

# Urban Water Resilience

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## Urban 20 White Paper

A contribution from Lizmara Kirchner, Laura Bonzanigo, Clémentine Stip, Diego Rodriguez and Maria Catalina Ramirez Villegas to the Urban 20 (U20)





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## About Urban 20

Urban 20 (U20) is a new city diplomacy initiative developed under the leadership of, Horacio Rodríguez Larreta, Mayor of the City of Buenos Aires, Anne Hidalgo, Mayor of Paris and Chair of C40 Cities Climate Leadership Group (C40). Launched on December 12, 2017 at the One Planet Summit in Paris, the initiative is chaired by the cities of Buenos Aires and Paris, and convened by C40, in collaboration with United Cities and Local Governments (UCLG).

U20 seeks to highlight the expertise of cities in a range of global development challenges and to raise the profile of urban issues within the G20. U20 offers solutions and clear recommendations for consideration by national leaders ahead of the 2018 G20 Summit. It will culminate in the inaugural U20 Mayors Summit in Buenos Aires on October 29-30. This will be a stepping stone towards ensuring a dialogue between cities and the G20.

In 2018, 26 cities have participated in Urban 20: Barcelona, Beijing, Berlin, City of Buenos Aires, Chicago, Durban, Hamburg, Houston, Jakarta, Johannesburg, London, Los Angeles, Madrid, Mexico City, Milan, Montreal, Moscow, New York, Paris, Rio de Janeiro, Rome, São Paulo, Seoul, Sydney, Tokyo, and Tshwane.

For more information, please consult: [www.urban20.org](http://www.urban20.org)

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## About the White Papers

Urban 20 is proud to present a series of White Papers from our Strategic and Advisory Partners that highlight the most relevant topics on the cities development agenda and the forthcoming urban trends. These papers define the challenges that local governments are currently facing and offer open recommendations supported by relevant, up-to-date research and data. The intention of this work is to broaden the understanding and perspective of decision makers and stakeholders as to enhance their ability to tackle these most pressing issues. The White Papers also represent the hard work and dedication of these agencies and organizations to keep the public well informed about the ongoing efforts to address the present and future challenges we share as humankind.

Image: Orbon Alija



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Urban Water Resilience is a White Paper prepared by subject matter experts from U20 Strategic Advisory Partners as a voluntary contribution to enrich the discussions of the Urban 20 process.

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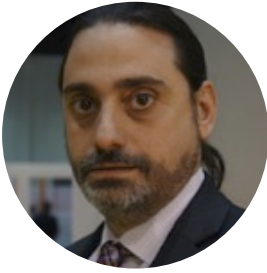
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## Executive summary

Global driving forces, including urbanization, water scarcity, climate change, and population growth, will affect the provision of water supply and sanitation (WSS) services around the world, from cities to rural areas. Rapid and disorganized urbanization is having substantial impacts on water availability and quality both inside and outside city boundaries through overexploitation of water resources, decreased water security, increased vulnerability to floods and other natural disasters, and water-related health impacts. Meanwhile, climate change impacts will be felt through more frequent or more severe extreme weather events, including floods and droughts, different rainfall patterns and temperatures, and seasonal shifts.

An overwhelming body of scientific evidence shows that historical records by themselves may no longer be a reliable guide to current and future climate, and the exact impacts of climate change on local climate, including local extreme weather-related events, are highly uncertain. In addition, climate change is not the only uncertainty: population growth, urbanization patterns, and changes in water demand are also difficult to predict. These trends and the mounting awareness of their uncertainty sharpen the need for a more systematic, comprehensive, and resilient approach to urban water management.

This paper advocates for a shift in the current practices of urban water management. In addition to pursuing integrated approaches, cities should incorporate analytics on resilience and uncertainty in water systems planning and investment design to bolster their capacity to survive, adapt, and grow no matter what chronic stresses and acute shocks they face.

Cities must build diversified and dynamic water resource portfolios and make the most of available water sources through fit-for-purpose approaches that consider the needs of each type of water use. Service providers must shift from linear urban water practices that focus on achieving service standards in a financially sustainable way to an integrated water management approach that secures reliable and sustainable water supplies (World Bank 2018).

Planning for the wrong future can lead to stranded assets, with significant costs to cities if that specific future does not materialize. Cities ought to view their assessments of many future conditions—including climate change, technological change, economic growth, and demographic trends—not as accurate predictions or forecasts but rather as candidate scenarios for the future. Service providers must work with local governments and other urban stakeholders to entrench an integrated approach in planning processes to ensure that cities' water planning accounts for this variability and is prepared for coordinated action.

Urban water resilience is a broad concept that includes stakeholders from sectors and institutions beyond the water space and beyond the city-scale to represent implications for the broader watershed. Building urban water resilience thus requires a mindset in which all stakeholders recognize the short- and long-term challenges that the city is facing and are determined to solve them in the long run, whether these issues affect their sector directly or not. For instance, housing regulations can be adapted to reduce run-off and mitigate flood risks, a change that directly benefits the water resources sector though within another sector's (housing) control (World Bank 2016a).

Planning for resilience is an opportunity to manage the tradeoffs in water management. Elements of the urban water cycle need to be integrated with the city's urban development and with river basin management to maximize economic, social, and environmental benefits in an equitable manner and to build resilience.

Improving the resilience of cities' water systems will require shifting the focus from seeking highly precise predictions toward discovering future consequential scenarios. Planning for multiple scenarios avoids costly surprises and helps reach consensus, as people can agree on



a strategy or a project for different reasons. Exploring different futures enables the inclusion of possibly diverging views of what the future may look like. This helps avoid gridlock and leads to a better understanding of how to prioritize beneficial actions across plausible futures.

To build consensus on prioritized portfolios of actions, stakeholders should carefully explore the consequences of possible actions, considering a diverse suite of metrics of a project's performance (cost, reliability, equity, resilience). Taking these varied perspectives into account early in the process can help identify tradeoffs and build stakeholders' ownership over the process and choice(s).

The specific setting and its associated context and challenges at the city, watershed, regional, and national levels will shape the solutions for resilient urban water management in that context. This means exploring a wide array of measures, including a mix of soft and hard interventions. Given present and future water challenges, urban water management approaches need to adapt creatively to changing environmental conditions and socioeconomic shifts (World Bank 2018).

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# Glossary

**Climate change** refers to a change in the state of the climate that can be identified by changes in the mean or the variability of its properties, and that persists for an extended period, typically decades or longer. Climate change may be due to natural internal processes or external forces such as modulations of the solar cycles, volcanic eruptions, and persistent anthropogenic changes in the composition of the atmosphere or in land use.

**Deep uncertainty** is uncertainty that occurs when parties to a decision do not know or cannot agree on models that relate the key forces that shape the future, the probability distributions of key variables and parameters in these models, and the value of alternative outcomes (Lempert 2003).

**Integrated Urban Water Management** means integrating urban and water considerations through a holistic planning approach allows cities to prioritize investments in pursuit of a livable, greener, competitive and more resilient city. This can be realized at the investment or project level by involving stakeholders of linked or affected sectors, as well as at a programmatic level by developing a holistic masterplan or framework with different stakeholders.

**Regret** can be defined as the difference between the performance of a strategy in a future state of the world, given some value function, and that of what would be the best-performing strategy in that same future state. In other words, regret is a measure of how big a mistake one can make when making choices under uncertainty. A no-regret action provides benefits under all future conditions.

**Reliability** is the probability that supply is sufficient to fulfil demand fully, or to an acceptable agreed level, for instance, 99 percent of the time.

**Resilience** refers to the capacity of a project or system to absorb the shocks or stresses imposed by climate change and other factors and to evolve into greater robustness. Projects planned with resilience as a goal are designed, built, and operated to better handle not only the range of potential climate change and climate-induced natural disasters, but also contingencies that promote an efficient, rapid adaptation to a less vulnerable future state.

**Robustness** refers to the ability of a solution to perform well no matter what future is considered. This is defined in contrast to an optimal solution, which often performs well only under a specific future condition. Often there is no single robust strategy but a set of reasonable choices that decision makers can choose among; they may evaluate the trade-offs between robustness and other decision criteria, such as costs and feasibility. Stresses are factors that make the effective operation of the water services more difficult. Stress can be induced by many factors including limited financial resources, poor management capacity, or impacts from climate change.



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# Introduction

**By 2030, half of the world's population will be living in water-stressed<sup>1</sup> areas (UNDESA 2014).**

Global driving forces, including urbanization, water scarcity, climate change, and population growth, will affect the provision of water supply and sanitation (WSS) services around the world, from cities to rural areas. Rapid and disorganized urbanization is having substantial impacts on water availability and quality both inside and outside city boundaries through overexploitation of water resources, decreased water security, increased vulnerability to floods and other natural disasters, and water-related health impacts. Meanwhile, climate change impacts will be felt through more frequent or more severe extreme weather events, including floods and droughts, different rainfall patterns and temperatures, and seasonal shifts.

**An overwhelming body of scientific evidence shows that historical records by themselves may no longer be a reliable guide to current and future climate,** and the exact impacts of climate change on local climate, including local extreme weather-related events, are highly uncertain. In addition, climate change is not the only uncertainty: population growth, urbanization patterns, and changes in water demand are also difficult to predict. Planning for the wrong future can lead to stranded assets, with significant costs to cities. These trends and the mounting awareness of their uncertainty sharpen the need for a more systematic, comprehensive, and resilient<sup>2</sup> approach to urban water management.

**To deal with the increasing water-related challenges in urban areas, several approaches seek to improve the way cities manage water.** Traditional approaches built on a conventional engineering focus with a cost-minimization objective and gave primary consideration to the supply cost of diverse options. Newer approaches generally integrate the different elements of the urban water cycle—water resources, water supply, sanitation, stormwater, and waste management—into water management while also minimizing disruption to natural systems (World Bank 2016a). These efforts—variously referred to as low-impact development, cities of the future, sustainable cities, sponge cities, integrated urban water management, water scarce cities, or eco-cities—typically involve planning and redesigning the urban landscape as an integral part of water basins, using integrated water resources management principles in managing cities' water resources. This can be achieved by promoting the sustainable use of natural resources (such as water portfolio diversification), closing the water loop (as with reuse and recycling), and mimicking nature in reproducing the hydrological cycle within the city (World Bank 2016a; 2018).

**While these new approaches promote integrated planning and look beyond traditional solutions to demand management, they do not systematically incorporate uncertainty.** Many stakeholders, managers, and investors do not yet fully consider future climate and other uncertain conditions such as population growth as a necessary part of business risk analysis and long-term planning. Yet, to ensure resilience, cities must adequately consider the full range of plausible risks and opportunities during planning and investment design.

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<sup>1</sup> According to the United Nations, an area experiences water stress when annual water supplies drop below 1,700 cubic meters (m<sup>3</sup>) per person. When annual water supplies drop below 1,000 m<sup>3</sup> per person, the population faces water scarcity, and below 500 m<sup>3</sup> it faces absolute scarcity.

<sup>2</sup> Resilience refers to the capacity of a project or system to absorb the shocks or stresses imposed by climate change and other factors and to evolve into greater robustness. Projects planned with resilience as a goal are designed, built, and operated to better handle not only the range of potential climate change and climate-induced natural disasters, but also contingencies that promote an efficient, rapid adaptation to a less vulnerable future state.

“Acknowledging that cities and urban water systems face deep uncertainty allows planners to devise resilience strategies”.

Deep uncertainty occurs when parties to a decision do not know or cannot agree on models that relate the key forces that shape the future, the probability distributions of key variables and parameters in these models, and the value of alternative outcomes (Lempert 2003). Most projections of future socioeconomic conditions (population, prices) are deeply uncertain, and many projects have nonmonetary impacts (lives saved, regional equity) that cannot be valued straightforwardly or without controversy. Despite this, uncertainty about future trends receives inadequate attention, and considerations of climate change in combination with other uncertainties receive even less.

In recent years, different approaches have been developed that recommend the incorporation of analytics on resilience and uncertainty in water systems planning and investment design (World Bank 2015). Application in a few cities around the world has shown that cost-minimization investments—based on supply cost curves of alternative investments—do not necessarily improve resilience or robustness. Tradeoffs need to be properly analyzed to ensure that priority investments can maximize resilience and robustness while minimizing costs. Maximizing resilience also requires properly estimating the net economic benefits to society. This approach differs from traditional investments that do not measure resilience as a desired outcome or objective.

**Resilience dividends include recovering from a shock or stress as well as an array of other co-benefits that are not measured in traditional cost–benefit analysis.** Resilience requires valuing the elements of a given system over time and considering how those elements provide a resource, relax constraints, or increase opportunities for stakeholders. The system under analysis is dynamic and uses capital stocks to produce goods and services that are consumed by society and result in improved well-being (RAND 2017). Even when “safer” options are chosen, such as large dams, the risk with using traditional analysis is that the options will be badly matched to future conditions or may not be needed at all. Considering climate and other risks along with their related uncertainties is likely to improve the resilience of service providers and thus result in increased reliability and operational effectiveness in both the short and long terms. This may, in its turn, directly benefit the local economy, national resource security, and national economic growth.

While these new methodologies do not supplant approaches aiming to integrate basin planning into urban analysis, they do promote such actions as managing the different elements of the urban cycle together and exploring different hard and soft measures (such as capital investments in dams, nature-based solutions, and demand management). To incorporate resilience in planning, these approaches change the analytical framework for planning. Instead of building a plan based on one projection of future changes, they suggest explicitly managing uncertainty about future conditions by “stress testing” the urban system and proposed plans. This is done using a wide range of plausible futures to identify investment trajectories that are robust across different scenarios. Moreover, they help prioritize investments to avoid lock-ins if the future does not unfold as expected.

## The growing need for urban water resilience

By 2050, 66 percent of the world’s population is expected to reside in urban areas (up from 54 percent today), with nearly 90 percent of the increase concentrated in Asia and Africa (3.9 billion people; UN 2014). While urbanization tends to be accompanied by positive impacts on



economic growth—reflecting cities’ capacity to agglomerate, generate, and sustain economic activities—rapid urbanization and growth increase competition for water, putting pressure on declining resources. Unplanned urban growth also reinforces social and economic inequalities, as poorer residents relocate to informal areas without access to basic services and often at greater risk of climate extremes, disasters, or sea level rise (World Bank 2017, 2018).

**“Rapidly expanding urban populations and their demand for water can overstretch water resources in river basin systems that supply water to cities and increase the risk of water scarcity”.**

Competing uses for water resources from other settlements and other sectors (agriculture, industry) within small river basins can affect the current and future availability of water for people in cities. The uncontrolled sprawl of urban areas can also affect water supply through deforestation of river catchments and changes to river hydrology. Overextraction of groundwater threatens the sustainability of aquifers. When water abstraction exceeds natural recharge, groundwater becomes depleted, and contaminated surface water—and salt water in coastal areas—can flow into aquifers (Closas, Schuring and Rodriguez 2012). Urban areas are also at risk of land subsidence due to over-abstraction, as in Bangkok, Jakarta, and Mexico City. Moreover, governance structures are seldom in place to monitor and regulate groundwater use or new well construction.

**External shocks exacerbate this pressure on a city’s water resources.** The number of urban residents living with seasonable water shortages is forecasted to grow from close to 500 million people in 2000 to 1.9 billion in 2050 (World Bank 2016b). In addition to steady, though still fast, urban population growth, cities are also facing sharp inflows of people displaced by political instability and extreme weather events. Droughts and heat waves threaten rural livelihoods, forcing families to seek alternative arrangements in urban areas. Sea-level rise and floods also jeopardize life on the coastlines, with severe impacts on key elements of the urban social fabric and services: harbors and food storage infrastructure, green spaces, and homes, but also wastewater treatment plants, power plants, and groundwater aquifers, through seawater or polluted water intrusion. As earthquakes and violent storms endanger infrastructure and services, cities may have to cope with reduced access to water resources and more people who depend on cities for these services. Repeated water shortages and vulnerability to extreme weather events create perceptions of government failure, deepen social inequalities, and intensify existing tensions (World Bank 2018).

**Damage to physical assets and human exposure to floods increase due to the lack of proper drainage systems and uncontrolled urban development,** such as informal settlements in coastal areas, natural flood plains, and channel margins. These impacts are compounded by land subsidence and the increase in impervious surfaces caused by the development of grey infrastructure and increased paving in urban developments, which also reduce aquifer recharge. In coastal cities, flooding can be exacerbated by high tide events and sea level rise. (Closas, Schuring and Rodriguez 2012). These factors will aggravate cities’ vulnerability to both dry and wet shocks.

**Low efficiency and coverage of infrastructure services in cities have a direct impact on service quality and reduce cities’ ability to cope with extreme events,** while lack of cost recovery limits the ability to maintain and expand existing networks and threatens the financial resilience of urban water systems. This results in poor continuity of water supply service. Moreover, lack of adequate maintenance leads to large water losses in the system, further exacerbating pressures of increasing demand and dwindling water resources. Limited finances



Source: World Bank flickr

make it difficult for utilities to keep up with the rapid pace of urbanization and water demand growth. Residents of cities that lack adequate connections to the water supply system increasingly rely on insecure sources of water (springs, shallow wells, informal tankers), which are subject to pollution and contamination, especially after flood events (Closas, Schuring and Rodriguez 2012).

**Insufficient metering makes it difficult to estimate water consumption and nonrevenue water losses, and lack of proper pricing mechanisms makes water conservation more difficult.** At the same time, lack of information on system losses renders demand management campaigns difficult to implement as customers are unlikely to reduce consumption unless the city can demonstrate the system's efficiency. Finally, the absence of measures of utility performance to ensure minimum levels of efficiency can result in higher costs and tariffs, as well as low efficiency in service provision. Properly addressing these inefficiencies could delay the need to develop new infrastructure-intensive sources and represent an untapped set of soft resilience measures and resources.

**The lack of adequate wastewater collection and the discharge of untreated domestic and industrial effluent into rivers pollute water bodies downstream, as well as strategic water resources and natural ecosystems.** Surface and groundwater pollution result from unsafe and untreated wastewater effluents as well as poorly managed and maintained septic tanks. Wastewater connections made with poor quality materials, together with deficient management practices, are another source of contamination (Closas, Schuring and Rodriguez 2012). Where onsite sanitation systems such as septic tanks are in place, poor design and inadequate fecal sludge management (including collection and treatment) also lead to contamination of the environment or overloading of drainage and treatment plants. This level of environmental degradation threatens a cities' water resources and creates a vulnerability as contaminants can be spread citywide in the event of a flood.

**Water resources are also affected by activities in other sectors.** Public understanding of the importance of certain urban water-related services tends to be low, especially for stormwater and solid waste management. As a result, there is little willingness to pay for operation, maintenance, or cost recovery of investments, compromising the feasibility of charging for these services. Lack of investment in solid-waste collection systems and suitable landfill sites for the safe disposal of solid waste and industrial by-products, as well as low rates of recycling, threaten the quality of surface water and groundwater, cause drainage problems, and increase a city's vulnerability to flooding.

**These factors are aggravated by the increased variability in water resources availability stemming from the effects of climate change, including rising temperatures, changes in precipitation patterns, and greater climate variability** (World Bank 2016a). Models show that the

spatial distribution of runoff will become more uneven across the globe by 2050, exacerbating scarcity in water-stressed areas and causing more floods in flood-prone areas, for example in islands across Southeast Asia (World Bank 2016b). Vulnerability to the effects of increasing water insecurity and climate change differ across and within cities, and differences in adaptive capacity are largely determined by poverty and inequality, as well as by access to infrastructure, institutions, and information. The urban poor are most vulnerable to these challenges, as they have less access to resources to cope with extreme weather events and are often left out of decision-making, particularly when they reside in the informal settlements of growing urban areas in developing countries (World Bank 2016a).

**Climate change impacts threaten not only cities themselves, but the systems they rely on.** As climate change alters water availability and quality, agricultural production suffers from changes in the spatial and seasonal distribution of water. For example, floods and droughts associated with El Niño–Southern Oscillation events are likely to result in crop yield variability of 15–35 percent (World Bank 2016b). Securing water for energy production, especially given the “thirsty” nature of some cleaner energy sources like hydropower, will also be a challenge, as water withdrawals for energy production are expected to increase by 20 percent by 2035 (World Bank 2016b). Energy inputs to water transfer and treatment, and also to the new water sources envisioned to strengthen resilience to drought, such as desalination and reuse, are also significant. The tenuous balance between ecosystem needs and economic pressures when deciding on water allocations, uses, and environmental flows further threatens cities’ broader environment and magnifies their impact on the basins they inhabit.

“Institutional fragmentation and lack of coordination across sectors and government bodies are an underlying challenge in managing urban water services”.

Fragmented institutional settings for different levels of government slow policy implementation and can make urban services management and planning inefficient. In many cities, this situation is compounded by the institutional fragmentation of urban water services, so that water supply, sanitation, and drainage interventions are undertaken without common goals and often with conflicting agendas and impacts. This fragmentation creates undefined mandates, roles, and responsibilities; contributes to the poor enforcement of regulations; and reduces incentives for integrated planning.

**Often, city water management and planning do give adequate attention to sustainability, coordination with multiple users, or opportunities to develop local and more economical resources.** Management and planning are disconnected from the watershed and build on the assumption that future conditions will unfold within historical patterns, further undermining cities’ resilience to shocks. Yet, service providers are already being challenged by events that lay outside the known historical records. For instance, in March 2017, Lima’s water supply was interrupted for four days by intense rains, which had never been experienced before, leading to severe landslides that filled the river with mud. The main water treatment plant could not handle the resulting turbidity and suspended solids. This example is far from unique given the increasing severity of the floods and droughts being experienced globally, but it exemplifies the surprises that even well-organized utilities such as Servicio de Agua Potable y Alcantarillado de Lima (SEDAPAL) are facing. As a result, many cities underperform in their efforts to sustainably manage their water resources because they have not planned for these different scenarios (World Bank 2018).



## Building water-resilient cities

**A paradigm shift is needed in managing water resources in the urban context.** To bolster cities' capacity to survive, adapt, and grow no matter what chronic stresses and acute shocks they face, cities must build diversified and dynamic water resource portfolios and make the most of available water sources through fit-for-purpose approaches that consider the needs of each type of water use. Service providers must shift from linear urban water practices that focus on achieving service standards in a financially sustainable way to an integrated water management approach that secures reliable and sustainable water supplies (World Bank 2018). Planning for a single future can lead to stranded investments and assets as well as high losses if that specific future does not materialize. Cities ought to view their assessments of many future conditions—including climate change, technological change, economic growth, and demographic trends—not as accurate predictions or forecasts but rather as candidate scenarios for the future. For example, likelihood estimates for long-term land-use patterns or urban and global economic growth are neither well characterized nor verifiable. Service providers must work with local governments and other urban stakeholders to entrench an integrated approach in planning processes to ensure that cities' water planning accounts for this variability and is prepared for coordinated action.

**Building urban water resilience requires consensus about the decisions of the service provider.** Urban water resilience is a broad concept that includes stakeholders from sectors and institutions beyond the water space and beyond the city-scale to represent implications for the broader watershed. Building urban water resilience thus requires a mindset in which all stakeholders recognize the short- and long-term challenges that the city is facing and are determined to solve them in the long run, whether these issues affect their sector directly or not. For instance, housing regulations can be changed to reduce run-off and mitigate flood risks, a change that directly benefits one sector (water resources) while making another sector (housing) tackle an issue that does not directly affect it (World Bank 2016a).

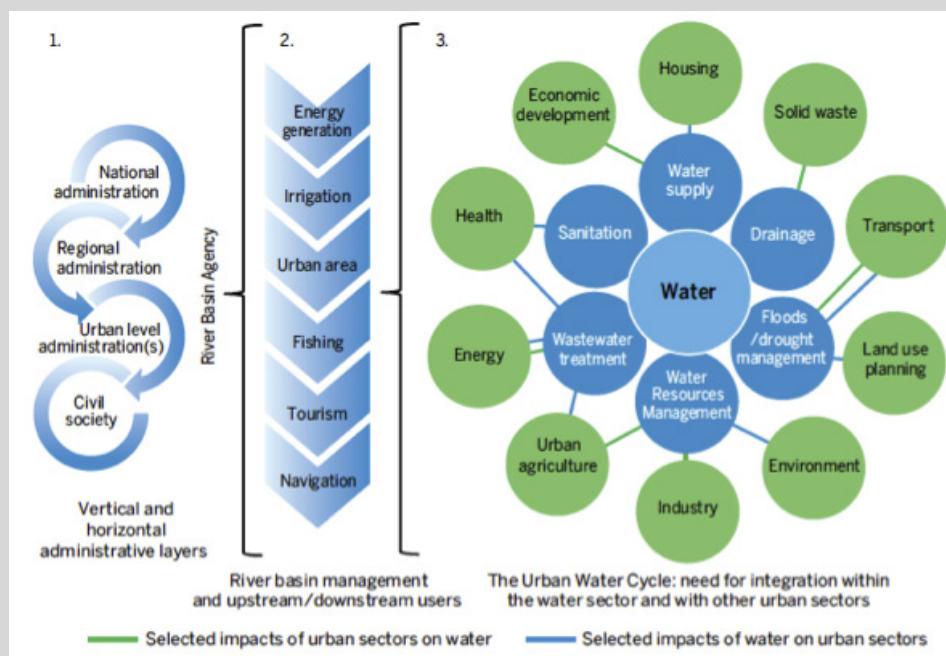
**Water management is often conflictual because users have different priorities.** Building consensus about the decisions that a city makes about its water resources and water-related services is important for their successful functioning. Even without deep uncertainty about future conditions, a city needs to continuously negotiate with users. Uncertainty about future trends is also linked to disagreements among stakeholders and makes consensus building harder. Contention in planning can threaten the ability to implement projects as planned. People or groups with different (and sometimes competing) values, priorities, or interests often differ about the likelihood that various events will take place. Deep uncertainties are therefore also a threat to the ability to build consensus on the right policies or project design to address future climate and other changes. Since broad consensus is critical to project success, deep uncertainties are a threat to cities' master planning and their assumptions about future system performance.

“Planning for resilience is an opportunity to manage the tradeoffs in water management”.

Elements of the urban water cycle need to be integrated with the city's urban development and with river basin management to maximize economic, social, and environmental benefits in an equitable manner and to build resilience. In most metropolitan regions, this involves coordinating linkages between urban water services (water supply, wastewater, stormwater, and solid waste management) and urban development (land use, housing, energy, industry, and transport), as well as river basin management, across a number of neighboring jurisdictions at municipal, regional, and national levels (World Bank 2016a). Figure 1 depicts the multisectoral and

administrative layering of coordination needed to achieve these goals. Although all new investments should consider this integration and seek to build resilience, service providers do not always have the financial ability to realize such solutions—for example to diversify water sources or invest in larger drainage canals or in a second water treatment plant. So, what should urban planners and service providers do?

**Figure 1.** Multiple layers of coordination and integration in water management



**Source:** World Bank (2016a) IUWM Guidance Note, based on ICLEI (2011)

**Note:** Considering the needs of all users within the basin (2) while working across vertical and horizontal administrative boundaries (1) to overcome the traditional fragmentation of the urban water cycle (3) and integrate interdependent urban and water sectors

## Box 1. What is resilience?

Climate change response increasingly focuses on resilience and needed modifications to infrastructure design practices, investment analysis processes, and policy decisions about financing and disaster risk management. Fundamentally, resilience is “the capacity of any entity—an individual, a community, an organization, or a natural system—to prepare for disruptions, to recover from shocks and stresses, and to adapt and grow from a disruptive experience” (Rodin 2014, 3).

The modern concept of resilience builds on insights from engineering, ecology, and operations research. The engineering application of resilience focuses on combining strength with flexibility or redundancy. The ecological application appreciates the occurrence of large changes through which the system can absorb shocks without collapse (regaining stability). Operations research considers feedback loops and time delays, which can create chains of cause and effect that differ significantly from what people might infer.

Resilience helps integrate considerations of disasters and shocks into a broader theory of system function and change. This connection matters because extreme events will be one of the primary ways that the effects of climate change are felt. In addition, such extreme events may catalyze desired changes in an urban system. Drawing on its ecological roots, resilience acknowledges that some systems may in fact thrive on shocks. For instance, many forests in the western United States require periodic fires to clear out undergrowth and allow new trees to grow. Without such fires, the system loses resilience because trees become too old and build up fuel with potential for catastrophic firestorms. Ecologists capture this idea through the concept of the four-phase adaptive cycle. The system begins with rapid growth and reaches a period of stasis. A disruption then releases the system so that it can reorganize and begin another period of change or growth.

When risks are managed in an urban water services setting, resilience should be viewed as an all-encompassing goal. Resilience should be part of a risk governance process in which a broad group of decision-makers managing the city's risks can deliberate around the features of resilience identified as most suitable for a service provider, its stakeholders, and other water users. For this reason, this guidance note does not advocate for a specific definition of resilience. Instead, it describes an effective process that cities and water supply and sanitary services providers can follow as they strive to increase resilience.

**First, to preserve efficient service delivery, water utilities need to shift from a primarily reactive approach to a mostly proactive set of action plans that combine efficient operations, preparedness, emergency responses, and longer-term capital investments.**

Proactive solutions should include both short-term choices (such as reducing leaks; improving financial stability; optimizing operations; establishing early warning systems; creating incentives for efficiency gains, operation and maintenance, and improved metering; and monitoring demand) and longer-term choices (such as infrastructure investments). An ongoing World Bank study with Lima's water utility (SEDAPAL) shows that adding storage alone will not ensure reliable water supply in case of drought, despite the large upfront cost (World Bank, forthcoming). More cost-effective measures to increase resilience to droughts are investing in loss reduction and establishing measures to curtail demand as soon as the first drought triggers are activated. To avoid maladaptation and future bias, service providers should understand that short-term operational choices have an impact on longer-term reliability. For example, the U.S. Water Utility Climate Alliance (WUCA) recommends that service providers integrate near- and long-term choices on issues ranging from excessive debt, stranded assets, and overdependence on technology to decision on whether to add more storage or make institutional changes in pricing, demand management, or regional cooperation to boost resilience. WUCA further defines "no regret strategies" for water utilities as strategies that provide benefits under current and potential future climate conditions by reducing current stressors while making services more resilient to future changes (Heyn and Winsor 2015). This decision-making process must involve both urban and water stakeholders if such strategies are to be implemented at the city scale across the sectors affected by urban water management.

**Second, cities should favor a flexible, dynamic approach that avoids lock-ins.** Because of the large uncertainty associated with future conditions, it is wise to avoid investments that may lead to lock-ins. Robust strategies are flexible and adaptive. A city's climate plans will evolve in response to new information. When building a map of how a city's planning efforts will navigate many possible futures, planners must consider whether actions are irreversible and whether they can be connected across time. Many low-regret, short-term actions (water conservation incentives, self-insurance, pricing, maintenance) are reversible and easily paired with challenging

capital-intensive projects (Closas, Schuring and Rodriguez 2012). In some cases, capital-intensive projects can be eliminated with the successful implementation of low-regret, short-term interventions. Flexibility is crucial for avoiding overinvestment and stranded assets and for allocating financing more efficiently across a city's priorities. Flexible strategies help avoid the frequently high cost of unplanned learning that occurs when organizations respond to events as they occur but devote little attention or resources to understanding how to make the learning process more durable and effective (NRC 2009).

**Third, building demand management and capacity flexibility into a city's water system is critical for improving robustness and resilience, particularly when future conditions are difficult to predict.** Gaining efficiency first and delaying investments builds flexibility and resilience. When a service provider is vulnerable to a threat—if protection is too expensive or not feasible for another reason—knowing it early allows city actors to monitor the situation and respond in time (and efficiently) if the threat materializes.

**Finally, to deal with these new water challenges, cities need a robust decision-making framework that increases resilience while they deal with uncertainties, particularly the deeply uncertain changes in current stressors and new failure mechanisms brought about by climate change.** The guidance in this document builds on state-of-the-art methodologies, referred to as decision-making under deep uncertainty<sup>3</sup>. These approaches are increasingly being used in planning exercises around the world (box 2), and water utilities and the cities they serve are sometimes at the forefront of associated innovations. A 2015 World Bank guidance note on the application of these methodologies ("Confronting Climate Uncertainty in Water Resources Planning and Project Design: The Decision Tree Framework") is increasingly being applied in projects around the world (World Bank 2015). The objectives are to distinguish tradeoffs among strategies, identify robust options, and provide decision-makers with clear information. The methodologies advocate for a heavily participatory process, which helps build consensus so that in the end, decision-makers can make consensual, informed choices<sup>4</sup>.

**The key concept to master to improve the resilience of cities' water systems is to shift the focus from seeking highly precise predictions toward discovering future consequential scenarios.** Planning for multiple scenarios avoids costly surprises and helps reach consensus. People can agree on a strategy or a project for different reasons. Exploring different futures enables the inclusion of possibly diverging views of what the future may look like. This helps avoid gridlock and leads to a better understanding of how to prioritize beneficial actions across plausible futures.

**To build consensus on prioritized portfolios of actions, stakeholders should carefully explore the consequences of possible actions, considering a diverse suite of metrics of a project's performance** (cost, reliability, equity, resilience). For instance, a local government may prioritize equity, a utility may prioritize reliability, and nongovernmental organizations (NGOs) may prioritize environmental impacts. If the resilience-enhancing process considers all three measures and presents the tradeoffs transparently, the three entities involved can have an informed dialogue that leads to compromise. They may even find that certain options perform better than expected across all three metrics.

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<sup>3</sup> [www.deepuncertainty.org](http://www.deepuncertainty.org).

<sup>4</sup> See the Decision Tree Framework (World Bank 2015) and [www.deepuncertainty.org](http://www.deepuncertainty.org) for a deep assessments of the available methodologies.



“Developing robust strategies that augment the resilience of a city’s water system requires defining diverse metrics for success and failure, considering alternative options, and assessing performance under many possible future conditions”.

The most robust strategies perform well (although not necessarily optimally) according to several metrics of success under a wide number of future conditions—and can include all stakeholders’ views on what the future may look like—and thus build the broadest consensus.

**Finally, context is key.** The specific setting and its associated context and challenges at the city, watershed, regional, and national levels will shape the solutions for resilient urban water management in that context. Given present and future water challenges, urban water management approaches need to adapt creatively to changing environmental conditions and socioeconomic shifts (World Bank 2018).

## Box 2. World Bank urban water projects exploring resilience-building options using decision-making under deep uncertainty principles

Evaluating Lima’s Long-Term Water Resources Master Plan (Kalra et al., 2015). Decision-making under deep uncertainty (DMDU) principles were applied to help SEDAPAL, Lima’s water utility, prioritize investments of their Master Plan through a resilience lens. This exercise allowed the Superintendencia Nacional de Servicios de Saneamiento (SUNASS), Lima’s water supply and sanitary services regulatory agency, to confidently approve (contrary to many people’s expectations) the first tranche of no-regret investments of the master plan.

Mwache Multipurpose Dam, Kenya (2016). DMDU principles were applied through the decision tree framework (DTF) to assess the performance of the project under the effects of climate change. Alternative demand and supply management options were evaluated to mitigate long-term risks and inherent tradeoffs to identify robust adaptation options.

Cutzamala Project, Mexico (forthcoming). DMDU principles were applied through the DTF to evaluate the vulnerability of the water system to climate and demand changes, especially its ability to deliver water to Mexico City, and identify options to address this vulnerability.

Sacmex, Mexico City (forthcoming). DMDU principles were applied through the DTF to develop a proper accounting of water inflow and outflow in Mexico City using a lumped model that distributes water available from all sources to each delegación to explore the sensitivity of the water allocation (and associated aquifer abstraction)

to declining water available from the Cutzamala system.

Preparing for Future Droughts in Lima, Peru: Enhancing Lima's Drought Management Plan to Meet Future Challenges (forthcoming). Building on the 2015 study, the World Bank has supported SEDAPAL in reviewing the performance of its current drought management plan under uncertain future conditions. It finds that it is extremely important to continue investing in efficiency measures now, before considering extra storage capacity, which will help only if the climate were to become much drier than current conditions.

## Planning for water resilient cities

**“Sustained, multisectoral coordination across urban and water-related services, together with participation in decision-making by all stakeholders, is required for improved urban and water services delivery; local governments are at the center of this process”.**

Resilient urban water management is as much about institutions and processes as it is about infrastructure and investments. The wide array of urban and river basin-level systems and institutions implies that challenges will emerge in managing common issues, such as wastewater and stormwater discharges that pollute a water supply source or the impact of disorganized urban growth on drainage. Cities that can coordinate water management institutions or incentivize them to operate under the same plans, guidelines, or goals tend to perform better on water management than cities that do not (Porto and Tucci 2010).

**Applying the principles of decision-making under deep uncertainty helps integrate some of the key elements of resilient urban water management through an explicit consideration of potential risks and solutions.** The phases highlighted below can be applied to an entire city's water system or to a single project<sup>5</sup>:

### Phase 1. Knowing the system.

Planners, operators, and other stakeholders should first identify the problematic and critical elements of the system, the potential threats that may affect these elements, the consequences of their individual or joint failure, the performance objectives that the service provider wants the water system to achieve, and the available solutions. While doing this, it is important to:

- Recognize the value of alternative and diversified water sources (securing local sources such as strategic aquifers, exploring new sources such as desalination or wastewater reclamation).
- Differentiate the potential uses of water sources and required quality to promote fit-for-purpose water sources, in terms of quality and quantity.
- View water storage, distribution, treatment, recycling, and disposal as part of the same

<sup>5</sup> These steps build on Building the Resilience of WSS Utilities to Climate Change and Other Threats—A Road Map (World Bank, forthcoming).

resource management cycle.

- Include demand management and infrastructure efficiency as key elements of preparedness and response.
- Recognize the relationships among water resources, land use, energy, and economic development.
- Simultaneously pursue different metrics of success (such as economic efficiency, social equity, environmental sustainability, and metrics relevant to the specific context).
- Account for nonurban users who depend on the same water source within the wider catchment.



Source: John Hogg, World Bank flickr

## Phase 2. Identifying vulnerabilities.

Analysts (internal or external experts) use the information gathered in phase 1 to stress test options over a wide range of futures. The stress-test assesses the performance of the system, with and without the possible interventions, in meeting the objectives defined in phase 1 in each possible future. The stress-test results in a concise description of the conditions in which the water system is likely to fail to meet one or more objectives. These conditions may be summarized as scenarios that capture the mix of factors that, when combined, yield successes or failures. Analysts also identify options for reducing vulnerabilities and improving performance over the same wide range of futures. Where lack of adequate data makes modeling unreliable, a qualitative analysis can be based on a range of likely scenarios and criteria (temperature change, precipitation, demand projections) according to stakeholders' assessment of the options in meeting objectives under these scenarios.

## Phase 3: Choosing actions.

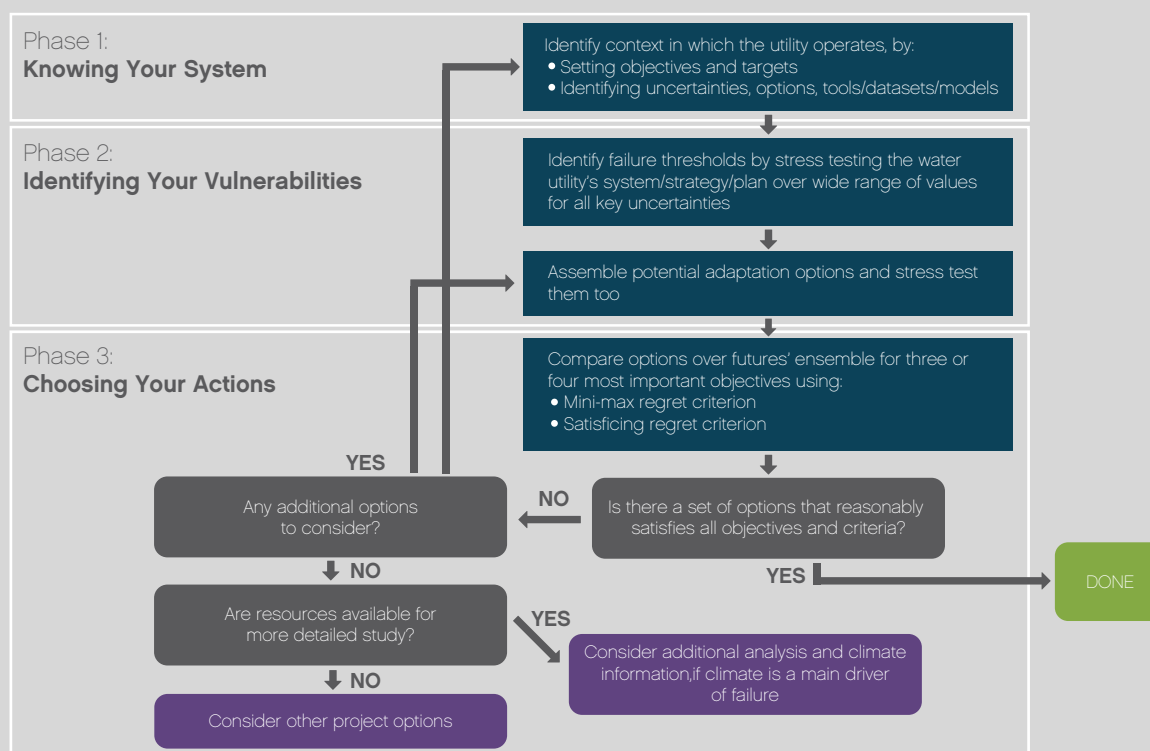
Analysts organize these options into potential robust and flexible strategies and examine the tradeoffs among them. Additionally, the options should include careful monitoring for conditions of concern (such as tracking whether the system is moving outside the scenarios in which performance is acceptable) .

As an integral part of this process, analysts present current vulnerabilities, options, and tradeoffs to other teams within the service provider, to the board, and possibly to external stakeholders to define an acceptable, actionable, robust, and consensual road map for the service provider.

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<sup>6</sup> For more details on these approaches, see Ray and Brown (2015) and World Bank (forthcoming).

**Figure 2. Phases to Improve Resilience of WSS Utility**



**Source:** World Bank (forthcoming) Building the Resilience of WSS Utilities to Climate Change and Other Threats—A Road Map.

**Note:** These phases are meant to be revised regularly. The idea is to update the plan whenever more information is available and priorities shift.

When applied in a context of city-level planning, these strategies are carefully examined by stakeholders to identify which ones meet their objectives and promote increased resilience of the city's water system. Depending on the complexity of the project, one or more rounds of joint stakeholder participation is needed to refine objectives or threats or adjust the options available to decision-makers. This is key in aligning the formal institutions (organizations, legislation, and policies) and informal practices (norms and conventions) that govern water in and for cities. Involving constituents early builds ownership of a city's water management decisions and promotes good governance by holding city decision-makers to account.

**“Resilient urban water management is an iterative, long-term process”.**

The characteristics and challenges of urban areas change over time, so planning becomes a cyclical process that continuously revisits urban challenges, priorities, and the means and actions to address them and build further resilience according to the priorities. An iterative and participatory planning process allows short- and long-term agendas to be combined using a long-term vision to inform the actions taken today. The steps described above help ensure that this process has a solid foundation and is informed by sound science and technical analysis, including solid financial, economic, and social assessments to meaningfully inform decision-making.



# RECOMMENDATIONS





**To bolster cities' capacity to survive, adapt, and grow no matter what chronic stresses and acute shocks they face, cities must build diversified and dynamic water resource portfolios.** Diversifying water and financing sources and making the best of available water sources through fit-for-purpose approaches will help cities respond to a variety of scenarios. In this sense, planning for just one future is risky, and governments should encourage and support urban centers to take new approaches to water management. Specific measures could include supporting initiatives that promote resilient design, like the Rockefeller Foundation's project preparation facility, the creation of special financing windows to improve urban water resilience, or the inclusion of appraisal criteria that give ample weight to resilience in urban water projects applying for national public financing.

**To incorporate this innovative thinking into planning and decision-making, cities should build on processes already in place,** draw on the tacit knowledge of the water system and behaviors present across city institutions, and use existing platforms and international mechanisms for knowledge exchange. Examples include the 100 Resilient Cities Network, C40 Cities, the International Water Association's Water Wise Cities, the World Bank's Water Scarce Cities Network, and Water Sensitive Cities community of practice.

**National governments should act as catalysts for coordination while empowering city-level stakeholders to take ownership of the planning process.** For example, a national-level strategy on resilience for water management can set the principles for the application and dissemination of the methodologies presented here and provide direction for each city to take this agenda forward.

**Because urban environments evolve, cities' planning process must be iterative and participatory to allow for regular adjustment to a changing reality.** National governments can support the establishment of structures or mechanisms that allow for cyclical planning, avoid lock-ins, and reduce regret. At the same time, climate change provides the impetus for cities to adjust priorities and reduce costs in the long run through a combination of performance improvements, cost-effective solutions to future states of the world, and decisions that allow for adaptation.

**Urban water management has implications for the broader watershed in which a city is located—and sometimes even beyond, as in the case of long-distance transfers.** Interactions with the governance structures in place at this larger scale must also consider resilience, to ensure integration and agreement between the city's planning and actions and other users of a water source. Strengthening these structures and encouraging dialogue among stakeholders for integrated water resources management is also vital in planning for urban resilience.

**Stakeholders must be involved throughout the planning process to ensure that their priorities are heard when strategies and solutions are being identified.** Governments and utilities must consider communities' point of view, especially for investments that will affect their local environment or require behavior change. Cities must look for ways to break the customs of fragmentation and integrate the perspectives of the different sectors that affect and are affected by urban water management.

**A wide array of measures can be used to increase the resilience of urban water systems, including a mix of soft and hard interventions.** Solutions are always context-specific and should be derived thorough a consultation process that tests for the ability to meet the objectives identified by all relevant actors in the urban space. Given present and future water challenges, urban water management approaches need to be creatively adapted to changing environmental conditions and socioeconomic shifts.

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## Case studies

This section presents a series of five city case studies that illustrate the challenges of resilient urban water management, as well as potential solutions that involve the application of some of the principles or recommendations discussed above. The case study cities have experienced and are experiencing urban water challenges, but they have taken different approaches to solving them. The intention here is to highlight where the recommended principles are being applied and, where they are not, to suggest ways in which they could be.

### Buenos Aires

#### Challenges in urban water management

Buenos Aires Metropolitan Area (AMBA) does not have a metropolitan authority. The area has experienced rapid urbanization and expansion and fundamental institutional shifts over the last two and a half decades. Water supply and sanitation (WSS) services shifted from public provision to a private concession in 1992, in an example of water privatization that was unique and controversial due to its large scale and rapid implementation. Starting in 2001, Argentina experienced a financial crisis that contributed to the unraveling of the concession, and in 2006 the national government rescinded the concession contract and established Agua y Saneamientos Argentinos S.A. (AySA) as a regional water company for the Buenos Aires metropolitan area. In recent years, AySA has expanded its concession area, incorporating close to 4 million people in 10 municipalities.

AySA is the main water and sanitation service provider in the AMBA<sup>7</sup>. It provides water and sewerage services to the capital district of Buenos Aires and the surrounding 24 administrative districts<sup>8</sup>. With a service area of 3,304 square kilometers (km<sup>2</sup>) and serving close to 13.8 million people, AySA is one of the world's largest water companies.

The AMBA has ample water resources. It is located in one of the largest river basins in the world, the Rio de la Plata, with an average flow of 25,000 cubic meters (m<sup>3</sup>) and with vast groundwater supply (Pampeano and Puelche aquifers). The AMBA develops over three major rivers that drain into the Rio de la Plata: Matanza-Riachuelo, Reconquista, and Lujan, and a handful of smaller creeks.

AySA is expanding water service coverage, using Rio de la Plata as the main source for AMBA's drinking water, complemented by some groundwater in areas far from Rio de la Plata. Water supply service is generally good, with continuous service that meets drinking water standards. AySA currently provides water to approximately 10.5 million people, or 76 percent of its service population, and has ambitious plans to expand to 100 percent service coverage, targeting primarily low-income customers for expansion. The abundant water resources, combined with a history of low tariffs (these are being updated) and the lack of metering, have resulted in one of the highest per capita water allocation<sup>9</sup> rates in Latin America, estimated at around 520 liters per capita per day (AySA has estimated a consumption rate of 344 liters per day per capita in 2014, which is also very high).

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<sup>7</sup> Currently, only one municipality in AMBA is not included in AySA service area, being Berazategui, where the service is provided by the own municipality.

<sup>8</sup> Buenos Aires Metropolitan Area that includes the Autonomous City of Buenos Aires and 24 municipalities: 1. Almirante Brown, 2. Avellaneda, 3. Berazategui, 4. Esteban Echeverría, 5. Ezeiza, 6. Florencio Varela, 7. General San Martín, 8. Hurlingham, 9. Ituzaingó, 10. José C. Paz, 11. La Matanza, 12. Lanús, 13. Lomas de Zamora, 14. Malvinas Argentinas, 15. Merlo, 16. Moreno, 17. Morón, 18. Quilmes, 19. San Fernando, 20. San Isidro, 21. San Miguel, 22. Tigre, 23. Tres de Febrero, 24. Vicente López.

<sup>9</sup> Water production is used instead of water consumption, as very little water consumption is actually metered.

Storm water drainage is a major challenge for the AMBA. In Argentina's federal organization, subnational administrations—in this case, the city and the province of Buenos Aires—have competences in water management and environmental protection. When natural resources are shared by two or more subnational jurisdictions, the federal government prevails over other jurisdictions, as with the Matanza-Riachuelo Basin Authority. This complexity and institutional fragmentation limit the extent of integrated water management in the AMBA.

Floods in the AMBA are produced mainly by intense rainfall, a wind effect on Rio de La Plata called Sudestada, high water levels in the many rivers and creeks, and a rise in the groundwater table. Floods are made worse by rapid and uncontrolled urbanization, resulting in lack of urban planning, increased impermeability, and expanding settlements and infrastructure in vulnerable areas. Most of AMBA's stormwater infrastructure, constructed in the 1930 and 1940s, is in the Autonomous City of Buenos Aires (CABA), located in the heart of the AMBA, downstream of the Matanza-Riachuelo, and crossed by smaller creeks.

Since 2004,<sup>10</sup> CABA has had an updated hydraulic masterplan (only for its creek networks) that lays out a comprehensive strategy of protection against floods and the resultant economic and social losses. The hydraulic masterplan takes a basinwide approach (dividing CABA into 10 creek basins) and details a set of priority nonstructural and structural measures. Implementation of the hydraulic masterplan has resulted in significant improvements in drainage capacity and the incorporation of flood risk management principles in urban planning and construction codes. The new drainage system in the Maldonado Creek Basin resulted in a threefold increase in drainage capacity within the basin, benefiting around 1 million people. Another 1.3 million people living in the Cildañez, Vega, and Maldonado basins will benefit from major and secondary drainage systems being constructed, and some 1.7 million commuters are estimated to benefit from these investments.

Water pollution is also a major issue for the AMBA. The Matanza-Riachuelo River, the most polluted in the country, has received considerable attention. The Reconquista River has similar problems but has received less publicity. The rapid urban sprawl has not been matched by adequate sanitation infrastructure. Many industries have settled in the AMBA, particularly those based on cattle processing such as slaughterhouses and tanneries, as well as metal-based industries. Approximately 10 million people live in the Matanza-Riachuelo River and Reconquista River basins. Almost none of the municipal and industrial wastewater was treated in the past. In the lower reaches of both rivers, there is essentially no dissolved oxygen, and the water is devoid of aquatic life. The historical neglect of environmental conditions in these rivers has caused the city to turn its back on them, with slums filling the space along the banks. Several governments have promised to clean up the Matanza-Riachuelo river, and multiple initiatives have been introduced since the 1990s.

## **Framework for integrated water management and increased urban water resilience**

The judicial system was the main driver of the current Matanza-Riachuelo River Restoration Program. In 2008 the Supreme Court of Argentina ruled that the government of Argentina, the City of Buenos Aires, and the Province of Buenos Aires were equally negligent and responsible for not preventing the degradation of the Matanza-Riachuelo River. The court ordered an accelerated clean-up program for the river (PISA). The court also decreed that the newly established river basin organization, Autoridad del la Cuenca de Matanza-Riachuelo (ACUMAR), would coordinate implementation of PISA. ACUMAR includes federal, provincial, and city government representatives. The PISA was updated in 2016 and currently has 79 programs or projects under 14 action lines.

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<sup>10</sup> The plan was approved by Law in 2006.



The court devised a three-prong strategy to implement its ruling: the Auditor General of Argentina has financial and budgetary control of the program; a Citizens Advisory Group (Cuerpo Colegiado de Control de la Gestión del Plan), composed primarily of the NGOs that brought the lawsuit, directs implementation of the program; and a federal judge, whose decisions are final and cannot be appealed, oversees the program. The regional water company AySA and the government of Argentina have responded to the court ruling with a comprehensive and ambitious wastewater investment program.

The 2020 water quality objective for the Matanza-Riachuelo River is to achieve Class IV standards suitable for passive non-contact recreation and with dissolved oxygen concentrations above 2 milligrams per liter at least 90 percent of the time. The strategy is to gradually eliminate the point and non-point pollution discharges into the river. ACUMAR has estimated that 80 percent of the organic pollution comes from domestic sources and 20 percent from industrial sources.

For the domestic pollution sources, AySA has developed a decentralized system for treating wastewater to meet the required discharge standards. First, taking advantage of the large dilution capacity of the Río de La Plata, wastewater is collected in large interceptors and conveyed to two large pre-treatment plants (Berazategui, 33 cubic meters a second, and Dock Sud, 27 m<sup>3</sup>/s peak capacity), which screen for trash removal and skim off floatable materials such as oil and grease before discharging the wastewater through long outfalls (Berazategui, 7.5 kms, and Dock Sud, 12 kms) with diffusers to dilute the wastewater. Water modeling studies indicate that the partially treated wastewater will have limited impact on the water quality in the Río de la Plata. Second, AySA is constructing several smaller secondary wastewater treatment plants in the middle and upper part of the Matanza-Riachuelo River to avoid the high costs of constructing long interceptors and accelerate the timeframe to expand networks, connect users, and improve system operation. Though the decentralization of its wastewater treatment system is expected to increase the city's resilience to climate shocks by diffusing the treatment capacity locally and decreasing reliance on larger elements, further analysis is required to assess the system's performance under different scenarios.

On the industrial pollution side, ACUMAR has responded to the court ruling with a dynamic comprehensive program to eliminate industrial pollution, which is required if Class IV water quality standards are to be achieved. Since 2010, ACUMAR has aggressively pursued an industrial pollution reduction program emphasizing the most polluting industries, particularly slaughterhouses, tanneries, and electroplating enterprises. ACUMAR has identified approximately 17,000 industries, of which 458 are considered pollution sources and about 40 percent have presented pollution control plans that are completed or underway. ACUMAR is also offering financial and technical assistance to small- and medium-size enterprises to help them meet their pollution control obligations.

ACUMAR has moved rapidly on the environmental restoration of the Matanza-Riachuelo River banks. Over 70 percent of the 318 km of riverbanks have been cleaned and improved, mainly by employing low-income workers through local cooperatives under the "Argentina Works" program. Approximately 114 tons of solids have been removed from the river surface, as well as 61 sunken ships and over 70 cars. In addition, ACUMAR, in partnership with the city and province of Buenos Aires, has relocated approximately 2,777 low-income households living in precarious situations along the river and provided many of them with new housing units. There has been a dramatic environmental shift along the river, which is greatly appreciated by local residents and marks the first step in a long-term process to restore the Matanza-Riachuelo.

ACUMAR also has a role in flood risk management and has developed a preliminary drainage plan that delineates the types of actions that should be implemented for macro drainage of the basin. COMIREC (Comité de Cuenca del Río Reconquista) is the river basin authority for the Reconquista River. It was created in 2001 to oversee integrated management of the basin and

to preserve the water resources within the basin. COMIREC works under the government of the Province of Buenos Aires. Before COMIREC, the Province of Buenos Aires had invested in structural measures along the basin for flood risk management (1996 to 2005), drastically changing the impacts of flooding in the basin.

Similar to the Matanza-Riachuelo basin, the main pollution sources are domestic and industrial, but a large share also comes from inadequate solid waste disposal. Most of AMBA's solid waste is deposited in landfills within the basin. COMIREC activities are organized around three pillars: environmental cleanup, infrastructure works, and other actions.

## Lessons

The challenges for a metropolitan area without a metropolitan water authority are huge for urban water management. Institutional fragmentation and lack of coordination are the main challenges. Nevertheless, programs such as those for cleanup of the Matanza-Riachuelo River basin, COMIREC, and the CABA's hydraulic master plan demonstrate key integrated urban water management principles in practice. There is potential, looking forward, for the application of principles of decision-making under deep uncertainty, as presented in this guidance note, to ensure that water resources development in the AMBA can improve the resilience of the city's water system over time.



Source: Image by Wally Gobetz, <https://www.flickr.com/photos/wallyg/7850653078>



Source: ACUMAR

## Cutzamala system and Mexico City Metropolitan Area<sup>11</sup>

### Challenges in urban water management

The Mexico City Metropolitan Area (MCMA) is home to over 20 million people, with close to 9 million people living in the Federal District. Potable water coverage in the MCMA is almost universal,<sup>12</sup> with a small percentage of the population relying on tanker trucks or self-supply. Wastewater treatment covers only 13 percent of the wastewater produced in the valley, however.<sup>13</sup> Given the size of the metropolitan area, responsibilities are split geographically between the municipalities and the Federal District's Water Department to provide water supply and sanitation (WSS) services to their constituents, which complicates coordinated action across the MCMA.

The MCMA faces severe urban water challenges linked to groundwater overexploitation, land subsidence, reduction of recharge areas due to increased urbanization and the expansion of grey infrastructure, and the hilly structure of the city. These conditions worsen the impacts of urban flooding, especially in poor neighborhoods located on sloped ground. Responding to its historical vulnerability to flooding, the city developed a deep drainage system to channel water and wastewater away from the most active neighborhoods, but neighborhoods on the periphery are still affected by floods.

Water availability per capita in the MCMA remains the lowest in the country and has been declining: from 190 cubic meters (m<sup>3</sup>) per capita per year to 160 m<sup>3</sup> over the past 10 years. Local water scarcity and rapid population growth have led the MCMA to rely on water transfers. Prolonged droughts in 2007–09 and 2011–13 exacerbated the water scarcity, even affecting water transfers.

The National Water Commission of Mexico (CONAGUA) is responsible for managing and

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<sup>11</sup> This section draws on World Bank and University of Massachusetts, Amherst (forthcoming) and CONAGUA and World Bank (2015).

<sup>12</sup> [http://www.ingenieria.unam.mx/javica1/Plan-Proyectoteca/Proy\\_Plan-2017-1/Abastecimiento%20Agua%20Zona%20Metropolitana%20ValledeMexico.pdf](http://www.ingenieria.unam.mx/javica1/Plan-Proyectoteca/Proy_Plan-2017-1/Abastecimiento%20Agua%20Zona%20Metropolitana%20ValledeMexico.pdf)

<sup>13</sup> [http://www.ingenieria.unam.mx/javica1/Plan-Proyectoteca/Proy\\_Plan-2017-1/Abastecimiento%20Agua%20Zona%20Metropolitana%20ValledeMexico.pdf](http://www.ingenieria.unam.mx/javica1/Plan-Proyectoteca/Proy_Plan-2017-1/Abastecimiento%20Agua%20Zona%20Metropolitana%20ValledeMexico.pdf)

preserving Mexico's waters, providing bulk water supply to the MCMA, and operating the hydraulic works necessary to transfer water to the area from other parts of Mexico. The Cutzamala Water System (CWS), for example, provides about 30 percent of the freshwater used by the MCMA. The CWS is managed by the Basin Agency for the Valley of Mexico (OCAVM), a member of CONAGUA, whose mission is to supply drinking water to the MCMA.

The CWS is a complex interbasin transfer system that brings water from the headwater sub-basins of the Cutzamala River, located in the States of Mexico and Michoacán, to the MCMA over an elevation change of 1,100 meters through a combination of seven reservoirs, six pumping plants, and 322 kilometers of canals and tunnels. Built in three stages between the late 1970s and 1994, the CWS supplies about the 13 m<sup>3</sup> per second to the city's water utility SACMEX (Sistema de Aguas de la Ciudad de Mexico) and has been crucial to the city's water supply and economic development. The system traverses mountainous forested areas and several sub-basins whose populations also draw from this water for supply and livelihood activities (agriculture and other uses). The remaining water is then considered available for delivery to Mexico City. Reservoir levels are operated to optimize the reliability of water supply for different users, maintain acceptable water quality, and satisfy recreational use preferences.

There is growing concern for climatic and demographic changes that are challenging the ability of the CWS to fulfill its operational mandate, especially as competition over water use increases. Moreover, rapid population growth and urban expansion in the MCMA are creating new water demands that are becoming increasingly difficult to meet, increasing the area's vulnerability to climate change.

## **Framework for integrated water management and increased urban water resilience**

The World Bank's Decision-Tree Framework<sup>14</sup> was applied to assess the resilience of the CWS and provide recommendations to improve its ability to meet the water demands of the MCMA under varying climate conditions. The Decision Tree Framework proposes similar steps to those outlined above in the section on planning for resilient cities. The strategy is to move away from reliance on the prediction of a single future and instead stress test the system and proposed solutions under a broad range of plausible future conditions to identify a robust investment pathway.

Analysts stress tested the CWS system and the alternative options under different scenarios of climate change, demand, and costs. The first step was to evaluate the vulnerability of the current CWS to climate variation using hydrologic and water resources systems modeling. The modeling revealed high sensitivity to climate change. According to projections, very small changes in precipitation and temperature will impair the system's ability to deliver the target supply at the historical rate of reliability. By 2050, in almost all climate change projections, the system will be unable to deliver sufficient water reliably without an increase in average precipitation, suggesting vulnerability to climate change. Though increases in precipitation, were they to happen, would more than make up for the temperature effect, the climate projections considered mostly agree that the CWS is vulnerable to projected changes, which consist mainly of declining precipitation and moderate warming. The vulnerability of the system was already high already under current demand, so the system would not be able to reliably meet higher demand.

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<sup>14</sup> The Decision-Tree Framework provides a scientifically defensible, repeatable, and clear method for demonstrating the robustness of a project to climate change. The framework adopts a "bottom-up" approach to risk assessment that aims at a thorough understanding of a project's vulnerabilities to climate change in the context of other non-climate uncertainties (for example, economic, environmental, demographic, or political). It helps to identify projects that perform well across a wide range of potential future climate conditions, as opposed to seeking solutions that are optimal in expected conditions but fragile to conditions deviating from the expected.



The second step of stress testing was to evaluate the system under different options to improve its performance. Investment alternatives were evaluated for their ability to reduce the vulnerability of the current system and increase future resilience to change. The analysis focused on measures that would maintain or increase the resilience of the CWS to deliver water to MCMA, including increased storage at certain reservoirs or new reservoirs, increased canal capacity or new canals, decreased dead storage levels, changes in operational rule curves for certain reservoirs, and different levels of maintenance. The analysis did not include options under the mandate of SACMEX (and not of OCAVM), such as demand management measures, non-revenue water reduction programs, stormwater capture, water reuse, and others. The selected alternatives were evaluated against five performance metrics: reliability, resilience, drought performance (all three linked to deliveries to MCMA), maximum reliable yield, and robustness. The investments were evaluated individually and as optimized portfolios.

Development of the Temascaltepec Reservoir provides the largest increases in maximum reliable yield, robustness, and resilience of the system, but is the costliest and may not be feasible because of probable high social and environmental impacts. The options of raising the Villa Victoria Reservoir level and canal expansion and pumping at Tuxpan were selected in many of the highest performing investment portfolios. The best performing investment portfolio that does not include Temascaltepec consists of raising the Villa Victoria Reservoir level, reducing dead storage in Bosque reservoir, and the Tuxpan Pump projects<sup>15</sup>.

The options of optimizing reservoir and canal operations performed as well if not better in some cases than options with high capital investments. Though a study of hydrologic forecasting at key inflow points would be needed to realize such improvements in practice, these results justify pursuing such a course.

The analysis also showed that proper maintenance of the system is critical for its long-term reliability and resilience: without proper maintenance, not even the portfolio with Temascaltepec Reservoir can ensure acceptable reliability. A sensitivity assessment of the system to lack of maintenance of major system components identified elements that would have the most severe negative impacts on maintaining acceptable performance of the CWS and that could serve as inputs to an optimized maintenance plan for a given budget constraint. This finding is important because it is often easier to secure financing for larger capital investments than for daily and annual maintenance interventions.

The analysis also explored the impacts of increased agriculture uses in the region, but the current allocation rules prioritize water supply to Mexico City, so no large impacts emerged. However, the likelihood is that the allocation rules may have to be renegotiated in the future. Therefore, future analysis could expand on water use scenarios, especially to ensure that potential impacts on other users in the basin are understood in the decision-making process.

## Lessons

The application of the Decision-Tree Framework methodology enabled an improved understanding of the vulnerability of the CWS to climate variations and demand increases and helped OCAVM and SACMEX identify a set of no-regret actions that would allow deferring large capital investments until (and if) the right triggers materialize.

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<sup>15</sup> An additional option was considered after the report initial draft - the Villa Victoria Pressurize – and in conjunction with an expansion of Villa Victoria's current capacity yields significant improvements in all performance metrics considered, becoming the best performing investment that does not include Temascaltepec.

## Challenges in urban water management

Melbourne is the capital of the state of Victoria and the second most populous city in Australia. The Melbourne metropolitan area covers 7,694 km<sup>2</sup> (about the same as the greater London area or Los Angeles) and has a population of about 4.3 million. The Greater Melbourne area is undergoing unprecedented population growth, with the inner City of Melbourne (the business district, with a population of just over 127,000 residents) registering a growth rate of 10.5 percent in 2012–13. This trend is expected to continue over the next two decades as Melbourne is set to become Australia's most populous city by 2050 (City of Melbourne 2009).

The Greater Melbourne area is spread over 31 municipalities. It has a large urban footprint and a low population density (430 residents per square kilometer). Melbourne Water, the main water authority, manages Greater Melbourne's water supply watersheds, sewerage, rivers, and drainage systems. Residential water supply services are provided by three major "retail" utilities, while Melbourne Water acts as a "wholesaler" water utility: it abstracts, treats, and transfers water to retail water utilities for further sale to residential customers. Melbourne Water is a direct provider of sanitation services, removing and treating all of Melbourne's sewage.

Melbourne Water's customers include the three major retail authorities (City West Water, South East Water, and Yarra Valley Water) as well as other water authorities, local councils, irrigators, and land developers. Melbourne Water is also responsible for protecting water resources, managing flood risks, and planning for water resources sustainability. It is owned by the State of Victoria and governed by an independent board of directors in conjunction with the Minister for Water. Between 1997 and 2009, the State of Victoria experienced 13 consecutive years of drought—known as the Millennium Drought—which resulted in conditions below the threshold under which the water supply infrastructure and regulation were designed to operate.

Melbourne's 2009 Climate Change Adaptation Strategy identified several priority climate risks with the potential to threaten the future of Melbourne and its economic attractiveness: reduced rainfall and drought, extreme heat waves and bushfire, intense rainfall and wind storms, and sea level rise (City of Melbourne 2009). The record hot summer of 2012–13 (which included the hottest month and hottest day on record), which was linked to the effects of climate change in Australia, reinforced climate adaptation as a priority for the City of Melbourne.

## Integrated water management framework for increased urban water resilience

The adaptation response to these climate risks was largely driven by Melbourne Water, which championed an integrated water management response in the midst of the Millennium Drought in Australia. Until then, water resource planners had not considered resilience to be an issue, as Melbourne's drinking water supply is provided by seven reservoirs, mostly in protected watersheds, which had been expected to guarantee high-quality and reliable drinking water and low-energy service thanks to gravity-fed water supply. Water resources planning had been based on historical trends; if Melbourne needed more water, the approach was to increase surface water storage capacity. However, expanding capacity takes time, and the system was not ready to cope with the atypical shortage of rainfall in 2004–05, exacerbated by fire hazards in the forested catchment areas, which threatened the sustainability of water supply for the city.

The approach chosen by Melbourne aligned with the principles outlined in this guidance note, especially those related to recognizing the value of alternative water sources, allowing a better

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<sup>16</sup> World Bank 2016a. Mainstreaming Water Resources Management in Urban Projects: Taking an Integrated Urban Water Management Approach.

allocation of source to use and letting the water system recover through the introduction of fit-for-purpose water; closing the water cycle; managing water demand; accounting for nonurban users, including the needs of the environment; and encouraging participation by all stakeholders. New significant risks have emerged for Melbourne—floods and sea-level rise—and these have been incorporated into their planning process. The city relies heavily on flood modeling under different possible climate scenarios to identify the most vulnerable areas in the city and solutions with the most impact on flood reduction locally. The City of Melbourne and Melbourne Water are currently analyzing the effects of green infrastructure on protecting the city under different scenarios and are working with the Cooperative Research Center for Water Sensitive Cities to identify measures to reduce the urban heat island effect in the city<sup>17</sup>.

This approach was supported by several structural and nonstructural measures as part of a comprehensive approach to the challenges the city faces (Melbourne Water 2013). These solutions helped mitigate the city's vulnerability to recent drought events and have enhanced its ability to respond to variability in climate conditions, though no event as extreme as the Millennium Drought has tested the system since the measures have been put in place. The measures implemented include:

- Providing recycled water (32 gigaliters) to irrigators, the tourism industry, municipal and environmental services, and a small but growing number of residential developments equipped with dual-pipe schemes.
- Constructing a large desalination plant (150 gigaliters per year) to provide additional capacity in times of low storage levels.
- Upgrading and reforming the irrigation district north of Melbourne with annual savings of about 225 gigaliters for increased environmental flows, irrigation, and water supply storage for the city.
- Expanding the water distribution system to connect Melbourne's water system with the desalination plant and the North-South pipeline.
- Managing aquifer recharge for the capture and use of treated stormwater or recycled water for later recovery and use or for environmental benefit. Water deposits are made in times of surplus—commonly in winter—and extraction occurs during peak demand in summer, when traditional supplies struggle to meet demand. Multiyear balancing is also possible for long-term storage.
- Licensing stormwater harvesting in some watersheds.
- Introducing a planning amendment in a pilot watershed requiring developers who increase impervious surface area by more than 10 m<sup>2</sup> have to treat runoff onsite instead of letting flows enter the stormwater system, to determine if this type of planning control is effective in reducing stormwater flows and improving urban waterway health.

Melbourne Water has also introduced permanent water demand management measures to encourage consumers to use less water through advertising, education, pricing, and appliance redesign with strong collaboration with stakeholders across several dimensions. For example, stakeholders are engaged in long-term planning at the regional and municipal levels to address the needs of a growing population and the forecast impacts of climate change and variability. They are also collaborating with the State of Victoria and retail utilities to develop regional integrated water cycle strategies to guide investment in water projects across Melbourne until 2050, which should include climate projections and stress tests of various options with considerations for the objectives of all stakeholders involved.

## Lessons

Melbourne Water has done much to report and share the lessons of the past decade of implementing measures under an integrated water management framework in the city. Flexibility

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<sup>17</sup> [https://watersensitivecities.org.au/wp-content/uploads/2016/08/Urban-Heat-Briefing\\_Final.pdf](https://watersensitivecities.org.au/wp-content/uploads/2016/08/Urban-Heat-Briefing_Final.pdf)

and outcome-focus are key, and different approaches are needed for different areas of the city to match local drivers and ensure the cost effectiveness and affordability of the proposed measures. Community engagement throughout the process is a crucial success factor. In addition, there are risks and associated costs for the municipality or utility when shifting from input-based solutions to an outcomes-based mindset, as the increased complexity of the system requires a different skillset. The shift within utilities from managing assets to managing behavior requires new skills and thus may face considerable resistance initially.

Melbourne Water still faces challenges in adopting some measures. One is the need to diversify the customer base for recycled water to ensure cost recovery and understand the changes in customer demand related to the availability of water resources. Another is the difficulty of sharing the costs and benefits of integrated water cycle management projects across organizations, which has prompted Melbourne Water to consider developing a framework to clarify cost- and benefit-sharing. Creating a road map for resilience and applying the principles of decision-making under deep uncertainty in planning and decision-making processes could help resolve some of these challenges by ensuring that the objectives that are important to these different stakeholders are considered when different possible strategies and investments are considered.

## Amman<sup>18</sup>

### Challenges in urban water management

Amman is the capital and largest city in Jordan. Its 4 million inhabitants make up 42 percent of the country's population, 94 percent of whom live in urban areas. The population of Jordan has recently increased sharply because of the influx of about 1.6 million refugees, one-third of whom live in Amman. Jordan is one of the poorest countries in the world in terms of water availability. The 50-year mean annual rainfall in Amman is about 350 millimeters, but with an average evaporation rate of about 90 percent, estimated water infiltration rates are just 4–10 percent of precipitation.

The roles and responsibilities for governing the water sector are defined in the country's legal framework. The Ministry of Water and Irrigation (MWI) develops strategies and policies to increase the sector's resilience through improved efficiency and effectiveness of operations and investments. The most recent strategy was the National Water Strategy 2016–25, which is accompanied by a set of new policies and a National Capital Investment Plan to prioritize investments (MWI 2016). The Water Authority of Jordan (WAJ) is responsible for ensuring that drinking water is safe and its quality complies with national standards. Miyahuna, the service provider, is responsible for treating water and wastewater and delivering water that complies with the national regulations and standards. Water supply in Amman was privatized in 1999 but service responsibility was returned to a local government-owned company in January 2007.

Groundwater represents the main source of water in Amman. Most of the groundwater is abstracted from the Basalt aquifer and B2/A7 layers. This area includes the highest concentration of wells, which increased in number from 672 in 1995 to 955 in 2015, mainly to supply water to the growing population in the Amman-Zarqa River Basin as a result of the influx of refugees. Abstraction from the Amman-Zarqa basin started in the mid-1960s and increased from 8.46 million cubic meters per year to 119 million m<sup>3</sup> per year in the late 1990s and 156.3 million m<sup>3</sup> in 2013. The estimated annual recharge is approximately 70 million cubic hectometers per year, and the safe yield is 87.5 million cubic hectometers; current overuse is depleting the groundwater in the basin, where available resources and water quality have reached critical conditions.

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<sup>18</sup> World Bank. 2018. Water Scarce Cities: Thriving in a Finite World. World Bank, Washington, DC. © World Bank. <https://openknowledge.worldbank.org/handle/10986/29623> License: CC BY 3.0 IGO."



Water supply to Amman is also obtained from surface water, nonrenewable groundwater, desalinated brackish water, and treated municipal wastewater. Most important among these other sources are the Zai Water Treatment Plant, Zara Desalination Plant, other treatment plants, King Abdullah Canal, and the Disi fossil aquifer.

Domestic water use in Amman is approximately 376 million m<sup>3</sup> per home per year. Per capita consumption is currently 69.7 liters a day, according to records for billed water in 2015. Because of the increased demand for water, national water resources face growing pressures from overabstraction and the effects of climate change. The exponential rise in water demand has led to severe competition for resources among different socioeconomic sectors. The National Water Strategy gives priority to the domestic sector, followed by the growing tourism sector. Third priority was given to the industrial sector.

## Integrated water management framework for increased urban water resilience

The National Water Strategy focuses on increasing water supply to meet the demand for Jordan and the Syrian refugees by optimizing surface water resources, using more treated wastewater, introducing nonconventional water resources (including desalination), decreasing the level of groundwater exploitation, and maintaining the daily water per capita allocation despite the sudden increase in population. In 2016, Jordan also developed its Climate Change Policy for a Resilient Water Sector,<sup>19</sup> which outlines the climate risks the country is facing, reviews sources for climate data and projections modeling, and sets out an approach to incorporate resilience in solutions planning for the water sector going forward. Though this methodology does not seem to have been applied yet in Amman's Capital Investment 2016–25,<sup>20</sup> the country and the city are working on streamlining the methodology.

A key pillar of the National Water Strategy is the addition of treated wastewater to the water budget, with priority given to agriculture for unrestricted irrigation. The main elements of this substitution policy call for winning public acceptance; ensuring the suitability, adequacy, and sustainability of high-quality water; and enforcing laws. These measures have increased the use of treated wastewater in place of freshwater in irrigation, while meeting the quality guidelines and standards of the World Health Organization and the Food and Agriculture Organization of the United Nations. Industry use of treated effluents has also been increasing.

Another key pillar of the strategy has been the improvement in the efficiency of service providers. Nonrevenue water in Amman results in physical, commercial, and administrative losses. The government put in place a management plan to reduce nonrevenue water to 45 percent. The target was surpassed by 2015, when the rate declined to 37 percent. The National Water Strategy set a goal of reducing nonrevenue water to 25 percent by 2022, a target that seems achievable. Recently implemented projects have already reduced nonrevenue water to 28 percent in the Tareq area (Rothenberger 2009). Controlling illegal connections (3,832 cases in 2015), replacing water meters, and developing evaluation and monitoring programs have been instrumental in reducing nonrevenue water.

The government has also embraced larger-scale private sector participation. In 2002, the Jordan signed a 25-year built-operate-transfer agreement for the design, construction, and operation of the As Samra wastewater treatment plant, the first public–private partnership in the financing and management of a public infrastructure project in the country.

The new supply from the Disi aquifer, which became operational in 2015, is probably the most

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<sup>19</sup> <http://www.mwi.gov.jo/sites/en-us/Hot%20Issues/Strategic%20Documents%20of%20The%20Water%20Sector/Climate%20Change%20Policy%20for%20a%20Resilient%20Water%20Sector%2025.2.016.pdf>

<sup>20</sup> <http://www.mwi.gov.jo/sites/en-us/Hot%20Issues/Strategic%20Documents%20of%20The%20Water%20Sector/Capital%20Investment%20Plan%20CIP%20Report%20-%20FINAL25%20Feb%202016%20-.pdf>

important project undertaken to supply water to Amman. It allows Miyahuna to meet the increasing demand from the Syrian refugees. The project involves extracting 100 million cubic hectometers from the Disi aquifer and transporting it over 325 kilometers to Amman. In 2016, the total volume of water produced from all sources was 238 million cubic hectometers, of which 191.7 million were supplied to Amman and the rest was pumped to other cities—Zarqa, Madaba, and Balqa.

According to the National Water Strategy, electricity for pumping water represented 45 percent of operation and maintenance costs in 2014. The 22 percent increase in the electricity tariff applied in recent years led to a rise in operating costs of the utilities, particularly Miyahuna. The cost of electricity used in water pumping increased 220 percent. The cost of water production and distribution in Amman (\$1 per million cubic meters) severely limits Miyahuna's financial sustainability and ability to expand its services. To address these challenges, the MWI is developing projects based on energy audits and the use of renewable energy resources.

## Lessons

Despite these efforts, the gap between supply and demand for water resources for the approximately 700,000 subscribers in Amman is increasing. To address this challenge the WAJ is implementing several projects to explore new resources, with the objective of generating 187 cubic hectometers per year of additional freshwater and increasing the storage capacity of the country's dams by 25 percent (from the current 325 cubic hectometers to around 400 cubic hectometers). Moreover, to increase the supply for the city of Amman, the WAJ has identified two reservoirs 180 kilometers southwest of Amman with a storage capacity of 15 and 20 cubic hectometers, and potentially an additional 30 cubic hectometers for the following phases.

The MWI is also relying for its long-term solution on the Red Sea–Dead Sea Water Conveyance Project, which is expected to supply 30 cubic hectometers per year to Amman out of the 65 cubic hectometers per year of desalinated water it will produce through phase 1. This project will pump seawater from an intake in the northern end of the Gulf of Aqaba and desalinate it there. The project foresees construction of a brine conveyance pipeline, lifting pump stations, hydropower plants, and discharge facilities at the Dead Sea between 2017 and 2021. The project is expected to produce an additional 150 cubic hectometers per year under a second phase between 2020 and 2025.

With the increasing population and the country's social and economic development, the amount of wastewater is also increasing. By 2025, the volume of treated wastewater will be an estimated 240 cubic hectometers per day. As available freshwater resources become more limited, treated wastewater will be increasingly important to the country's development. Finally, the government is considering further developments to address stormwater drainage and to continue the rehabilitation, restructuring, and extension of Amman's water networks.



Image: Flavia Lorenzon

### Challenges in urban water management

Singapore is a tropical island city-state located just north of the equator in Southeast Asia. With a population of 5.6 million people on its 719 square kilometers, it has one of the highest population densities in the world. Singapore enjoys a high level of development; its gross domestic product (GDP) per capita of \$84,382 is the fourth highest in the world.

Providing a reliable water supply at affordable cost is essential for Singapore's economic success and survival. Singapore's ability to be globally competitive in attracting investments and jobs is based largely on its stable government and reliable infrastructure, including water supply. In addition, climate change and long-term periods with lower rainfall could affect the reliability of local catchments and the supply of imported water. Aside from direct economic damage from droughts or water supply disruptions, the impact of reputational damage would also be large, especially as Singapore is an important participant in the global water industry.

Singapore is often mentioned as an example of successful urban water management under resource constraints. Water supply, water resources and catchment management, and drainage and sanitation are managed in an integrated manner by the Singapore Public Utilities Board (PUB), which is a statutory board under the Singapore Ministry of the Environment and Water Resources.

Singapore's long-term average annual rainfall is 2,328 mm, with the driest month of February still receiving about 120 mm on average. Annual and monthly rainfall can vary significantly. For example, in 1997, the driest of the past 35 years, Singapore received 1,119 mm of rain. During a dry spell in 2014, several weather stations across the island did not receive any rain for more than a month. Although rainfall is generally abundant throughout the year, lack of space to store water and the absence of aquifers means that Singapore is dependent on neighboring Malaysia for part of its water supply.

Singapore signed agreements with the Malaysian State of Johor in 1961 and 1962 to ensure access to water resources, which were explicitly mentioned in the Separation Agreement for Singapore's independence in 1965. The 1961 agreement ended in 2011 and the 1962 agreement, which ensures a supply of 250 million gallons of water a day, expires in 2061. Singapore's dependence on Johor for its water supply gives Malaysia political leverage, and there have been some tensions over water (Kog 2015; Tortajada, Joshi, and Biswas 2013). As a result, and anticipating the expiration of the water agreement in 2061, Singapore aims to become self-sufficient to improve its water security.

Singapore has four sources of water, known locally as the "Four National Taps": local catchment water, reclaimed wastewater (called NEWater), desalinated water, and imported water. NEWater was introduced in 2002 and currently meets up to 30 percent of total demand; the first desalination plant opened in 2005, and desalination now meets up to 25 percent of demand. Public information is not available for the other two main sources, but the share of local catchment water is likely about 10–15 percent and that of imported water about 40–50 percent. Projections for 2060 show an increase in the share of NEWater of up to 55 percent and desalinated water of up to 30 percent, with total water demand expected to double.

Water consumption in Singapore is about 430 millions of gallons a day. Households used 44.7 percent of the water, which was equivalent to 148 liters per capita per day (lpcd) in 2016. The agricultural sector is very small, occupying less than 1 percent of Singapore's land (Republic of

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<sup>21</sup> Summary from World Bank. 2018. Water Scarce Cities: Thriving in a Finite World.

Singapore 2015), and does not use much water. Manufacturing constitutes about 25 percent of the economy (Republic of Singapore 2015). Singapore houses a large water-intensive petrochemical industry. Several large semiconductor fabrication plants use a significant share of the NEWater. The services sector is about 70 percent of the economy and is dominated by financial and business services and trade through the large port. Tourists spent a total of 14.5 million days in Singapore in 2014 (Republic of Singapore 2015), which is equivalent to about an additional 40,000 people in residence for a year.

Water demand is expected to increase by 25 percent by 2030 and to double by 2060 due to population increases and growing demand for nondomestic uses (PUB 2016b). PUB targets a reduction in domestic consumption to 140 lpcd by 2030. The growth in nondomestic demand would represent a worst-case planning scenario.

## **Adopting an integrated water management framework for increased urban water resilience**

Water challenges in Singapore overlap with development challenges, such as limited land and natural resources. Rapid economic growth, urbanization, and industrialization have encouraged Singapore to optimize land use, factoring in future economic and population growth projections. Long-term planning strategies have also been used to decide on the broad pace of development. Singapore has employed planning instruments such as concept plans, strategic land use, and transportation plans that guide development for the next 40–50 years. In addition, statutory master plans extend over a 10- to 15-year horizon and translate the long-term strategies of the concept plans into detailed plans for implementation by specifying permissible land uses and densities. These plans affect all types of development, including those of water resources. At independence in 1965, Singapore was importing some 80 percent of its water from Johor. Local water storage capacity was very limited, drainage and sewage infrastructure were missing, and recurrent droughts and floods affected both population and economic activity. Financial constraints restricted planning and investments in water supply, drainage, sewage, and flood alleviation projects. As Singapore became more affluent, it became easier to plan and implement water infrastructure projects.

From 1960 to 1970, Singapore focused on developing projects to import water and meet increasing demand. Later efforts focused on building local water supply sources, providing sanitation services for the growing population, and collecting and treating wastewater. In the mid-1980s, PUB focused on developing urbanized catchments and on developing technology for producing unconventional sources of water to increase the water supply. With time, reservoirs and waterways began to play an important part in recreation and urban design, with the objective of bringing people closer to water and of integrating parks, water bodies, and residential areas. Each of these strategies has resulted not only from water challenges but also from land use and energy challenges for which numerous institutional, policy, management, and development responses have been implemented.

Water resource strategies have included systematic, innovative, and forward-looking planning, regulatory, management, development, and technology measures. To address water quantity constraints, PUB proposed increasing the runoff that could flow to the reservoirs by indirectly increasing the water catchment area. This was done through runoff collection from nearby water catchment areas.

Interagency coordination played an important role in solving water quality problems. In 1960–1970, the then–Ministry of Environment extended the sewerage network to ensure that all wastewater was collected and treated. For example, the Bedok Reservoir was already earmarked under the 1971 Concept Plan as a potential water catchment area; the Urban Redevelopment Authority (URA), which oversees land use planning, rezoned land to protect it against polluting developments. The Housing and Development Board, responsible for public housing, excavated sand that it required for its future projects and stockpiled it elsewhere so



that Bedok Reservoir could be completed in time to meet increasing water demands (Tan, Lee, and Tan 2009).

In 1971, a long-term Concept Plan was prepared for Singapore's physical development, assuming a population of 4 million. A key aspect of the Concept Plan was the "ring" approach for creating a development ring around the central water catchment area. Major industrial areas would be located on the periphery of surrounding corridors, and major recreational areas would be developed from the central catchment area through to the coast. New towns would be built around the central catchment area, where the protected MacRitchie, Peirce, and Upper Seletar catchments were located. This framework protected the water bodies from pollution while also developing centers of population in areas other than the central area. The protected catchments were left in their natural state as much as possible. No development works were authorized in these areas. The same year, a Water Planning Unit was established under the Prime Minister's Office to assess the scope and feasibility of expanding water supplies. This unit prepared the first Water Master Plan in 1972. It considered both conventional and unconventional water sources and outlined strategies to ensure diversified and adequate local water supplies by creating urbanized catchments that would meet projected future demand (Tan, Lee, and Tan 2009).

To satisfy water demand, cleaning highly polluted rivers and water bodies became a national priority. Both the Concept and Water Master Plans stressed the need to develop unprotected catchments. As a result, animal husbandry activities near catchment areas were relocated; antipollution legislation was introduced and enforced; and drainage, sewage, and flood alleviation projects were developed. In 1972, a growing focus on environmental issues resulted in the formation of the Ministry of the Environment (ENV), backed by new legislation. This was a pioneering move in Southeast Asia. In 1975, the Water Pollution Control and Drainage Act was enacted to control water pollution by discharging effluents into sewers and monitoring and regulating water quality. Part IV of the act addressed water pollution control for inland waters and made it a punishable offence to discharge any toxic substance into inland water. In addition, the 1976 Trade Effluent Regulations enabled the Director of Water Pollution Control and Drainage to ensure that trade effluents were discharged only into sewers.

With rapid urbanization, many waterways were upgraded to facilitate the collection of stormwater runoff. The Water Pollution Control and Drainage Department was entrusted with enforcement of the Water Pollution Control and Drainage Act (1975), the Surface Water Drainage Regulations (2007), and the Trade Effluent Regulations (1976). Numerous drainage projects have been developed and have reduced flood-prone areas by more than 95 percent over the last few decades, even as urbanization intensified.

Concurrent with the rapid development of Singapore, appropriate pollution control strategies were adopted, older legislation and regulations were amended, and new ones were drafted. For example, the Water Pollution Control and Drainage Act 1975 was repealed and its relevant powers were incorporated into the Sewerage and Drainage Act (SDA), which is administered and enforced by PUB, and the Environmental Pollution Control Act (now known as the Environmental Protection and Management Act (EPMA) was enacted in 1999. Each was accompanied by regulations. The Singapore River and the Kallang Basin were cleaned from 1977 to 1986, in conjunction with large redevelopment activities (Tortajada, Joshi, and Biswas 2013). Following clean-up of the Singapore River, a comprehensive plan was developed by the URA and the Singapore Tourism Board in coordination with other departments and statutory bodies. The Singapore River was chosen as 1 of 11 thematic zones identified in the Tourism Master Plan seeking to project Singapore as a tourism capital in the 21st century (STB 1996). In the late 1980s, the government began studying the development of Marina Bay as an alternative source of freshwater, as well as for flood alleviation purposes.

In the 1970s and 1980s, PUB considered the use of unconventional sources such as water recycling and desalination; however, these were not deemed feasible from technical and cost

perspectives. As more cost-effective technology was developed in the late 1990s, plans were made in 1999 to have the private sector build a desalination plant from which PUB would purchase the water. It was also agreed that the government would own and operate a smaller 10 million gallons a day desalination plant (PUB 1999).

PUB also announced that it was studying ways to increase local sources of water by developing suitable marginal catchments to collect stormwater runoff from new housing estates. Rainwater would be collected and treated to meet drinking water standards instead of being drained for flood control and sent out to the sea. PUB explained that these projects would be implemented with the development of drainage systems in the new towns. At the same time, PUB and ENV embarked on a joint assessment of the feasibility of water reclamation using secondary treated sewage effluents.

A demonstration plant for recycled water was built in 2000, and in 2002 the plan for producing recycled water began to be carried out. Equally importantly, a communication plan was also prepared to educate the public that this recycled water was safe for drinking, not simply to focus on the technology employed. To change the overall negative popular impression of recycled water, recycled wastewater was renamed “NEWater,” wastewater treatment plants were renamed “water reclamation plants,” and wastewater was called “used water.” The new terms were part of a strategy to change mind-sets, stressing the new approach to water management by communicating to the public the need to look at water as a renewable resource that could be used repeatedly. Similar to desalinated water, private participation was invited for the production of NEWater.

## Lessons

Singapore’s urban water and wastewater management during the past 51 years has been exemplary by any standard. This remarkable transformation to becoming a water sensitive city has been possible primarily because PUB has been a consistently efficient and progressive institution. Singapore is the only city in the world with an urban water management plan that extends to 2061, when the treaty to import water from Malaysia expires. The plan is updated every five years taking into consideration the latest technologies; changes in social, economic, and environmental conditions; and new management techniques.

Over the past five decades, Singapore’s national water management has consistently received strong support from national political leadership. For example, from 1965 to 1990 Prime Minister Lee Kuan Yew treated water as a strategic resource for Singapore’s survival and future economic development. Yew’s commitment to water security is one of the main reasons for Singapore’s urban water transformation and progressive water agenda.

Although Singapore has had success with urban water management over the past 50 years, challenges to urban water resilience and security remain. At present, nearly half of its water comes from the Linggiu Reservoir in Johor, Malaysia. In late 2016, Linggiu storage was at a historic low. In January 2017, Foreign Minister Vivian Balakrishnan noted in Parliament that there is a significant risk that the reservoir may have no water if 2017 were another dry year, though by March 2018 it had recovered.

Because of the effects of climate change in recent years, there is a probability that a significant source of the water used in Singapore may disappear before 2061, when the water import treaty with Malaysia expires. Furthermore, if the Linggiu Reservoir becomes dry, there will be a significant reduction in water supply, wastewater generation, and NEWater production.

Domestic water use in Singapore in 2016 was relatively high at 148 liters per person per day. Other cities in the developed world have brought their consumption down below 100 liters with measures that include public awareness campaigns and economic incentives. Singapore plans to follow suit. In the past, Singapore has used technological improvements to reduce

domestic water consumption and nondomestic water use. In the future, it is likely that technological developments will bring only incremental benefits. Therefore, significantly more emphasis needs to be placed on behavioral and attitudinal changes to meet a target of reducing per capita daily water use to 140 liters by 2030.

Until 2017, Singapore's water price had remained unchanged for 17 years. In early 2017, PUB announced that the water price would increase by 30 percent over a two-year period. The small increase in price barely makes up for inflation over the previous 17 years and is unlikely to appreciably reduce water consumption. A survey in 2017 indicated that 75 percent of Singaporeans did not know how much they paid for water. Overall and looking forward, trends show that Singapore needs to change its narrative from an argument of cost recovery for domestic and nondomestic water uses to one of managing a scarce resource.



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## Acknowledgments

This paper is a compilation from World Bank publications on urban water management, notably *Water Scarce Cities: Thriving in a Finite World* (World Bank 2018); *Mainstreaming Water Resources Management in Urban Projects: Taking an Integrated Approach* (World Bank 2016a); *Building the Resilience of WSS Utilities to Climate Change and Other Threats—A Road Map* (World Bank forthcoming); *Pilot Studies of the Cutzamala Water System, Mexico, Including Climate Uncertainty in Water Resources Planning and Project Design—Decision Tree Initiative* (World Bank and University of Massachusetts, Amherst, forthcoming); *Integrated Urban Water Management—Lessons and Recommendations from Regional Experiences in Latin America, Central Asia, and Africa* (Closas, Schuring and Rodriguez 2012); and others. The paper was prepared by Lizmara Kirchner, Laura Bonzanigo, Clémentine Stip, Diego Juan Rodriguez, and Maria Catalina Ramirez Villegas, with support from Ernestina Ataffuah. The authors are grateful to the following colleagues, who provided valuable input to this paper: Maria Pilar Garcia Plorutti (City of Buenos Aires), Katrin Bruebach (100 Resilient Cities), Greg Browder (World Bank), Alex Bakalian (World Bank), Stephane Dahan (World Bank), Amal Talbi (World Bank), Richard Damania (World Bank), Rita Cestti (World Bank), and Stela Goldenstein (World Bank).

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