), lack of access to services and low water quality threaten the health of urban water users and ecosystems located downstream of cities (WHO-UNICEF, 2014).

When referring to UWS, this chapter refers to the infrastructure that cities rely on for managing the availability of good-quality water for different users. Key determinants of a well-functioning system include water for health and well-being, economic productivity, recreational and cultural benefits, and environmental services, as well as a system that is designed with respect to the available operational capacity (Hellestrom et al., 2000). The range of physical infrastructure is broad and involves large capital costs for construction, as well as for operations and maintenance. Typically, this includes water collection and storage facilities at source sites; transport via aqueducts (canals, tunnels, and/or pipelines); water treatment facilities; water treatment, storage, and distribution systems; wastewater collection systems and treatment; and urban drainage works to manage surface runoff.

Water systems have historically evolved sequentially as specific needs were identified and funding was obtained. So, for example, as cities learned and developed better systems for managing wastewater, the management of stormwater also improved. Generally, "mature" cities (i.e., those with a long history and a consolidated urban form) have a reduced rate of urban expansion compared to the rapid growth scenario commonly observed in emerging and less developed countries. In mature cities, there is often established water infrastructure, although service delivery may be inadequate. In the scenario of rapid growth, the pace of expansion often exceeds the ability of municipal authorities to provide basic services. This results in an increased burden on formal and informal water systems in those areas. However, the lack of pre-existing infrastructure presents an opportunity to address challenges not previously considered, such as climate change.

Stormwater management is now acknowledged as a critical component of "climate smart" urban infrastructure (Gill et al., 2007). Many cities are seeing trends of increased annual precipitation (see Chapter 2, Urban Climate Science), as well as heavy rains falling in short time frames during storm events, which lead to water runoff and flooding (see Section 14.3.5). As a result, stormwater management has become a key concern for many cities. In mature cities, this is managed in two forms: (1) combined sewer systems and (2) municipal separate storm sewer systems (MS4). Combined sewer systems are designed to collect rainwater runoff, domestic sewage, and industrial wastewater in the same pipe and deliver it to treatment plants. During heavy precipitation events, the capacity of combined sewers can be exceeded, leading to discharges of untreated wastewater directly to nearby water bodies. In MS4 systems, stormwater and wastewater are managed separately. Therefore, during intense precipitation events, stormwater can be discharged, but not sewage.

Developing cities often lack formal stormwater management systems, with water draining naturally along hydrologic gradients. Each system has its own challenges with respect to maintaining water security. For instance, MS4 systems are better for managing sewage discharge during large storm events than are combined sewers or informal systems. However, with climate variability and longer term change, existing network capacity will almost certainly be exceeded at times, with threats posed by runoff and pollution. Moreover, combined sewer systems are more common in older cities, where infrastructure is already built and adaptation options are more limited since wholesale retrofitting is very expensive. Areas with no infrastructure do not suffer from this limitation, although the significant upfront costs and a possible lack of human and financial capital to build these systems may impede the improvement of water security.

14.2 Stakeholders of Urban Water Systems

The challenge for planners responsible for adapting urban infrastructure to address future changes in climate is compounded by the range of actors whose engagement is important for an initiative to succeed. A variety of stakeholders are involved in the management of water, wastewater, and sanitation systems at the city level (Manila Water, 2007, 2013) (see Case Study 14.4). Notably, utilities (both public and privately owned) are often responsible for water supply and wastewater management. Municipal governments, with the exception of some countries in Africa where governance remains a challenging issue, are often responsible for the implementation of service delivery and the contracting of such services within a framework provided by national governments. Moreover, elected officials in cities often have different priorities than a city's technical staff. For example, the motivation to be re-elected may drive attention toward populist topics as opposed to the provision of basic services. Community organizations and nongovernmental organizations (NGOs) often play a key role in water security and, as such, need to be considered and consulted in infrastructure planning, particularly when slum neighborhoods are being retrofitted (Satterthwaite and Mitlin, 2013).

Industries are often heavy users of water and rely on secure supply for business continuity. In an increasing number of urban watersheds in upper middle-income countries such as India, Brazil, and Chile, heavy users in industries such as food and beverage processing, mining, and agriculture require a significant quantity of water to maintain operations. For example, the India Infrastructure Report of 2011 estimates that industrial water use in India is about 13% of the country's total freshwater withdrawal and that water demand for industrial uses and energy production will grow at a rate of 4.2% per year, rising from 67 billion cubic meters in 1999 to 228 billion cubic meters by 2025 (Aggarwal and Kumar, 2011). For industry, failure to adapt to changing water conditions due to climate change could lead to unsustainable business practices and reduced profits. Finally, individual consumers are now increasingly recognized as "clients," whose purchasing power can influence water demand considerably, particularly in contexts where effective pricing mechanisms and demand management are deployed (Cornish et al., 2004). Consumers may include, for instance, property owners who have potential to influence local hydrologic conditions (i.e., drainage and runoff) through the design of their private land.

In many developing countries, the range of actors in UWS is even more complex. For example, services are often supplied by informal providers, including delivery of water by truck. These informal systems can be efficient, although they often provide services at an exorbitant cost (Cornish et al., 2004). Equally important is the fact that informal providers are not regulated, nor are they generally willing to engage in formal water management since this would imply potentially losing access to their market. Another problematic approach leading to weak water governance is conflict between national ministries of water and state or city providers. Not only do political affiliations often differ between jurisdictions, there are also considerable overlaps in terms of administrative responsibilities. Thailand, as an extreme example, has more than 50 laws and more than 30 state organizations under 7 ministries working on water management (Nikomborirak and Ruenthip, 2013).

The challenge of managing conflicting stakeholder needs for water often arises during disasters (see Chapter 3, Disasters and Risk). Since 2010, there have been some high-profile failures that suggest a deep need for reform of federal-, state-, and local-level water management systems. For example, a postmortem of the 2011 flood disaster in Thailand noted that the primary problem was governance failure and poor decision-making as the flood was occurring, which resulted in nearly U.S. $47 billion in damages and a commensurate impact on employment (Haraguchi and Lall, 2015). There were many challenges, including water supply canals being overrun and failing sanitation systems, which led to enhanced health risks for people living in Bangkok. Similar failures in administrative planning and response for hydro-meteorological disasters were observed during the Indus floods in Pakistan in 2010 (affecting nearly 20% of the country), the Uttarakand floods in northern India in 2013, and flooding relating to Typhoon Haiyan in the Philippines in 2013. Each flood was the result of an extreme weather event that affected cities located either directly in the path of the storm (e.g., Tacoloban in the Philippines) or downstream (e.g., in the case of Thailand, the Indus River, and India). As Section 14.4 elaborates, better governance is a precondition for effective climate-related disaster management.

Finally, there is growing acknowledgment that key private-sector actors (including companies, banks, and investors) have a much larger role to play in supporting climate change adaptation. In fact, there is currently a "missing middle" – a large gap between available financing and the number of viable project ideas – which is a key reason for the current limited investment into adaptation being made by the private sector (Pegels and Pauw, 2013).

14.3 Climate Risks to Urban Water Systems

Current projections for global climate change in the 21st century identify a number of risks that are expected to be particularly challenging for UWS in terms of managing water supply, distribution, waste, and stormwater runoff[1]. These include:

- increasing temperatures (with attendant changes in evaporative demands, availability, and quality)
- changing precipitation regimes
- changing extreme weather regimes
- sea level rise and storm surges
- changing surface-water and groundwater availability and conditions.

14.3.1 Warming Temperatures

The WG1 contribution to the AR5 concludes that, in the next 20 years, global temperatures are likely to increase by at least +0.5°C, but are very unlikely to increase beyond +1.5°C. Regional differences are expected, however, such that warming will proceed more rapidly over land, particularly in continental interiors, and at high latitudes, followed by the tropics and subtropical lands (Kirtman et al., 2014). Unless significant reductions in GHG emissions occur by the end of century, the global temperature will likely have increased by between +1.5°C and +4.8°C (depending on emissions levels), with high-latitude warming continuing to be more rapid than the global mean (Collins et al., 2014).

Warmer temperatures result in larger demands for water in many cities (Schleich and Hillenbrand, 2009), particularly for household consumption and thermoelectric cooling. The extent of this temperature sensitivity, however, depends considerably upon climate, land uses, and energy dependency within cities (Zhou et al., 2000; Ruth et al., 2007; O'Hara and Georgakakos, 2008; House-Peters and Chang, 2011; Almutaz et al., 2012; Breyer, 2014; Donkor et al., 2014; Stoker and Rothfeder, 2014) (see Chapter 2, Urban Climate Science). For example, climate change may have a larger impact in cities that are reliant on older, less water-efficient, and coal-based thermoelectric plants than in cities that rely on newer, more water-efficient natural gas combined-cycle thermoelectric plants (Scanlon et al., 2013 a, 2013b).

Half or more of residential water is used outside of the home, mostly for irrigation (Hof and Wolf, 2014; Mini et al., 2014). This does, however, vary dramatically within and among cities, depending on the density of urban development and on climatic conditions (e.g., Lwasa et al., 2014). Extreme heat waves, which are projected to become more common and severe in the future, typically lead to disproportionately elevated demands for water (Zhou et al., 2001; Breyer, 2014). Such water demands are likely to be among the most affected by increasing temperatures (see Chapter 2, Urban Climate Science).

Warmer air temperatures and more extreme temperature ranges may physically damage UWS structures (Institution of Mechanical Engineers [IME], 2014), especially in high latitudes (Boyle et al., 2013), including areas with thawing permafrost or where warming results in soil desiccation (Vardon, 2014). Engineering materials and structures are most vulnerable to climate change in extreme cases of wet and dry conditions, high and low humidity, and solar radiation (Valdez et al., 2010).

1 A comprehensive list of potential impacts of climate change on UWS, from warming temperatures as well as from flooding and sea level rise, is available at: http://water.wuk1.emsystem.co.uk/home/policy/publications/archive/industry-guidance/asset-management-planning. Accessed December 29, 2014.

The overall effects of warming on the chemistry, biology, and contamination level in water supply and wastewater systems will likely be unique to each location. Warmer water temperatures can change the solubility and transport of contaminants as well as promote algal and other biological outbreaks (including invasive species) in water supply and wastewater/sanitation systems (Whitehead et al., 2009; Cisneros et al., 2014). However, warmer temperatures are generally conducive to improved biological reactions in water and wastewater treatment processes (Tchobanoglous et al., 2003; Whitehead et al., 2009). Some seasons or situations (e.g., extreme weather or runoff) may be more impactful on wastewater treatment than long-term average warming. For example, Plosz et al. (2009) showed in a Norwegian case study that changes in temperature during the winter may impact treatment processes more than changes in annual mean temperatures while also taking into account snowmelt (Langeveld et al., 2013).

Warmer temperatures can affect water use for industry and power generation that are either located in or serve urban systems (e.g., Koch and Vogele, 2009; Rebetez et al., 2009; Linnerud et al., 2011; Golombeck et al., 2012). For instance, high temperatures can decrease the efficiency of cooling for thermoelectric power generation, which is the largest or second largest (behind irrigation) use of water in many developed countries. As a result, decreasing efficiency can have a dramatic effect on electricity generation in urban areas (Kenny et al., 2009, Dell et al., 2014).

14.3.2 Changing Precipitation Regimes

IPCC's AR5 (2014) concludes that, at the largest of geographical scales, precipitation will very likely increase at high latitudes and, more likely than not, decline in the subtropics. The general rule that "the wet will get wetter, the dry will get drier, and the variable will get more variable" is projected to hold as warming progresses (Kirtman et al., 2014; Polade et al., 2014). However, most of these trends are small relative to the large natural variability in precipitation at regional scales, at least in the near term. Over continents, the mean projected change in precipitation in the 21st century is less than about 20% of historical totals and is in fact much less in many regions. There are some exceptions where precipitation is expected to rise by as much as 40–50%, including in Eurasia (reaching from Scandinavia to northern China) and around the Horn of Africa (Collins et al., 2014) (see Chapter 2, Urban Climate Science).

Mediterranean climates worldwide are projected to experience significant declines in precipitation (Polade et al., 2014; Seager et al., 2014). Drought, as measured by various indices, will become a normal state in many mid-latitude areas (including the Middle East, Central America, and Brazil) by the end of the century, unless GHG emissions are significantly reduced (Sillmann et al., 2013; Seneviratne et al., 2012; Collins et al., 2014; Polade et al., 2014). In Asia, increases in precipitation are very likely to be experienced at higher latitudes by mid-century, and for southern and eastern Asia by the end of the century (Hijioka et al., 2014).

In addition to changes in the quantity of precipitation, seasonal timing and the form of precipitation (e.g., snow vs. rain, heavy vs. light) are expected to change in response to atmospheric warming. In general, because of higher temperatures, precipitation is expected to fall increasingly as rain rather than snow (Berghuijs et al., 2014). Also, in some regions, the contrast between wet and dry seasons will increase (IPCC, 2013). Such changes in the timing and form of precipitation impacts the balance between the management of water supply and flood risk, with more runoff entering cities and water storage structures during winter seasons. Consequently, this results in more runoff taking the form of floods rather than steadier, more reliable, and manageable flows (e.g., Vicuña et al., 2013).

The nature of UWS vulnerability to climate change depends intrinsically on how precipitation is expected to change, and, unfortunately, vulnerabilities exist at both ends of the spectrum (Revi et al., 2014, Rosenzweig et al., 2010). In regions where precipitation increases, UWS can be threatened by insufficient conveyance systems leading to urban flooding and to combined sewer overflows that can contaminate water supply. This could also be the case in regions where precipitation decreases, since the overall frequency and magnitude of large storms, as well as dry spells, could increase (Polade et al., 2014). This could exacerbate the vulnerability associated with reductions in water supply that comes with a precipitation decrease.

UWS depends on water availability (McDonald et al., 2011; Cisneros et al., 2014; Revi et al., 2014), which is dependent on the nature, reliability, and diversity of sources that a city draws from. Changes in precipitation affect urban water demand (especially for exterior uses) (Ruth et al., 2007; Schleich and Hillenbrand, 2009; House-Peters and Chang, 2011), as well as water availability. For instance, drought often results in increased groundwater withdrawals (Konikow, 2013; Villholth et al., 2013), which have a much slower recovery rate than surface water sources. Even deep groundwater supplies can be vulnerable to precipitation changes over the long term (Cisneros et al., 2014; Georgakakos et al., 2014), which is further compounded by poor aquifer management (e.g., Suárez et al., 2014). This is an important concern because many cities depend on groundwater. It has been estimated that, in 2000, some 1.7 billion people were living in areas with threatened groundwater supply (Gleeson et al., 2012). The more overdrawn or generally threatened such supplies are, the more likely and quickly climate change impacts will become evident (Taylor et al., 2012). In terms of impacts on UWS, those systems that rely on local surface water supply may be most immediately at risk to changing precipitation regimes, followed by systems fed by more geographically diverse water sources, and, last, by systems that depend on shallow and then deep aquifer systems (O'Hara and Georgakakos, 2008; Crosbie et al., 2010; Newcomer et al., 2013).

14.3.3 Extreme Events

The WG1 contribution to the AR5 continues to support the long-standing expectation that heavy precipitation events will increase globally in both the near and long term (e.g., Min et al., 2011; Seneviratne et al., 2012). However, significant regional variation is expected, and extreme storms are not well represented in many climate models. Kirtman et al. (2014) conclude that the frequency and intensity of heavy precipitation will likely increase over many land areas, but may be masked by natural variability and other anthropogenic influences (e.g., deforestation) in the near term. Extreme precipitation events (e.g., with return periods >20 years) are projected to increase in frequency by 10–20% by the end of the 21st century for most mid-latitude land areas and even more so over wet tropical regions (Kharin et al., 2013).

More extreme precipitation could result in changes in frequency, extent, timing, and rapidity of stormwater runoff. This could cause flooding in many urban settings, especially given the impervious surfaces of most cities. Furthermore, this could pose added risks to public health and safety, property, and infrastructure (including UWS). Water quality could be affected by these extreme runoff events due to the increased concentration and build-up of contaminants during dry or low-flow conditions that are then released into the water supply with increased water flow (Langeveld et al., 2013). Many UWS infrastructural hubs are located in low-lying areas (e.g., California) that are more susceptible to flood damage (Porter et al., 2011). UWS infrastructure can also be at risk from wind damage and other non-precipitation storm effects, especially in the case where such infrastructure is either aging or exposed.

14.3.4 Sea Level Rise and Storm Surges

Current projections of likely global sea level rise (SLR) by the end of 21st century range from 0.5 to 1.2 meters, depending on whether aggressive climate mitigation measures are implemented in the coming decades and on the fates of polar ice caps (Horton et al., 2014, Church et al., 2014) (see Chapter 2, Urban Climate Science). SLR will vary around the globe from city to city, reflecting local to regional differences in plate tectonics, land subsidence (natural and anthropogenic), and long-term circulation and salinity variations across ocean basins (Church et al., 2014). For example, ensemble means suggest SLR will be higher in regions such as the central coast of Asia and the northeast coast of the United States, compared with lower increases off the southwest coast of South America (Church et al., 2014) (see Chapter 9, Coastal Zones).

In most settings, long-term sea level trends will have most immediate impacts by elevating the baseline upon which shorter term extreme sea level fluctuations (e.g., inter-annual fluctuations, wind-driven waves, storm surges, and even astronomical tides) will be superimposed (Lowe et al., 2010; Hunter, 2011; Obeysekera and Park, 2012). This may greatly increase the frequency and inland reach of otherwise "normal" high-water stands. (More details on sea level trends and impacts can be found in Chapter 9, Coastal Zones.)

Large portions of the world's urban populations (i.e., 13 of the 20 most populous cities, Hanson et al., 2011) and economies (>70–80% of world trade) (Hanson and Nicholls 2012) are located in coastal settings. In many such cities, wastewater and sanitation systems have important hubs (e.g., treatment plants and outfalls) located at or very near sea level to take advantage of the gravity-feed and marine-outfall options (e.g., Jacob et al., 2007; Aerts et al., 2013). These hubs and systems will be among the infrastructure that is most immediately at risk by SLR and/or increased storm surge conditions (Revi et al., 2014).

Some important water supply conveyance systems also have links that are near to sea level and thus are at risk to structural disruptions or water-quality impacts from SLR and storm surges. On a large scale, California's Delta is a key example (Hanak and Lund, 2012), and Hurricane Sandy uncovered others in the eastern United States (Manuel, 2013). Coastal cities that depend on local groundwater sources (e.g., coastal aquifers) for water supply will, in many cases, face risks of increased seawater intrusion into freshwater aquifers (Revi et al., 2014, Cisneros et al., 2014). However, Ferguson and Gleeson (2012) concluded that the direct impact of groundwater extraction in the United States has been and will be much more significant than the impact of SLR by the end of the 21st century. The IPCC WGII concluded that human-induced extractions from coastal aquifers will continue to be the main driver for aquifer salinization during the next century, with changing precipitation, increased storm frequency, and SLR further exacerbating these problems (Wong et al., 2014).

Similarly, when assessing impacts of SLR, it is important to take into account impacts of non-climate drivers such as subsidence. For example, Higgins et al. (2013) present research that land subsidence rates exceed local and global average SLR by nearly 2 orders of magnitude in the Yellow River Delta in China. Similar findings have been presented from the Nile River, where subsidence caused in part by the Aswan Dam is exacerbating SLR because sediment trapped in upstream reservoirs is reducing aggradation in deltas (Syvitski et al., 2009).

14.3.5 Changing Water Availability

Climatic pressures will interact at different spatial scales to have a synergistic impact on water availability, which depends not only on the amount of water at different sources, but also on water quality, infrastructural integrity, arrangements among competing users, and strength of institutions, as discussed in the next section. Figure 14.1 presents a conceptual depiction of these possible connections, some of which are further described later.

In response to warming, evaporation is projected to increase over most land surfaces globally, except primarily southern Africa and Australia, where declines in soil moisture availability are sufficient to reduce overall evaporation (Collins et al., 2014). Net water deficits (i.e., evapotranspiration minus precipitation) are projected to increase over most subtropical to mid-latitude lands, and decline over the higher latitudes, with precipitation increases compensating for increases in evaporation caused by warming temperatures (Kirtman et al., 2014). Projections of net deficits in the tropics are mixed. In most regions where net deficits

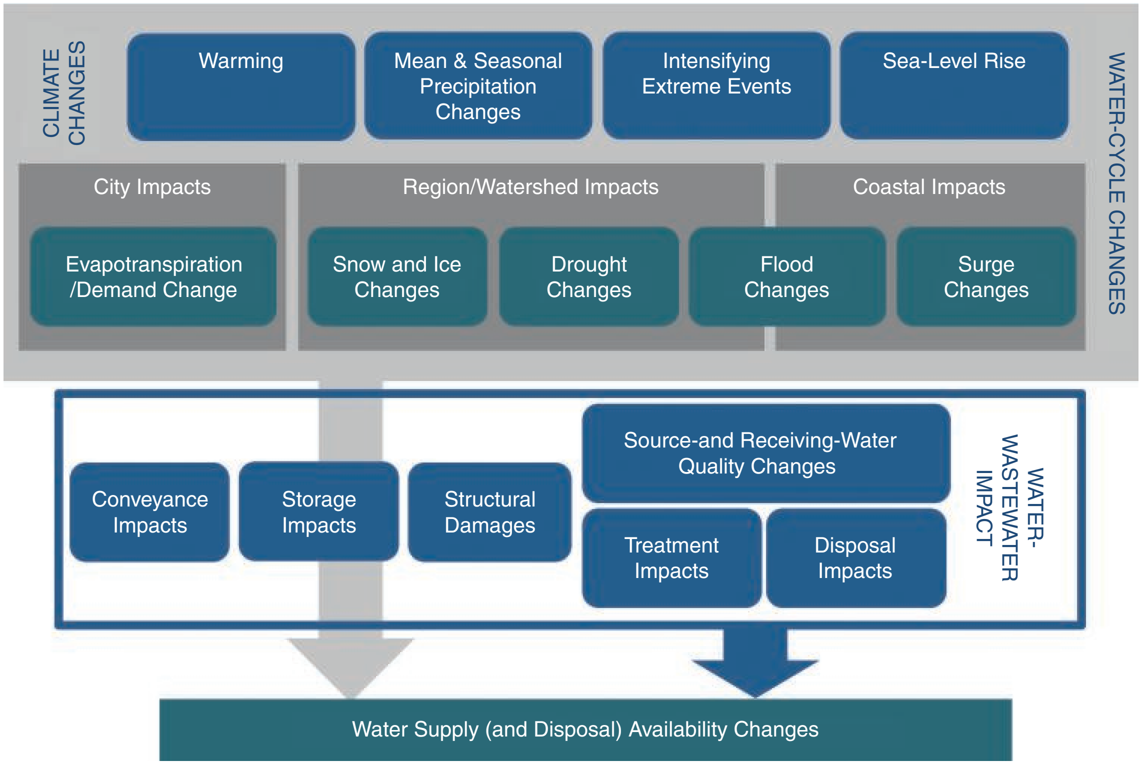

Figure 14.1 *Climate drivers impacting water availability.*

increase, runoff and recharge may be expected to decline, such that water availability is likely to suffer. Even in regions where net deficits decline somewhat, the amount of runoff and recharge derived from each unit of precipitation will likely decline due to enhanced evapotranspiration (e.g., Das et al., 2011; Georgakakos et al., 2014).

Warming-induced declines in snowpack, glaciers, and less seasonally persistent snowpack (e.g., earlier snowmelt) are expected to change the timing of water availability for 70% of major rivers and for water supplies around the world that depend on mountain-based seasonal snows as their source (Vuviroli and Weingartner, 2008). This alters the natural storage of water from cooler seasons with low water demands to warm seasons when demands are commonly highest. This shift in the seasonal timing of water availability is expected to challenge water management systems in many parts of the world (Barnett et al., 2005; Oberts, 2007; Kenney et al., 2008; Wiley and Palmer, 2008; Meza et al., 2014; Buytaert and De Bièvre, 2012).

Another potential impact on water supply has to do with climate change affecting erosion and turbidity levels, thus inhibiting water extraction from natural sources. For example, Mukundan et al. (2013) showed the negative effects of future climate on soil erosion and sediment yield, which are affecting a watershed that supplies water to New York. Recent high-turbidity events have occurred in the city of Santiago, Chile, that could be associated with the rising snow line, which leads to more silt in runoff, combined with intense precipitation events. Similarly, changes in water discharge could also alter critical water conditions, such as temperature, that could in turn affect water availability (van Vliet et al., 2013).

Together, these processes and connections will likely affect water availability in ways not previously experienced (Cisneros et al., 2014). McDonald et al. (2011) illustrate (see Figure 14.2) a projected set of current and future water availability challenges in large cities around the developing world. They found that many cities will have less water available under several of the climate change and land-use change scenarios that they studied. In India, for instance, an analysis of twelve major basins found deficits in the range of 38 billion cubic meters, the result of both climate and anthropogenic drivers (Gosain et al., 2006). These challenges in turn have the potential to threaten water supply, demand, and quality in many urban settings around the world, along with wastewater, stormwater, and sanitation systems.

Cities very often draw from water sources in areas located much further away from their water supply (McDonald et al., 2014). Therefore, urban water supply is very much dependent on climatic changes in surrounding areas in addition to climate pressures on supplies located within cities. Different water uses and users in urban settings have different water supply and wastewater/sanitation requirements. As Figure 14.1 illustrates, climatic risks for UWS are a complex set of considerations that are not

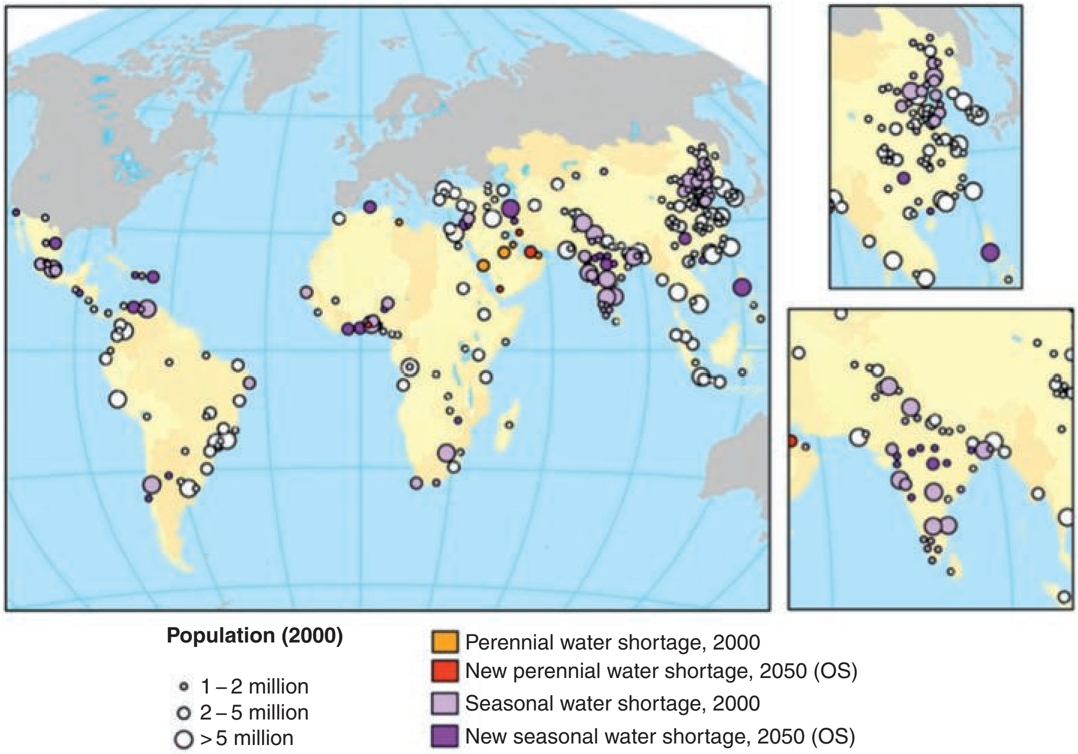

Figure 14.2 *Distribution of large cities (>1 million population in 2000) and their water shortage status in 2000 and 2050. Circle sizes reflect population in 2000; colors indicate statuses. Gray areas are outside the study area.*

Source: McDonald et al., 2011

necessarily related to each other. This creates a deep uncertainty in determining risks to UWS. Increasingly, the most appropriate response strategy is, to paraphrase Kennel (2009), "mitigate globally, assess regionally, and adapt and prepare locally."

14.4 Adaptation Strategies for Urban Water Systems

Since the ARC3.1 report was published in 2011, there has been a shift in the adaptation research community from analysis of impacts to an implementation/practitioner approach.[2] Adaptation is now widely acknowledged more as an iterative process than as an end in and of itself (Hinkel and Bisaro, 2016). Several key questions underpin the fundamental challenges of adaptation and are represented in Figure 13.3.

14.4.1 Identifying Adaptation Needs: Why Does the Urban Water Sector Need to Adapt?

Adaptation should either preserve or ideally improve water security within a city, without putting in peril water availability and quality for other uses within the basin. Understanding

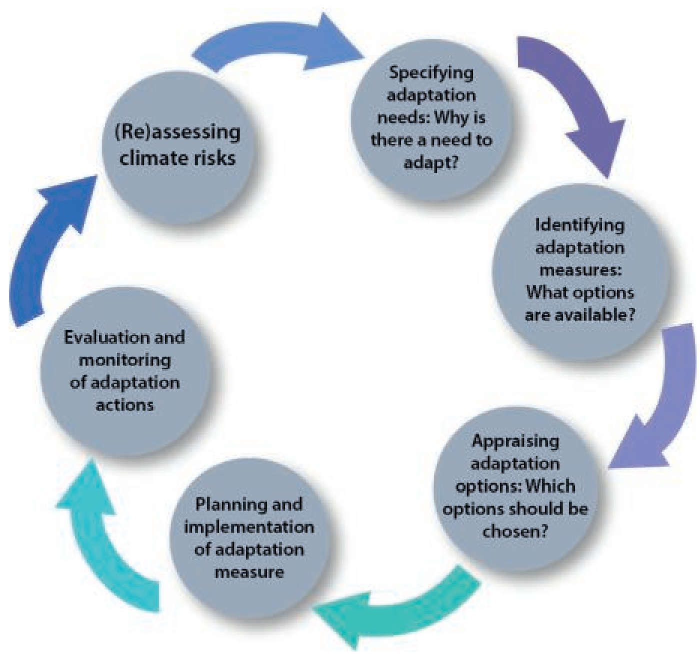

Figure 14.3 *Planning and implementing adaptation measures.*

Source: Adapted from PROVIA, 2013

2 For example, the emphasis on solutions is captured by the report *PROVIA Guidance on Assessing Vulnerability, Impacts and Adaptation to Climate Change* (PROVIA, 2013).

climate impacts is critical, but this must be complemented by a parallel process of identifying adaptation needs in order to prevent, moderate, or adjust to these impacts. This "vulnerability-led approach" starts with diagnosing existing problems and then identifying additional climate risks that can be addressed in parallel with existing problems, such as poverty and exposure to risks (Lafontaine, 2012). This assessment is critical because, in most cases, the barriers for implementing climate change adaptation are not due to a lack of knowledge about the future impacts of climate change, but rather the result of cognitive and institutional barriers to taking action toward long-term future change (Adger et al., 2009; Moser and Ekstrom, 2010). Barriers include the challenge of assessing future needs over a 30- to 50-year time horizon, short political windows of opportunity (often 4–5 years) in which to act, the immediacy of short-term challenges (i.e., health problems caused by lack of sanitation) that trump longer term plans, and making decisions in a context of uncertainty. In this regard, there are significant capacity differences between developed and developing world cities. For example, institutional flexibility, clear regulatory frameworks, enforcement capacity, and water price-setting are all elements that strengthen an institution's ability to respond effectively to climate challenges. In developing countries, where poverty and weak institutions play a significant role in shaping the magnitude of risks and opportunities, capacity analysis could be even more important than impact assessments (Hinkel and Bisaro, 2016).

14.4.2 How to Address Climate Risks? Adaptation Options for the Urban Water Sector

Since the publication of the ARC3.1 report in 2011, a variety of adaptation options have been promoted that are not only sensible ways of adapting to climate change, but are also sound options for sustainable development. Table 14.1 provides a list of adaptation measures, categorized according to the two components of water security (i.e., water as a resource or as a hazard). This section presents several strategies that are increasingly recognized as fundamental parts of a sensible adaptation strategy for urban water security.

Table 14.1 *Urban water system adaptation measures.*

Objective (Parameter of water security)	Primary Climate Risk(s)	Adaptation Strategy	Specific Options
Water as a resource: Sustainable access to adequate quantities of acceptable quality water for sustaining livelihoods, health, well-being and economic development.	• Precipitation reduction, glacier retreat, land erosion, or sea level rise leads to a reduction in water availability and/or worsening of water quality. • Ecosystems are threatened by excess stress on water resources caused by both climate factors and poor management.	(1) Ensure adequate quantities to sustain livelihoods and ecosystems.	Reuse of wastewater Groundwater use/recharge Distribution efficiency improvements Groundwater Transfer from other sectors Desalination Green infrastructure Reservoirs/Increase storage capacity Point source separation in new construction
		(2) Reconsider "adequate" and identify different water needs (both quantity and quality) for different uses.	Demand management through tariffs (user fees) or other demand management options Cultural changes Standards Restrictions Incentives
Water as a hazard: Ensuring protection against water-borne pollution and water-related disasters.	• A reduction in water flows could lead to an increased concentration in pollutants.	(3) Ensure that there is adequate quantity and flow to dilute pollution.	Similar Options as in Adaptation Strategy (1) Restrictions and flow control
		(4) Reduce vulnerability to pollution of marginal communities.	Water quality standards Water treatment
	• Increase in precipitation intensity, storms, storm surges could increase threat associated with floods.	(5) Reduce the exposure of people and infrastructure to floods/related disasters.	Riparian buffering Increase in percolation Fluvial flood protection Green infrastructure Coastal set-back lines Land use regulations Relocation
		(6) Reduce vulnerability to flooding of marginal communities.	Adaptive planning Housing improvements/modified building codes

Case Study 14.1 Climate Adaptation through Sustainable Urban Water Development in Can Tho City, Vietnam

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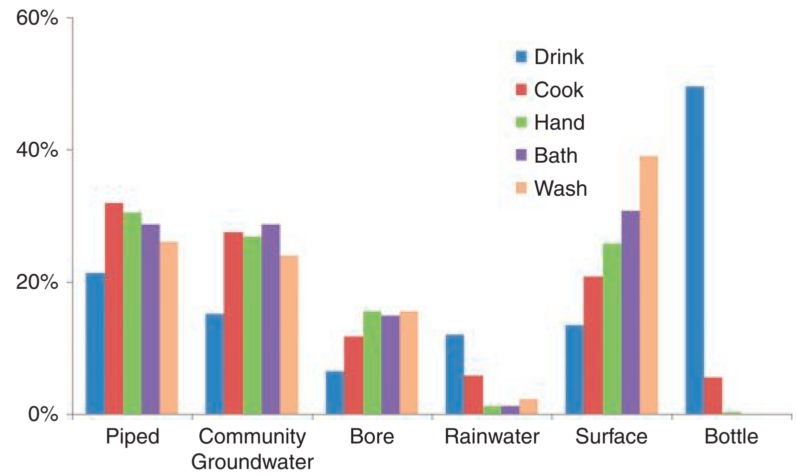
Keywords	Sustainable development, climate adaptation, integrated urban water management, strategic planning, pilot demonstration
Population (Metropolitan Region)	1,200,000 (CanTho Portal, 2015)
Area (Metropolitan Region)	1,400 km^2 (Statistical Office of Can Tho City, 2009)
Income per capita	US$2,050 (World Bank, 2017)
Climate zone	Aw – Tropical, Savannah (Peel et al., 2007)

The Climate Adaptation through Sustainable Urban Development Project was a research initiative aimed at bringing sustainable principles into practice as an effective means of adapting to climate change. The project demonstrated a sustainable development framework to improve the planning of urban water services to enhance the resilience to climate change of local communities and the government of Can Tho City of Vietnam, as a case study. The project was undertaken in collaboration by CSIRO Australia, Can Tho University, and Can Tho Climate Change Coordination Office.

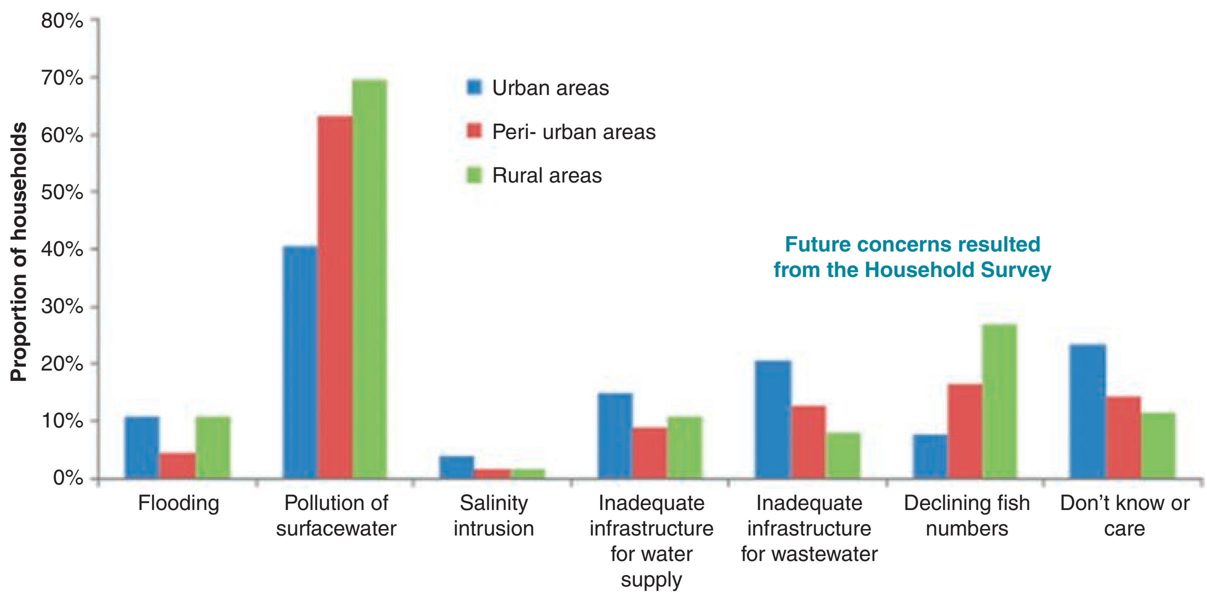
Can Tho is the central city of the Mekong Delta of Vietnam, with an approximate area of 1,400 square kilometers and population of 1.2 million (see Case Study 14.1 Figure 1). The region has very low-lying and flat terrain, with a dense network of waterways. Waterways are central to people's livelihoods and underpin the local economy, which is still based on agriculture and aquaculture. However, there is a rapid transition of the city toward regional and industrial services. The city has very mixed land uses, where old urban, new urban, peri-urban, industrial, and rural areas co-exist even within urbanized districts.

The sustainability of the water systems in Can Tho City, including both its physical infrastructure and its ecology, is under pressure from rapid urbanization and industrialization. Results from the project's large survey of 1,200 households and a comprehensive

Case Study 14.1 Figure 1 *Can Tho City, Vietnam.*



Case Study 14.1 Figure 2 *A result from the 1,200 household survey: Mixed uses of water for different purposes in peri-urban areas.*

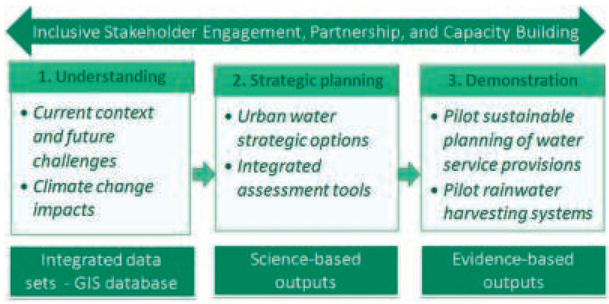


Case Study 14.1 Figure 3 *A result from the 1,200 household survey: Future concerns regarding water systems and environment.*

sector review (Neumann et al., 2011, 2013) indicated that water service provisions were greatly fragmented among urban and rural areas. Many peri-urban households draw water from multiple sources and use it for different purposes (see Case Study 14.1 Figure 2), presenting adverse implications for their health. Inadequate physical infrastructure is the main issue, resulting in limited access to clean water and sanitation, frequent urban floods, and increasing pollution in waterways, which was the utmost public concern (see Case Study 14.1 Figure 3). These issues are exacerbated by the impacts of a changing climate, such as more prolonged and frequent drought, heat waves, and inundations, which have already been experienced in recent decades.

INTEGRATION OF STRATEGIC PLANNING AND DEMONSTRATION

To deal with such a complex system of water and sanitation services and the environment, the research team applied the integrated urban water management (IUWM) principles (Maheepala et al., 2010). This provides state-of-the-art integrated assessment methodologies and participatory processes to assist in the strategic planning of urban water systems that are sustainable for specific conditions. IUWM aims to plan, design and manage the overall water cycle, including water supply, stormwater, and wastewater in a coordinated manner. This helps to minimize the impacts on the environment, maximize contributions to economic



Case Study 14.1 Figure 4 *Summary of the case study's approach with three focus areas and results.*

development, engender overall community well-being, and enhance the resilience capacity of local communities to future challenges, including climate change. The case study includes three focus areas, as summarized in Case Study 14.1 Figure 4 (Nguyen et al., 2012).[3]

A set of urban water strategic adaptation options was developed for the city water systems. Through an inclusive participatory engagement process, the stakeholders were positioned to play the main role in identifying the strategies, developing implementation pathways, and assessing factors influencing their likelihood of success (see Case Study 14.1 Figure 5). The strategies identified ranged widely from social behavior changes and household measures to infrastructure planning and covered all water supply, demand, and sewerage aspects. This process challenged stakeholders' preconceived notions, allowed them to develop integrated systems thinking, and highlighted the responsibilities of individuals or agencies in implementation (Moglia et al., 2013).

Pilot demonstrations of the identified strategic options were conducted to provide the stakeholders local evidence-based examples of sustainable development practices. An integrated conceptual design and planning exercise was undertaken to assess the sustainability of different integrated water supply and wastewater servicing options in a peri-urban area of 150 houses in Chau Van Liem ward, O Mon District, using a state-of-the-art sustainability assessment approach (Sharma et al., 2010). The purpose was to build the capacity of the local research partners and planning agencies to identify suitable and sustainable integrated water service options that consider cost-effective solutions, environmental impacts, service levels, community expectations, and suitable institutional arrangements to manage the system (Nguyen et al., 2012). The project also included another demonstration with two pilot systems of rainwater harvesting to evaluate rainwater quality and the use of rainfall to augment water supply with simple filtering techniques (see Case Study 14.1 Figure 6). A *Rainwater Harvesting Guidebook* was published to assist the public and agencies in appropriately harvesting, filtering, and

(a) (b)

Case Study 14.1 Figure 5 *Structured workshops providing opportunities for local stakeholders to contribute, lead, and develop ownership of the outcomes.*

3 The first focus area of the study (Figure 4) focused on understanding the local context through a number of activities, mainly for data collection, which can be divided into two approaches:
(1) Top-down activities include
a. A participatory workshop where stakeholders played the key role in defining key issues, identifying hotspots, and identifying data types and possible sources for the issues related to water systems and environment. In this way, the project set up an understanding and common language and obtained some commitment of providing data from the stakeholders.
b. Collection of the identified data (and beyond) from governmental agencies (e.g., Can Tho DONRE, 2008). This was done/coordinated by the local research partners.
c. CSIRO conducted a comprehensive water sector literature review that sought to understand the institutional context, identify data sources and data gaps, and crystallize the critical dilemmas facing the city (Neumann et al., 2011).
(2) Bottom-up activities include
a. A survey of 1,200 households on issues of water access, water quality, groundwater, and flooding (Neumann et al., 2013)
b. Two similar surveys of a few hundred of households targeted at specific areas or "hot-spots" for demonstration of planning and design
c. Other informal surveys, meetings, and interviews with local people, managers from different levels of government agencies, and experts, including researchers and academics.

Case Study 14.1 Figure 6 *Demonstration of rainwater harvesting systems for safe water supply: One pilot system on Can Tho University campus for research and testing water quality, and one at a peri-urban household in Le Binh ward, Cai Rang District, for reality check.*

maintaining rainwater fit for purpose to ensure safe domestic uses (Trung et al., 2004a).

LESSONS LEARNED

The project found that the water system in Can Tho City is highly fragmented and that a "one size fits all" solution would not be adequate to address all the issues for different areas of the city. However, the framework developed in this Case Study can be applied to other locations that are facing the same fragmentation problem, given the following two important considerations are met.

First, there is a need for strong inclusive engagement with local partners and stakeholders, not only through workshops and interviews, but also through delivering tangible outputs with pilot demonstrations that show directly relevant benefits to the stakeholders. This ensures that the partners and stakeholders have a buy-in and an ownership in the outputs, and it also ensures that the developed solutions are locally suitable and acceptable. This project developed a strong collaborative relationship between the research partners and key relevant stakeholders. Many tangible outputs, including a City Water Atlas (Mapbook) and Web-GIS (Trung et al., 2013, 2014b) served effectively as a collaborative platform among stakeholders in planning and management. The *Rainwater Harvesting Guidebook* (Trung et al., 2014a) and the Synthesis Report with recommendations to the city (Nguyen et al., 2012) have been adopted by various city agencies and nongovernmental organizations. As a result, the research was underpinned by strong partnerships and the active involvement of local research partners and governmental agencies; it received the 2012 Can Tho City Award for its contribution to the City's Adaptation Plan.

Second, there is a need for capacity-building for the local institutions, to allow them not only to effectively participate, but also to maintain any knowledge and technology developed in the project. Local capacity-building also helps improve institutional capacity for planning and maintaining the water systems. This project had a strong focus on capacity-building, which included consistent hands-on training during the project for researchers from Can Tho University. They have become active trainers for many training workshops for local stakeholders on the project outcomes. This "train the trainers" program using a practical hands-on approach (Nguyen et al., 2012) resulted in the leading role of Can Tho University in delivering many final outputs of the project and bringing the knowledge to students, the next generation of experts for the city and the region.

14.4.2.1 Water Supply and Access

Water supply options work both within and beyond city limits. Water storage infrastructure, water transfers, and new sources of water supply (e.g., desalinization) are all examples of options that are implemented beyond city limits (Vicuña et al., 2014a). Available options are very much dependent on the relative position of cities within a river basin, as discussed in Case Study 14.2, which presents a basin-level approach for addressing urban water supply in Santiago, Los Angeles, and Bangalore. The relative position of a city within a basin determines the type of water supply options available, as well as water-pollution issues, with consideration for other users located either up- or downstream of the city.

14.4.2.2 Water Demand Management

A core principle for adapting and securing urban water supply to future climate change is to ensure that demand is managed well. Water demand management aims to reduce water use and limit the need for new sources of water supply without affecting well-being or economic productivity. Common tools used to manage demand include introducing pricing structures where excessive water users pay higher rates, wastewater reuse, low-flow household plumbing and appliances, drip irrigation, and social marketing to inform consumers about the environmental impacts of their daily practices (Breyer and Chang, 2014). Critical to ensuring adequate quantities of water for different purposes is understanding end-use consumption patterns in order

Case Study 14.2 Using a Basin-Level Approach to Address Climate Change Adaptation of Urban Water Supply: The Case of Santiago, Los Angeles, and Bangalore

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Keywords	River basins, adaptation, water supply, demand management
Population (Metropolitan Region)	Santiago: 7,007,600 (Instituto Nacional de Estadistica [INE], 2012) Los Angeles: 12,828,837 (U.S. Census Bureau, 2010) Bangalore: 9,621,551 (Census Population Data, 2011)
Area (Metropolitan Region)	Santiago: 15,403.2 km² (INE 2012) Los Angeles: 12,557.43 km² (U.S. Census, 2010) Bangalore: 2,196 km² (Census Population Data, 2011
Income per capita	Chile: US\$23,270 United States: US\$56,180 India: US\$1,680 (World Bank, 2017)
Climate zone	Santiago: Csb – Temperate, dry summer, warm summer Los Angeles: Csa – Temperate, dry summer, hot summer Bangalore: Aw – Tropical savannah (Peel et al., 2007)

Cities have a number of different adaptation options at their disposal for addressing shortages in water supply linked to climate change or climate variability. At the city level, these options can be considered through two lenses: (1) by considering the city as an isolated system with limited inputs and (2) by taking into account water supply options that fall within the city boundaries. For the former, measures could include reducing total water consumption, either through improved efficiency around water use or improving the distribution system (see Case Study 14.2 Table 1). For the latter, they may include groundwater extraction or wastewater reuse.

An additional influence on which options are available to secure supply in a changing climate depends largely on the position of a city in the river basin, for example, whether the city is located near the headwater or the outlet of the basin. In a situation where a city is facing a reduction in surface water availability, a potential adaptation measure available to both "headwater cities" and "outlet cities" could be constructing a reservoir to be drawn on in times of need. Other measures adopted by these cities would differ due to their relative position in the basin. For instance, a "headwater city" may have only one option: reduce water use by neighboring users located upstream (assuming that the costs are high to pump water upland and over great lengths). An "outlet city" located in this same basin, however, has additional options including:

- Improving water use efficiency in the agriculture sector, including for irrigated areas located in the lower portions of the basin
- Increasing water flow via an interbasin transfer or by drawing from a tributary river
- Sourcing water from the ocean through the use of a desalinization plant

To highlight this point further, the cities of Santiago, Chile; Los Angeles, United States; and Bangalore, India are compared here.

Case Study 14.2 Table 1 *Comparison of Santiago, Los Angeles, and Bangalore.*

	Cities		
Variables	**Santiago, Chile**	**Los Angeles, USA**	**Bangalore, India**
Area (metropolitan region) km²	15,403.2 (INE, 2012)	12,557.43 (U.S. Census Bureau, 2010)	2,196 (Census Population Data, 2011
Population (metropolitan region)	7,007,600 (INE, 2012)	12,828,837 (U.S. Census Bureau, 2010)	9,621,551 (Census Population Data, 2011)
Density (city, metro area) (inhabitants/km²)	8,464	2,729	11,905
Latitude and longitude	33.45° S, 70.67° W	34.05° N, 118.25° W	12.97° N, 77.56° E
Climate zone (Köppen-Geiger Climate Zones)	Temperate, dry summer, warm summer (Csb)	Temperate, dry summer, hot summer (Csa)	Tropical savannah (Aw)
Human Development Index	[0.52–1]	>0.9	0.753 in 2001 (for Bangalore Urban Dist.)
Water supply options available (1)	A; S	A; S; R; ST; T	A; S
Water management strategies (2)	T in summer months; A	C; A	Informal water supply system (Tanker Market), A

Case Study 14.2 Table 1 (*continued*)

	Cities		
Variables	**Santiago, Chile**	**Los Angeles, USA**	**Bangalore, India**
Relative location	City located at Andes Mountains foothills	City located in Southern California coast	City located on Deccan plateau
Shares water with (3)	A	A	A
Users upstream (3)	H	H, A, RE, C	A
Users downstream (3)	A, RE, C	None	A
Potential climate change impacts (4)	W, D, T, F	W, D, T, F, SI	W, F
References	Meza et al. (2014)	http://www.ladpw.org/wmd/irwmp/	Lele et al. (2014)

(1) A, Aquifer, S, Surface; R, Reuse; D, Desalination; ST, Storm runoff capture; T, Transfers

(2) T, Tarif controls; C, Conservation measures; L, Lawn irrigation restrictions; A, Awareness campaigns

(3) H, Hydropower; A, Agriculture; RE, Recreation/Environment; C, Cities

(4) W, Reduction in water supply; D, Increase in water demand; T, Increase in high turbidity events; SI, Salt water intrusion/Storm surge; F, Increase flooding

SANTIAGO DE CHILE

Santiago is the largest city in Chile, home to nearly 7 million people and producing nearly 40% of the nation's total gross domestic product (GDP). It is located in a semi-arid, Mediterranean climate at the foothills of the Andes Mountains. The city of Santiago relies on the Maipo River, which runs from the Andes Mountains to the Pacific Ocean, for 80% of its water needs. The remainder is derived from groundwater extraction. To address seasonal and interannual variability, the city operates a 200 million cubic meter reservoir located in the Andes mountains. In addition to pressure from growth in population and industry (Puertas et al., 2014), Santiago faces potential impacts from climate change, including a projected increase in temperature (+1.5 to +3.5 C by the end of the century) and reduction in precipitation (–10 to –40% by the end of the century), all of which is expected to further hinder water availability (Meza et al., 2014). Depending on the global circulation model (GCM) projection, the greenhouse gas (GHG) emission scenario, and the time horizon being considered, the Maipo River may face a reduction in total discharge of 10–40%, with river runoff peaking 1–4 weeks earlier than it does currently (Meza et al., 2014). Similar runoff projections are expected in other snowmelt-dominated basins in central Chile (Vicuña et al., 2010). A series of adaptation options were studied by Bonelli et al. (2014) in order to address this situation and to begin planning appropriately. One of the options considered is a reduction of water distribution losses that are currently near 30% of surface water extractions. When applying a basin perspective to urban water supply, the main option available is to increase the portion of water rights held by the city in relation to the agriculture sector. According to Bonelli et al. (2014), the share of water rights should increase from the current 24% to at least 40% by 2050 in order to cope with climate change impacts and population growth.

LOS ANGELES

The Greater Los Angeles region (including Los Angeles, Orange, San Bernardino, Riverside, and Ventura Counties) is located on the coast of southern California. This region is home to more than 14 million people and supports more than US$700 billion in economic activity (2010). Similar to Santiago, the climate in the Greater LA region is Mediterranean and semi-arid. However, the region has a more diverse portfolio in terms of water supply, in part due to its location at the outlet of a basin or system of basins. According to the Integrated Regional Water Management Plan for the Greater Los Angeles County (GLAC) – which covers the Greater Los Angeles region with the exception of Riverside County[4] – 57% of the region's water is imported from three different regions: (1) the Sacramento River in Northern California through the State Water Plan system of aqueducts, (2) the Colorado River through the Colorado River Aqueduct, and (3) the Mono Basin and Owens Valley through the Los Angeles Aqueduct. The remainder of the region's water supply is sourced from groundwater extraction (35%) and recycled water (1.5%). Demand management strategies, such as water use efficiency and conservation, account for 3% savings in water extraction (GLAC IRWM, 2013, Plan Update). According to the GLAC Plan Update, climate change could affect imported and local water supply due to a progressive reduction in average annual runoff. Also, there may be a missed opportunity to capture rainwater from more intense storms. A series of water management strategies is listed in the GLAC Plan Update for dealing with shortages in water supply, which include water desalination, groundwater management, combined use of surface water and groundwater, water storage, improved water conservation and efficiency of urban water use,[5] water recycling, and water transfers from different regions in the state.

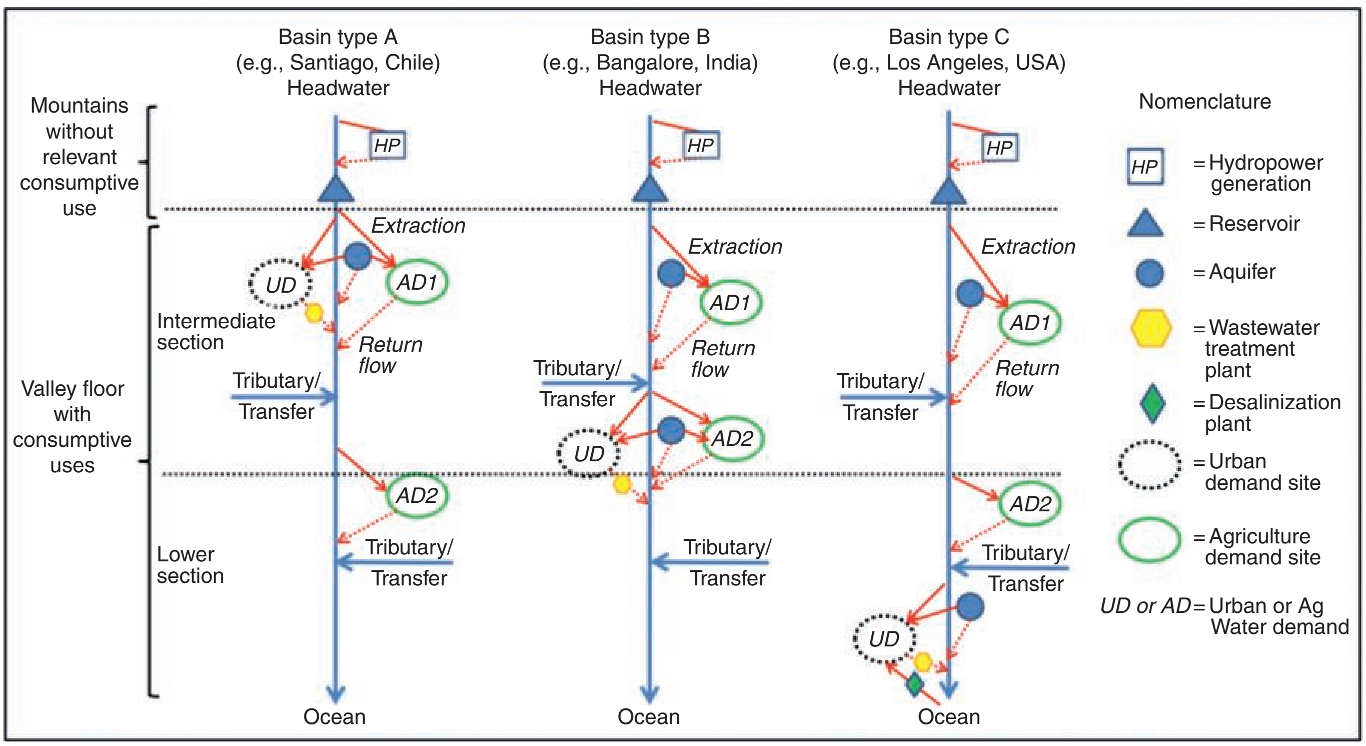
4 http://www.ladpw.org/wmd/irwmp/

5 The State of California faced an extreme drought that required a declaration of a State of Emergency by Governor Brown in January 17, 2014. Enforceable water conservation measures were one of the key strategies. Governor Brown sought to reduce water usage by all Californians by 20% to confront this emergency. Accessed August 17, 2015: http://www.waterboards.ca.gov/board_decisions/adopted_orders/resolutions/2014/rs2014_0038_regs.pdf http://www.sacbee.com/2014/07/29/6591112/new-statewide-water-waste-prohibitions.html

BANGALORE

The city of Bangalore, located in southern India and home to nearly 10 million people, has more than doubled its population over the past 20 years. It has also seen rapid growth of investment in business, with companies such as Boeing, Samsung, Tata, Toyota, and a number of IT firms opening their doors in the city. These industries, including agriculture in the city's periphery, rely on water from the Arkavathy River basin, where the city is located. Researchers at the Ashoka Trust for Research in Ecology and the Environment, recipients of the government of Canada fast-start climate financing, have developed a land-use map for the basin and are investigating the impacts of rapid environmental change on water availability. The situation is dire: one of two major reservoirs has dried up entirely, and the other operates at one-fifth of its capacity due to extreme water shortage. The city instead imports water from more than 100 kilometers away, at great cost, while rural areas continue to pull from a depleting groundwater aquifer. Groundwater levels have dropped dramatically over the past 20 years, with bore well depths at 800–1,000 feet (down from at 200–300 feet 20 years ago), and the rate of replenishment is falling far short. The research suggests that while climate change may compound the problem, unregulated groundwater extraction, industrial pollution, and changes in land use are likely the greatest threats to water quality and availability. Preliminary recommendations include regulating groundwater extraction, increasing water reuse, distributing river water more evenly among users, and encouraging users to diversify their water sources.

The portfolio of adaptation options for addressing water supply that are available to a city located at the headwaters of a basin (e.g., Santiago), compared with one located at a halfway position (e.g., Bangalore) or at its outlet (e.g., Los Angeles) are different, as depicted in Case Study 14.1 Figure 1. There are other issues that also become evident when applying a basin perspective to adaptation for securing urban water supply. When the efficiency of water use inside a city increases, or if there are transfers from relatively inefficient agricultural users to urban users, then the downstream flow of water can be reduced, thus affecting supply. In a simple theoretical example, Vicuña and Meza (2012) show that with a 20% reduction in water availability, the cascade of adaptation measures (mostly improvements in irrigation efficiency for neighboring and downstream irrigation districts) used by a city located in the headwaters of a basin would result in more than 80% reduced flow at the basin's outlet. Users located near the outlet of the basin would also be affected disproportionally through the implementation of these types of measures. This is an issue that is also relevant in the case of Bangalore, India, for example (Lele et al., 2013). In sum, additional efficiency upstream may paradoxically create a more challenging situation downstream.



Case Study 14.2 Figure 1 *Schematics representing three possible urban water supply systems using a basin perspective.*

Source: Adopted from Vicuña et al., 2014b

to determine how much water will be required in the future. Demand management options are among the most politically viable actions and can help ensure that consumers are able to adapt to different water availability scenarios.

Key to the adoption of demand management is adequate governance, finance, and enforcement for ensuring compliance. For example, safe wastewater use is an increasingly popular way of matching water quality with water use (i.e., drinking water need not be used for agriculture). Safe use of wastewater, however, requires an operational capacity that is not always present in many developing countries (Drechsel et al., 2009). A graduated stepwise approach to implementing demand management needs to be adopted with a realistic assessment of the capacity to implement.

14.4.2.3 Storm Runoff Management

Increases in precipitation or storm surge intensities can increase the risk associated with urban flooding due to systems' inability to quickly absorb or redirect excess water or manage river overflow. A series of strategies can be implemented to diminish the physical causes of such risks. For example, peri-urban wetlands slow excess floodwaters, treat polluted waters, and provide valuable habitats for animals and plants (Kadlec and Wallace, 2008). The preservation of wetlands in and around cities is a key "ecosystem service" that is currently at risk from climate change and human pressures. As described in the study by Day et al. (2007), Hurricanes Katrina and Rita unveiled the vulnerability of coastal communities, and the authors described how human activities that caused the deterioration of the Mississippi Deltaic Plain served to exacerbate this vulnerability (see Chapter 8, Urban Ecosystems). Another key strategy is the revision of design criteria for urban drainage infrastructure that takes into account climate change impacts (Mailhot and Duchesne, 2010). Finally, in the case that the physical causes of risk cannot be avoided, strategies such as risk-based urban planning could be implemented (see Chapter 5, Urban Planning and Design).

14.4.3 Planning and Implementing Adaptation Options

The implementation of adaptation actions requires a deliberate investment in and planning of options that reduce exposure to future climate risks (Agarwala and Fankenhauser, 2008). There is no one-size-fits-all solution. Adaptation is necessarily local, and it is an iterative process that requires continual assessment and renewal of decisions as new climate information becomes available (Resurreccion et al., 2008). Although local in nature, the assessment of adaptation options should also consider multiple scales. For instance, the case study of the city of Naples in Italy (see Case Study 5.A in Annex 5) provides a good example of how different scales are connected in a storm runoff/flooding adaptation strategy, including components at the household, neighborhood, city, and basin levels.

14.4.3.1 Dealing with Uncertainty, the Importance of No-Regrets, and Avoiding Maladaptation

Once potential adaptation measures are identified, an appraisal is done to assess those that are best to implement given the context. Key in this appraisal is to take into account current climate/risk/vulnerability conditions and to assess uncertainties relating to future climate and non-climate drivers. In some cases, it may be impossible to perform a formal probabilistic assessment of future scenarios (Kiparsky et al., 2012). Risk-based decisions for engineering solutions using quantitative tools (such as decision matrices and probabilistic risk assessments) could be used, as suggested by Rosner et al. (2014). Recognizing the difficulties associated with uncertainty in climate change projections, experts conducting adaptation options appraisals have shifted their focus from a future climate (GCM) impact-based approach to more of a vulnerability-stakeholder driven process. Robust decision-making (RDM) or adaptation pathways are some of the recent frameworks that have been applied to water case studies, some of which are focused on urban areas. RDM provides an iterative decision framework for identifying robust strategies that fit a wide range of future scenarios. On the other hand, adaptation pathways provide an analytical approach for exploring and sequencing a set of possible actions based on alternative external developments over time. See specific examples of the application of these methods in Brown et al. (2012), Lempert and Groves (2010), and Haasnoot et al. (2013).

In most cases, however, the complexity of adaptation and the inability to precisely connect climate scenarios with impacts has led decision-makers to focus on options that offer a positive development pathway under a range of climate scenarios.[6] Such options for the water sector are generally considered as standard good practice for environmental stewardship and/or conservation. For example, of the options proposed by several of the authors and of those that are used in practice in many cities (e.g., leakage control, demand management, wastewater reuse, and restrictive land-use planning, see Table 14.1), most are already considered common-sense applications for smart water management (see Hallegatte, 2009). At its core, adaptation is local; it is about processes that improve decision-making, have embedded flexibility, and present decisiveness with imperfect information over long-term time horizons (Tyler and Moench, 2012; Ziervogel et al., 2010; Hallegatte, 2009).

The issue of maladaptation is a considerable risk to cities trying to meet urban water supply needs and must be avoided. Maladaptation refers to a situation in which an action, even if well intended, has other negative consequences. For instance, desalination, while addressing immediate water needs, can be considered maladaptive since it requires an enormous amount of energy and therefore GHG emissions (Hallegatte, 2009). Similarly, interbasin transfer of water (e.g., from the Cauvery River located more than 100 kilometers away to supply water to Bangalore) is not only costly, but also energy intensive. Such investments are often capitalized through debt but may not have adequate management to ensure that operation and maintenance costs are covered in the long term. The results are long-term financial liabilities that are difficult to manage. Such large-scale interbasin transfers are popular engineering projects but are frequently promoted before lower cost demand management solutions, which can be politically challenging

6 Sometimes called "low-regret" or "no-regret" options.

(i.e., raising prices to cover water supply and treatment costs). The implementation of some of these projects could also be related to a second form of maladaptation in which a given investment can address short-term climate variability but have negative long-term consequences. For example, investments in irrigation infrastructure can increase cultivated acreage in the short term but stress water basin capacity limits (e.g., Vicuña et al., 2014b). One useful way to implement the best adaptation options and avoid maladaptation is to sustain a close relation between researchers and decision-makers (see Case Study 14.3).

14.4.3.2 Financing Adaptation

Adaptation of the water sector in cities is expected to cost tens of billions of dollars, although specific estimates are required in order to improve planning and responses (Stern, 2006). Yet, due to the lack of reliability in available data, it is extremely difficult to accurately forecast the cost of adaptation. Estimates of the investment required to adapt the urban water supply and sanitation sector vary. Early cost estimates from the IPCC (2007) suggested that an additional investment of US$9–11 billion annually would be required to accommodate water infrastructure to climate change impacts, not including the costs for extending services to unserved areas (IPCC, 2007). This amount was considered too low by others (Parry, 2009). Such variance stems from the lack of adequate data with which to specify costs and benefits of different adaptation options, as well as the large range of possible futures on the basis of existing climate scenarios. For the urban water sector, most of the benefit of adaptation comes in terms of avoided damage costs associated with extreme weather. This interests insurers to the extent that they have invested in economic assessments of damage in different sectors, including the water sector (see, e.g., Swiss Re, 2014).

Understanding the costs and benefits of adaptation is a key concern for implementation. Some adaptation actions are low cost but require behavioral change, whereas others are high in capital and operation and maintenance expenditures

Case Study 14.3 Denver, Seattle, Tucson: How Can Climate Research Be Useful for Urban Water Utility Operations?

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Keywords	Water management, utilities, multistakeholder, climate information
Population (Metropolitan Region)	Seattle: 3,733,580 Tucson: 1,010,025 Denver: 2,814,330 (U.S. Census Bureau, 2015)
Area (Metropolitan Region)	Seattle: 15,209 km² Tucson: 23,794 km² Denver: 21,616 km² (U.S. Census Bureau, 2010)
Income per capita	US$56,180 (World Bank, 2017)
Climate zone	Seattle: Csb – Temperate, dry summer, warm summer Tucson: BSh – Arid, steppe, hot Denver: Dfa – Cold, without dry season, hot summer (Peel et al., 2007)

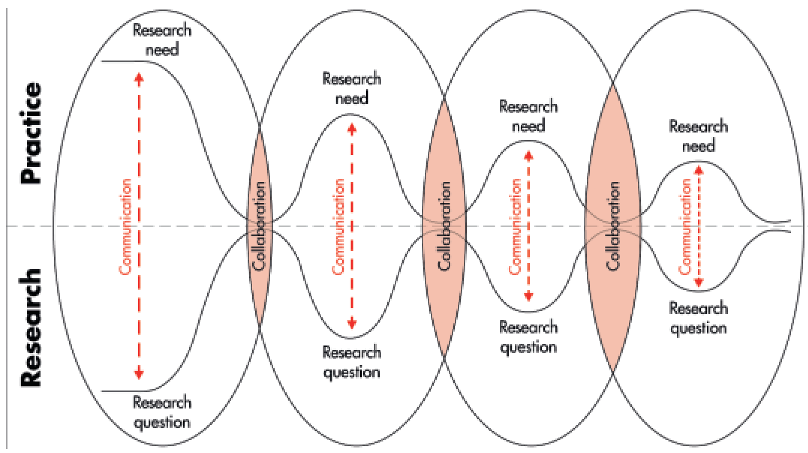
Municipal water utilities in Denver, Colorado; Seattle, Washington; and Tucson, Arizona, each interacted with climate researchers. These experiences yielded a series of insights about how to foster productive collaboration between water management practitioners and climate researchers. The cities in which this research was conducted represent a range of water resource management settings for middle-sized cities (population of around 600,000) in the United States. Annual precipitation ranges from 300 (Tucson) to 940 millimeters (Seattle), resulting in notably different supply contexts. Seattle relies on two major watersheds for municipal water; Denver primarily utilizes four watersheds; Tucson – in the Sonoran Desert and without access to perennial surface water – has historically depended on groundwater. In recent years, however, supply has been bolstered by the Central Arizona Project, a 540 kilometer-long canal that brings water from the Colorado River to parts of Arizona that don't have access to perennial surface water.

These different contexts shape the climate information each utility needs to support its decision-making, but the processes for how information flows back and forth across the science/practice divide are relatively consistent. A central lesson from this work is the need to shrink the conceptual distance between the way in which climate researchers and water resource practitioners formulate climate-related problems for water resources, as well as potential solutions, in order to grow collaborative space for more integrated work.

This research yielded a series of ten heuristics or rules of thumb (Ferguson et al., 2014) meant to guide researchers and water resource practitioners who are seeking to collaborate. Three fundamental concepts underpin these rules of thumb. First, a key indicator of successful collaboration is persistence. Most of the heuristics point toward the need for sustained commitment to the common goal of solving a complex problem despite the challenges that arise from researcher–practitioner collaborations. Next, processes that encourage purposeful, thoughtful, and iterative interaction across the science–practice divide are the cornerstone of successful collaborations. A stand-alone workshop to disseminate research results or to gather stakeholder input may be a useful tool, but it is insufficient for building lasting collaborations to solve complex environmental problems. This highlights the critical importance of interdisciplinary research operating across social and natural sciences, as well as with practitioners, in order to bridge the sometimes disparate approaches to problem-solving.

Case Study 14.3 Figure 1 is an idealized diagram of the evolution of a collaborative partnership between resource management professionals and scientists. Each large oval represents a problem common to both the practitioner community and research community. The dashed line down the center of the figure is the conceptual boundary between research and practice. While the problem may be common (e.g., better understanding of long-term streamflow variability in a basin), the motivations and ways of framing and addressing it are often distinct for each community. The left side of the figure illustrates early efforts to collaborate, where communication between the two communities may be infrequent and unfocused, as suggested by the dashed vertical lines. These problems become more commonly defined as more communication and tangible collaborations take place (e.g., moving from left to right across the figure). In this idealized scenario, the series of activities represented by the "collaboration" ovals may initially involve tasks focused on relationship-building and improving communication, like co-convening a workshop to discuss the particular problem (e.g., on the left side of the figure).

As practitioners and researchers communicate more, their mutual understanding of each other's professional language and culture grows, allowing those collaborative activities to become more complex and resulting in more integrated problem-solving. The net effect of the growth and evolution of these collaborative relationships is that the space shrinks between the research demand and the research supply, and the collaborative space grows. It is important to note that while the space between research needs and research questions shrinks, it never disappears. Even in fully collaborative, long-term relationships between researchers and practitioners, these are distinct communities with different motivations and mandates.



Case Study 14.3 Figure 1 *Shrinking the distance between research supply and demand by growing collaborative space.*

Source: Ferguson et al., 2014

(Agarwala and Fankenhauser, 2008). In India, an analysis of different adaptation measures for the water sector of the nation found that a US$24 billion investment in a mixture of rainwater harvesting, water metering, desalination, drainage, and channel improvements would greatly help reduce the deficit between supply and demand. Desalination, which some argue to be maladaptive due to the high energy costs and demand, would account for an expected reduction of 50% of the deficit alone (Markandya and Mishra, 2010; Hallegatte, 2009). A system of wastewater reuse based on existing infrastructure costing US$110 million per year would help meet around 6% of the expected deficit.

The coverage of available information on the economics of adaptation for cities and, in particular, the water sector is sparse compared with agriculture (Agarwala and Fankenhauser, 2008). The literature, however, points to some important elements for consideration in developing a city-based adaptation strategy. For example, Hallegatte (2009) assesses how uncertainty is a natural fact of climate science, and decisions are required without perfect information. Tyler and Moench (2012) have developed "A Framework for Urban Climate Resilience," which profiles the preconditions for successful adaptation to climate change and touches on the water sector. Tested in ten Asian cities, the research concluded that social learning – a process whereby local planners engage with a range of stakeholders to identify the preferred strategy to adapt – is likely to lead to the strongest solutions and help secure stronger adaptive capacity.

Despite a range of initiatives to finance adaptation in the water sector, access to finance, particularly in resource constrained–countries (i.e., much of Africa) is a significant challenge (Tippmann et al., 2013). If adaptation is not connected with existing financial priorities, it is likely not to receive adequate funding. Therefore, mainstreaming adaptation into ministries of water and urban development is beneficial. Financing adaptation will likely mean increased water bills for different users, which is politically delicate. Private finance in the water sector, with riskier investments underwritten by development banks and public finance, and with incentives to provide adaptive solutions, are promising options; however, there is large variance among countries in the degree to which this is being done (Biagini and Miller, 2013). An option could be the development of "adaptation export credits" in countries that export materials and technologies used in infrastructure for conserving water. In most instances, the urban water sector benefits from having well-established monitoring regimes in place that help manage water supply and demand. This monitoring should be extended to longer time horizons, incorporating relevant climate data that can then provide feedback to inform decision-making.

14.4.3.3 Good Governance: The Precondition for Adaptation

For water management to be "adaptive," a significant investment in the quality of water resource governance is required (Pahl-Wostl, 2007; see Chapter 16, Governance and Policy). Adaptation requires adequate political and administrative will, but action is hampered by the lack of good governance in many instances. Urban resilience and the ability to implement deliberate adaptation is based on existing political and administrative structures that are accumulated over time and through city development (Satterthwaite, 2013). Adaptation also requires policy regimes that are flexible and that can adjust as new evidence becomes available (Swanson and Bhadwal, 2009). This point is underpinned by a study of 100 urban climate change projects that have pointed to experimentation and iterative social learning as key determinants in the success of such initiatives (Castan Broto and Bulkeley, 2013). Yet, in many cities, a lack of accountability and the inability to provide even basic services suggests that adaptation will be a key challenge (Lockwood, 2013). Research on how to adapt Cape

Case Study 14.4 Operationalizing Urban Climate Resilience in Water and Sanitation Systems in Manila

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Keywords	Water and sanitation, adaptation, infrastructure, business, floods
Population (Metropolitan Region)	11,855,975 (Philippine Statistics Authority, 2015)
Area (Metropolitan Region)	620 km² (Philippine Statistics Authority, 2015)
Income per capita	US$3,580 (World Bank, 2017)
Climate zone	Aw – Tropical savannah (Peel et al., 2007)

Manila is home to more than 16 million people within 17 cities/municipalities. The densely populated metropolis sits on a low-lying isthmus and includes many unplanned slums. It is among those areas of Southeast Asia most vulnerable to climate change because of its high population density, high risk from climatic hazards, and only moderate adaptive capacity (Yusuf and Francisco, 2009).

The metropolis has made significant progress toward more climate-resilient water supply and sanitation services since 1997. Prior to 1997, a public utility managed these services and was inefficient, overstaffed, and overburdened with debt. This had negative impacts on the quality and availability of these services for the population. To expand and improve these services, the Philippine government privatized them in 1997. It split the metropolis into "east" and "west" zones and awarded each to a different business consortium via build-operate-transfer contracts. These contracts are a form of project financing in which a private entity receives a concession from the public sector to finance, design, construct, and operate a facility or service, with the public sector retaining asset ownership. The Manila Water Company, Inc. won the east zone and Maynilad Water Services, Inc. won the west zone. This Case Study focuses on Manila Water in the east zone.

PROGRESS TOWARD RESILIENT SERVICES

Manila Water has significantly improved water supply and sanitation service levels and its climate resilience since 1997, distinguishing itself as among the most proactive Philippine companies on climate change. Case Study 14.4 Table 1 displays data on these service improvements.

These service improvements strengthened the company's financial position, providing opportunities to pilot additional adaptation measures. Manila Water was among the first Philippine companies to develop a climate policy in 2007, updating it in 2013 (Manila Water, 2007, 2013). The policy includes activities on energy and fuel efficiency, vulnerability assessment, climate-resilient assets, disaster risk reduction and management, water source protection and development, and multistakeholder partnerships.

The company continuously recalibrates its disaster planning based on actual experience with the climate impacts that affect the country. This includes experience outside Manila when it provided water-related humanitarian assistance (e.g., mobile treatment facilities) after major climatic calamities, including Typhoons Bopha (in 2012) and Haiyan (in 2013). Manila Water was an initial convenor of the Philippine Disaster Recovery Foundation, a coalition of

(a)

(b)

Case Study 14.4 Figure 1 *The award-winning and flood-resilient Olandes (left) and Poblacion (right) sewage treatment plants of Manila Water.*

businesses that share lessons and coordinate their responses with the government.

Manila Water regularly assesses the vulnerability of its infrastructure and operations to climate hazards. It revised asset standards to retrofit existing facilities and construct new ones to be climate-resilient. Case Study 14.4 Figure 1 depicts two of its facilities that won international awards for their innovative, flood-resistant designs. Medium-term plans include establishing interoperability protocols among the metropolis's lifeline utilities (power, communications, and fuel supply) and strengthening the resilience of its supply chain, which is a major dependency for restoring disaster-affected operations.

PROGRESS TOWARD A RESILIENT POPULATION

There is also evidence that Manila Water's improved services positively affected the individual resilience of their customers. Doczi (2012) performed an impact evaluation of Manila Water's services in the east zone compared to Maynilad's in the west zone from 1997 to 2007.

The study assessed the comparative impact of these water supply and sanitation services on their population's health, wealth, and education using regression analysis on national survey data. It found a positive impact on the wealth and education of that portion of the population who reported receiving Manila Water's water supply services compared to those of Maynilad, particularly for poorer groups who reported receiving their water supply in the form of a public standpipe in their community. However, these services provided little health benefit, particularly for standpipes. This may be because Manila Water focused on improving water supply during this 10-year period, making less progress on sanitation until recently. The study also argues that the greater health detriment from standpipes suggests that these are more easily contaminated. This needs to be balanced with the finding that these standpipes may boost wealth and education outcomes – and therefore individual climate resilience – as compared to a lack of service.

Doczi's study supports Manila Water's service impact but suffered important shortcomings. It used a national dataset with significant errors and missing data that affected the analysis. It also assumed that respondents received their services from either Manila Water or Maynilad. However, Cheng (2014) suggests that informal providers still serve significant portions of these zones. Nonetheless, Doczi's study remains unique in its assessment of Manila Water's services at the level of impacts rather than outputs.

LESSONS AND CHALLENGES

At least four factors drove Manila Water's progress, and these offer lessons to other cities: favorable initial conditions, proactive corporate culture, performance-based management systems, and strong branding to build public trust (Rivera, 2014; Luz and Paladio-Melosantos, 2012; Wu and Malaluan, 2008). The company received a smaller share of the public utility's debt in 1997 than did Maynilad, suffering less as a result during the Asian Financial Crisis of

Case Study 14.4 Table 1 *Comparative service improvements in Manila's East Zone from 1996 to 2012. Source: Rivera, 2014*

City	Population (Million)	24/7 Water Availability (% of Network)	Water Coverage (% of Population)	Non-Revenue Water[a] (% of Production)	Staff per 1,000 Connections
Manila East Zone (1996)	~2	26	67	63	9.8
Manila East Zone (2012)	>6	99	89	11	1.4

[a] Nonrevenue water is water that leaks or is stolen from supply networks between the production source and end users

1997–1999. The company was also better able to motivate the staff it inherited from the public utility through decentralized decision-making, target-based systems to promote personal accountability, and institutionalized values of integrity and customer centricity. These in turn promoted climate-resilient service improvements and helped to create a strong brand.

Challenges remain, including Manila Water's enabling environment in terms of its relationship with its public regulator. A public agency regulates both Manila Water and Maynilad, and their relationship dynamics have occasionally hindered progress. The agency ensures that the companies deliver on their service obligations while keeping water prices affordable. This involves reviewing the companies' infrastructure investment plans, for which expenses should be recovered through the water tariff. In times when the desire to temper tariff increases prevails, Manila Water's investments may be deferred or disallowed by the agency, which places at risk the company's commitments on adaptation, water availability, or environmental compliance. The agency is not immune to political pressure, illustrating the importance of creating regulatory environments that incentivize – rather than hinder – progress.

In conclusion, Manila Water succeeded in rapidly absorbing and revitalizing the staff and services of an inefficient and indebted public utility. This drove progress on service improvements that positively affected their customers' resilience and provided fiscal space to pilot dedicated adaptation initiatives. Challenges remain, including the company's regulatory environment. The less successful case of Maynilad prior to 2007 also highlights that progress is not guaranteed even within a similar context and that public–private relationships must be carefully considered. Nonetheless, Manila Water's case offers learning about how business can – in certain circumstances – drive progress toward delivering resilient urban water supply and sanitation services.

Town's water supply infrastructure, for example, also points to the value of seeing adaptation more as a process than an outcome if it is to ensure the sustainability of water supply solutions (Ziervogel et al., 2010). An additional challenge is the rapid rise of secondary cities, many of which have only rudimentary systems of governance and, in some cases, zero climate change knowledge or adaptive capacity. Table 14.2 documents how existing water resource management and infrastructure relates to the ability of a city to adapt to a changing climate; basic governance is a precondition for adaptation.

Other barriers exist that impede effective decision-making regarding the implementation of adaptation strategies. For example, the uncertainty of climate scenarios and the temporal scale

Table 14.2 *Adaptive capacity and urban water systems. Source: Adapted from IPCC Working Group II, Chapter 8 (2014) with additions from authors*

Level of Adaptive Capacity	Very little adaptive capacity or resilience/ 'bounce-back' capacity	Medium adaptive capacity or resilience/ 'bounce-back' capacity	Adequate capacity for adaptation and resilience/ 'bounce-back' but needs to be acted on
LEVEL OF WATER SECURITY	**LOW**	**MODERATE**	**HIGH**
Basic service delivery (water and sanitation)	0–30% of the urban center's population served; most of those unserved or inadequately served living in informal settlements. Women and children heavily burdened. Unequal access.	30–80% of the urban center's population served; most of those unserved or inadequately served living in informal settlements	80–100% of the urban center's population served; most of those unserved or inadequately served living in informal settlements
Service financing	Major challenge – unclear rules lead to limited investment; weak institutions limit cost recovery; donor dependency; private sector largely inactive	Some donor dependency; cost recovery evolving; PPPs; limited ability to leverage funds from capital markets without loan guarantees	Cost recovery adequate (few problems with bill payments); ability to secure funds from capital markets for investment in infrastructure; private sector active; regulations enforced
Institutional set up	Informal institutions predominant; lack of visibility of city authorities in some settlements; land tenure unclear; overlapping policy/mandates/unclear legal frameworks; traditional systems of governance; significant resource limitations; informal settlements predominant	Some formal institutions are present; may have active state intervention in service delivery; mix of traditional and modern governance; service provision in transition; mix of formal and informal settlements; legal framework for services evolving	Clear rules, roles, and responsibilities; resources available to support service delivery; adaptive policy framework with built-in flexibility; reasonable level of accountability in governance
Examples	Dar es Salaam; Khulna; Ouagadougou; Dhaka; Kinshasa	Mumbai, Nairobi, Colombo, Dakar, Accra	Most developed country cities; Santiago de Chile; Rio de Janeiro; Istanbul

of such scenarios are often discordant with short- or immediate-term decision-making needs for water and sanitation. Short time horizons among urban authorities also impede long-term decision-making that is required for climate change adaptation. Economic incentives are also skewed to short-term returns without adequately considering the long-term costs and benefits of adaptation. Moreover, the benefits of adaptation are extremely difficult to assess using conventional economic methods that exacerbate uncertainty (Chambwera et al., 2012). An additional barrier to adaptation is unequal power dynamics between different water users and a lack of ability to mediate interests in the context of uncertainty. An effort led by the International Institute for Environment and Development (IIED) pioneered a stakeholder-based cost-benefit analysis methodology as one tool that can help to manage negotiations between different water users. A central element of the approach is using climate information to consider the differentiated impacts of solutions on different stakeholder groups. For example, a subsidized investment in a drip irrigation system in Morocco was found to have more economic benefits for medium- and large-scale farmers than for small-scale farmers. Instead of aggregating impacts, a stakeholder-based cost-benefit analysis helps identify "winners and losers" and can improve compensation regimes and the allocation of benefits (Chambwera et al., 2012).

These challenges are compounded by underlying governance problems that impede effective stakeholder engagement and basic governance, let alone longer climate change adaptation decision-making. Examples of successful city-level multistakeholder engagement exist, such as in Cape Town, where researchers from the University of Cape Town have capitalized on a strong relationship with the city to work in several informal settlements on adaptation planning (Wadell, 2014). The main challenge for service provision to areas affected by SLR and coastal flooding is a failure of trust between these settlements and the city. As brokers, university staff have helped to rekindle some of this trust. The city has also shown leadership and established a set-back line, across which development cannot occur, in order to limit wasted investment in water and sanitation infrastructure that will be damaged through future storm surges and flood events. Case Study 14.5 explores the role that citizens could have in climate change adaptation.

Case Study 14.5 New Citizen Roles in Climate Change Adaptation: The Efforts of the Middle-Sized Danish City of Middelfart

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Keywords	Cloudbursts, urban-based adaptation, sustainable urban drainage system (SUDS), citizen involvement, floods
Population (Metropolitan Region)	37,981 (Statistics Denmark, 2015b)
Area (Metropolitan Region)	298.79 km² (Statistics Denmark, 2015a)
Income per capita	US$56,730 (World Bank, 2017)
Climate zone	Dfb – Cold, without dry season, warm summer (Peel et al., 2007)

A preliminary study of the city of Middelfart shows that, in the absence of climate change adaptation, current problems with flooding from heavy rain will worsen as the climate is expected to change over the next 50 years. Middelfart Wastewater Utility has over the past years invested tens of millions DKR to increase the capacity of the sewer system in parts of the city. However, now the utility together with Middelfart Municipality (Middelfart Municipality/Water Utility, n.d.) has decided to change the strategy to create solutions in synergy with the development of urban space to retain rainwater locally and increase urban livability. This involves changing the current roles of citizens from passive service receivers to actively handling rainwater on their private ground.

This is in line with a growing body of urban water professionals who are focused on transitioning to more resilient urban water management due to the impacts of climate change (Brown et al., 2009). The experienced challenges with especially heavy rain and increased incidents of flooding demand more resilient cities and water management systems. Flexible and differentiated systems include both centralized pipe solutions below and above surface – solutions such as sustainable urban drainage systems (SuDS) to relieve the system in situations of heavy rain. The SuDS also correspond with the growing view on green and blue urban structures as desirable to create a livable city.

This transition demands new roles and responsibilities in relation to the design, operation, and maintenance of the water management system. Achieving this transition requires that the municipality and the wastewater utility work together and find new ways of engaging citizens in designing, developing, and, to a certain extent, maintaining the water management system. A very tangible example is that, in order to retain more rainwater locally instead of leading it through the sewer system, the individual plot owners have to be part of the process.

Citizens may further be regarded as a valuable knowledge resource when it comes to their local area and neighborhood and as a creative resource in urban development and the making of "livable cities" and innovative partnerships. Even though citizens do not have knowledge of water systems or urban planning, they are experts in their local neighborhood and have a unique knowledge of, for example, where there are local issues with flooding and how the local area serves different recreational purposes. This is knowledge that can be used (e.g., in risk assessments and in designing new solutions that fit local needs).

The city of Middelfart, Denmark, is working with green and blue structures, aboveground SuDS, and new citizens roles through two different projects:

- the transformation of private gardens into "rain gardens:"

- the development of a resilient urban area called Kongebro, with the aim to be Denmark's most beautiful climate change adaptation project

THE RAIN GARDENS

Over the course of 18 months, the municipality together with the Danish garden society have worked with the citizens through workshops and individual garden visits. The project is realized in collaboration with the Municipality of Middelfart, Middelfart Wastewater utility, and citizens (garden owners). The process has strengthened the already good neighborhood and also made it possible to combine some SuDS elements across garden boundaries.

As a pilot project, seven very different gardens have been established to investigate and show the potential of private gardens in climate change adaptation. Common to the seven gardens is that 95% of the roof and surface water is percolated into the garden, and the remaining 5% is surface discharged to a small stream in the woods.

This is a more aesthetic and more environmentally friendly option than separate sewer systems for both the utility and the garden owner. Furthermore, it has taught the professionals as well as the citizens to think of rainwater as a resource. Also, the process has inspired citizens in the area to redesign the gardens for both recreative and functional purposes.

DENMARK'S MOST BEAUTIFUL CLIMATE CHANGE ADAPTATION PROJECT

This project includes the implementation of an urban design and the subsequent implementation of a climate change adaptation project in the Kongebro area (KlimaByen, 2015; Middelfart Kommune, 2014). Citizens have provided input during the pre-study phase of the area about the local qualities such as viewpoints, nature elements, and meeting spots, as well as about the problems they wanted to address in the urban development (e.g., flooding, road safety, accessibility). Citizens were invited to an introductory workshop held by the project group. The project group involves representatives from Middelfart Municipality and Middelfart Wastewater Utility. They provide input to an architectural competition program for the development of the area, and the dialogue group will then contribute to further develop the winning projects in collaboration with architects and engineers. Furthermore, a dialogue group of citizens has been established in which citizens and businesses are volunteering to take active part in the process.

In addition, two sixth-grade groups of school children who live in the area of Kongebro have contributed to the project by taking place in a "Walk and Talk Workshop." At the workshop, the children were first introduced to basic principles of local rain water management and the idea of using rain water for recreational purposes in the urban environment. Then the children went for a walk in the neighborhood and mapped the path they follow from the school to the sporting facility in the Kongebro area. Along the way, the children were asked to reflect on ways in which rainwater and green elements in the city can be used to increase the livability of the city. The school and its pupils are also involved in the development of a new playground that is designed to use rainwater as an element in children's' play, and the project is used to support teaching about climate change. Finally, residents of the area and other citizens have been given the opportunity get information and contribute local perspectives that will be incorporated into the program for an architectural competition. Later in the process, on-site workshops – so called "End-of-the-Road Workshops" – will be launched. Here, the residents are invited to talk to engineers and landscape architects about the implications of the project for their gardens and their local part of the Kongebro area. Along with these activities, citizens are informed about project development through newsletters and updates on the project website and through social and local media.

14.5 Mitigation Strategies for Urban Water Systems

Many cities are faced with significant needs in terms of rehabilitating and modernizing their UWS because many of their components have reached the end of their useful life (i.e., 40–50 years). This lack of adequate infrastructure is an opportunity to build treatment technologies that take into account an efficient use of energy.

UWS produce harmful GHGs in two ways. First, water systems are generally energy intensive, especially at the stage of pumping stations and wastewater treatment, where there are the most opportunities to reduce CO_2 emissions. For example, Friedrich et al. (2009) carried out a life cycle assessment of the urban water cycle for the Durban municipality in South Africa and found that, among the individual processes involved in the provision of water and wastewater, treatment of wastewater with activated sludge technology produced the highest emissions (41% of the total from the UWS) due to its high energy consumption; the distribution of potable water came in second place (18%). A second source of emissions comes from off-gassing from the wastewater itself (e.g., methane emissions from biological waste).

New infrastructure investments into water systems can be optimized by identifying potential adaptation and mitigation benefits. There is a growing range of options available to reduce emissions associated with water and wastewater management. For example, biogas recovery for electricity production is a mitigation measure that may be applied in conventional municipal wastewater treatment plants (i.e., activated sludge–sewage that is aerated and broken down by micro-organisms). This approach not only reduces the emission of methane, but also helps substitute the draw-down of electricity from the grid. The amount of recovery can be as much as 100% of the total electric consumption in large treatment plants when combined heat and power equipment and other energy-efficiency measures are considered (McCarty et al., 2011; Nowak et al., 2011). San Antonio, for example, installed biogas recovery in a large wastewater treatment plant that generates US$200,000 in revenue per year, helping to cover operation and maintenance costs (Casey, 2010). In the case of developing countries with warm climate conditions, anaerobic technologies are increasingly applied to direct sewage treatment through the use of up-flow anaerobic sludge blanket (UASB) reactors, an effective method to treat wastewater in tanks and remove organic pollutants (see Figure 14.4).

A recent survey in Latin America (Noyola et al., 2012) sampled 2,734 wastewater treatment plants in six countries to assess GHG emissions for different categories of treatment. The survey identified three major treatment technologies for municipal wastewater: (1) activated sludge was the most significant based on treatment capacity (nearly 60% of total wastewater flow is treated by activated sludge), (2) stabilization ponds were the most common based on the number of facilities, and (3) UASB reactors. Each system has both advantages and disadvantages. In general, activated sludge is a compact but energy-intensive technology. Stabilization ponds, on the other hand, have low operating costs. However, in pond systems, methane is released into the atmosphere without burning, which is a major drawback for this kind of treatment systems. In contrast, the UASB reactor has also low energy needs and includes an arrangement for biogas capture and burning for electricity generation. An additional

Figure 14.4 *A pilot UASB reactor installed in Belo Horizonte, Brazil.*

Source: Sustainable Sanitation Alliance, 2013

advantage is that, as a compact technology, UASB reactors require a very small footprint, which is an important advantage for urban areas. A drawback of anaerobic sewage treatment is that 20–30% of the methane produced in the process leaves the system as dissolved gas in the effluent, which, depending on post-treatment, can lead to increased emissions (Noyola et al., 1988; Souza et al., 2011). Also, biogas – a useful source of energy – produced in small treatment plants cannot be used for energy purposes due to the limited amount of organic matter in conventional sewage (400–600 mg/L of chemical oxygen demand, COD). In these cases, biogas is best burned to reduce the warming potential of these emissions (Noyola et al., 2012). As Box 14.1 Table 1 illustrates, systems that allow for biogas recovery and burning for electricity generation have the greatest benefit in terms of emissions and energy efficiency.

To provide a solid evidence base for decisions on what type of wastewater treatment for which situation, Noyola et al. (2013) developed a life cycle analysis of municipal wastewater treatment technologies (e.g., stabilization ponds, activated sludge, and UASB reactors) in Latin America. Focusing on GHG emission potential, the results showed that, in descending order of impact, stabilization ponds have the highest impact due to the venting of methane. Extended aeration, a variant of activated sludge, ranks second due to the indirect CO_2 emissions generated by electricity use in the aeration tank. The contribution of conventional activated sludge to emissions comes from the anaerobic sludge digesters where biogas is produced. This in turn can be an asset for reducing electricity consumption from the grid and diminishing GHG emissions from the technology. Finally, UASB reactors showed the lowest impact due to efficient methane capture and burning. In addition, UASB reactors have a better overall environmental performance due to low energy requirements and the limited amount of excess sludge produced.

The future adoption of anaerobic treatment technologies in developing countries would reduce GHG emissions, accomplishing at the same time lower capital investments and reduced operational costs when compared to conventional full aerobic options. This technological option will therefore result in more sustainable systems, thus representing an attractive policy measure for developing countries. Box 14.1 presents an assessment of emission reduction options for municipal wastewater treatment technologies in Mexico.

14.6 Conclusions

In cities, successful adaptation to climate change will rely on good planning and governance, appropriate sources of finance for investment, social equity in provision, ensuring that the right capacity exists for implementation, and operational infrastructure that is resilient to rapidly changing conditions. With the increasing number of people living in cities and informal urban settlements, particularly in developing countries, water security is a growing concern under changing climate conditions. This chapter has profiled the threat posed by climate change to UWS and, ultimately, water security in and around cities. Planners attempt to address these challenges by not only managing water as a resource, but also by avoiding the risks associated with extremes in water flows (e.g., flooding, scarcity, and pollution). Climate change will, in most cases, exacerbate the situation through changing precipitation patterns, extreme events, and SLR. A key challenge is the uncertainty embedded in future climate scenarios – an uncertainty that raises questions about when thresholds are crossed. For example, when poor water management and climate change leads to the unsustainable exploitation of water in a basin and thus leads to direct impacts on people and economies.

Many solutions exist that can be brought to the municipal scale. The use of alternative sources of water (i.e., safe use of wastewater), embedded flexibility to alter policy as new information comes to light, and finding the political will to establish proper cost recovery in order to ensure the sustainability of investments in water and sanitation systems are just some of the solutions presented in this chapter. Ensuring a balance between water and energy benefits is also critical. Importantly for decision makers, most solutions are not new options and have been a part of classic good practice in urban water management for many years. In other words, these are not necessarily radical ideas.

Mitigation options for reducing emissions were described in this chapter, several of which stand out as important areas for

Box 14.1 Municipal Wastewater Treatment as a Greenhouse Gas Emission Mitigation Strategy in Mexico

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As with many developing countries and emerging economies, Mexico requires important investment in urban wastewater treatment infrastructure to increase its current coverage. At present, only 45% of collected municipal sewage is treated, while the difference is discharged either untreated or partially treated into bodies of water used for irrigation, resulting in higher risks to public health and the environment. To tackle this problem, investments are being made in new treatment facilities. The proper selection of treatment technologies is an important opportunity for contributing to Mexico's ambitious national climate change strategy goal of a 30% reduction in greenhouse gas (GHG) emissions by 2020 and 50% by 2050 (SEMARNAT, 2013).

To support decision-making for more sustainable water treatment systems, five technology options were analyzed, aiming at a 100% treatment coverage by 2030. A "business as usual" scenario was considered as a baseline (i.e., maintaining the present rate of building new infrastructure and using the present distribution of wastewater treatment technologies). Five improvement scenarios were considered based on currently employed technologies, as well as using a combined approach of upflow anaerobic sludge blanket (UASB) reactors followed by aerobic processes for post-treatment (see Box 14.1 Table 1).

Results show that GHG emissions from sewage treatment in Mexico could be reduced by up to 34% relative to the baseline "business as usual" scenario by using the combined anaerobic-aerobic processes. This technology has a 95% methane burning efficiency and also provides opportunities for electricity co-generation in facilities with treatment capacity above 500 L/s. If electricity production through biogas recovery is not considered, then reduction of emissions is limited to 14%. The research also shows that the adoption of anaerobic reactors, where technically feasible, can reduce operating costs by around 40% compared to conventional aerobic wastewater treatment systems.

The study estimated emissions based on the Guidelines for Greenhouse Gas Inventories proposed by the IPCC (2006). Emissions can vary according to on-site characteristics, so there is a need to determine emission factors for each country or region, taking into account specific conditions at least for the most representative wastewater treatment technologies. As a result, more precise emission inventories from wastewater treatment could be calculated, allowing the identification of more effective mitigation strategies in developing countries.

Box 14.1 Table 1 *GHG emissions from municipal wastewater treatment in Mexico under different technological scenarios, including expected future scenarios.*

	2010	2015	2020	2025	2030	
Scenario			Gg CO_2 eq.			**Percentage reduction (%)**
Baseline (BL)	13,334	12,367	12,302	12,140	11,867	–
WA	13,334	12,388	12,086	11,687	11,176	6
A	13,334	12,321	11,878	11,339	10,688	10
An+A	13,334	11,639	11,270	10,805	10,227	14
ZME	13,334	11,251	10,630	9,912	9,083	23
BE	13,334	10,793	9,931	8,926	7,809	34

WA, Water agenda (BL at 100% coverage); A, Aerobic-only processes; An + A, Anaerobic followed by aerobic post-treatment; ZME, Zero methane emission; BE, Biogas to energy investment: (1) ensuring the application of life cycle analysis to decision-making for water supply, treatment, and drainage; (2) the use of anaerobic reactors to improve the balance between energy conservation and wastewater treatment; and (3) eliminating high-energy options such as interbasin transfers of water wherever there are alternatives available. It is imperative that available options be carefully considered within local contexts to identify those that are most appropriate and cost-effective. It is also critical to assess options in the context of available local capacity. A major drawback of many infrastructure investments in the past has been the disregard for the operation and maintenance requirements and costs that can lead to failed systems.

A central criterion for all policy-making is finding ways to maximize public good in the most cost-effective manner. The strongest overarching conclusion we draw from this review of climate change in the water sector is the importance of building our collective capacity to act now in adapting UWSs and make them more resilient to climate-related risk. This will help reduce longer term costs (e.g., health, infrastructure, and industry) associated with reduced water security in the future.

Annex 14.1 Stakeholder Engagement

Stakeholder engagement in this chapter consisted of one formal event and a number of informal meetings at which ideas on urban adaptation in the water sector was the core topic. The formal side event at the ICLEI Resilient Cities meeting in Bonn, 2014, brought together ten practitioners and researchers to review the draft chapter and provide feedback. Informal meetings on the sidelines of larger events took place on numerous occasions, including the Istanbul Water Forum in 2014 and COP20 in Lima, 2014, where input was solicited. Each event provided additional substance for the chapter. Authors also had copy reviewed by colleagues to verify accuracy and substance. Generally, the stakeholder engagement either profiled work and case studies that the authors were unaware of or challenged assumptions within the text and added value by providing more specificity to arguments.

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