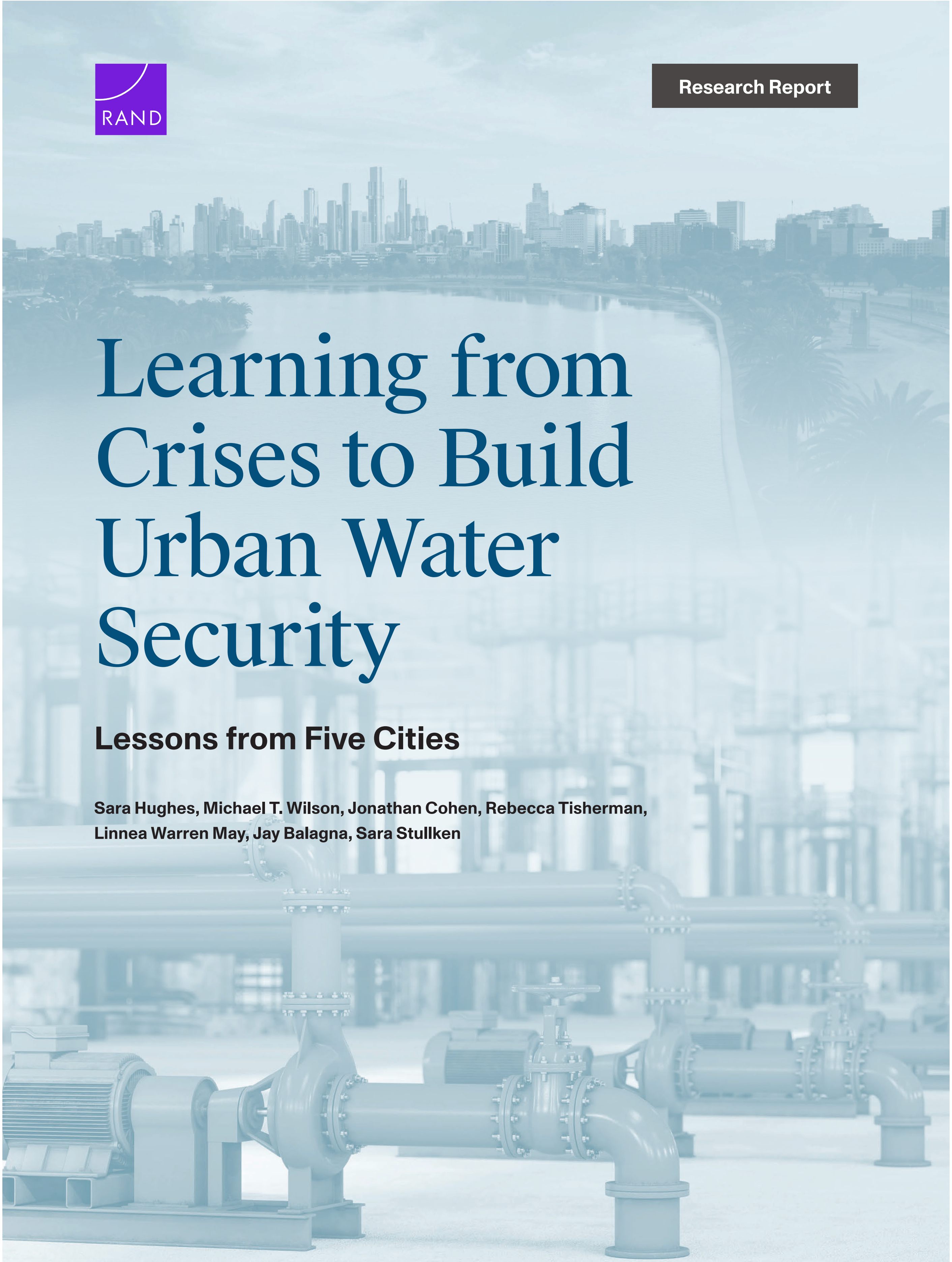

Research Report

Learning from Crises to Build Urban Water Security

Lessons from Five Cities

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Collecting natural spring water during the Day Zero water crisis in a plastic water bottle at the Newlands natural spring in Cape Town, South Africa, in an effort to ease the water shortage disaster.

KEY FINDINGS

- Cities' experiences with water supply crises point to five key strategies for building urban water security: plan and invest proactively, take a systems approach to urban water security, strengthen collaboration between governments, embrace innovation, and build trust and communication with water users.
- Urban water supply crises occur not only because of climate-driven stress to water supplies but also because of underinvestment in fiscal, social, and technical capacities.
- Shifting from crisis response to proactively building urban water security provides opportunities for capacity-building and avoiding the worst effects of supply shortages; mobilizing the resources and expertise needed to make these shifts will require strong local leadership, public awareness, and intergovernmental support.
- Cities have unique pathways to urban water security, which will depend on physical, infrastructural, financial, social, and political risks and opportunities.
- Several important areas for additional research include examining the challenges faced by smaller cities, developing monitoring strategies that can effectively anticipate a crisis and track progress on building urban water security, and developing methods to evaluate trade-offs in efficacy and equity in the long and short terms.

Introduction

Reliable access to safe and affordable drinking water is a core service provided by city governments around the world. These services are critical to people's health and well-being, local and regional economies, and environmental sustainability. As the climate changes, infrastructure ages, and populations grow, many cities are—or will be—facing serious threats to their ability to maintain or enhance the level of service they can provide and ensure the long-term resilience of their water supplies.

This report aims to identify the strategies available to decisionmakers—the people managing urban water systems and shaping the broader financial and regulatory environment in which they work—to proactively mitigate the possibility of catastrophic risk to urban water supplies. Too often, major supply disruptions because of drought or other disasters are not planned for, which leave communities vulnerable to these risks and decisionmakers in the position of crisis management. A 2014 study estimated that one-quarter of the world's 500 largest cities already experience year-round water stress or low availability relative to demand, which accounts for nearly 400 million people and $4.8 trillion of economic activity.[1] More-recent projections estimate that nearly one-half of the global urban population will face water scarcity in 2050.[2] Figure 1 shows the distribution of cities that have high baseline water stress along with an interbasin transfer—a mechanism by which water is moved from one river basin to another and a potential additional indicator of inadequate or vulnerable water supplies.

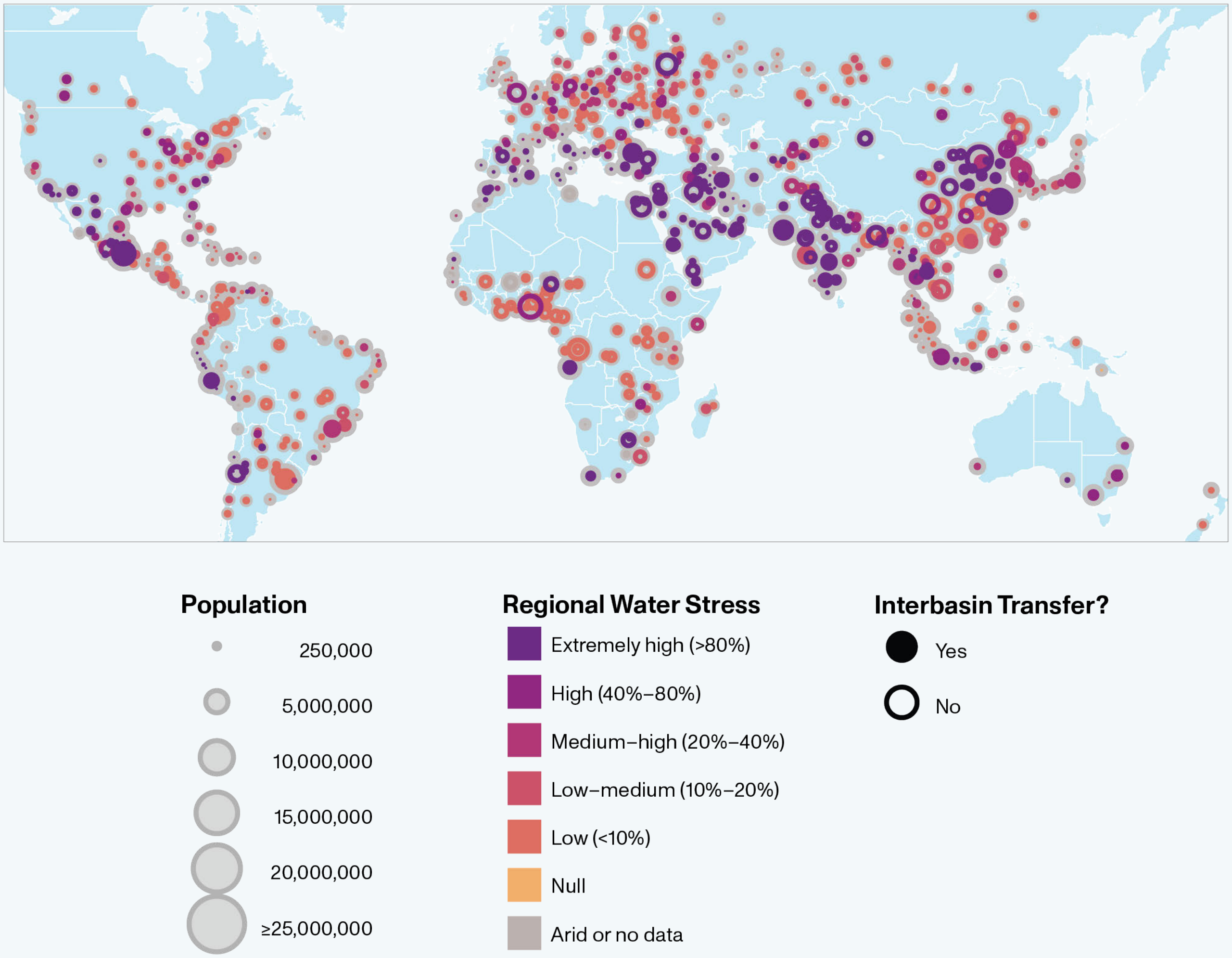
Such cities as Mexico City, Mexico; Cape Town, South Africa; and Phoenix, Arizona, in the United States make headlines when water supplies fall dramatically during a drought, but as temperature and precipitation patterns shift, cities that have not historically needed to worry about reliable water supplies may see new challenges emerge.[3] Population growth, aging infrastructure, and siloed decisionmaking can also leave systems vulnerable to increasingly stressful climate trends and extreme events.

Preparing for severe water supply stress is not straightforward. For example, in their global analysis, He and colleagues find that most large cities would be able to address future water scarcity through supply augmentation, such as desalination or additional reservoirs, but the relative costs and benefits of these options will vary from place to place, and there is significant lead time and public support needed for these investments.[4] The deep uncertainty about future climate conditions and their implications for urban water supplies further complicates decisionmaking.[5]

The strategy of *building urban water security* offers decisionmakers a proactive and holistic approach to potentially avoiding the worst effects of a water supply crisis. Although there are a number of terms and frameworks used to describe or prescribe water management

FIGURE 1

Map of Cities by Regional Baseline Water Stress and Presence of an Interbasin Transfer



SOURCES: Features information from World Resources Institute, "Aqueduct 4.0 Current and Future Global Maps Data," dataset, August 16, 2023; United Nations Educational, Scientific and Cultural Organization, Intergovernmental Hydrological Programme, "Percentage of Municipal Water Coming from Interbasin Transfers," dataset, 2016; and ArcGIS Hub, "World Cities," dataset, data updated March 27, 2023.

approaches,[6] we see the term *water security* as offering unique value in its emphasis on a state or set of capacities to continually pursue rather than a set of specific practices. For example, United Nations Water defines *water security* broadly as

> the capacity of a population to safeguard sustainable access to adequate quantities of acceptable quality water for sustaining livelihoods, human well-being, and socio-economic development, for ensuring protection against water-borne pollution and water-related disasters, and for preserving ecosystems in a climate of peace and political stability.[7]

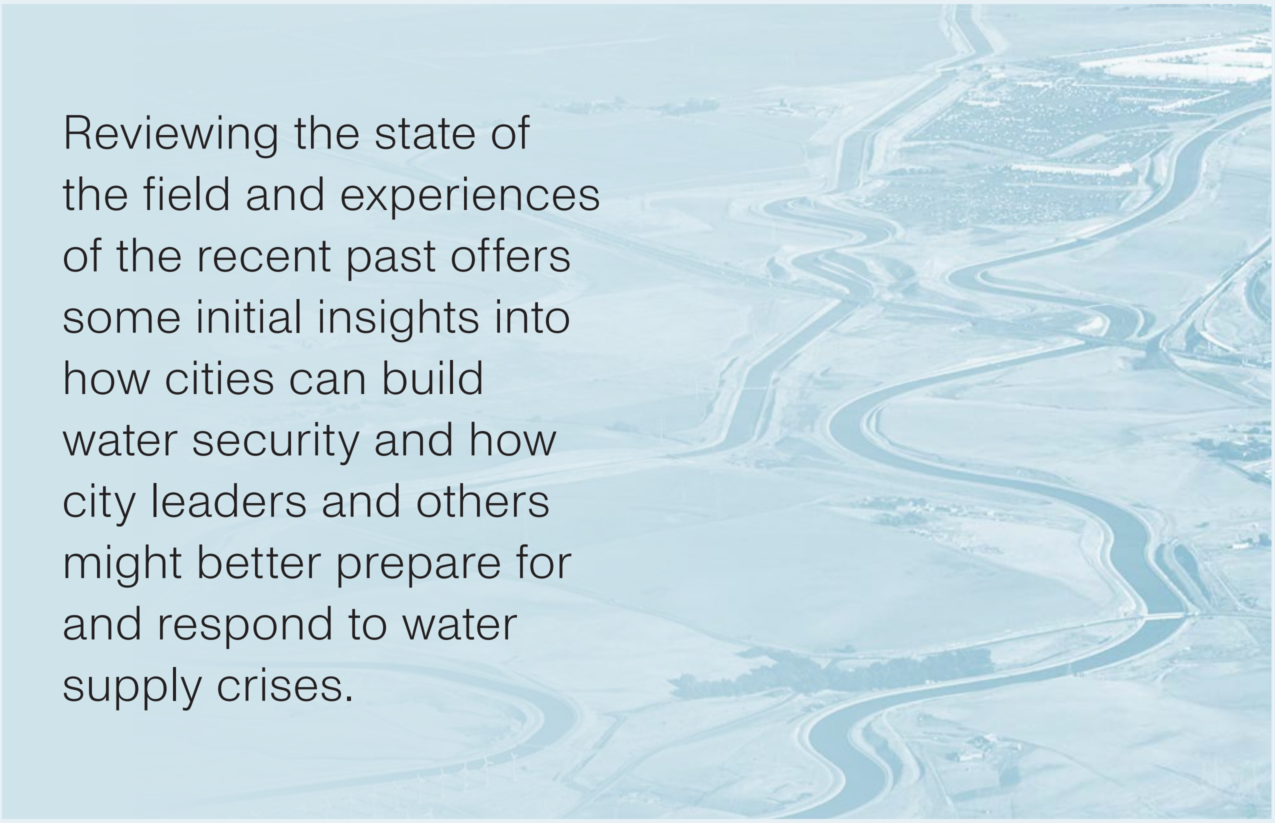
Therefore, building water security is not a task solely for extreme cases nor is it something that can be effectively achieved during a crisis. For cities confronting a changing climate and dynamic decisionmaking environment, *urban water security* can be defined as the ability to

Installing replacement pipes in a municipal water distribution system.

avoid a crisis or the condition of being prepared to respond effectively to one. Urban water security can often be bolstered by demand management and interconnecting water systems, including water recycling and reuse, creating water supply assets from stormwater management, matching water quality to end-use needs, and achieving environmental goals through multipurpose, multi-benefit infrastructure.[8] These strategies often produce co-benefits and require strong collaboration between decisionmakers, residents, and other partners.[9] Although the goal of providing sustainable access to safe and affordable water is not new for many water providers, the means of achieving it may not always be straightforward or immediately clear, particularly as the context in which decisions are made is rapidly changing.[10] Building urban water security outside the stress of an extreme event or ongoing crisis offers a more proactive approach than an emergency or crisis response, giving decisionmakers the tools and capacities needed to mitigate and even avoid a crisis and respond effectively when major supply stressors do occur.[11]

Research Questions

Although the emerging risks to water supplies and purpose and potential benefits of building urban water security have been relatively well developed in scholarly journals, government documents, and other reports from nongovernmental and private sector sources (see, for example, the World Resources Institute's work on water security, the Organisation for Economic Co-operation and Development [OECD] Council's recommendation on water, and the World Bank Global Water Security and Sanitation Partnership's *Towards Water Security: A Framework for Action),*[12] less is known about how urban water security can be best achieved in practice (i.e., the decisions, processes, and resources that need to be in place as leaders and policymakers shift to a water security approach).



Aerial photo of the California Aqueduct at the Interstate 205 crossing, just east of the Interstate 580 junction.

Our research aims to help fill this gap by evaluating the experiences of cities that have had to confront major water supply crises and identifying lessons for how to avoid catastrophic supply crises or ensure cities are better prepared for when a crisis does occur. We also look more broadly at cities, policymakers, and water utilities that have adopted innovative measures to build water security. Specifically, we seek to answer the following three research questions:

- What are the underlying drivers of an urban water supply crisis and what triggers a response and from whom?
- How do cities respond to a water supply crisis? Why do cities make the choices they do and what constrains the response?
- After a crisis, to what extent are cities and residents better prepared for the future? How permanent are the changes and are there spillover effects?

We use the answers to identify a set of strategies that can underpin and build urban water security and the multiple pathways that are available to cities as they take on the task of building water security. Reviewing the state of the field and experiences of the recent past offers some initial insights into how cities can build water security and how city leaders and others might better prepare for and respond to water supply crises. In the section that follows, we outline our research design and methods, including the case studies that inform our results. We present our findings for each of our three research questions, referencing examples and experiences drawn from the case studies and expert interviews.[13] The next sections draw out more synthetic and policy-oriented insights designed to inform decisionmaking and future efforts regarding urban water security. Finally, we conclude with recommendations and our thoughts on next steps for research and practice.

Research Design and Methods

To answer our questions, we gathered information in two ways. First, we conducted a targeted review of relevant academic literature and government reports (termed an environmental scan or a semi-structured literature review), drawing on both human and artificial intelligence to identify themes in research, including the conceptual development of urban water security, and map the experiences of cities' water supply crises (see the appendix for more details). This review resulted in the identification of 45 academic papers and several reports on relevant initiatives.[14] We collected and synthesized the insights from these papers and reports in relation to our research questions and lessons or recommendations proposed for policymakers.

Second, we developed illustrative vignettes of five cities that have confronted or are in the midst of severe water supply stress events.[15] For each selected city, we reviewed publicly available material, including policy documents, reports, credible media sources, and published literature. We conducted 16 interviews with decisionmakers, experts, and academics with deep familiarity with the cases, general expertise in urban water security in a variety of national and global contexts, and familiarity with the challenges cities face in addressing their water security needs. Interviewees were asked questions about the causes and consequences of the water supply crisis in their city and lessons that they think their experience offers decisionmakers in other places.

Hydrologists study the impact of severe drought.

The Second Los Angeles Aqueduct cascade, located in Sylmar, just east of the I-5 Freeway near Newhall Pass, in the San Gabriel Mountains foothills of the northeastern San Fernando Valley.

Case Studies

We selected five case study cities—Cape Town, South Africa; Melbourne, Australia; São Paulo, Brazil; and Las Vegas, Nevada, and New Orleans, Louisiana, in the United States—to provide some diversity across several dimensions: geographic location, acute or chronic crisis, population size, duration and recency of event, drivers of crisis (e.g., drought, overextraction, population growth, lack of governance, failing infrastructure), and type of response (e.g., equity-based, interbasin transfer, desalination). All our case study cities were affected by drought and primarily surface water dependent; Table 1 provides an overview of their characteristics. Abbreviated descriptions of each city follow for context, with more in-depth examinations of the water supply crisis events, responses, and implications in the "Findings" section.

TABLE 1

Case Study Cities Included in Analysis

Characteristic	Cape Town	Melbourne	Las Vegas	São Paulo	New Orleans
Metro population	4.8 million	5.2 million	2.3 million	22.8 million	1.3 million
Climate geography	Coastal Mediterranean	Temperate coastal	Subtropical hot desert	Humid subtropical monsoon	Humid subtropical
Long-term supply and demand stressor	• Population growth • Inadequate infrastructure	• Population growth	• Population growth • Inadequate infrastructure	• Population growth • Inadequate infrastructure • Deferred repairs	• Inadequate infrastructure • Deferred repairs
Length of drought	5 years	14 years	More than 23 years	3 years	1 year, with recurrence
Peak crisis year	2017	2006	2022	2015	2023
Impact (approximate capacity remaining)	13% in one system	33%	25%	5% in one system	75% (equivalent)

SOURCES: Features information from Hylke E. Beck, Niklaus E. Zimmerman, Tim R. McVicar, Noemi Vergopolan, Alexis Berg, and Eric F. Wood, "Present and Future Köppen-Geiger Climate Classification Maps at 1-Km Resolution," *Scientific Data*, Vol. 5, October 2018; C40, "Our Cities," webpage, undated; U.S. Census Bureau, "Metropolitan and Micropolitan Statistical Areas Population Totals: 2020–2023," webpage, last revised June 25, 2024.

Cape Town

Aerial view over a township near Cape Town, South Africa.

Cape Town, South Africa, relies on a series of six reservoirs for 95 percent of the city's water supply, which supports more than 4 million people, 14 percent of whom live in informal housing.[16] Three years of severe drought led the reservoirs to drop from 100 percent capacity in 2014 to as low as 38 percent capacity in 2018.[17] The city had successfully navigated prior droughts and not planned for such severe conditions.[18] Poor infrastructure maintenance, delayed capital investments, inadequate tariff structures, and population growth all contributed to the severe water shortage.[19]

The city responded with a combination of measures, including increased residential and agricultural water use restrictions (including household flow regulators), infrastructure improvements, some supply augmentation, increased water tariffs, and public awareness campaigns.[20] These efforts culminated in November 2017, when the city identified and publicized a potential Day Zero, the point at which water would be turned off in neighborhoods and citizens would need to fetch a daily 25-liter-per-person allocation of water at public points of distribution. A water dashboard was launched on Cape Town's official city website to provide weekly updates on dam levels and water use. This was supplemented with regular updates on what the city was doing to manage the system and household-scale maps of residential water use.[21]

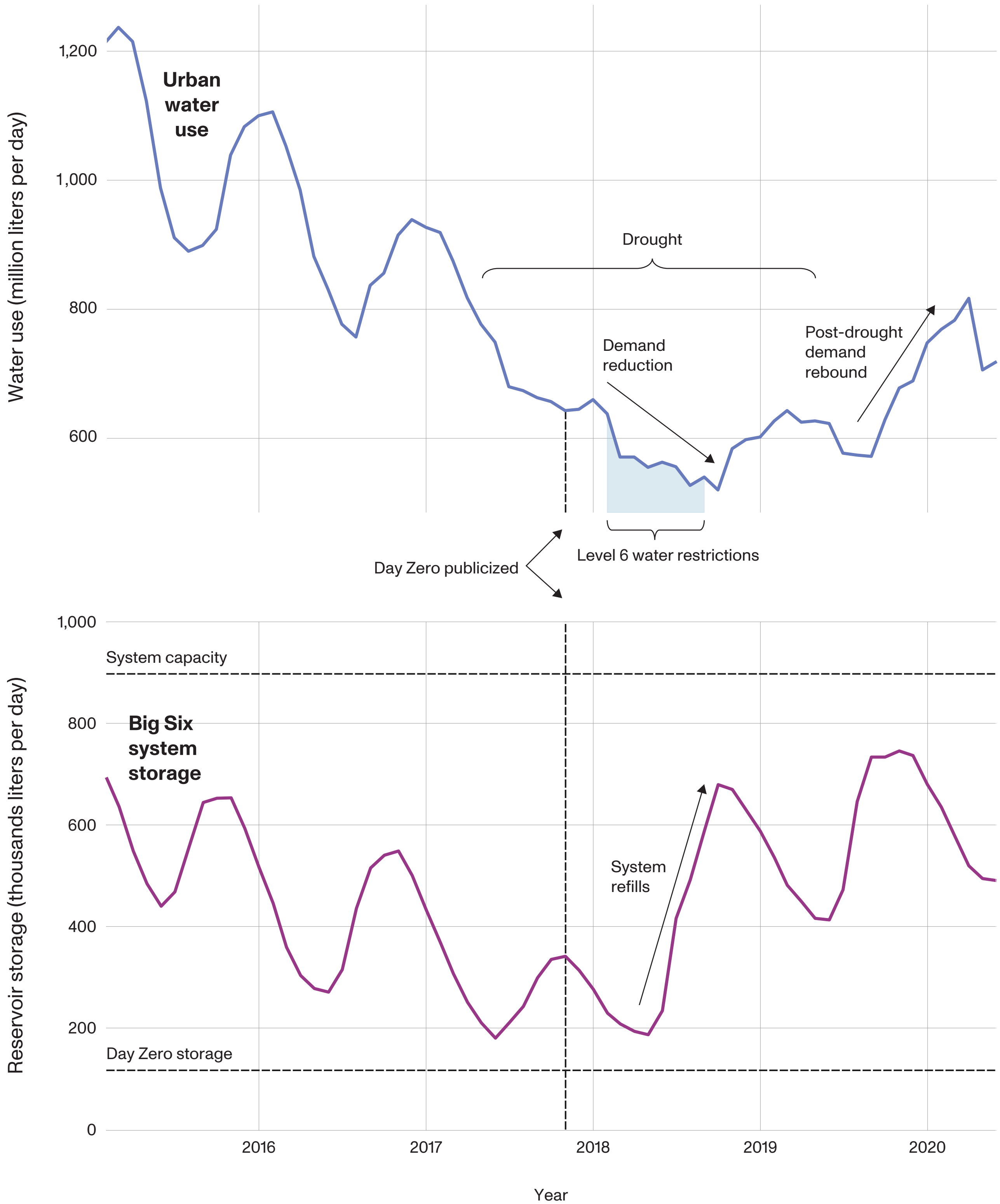
Cape Town responded with a combination of measures:

- residential and agricultural water use restrictions
- infrastructure improvements
- supply augmentation
- increased water tariffs
- public awareness campaigns

In spring and summer 2018, strong rainfall led to the cancellation of a Day Zero, and by the end of winter, the dams were above 75 percent capacity.[22] Conservation programs during the peak of the drought resulted in a 50 percent reduction in water consumption citywide.[23] But since the drought ended, conservation efforts have eased and water demand has been steadily increasing to pre-drought levels (see Figure 2). The city has continued to monitor and publicize water use and management efforts and is continuing to make needed infrastructure upgrades.[24] Challenges remain regarding supply diversification, intergovernmental communication and coordination, and trust-building between the city and low-income neighborhoods.[25]

FIGURE 2

Overall Water Use in the City of Cape Town



SOURCE: Features information from Climate System Analysis Group, “Big Six Monitor,” dataset, University of Cape Town, undated.

São Paulo

Drought soil near a dam that feeds a water supply system in the state of São Paulo, Brazil.

In summer 2013–2014, a critical period for rainfall in Southeastern Brazil, the Upper Tiete and Piracicaba-Capirvari-Jundiaí watersheds—both of which serve as surface water sources for São Paulo—received only one-half their normal annual precipitation (Figure 3).[26] The low rainfall followed a dry year, eventually leading to key reservoirs in the Cantareira system to fall below 5 percent capacity, resulting in withdrawals from the dead volume (water at the very bottom of the reservoir typically considered not available for use) in major reservoirs in 2014 and 2015.[27]

The crisis was primarily driven by three factors: drought, amplified by population-related growth in demand, and mismanagement. The 2013–2015 drought, which was the worst on record for the region, was the leading driver of the crisis.[28] Heavy population growth and industrialization in the São Paulo metropolitan region led to a new norm for São Paulo's water supply system, which did not properly adapt to higher water demand in advance of the drought.[29] At the time, the water distribution system was also actively losing 30 percent of supply because of leaks.[30] Mismanagement in adapting reservoir operations in bordering watersheds to these supply and demand changes and a failure to proactively fix the chronically leaky water distribution system intensified the magnitude of the water crisis.[31]

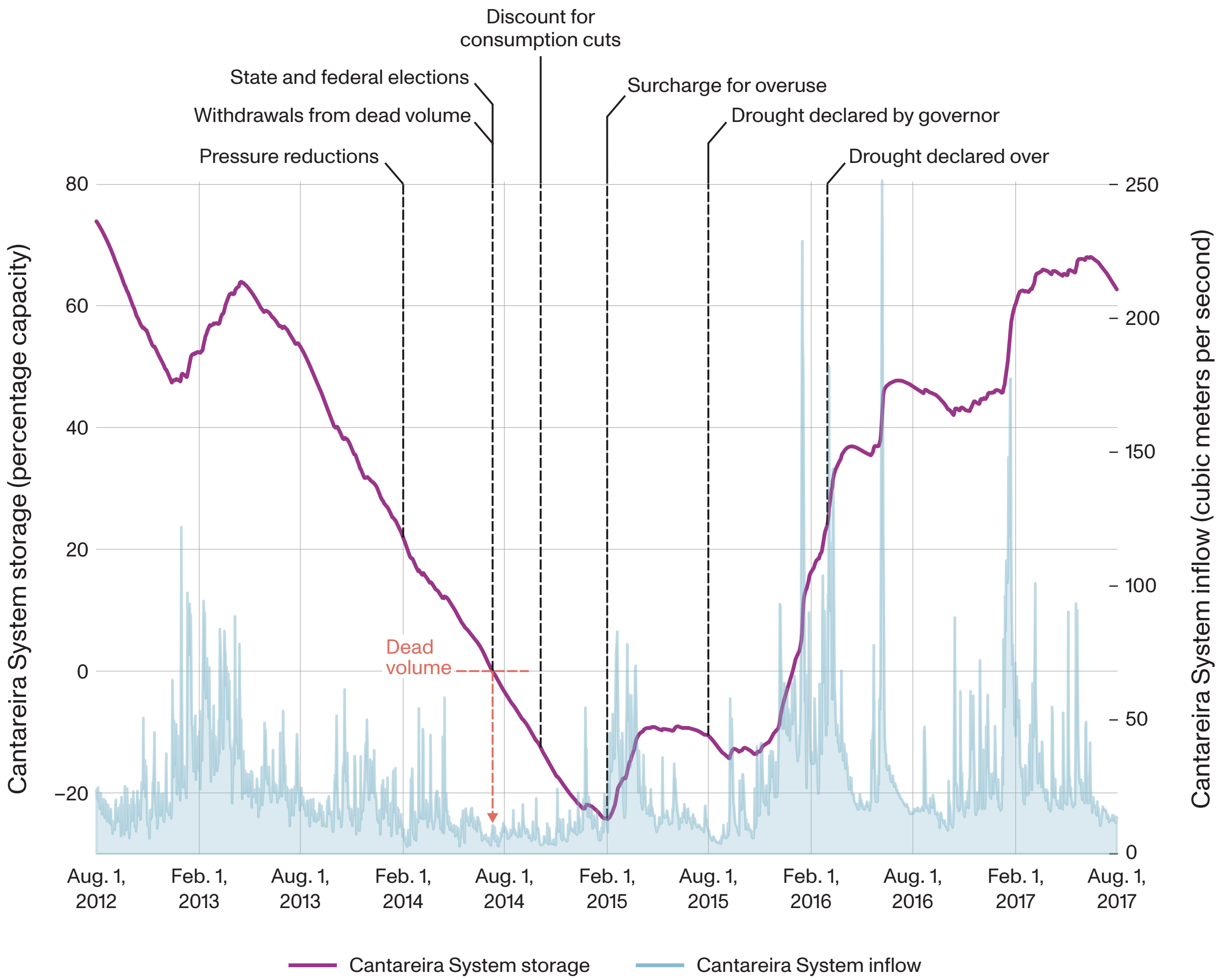
SABESP implemented major response measures:

- pressure reductions to reduce overall water use
- fiscal incentives
- surcharges in water pricing
- outreach campaigns to help reduce water use

In place of outright rationing, which would have involved turning off taps in certain areas at certain times, SABESP implemented three major response measures: pressure reductions to reduce overall water use; fiscal incentives, including discounts in water pricing for below-average water consumption and surcharges in water pricing for above-average consumption; and community outreach campaigns to help reduce water use.[32] However, campaigns to reduce water consumption were sometimes ineffective because SABESP had signed many fixed consumption contracts with business and individuals, which ended up disincentivizing such conservation solutions as

FIGURE 3

Storage and Inflow to the Cantareira System



water recycling. In addition, pressure reductions had a disproportionately high impact on lower-income communities and households, whose taps were more likely to run dry, thereby amplifying inequities in water supply across the city.[33] Responses also included large-scale interbasin water transfers between reservoir systems.[34] Many of the rivers in and around São Paulo were polluted because of poor sanitation infrastructure and deforestation practices.[35] This left the city quite reliant on transfers from other basins.

The crisis ultimately ended when normal rainfall returned to the region in 2016 and helped replenish storage in the Cantareira reservoir system. After the 2014–2015 crisis, SABESP implemented a strategic plan to help mitigate the impacts of future droughts. The plan includes institutional strengthening, pathways for public participation, tools for measuring water security, and plans for ecosystem restoration.[36] Major long-term responses by the Brazilian national and São Paulo state governments, which oversee water-resource management and reservoir operations in Brazil, include traditional hard-path water supply capacity-building techniques, such as expanding conveyance structure capacity for interbasin water transfers.[37]

Las Vegas

Aerial view of fountains in Las Vegas, Nevada.

The Las Vegas metropolitan area relies on water from the Colorado River Basin, from which 90 percent of its water supply is derived, and groundwater, from which it gets the remaining 10 percent. This reliance on the Colorado River has spurred a crisis because shifting allocations under the 1922 Colorado River Compact and drought conditions have pushed the amount of water available to the area consistently downward. In August 2021, Lake Mead, a key source of water supply storage for the region, had water levels hit a record low of 1,067 feet (325.2 meters, 35 percent of capacity), prompting the Bureau of Reclamation to announce water allocation cuts in the Colorado River Basin.[38] Nevada took the most significant reduction to 21,000 acre-feet (26 billion liters, about 7 percent of the state's typical annual allocation).[39] Water levels have continued to fall over subsequent years, reaching another historic low of 1,040 feet (317 meters) in July 2022 before beginning to rise again over 2023 and early 2024 because of wetter winter weather (see Figure 4).

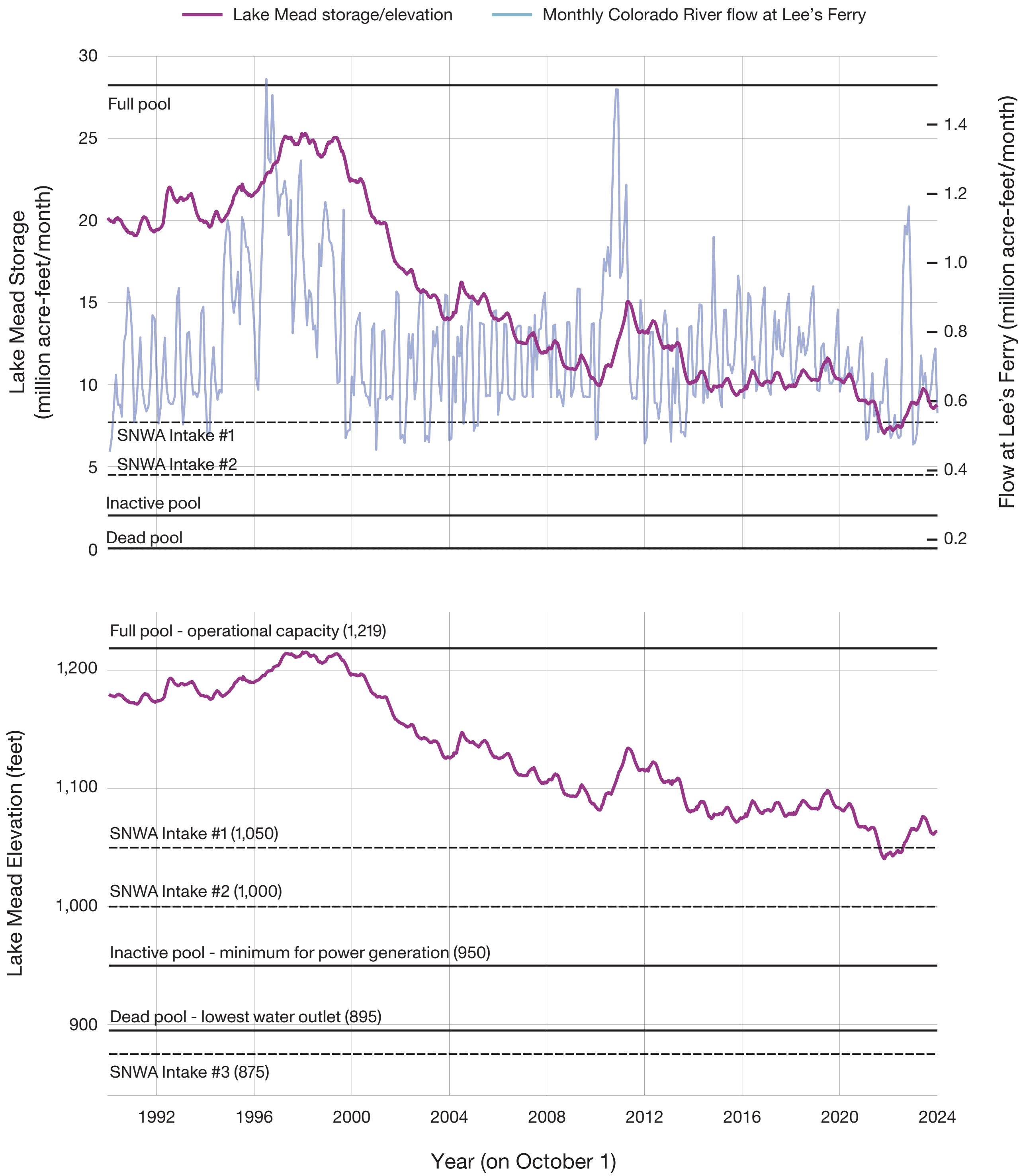
Starting in 1989, the Southern Nevada Water Authority (SNWA), a regional water management authority, proposed the Groundwater Development Project. The project called for a pipeline to pump groundwater from beneath Great Basin National Park to Lake Mead to secure a more-reliable water supply for Las Vegas; however, the proposal was shelved in 2020 because of protracted legal challenges and environmental concerns. In the years between the project's initial proposal and its failure to be implemented, two new infrastructure projects were initiated and completed to augment the city's water supply. Intake 3, initiated in 2008 and completed in 2015, draws water at reservoir elevations below 1,000 feet; and a low lake–level pumping station, initiated in 2015 and completed in 2020, increased water-pumping capacity below Lake Mead by 900 million gallons per day (3.4 billion liters per day).[40]

SNWA and the city of Las Vegas took steps to invest heavily in water conservation measures:

- the treatment and return of wastewater to the Las Vegas Wash and beyond to Lake Mead
- incentive-based programs around conservation
- ordinances that require water-efficient plumbing, fixtures, and cooling systems

FIGURE 4

Lake Mead Historic Elevation and Storage Levels from 1990 to 2024



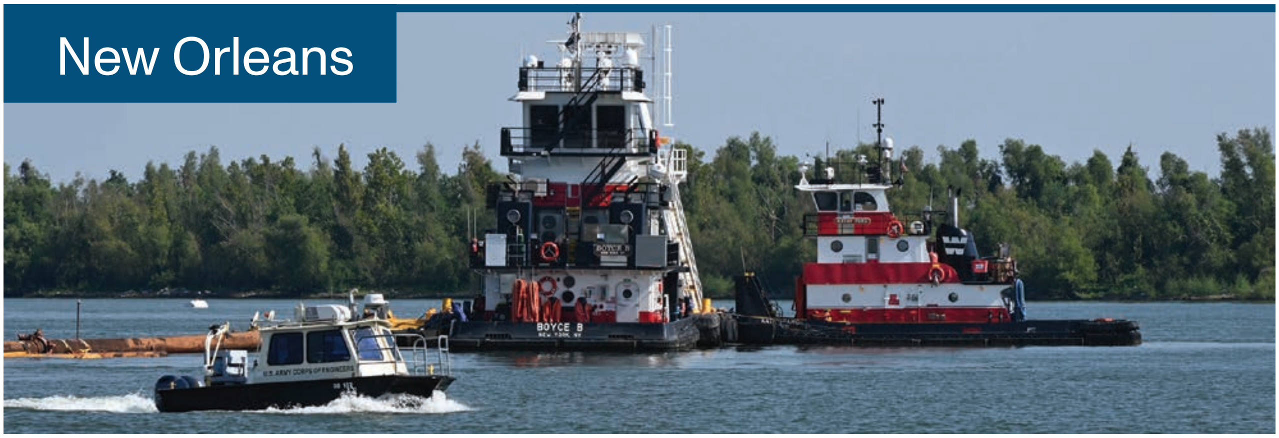
SOURCES: Features data from Bureau of Reclamation, "HydroData Navigator," database, last updated November 19, 2024. Intake elevations taken from National Park Service, 2022, and from SNWA, "Lake Mead Pumping Stations," infographic, July 2022.

SNWA and the City of Las Vegas have also taken steps in recent decades to invest heavily in water conservation measures. Since the mid-1950s, Las Vegas has treated and returned a significant portion of its wastewater to the Las Vegas Wash and beyond to Lake Mead. As a result, indoor water use only nominally taxes the overall system and most of the conservation policies have been focused on outdoor water use. The Las Vegas Valley Water District implemented incentive-based programs around conservation, offering financial assistance for homeowners to convert septic systems to be integrated into the centralized system and coupons for smart irrigation, car washes, and landscaping; and implementing water price and water waste fine increases. City and county ordinances now require water-efficient plumbing, fixtures, and cooling systems; prohibit new turf in residential and commercial developments; and require high-water use businesses, such as golf courses, to submit water use reduction plans. These policies have been particularly effective in the context of rapid population growth and housing development in Las Vegas in recent decades. The City of Las Vegas 2050 Master Plan prioritizes water conservation as a key element of city resilience, citing the success of past conservation efforts.[41] The city's response has also included community outreach to bridge the knowledge gap about water use, such as tools on finding desert-friendly plants and free classes and webinars on landscaping. These measures have reduced the metropolitan area's per capita water usage by 58 percent between 2002 and 2023 to 89 gallons per day (337 liters per day).[42]

As the region faces population growth and the effects of climate change, SNWA predicts an increase in per capita demand by 10 gallons per day (37.4 liters per day). Therefore, reducing water use per capita remains a priority, and the new per capita water use goal has been set at 86 gallons per day (325 liters per day) by 2035. Although influential, meeting per capita water use targets will be harder as the population continues to increase in the region: In 2022, the population of the Las Vegas metro area was 2.3 million, more than double what it was in 2000, and the University of Nevada–Las Vegas Center for Business and Economic Research projects an additional 1 million residents by 2060.[43] Furthermore, because of the aridification of the Colorado River Basin, drought-like conditions and decreases to Colorado River allocations are likely permanent, meaning that the area faces additional water resilience pressures in the future. Current water allocation agreements—the Colorado River 2007 Interim Guidelines to protect water elevations at Lake Mead and preserve hydroelectric generation capacity at the Hoover Dam—are set to expire in 2026 and, as of this writing in 2024, are being actively negotiated by parties representing various constituencies in the basin, including states, agricultural interests, and American Indian tribes.

People enjoying dancing waters in Las Vegas.

New Orleans



Construction partners working with the U.S. Army Corps of Engineers, New Orleans District, augment the underwater barrier sill in the Mississippi River on September 26, 2023, as part of their efforts to help arrest saltwater progression upriver during the 2023 low water event.

In 2023, an extended drought in the Mississippi River watershed caused lower than average river water levels.[44] The low water levels facilitated the movement of saltwater from the Gulf of Mexico upstream the Mississippi River because of the elevation difference and a slower than average river flow rate. River discharge (or flow rate) at the U.S. Geological Survey gage in Belle Chasse, just downstream from New Orleans, dropped to 150,000 ft^3 per second in September 2023 from around 600,000 ft^3 per second in May 2023.[45] To hold off saltwater from the Gulf of Mexico, discharge at the mouth of the Mississippi River needs to be at least 300,000 ft^3 per second.[46] Additionally, the U.S. Army Corps of Engineers (USACE) periodically dredges the bottom of the Mississippi River to enlarge and deepen the channel for maritime transport, but this process exacerbates the elevation difference and facilitates movement of the saltwater wedge upstream.[47] To stop the progression of the dense saltwater wedge, USACE built a sill on the bottom of the Mississippi River in July 2023 (Figure 5). On September 20, 2024, the saltwater wedge overtopped the sill and moved further upstream. After the overtopping event, initial estimates from USACE stated that the New Orleans Algiers drinking water intake would be inundated with saltwater by the end of October (see Figure 6).[48] Ultimately, repeated rainfall in the Midwest and Ohio River watershed increased flows in the lower Mississippi, which moved the saltwater wedge downstream before it reached the drinking water intakes for New Orleans.[49]

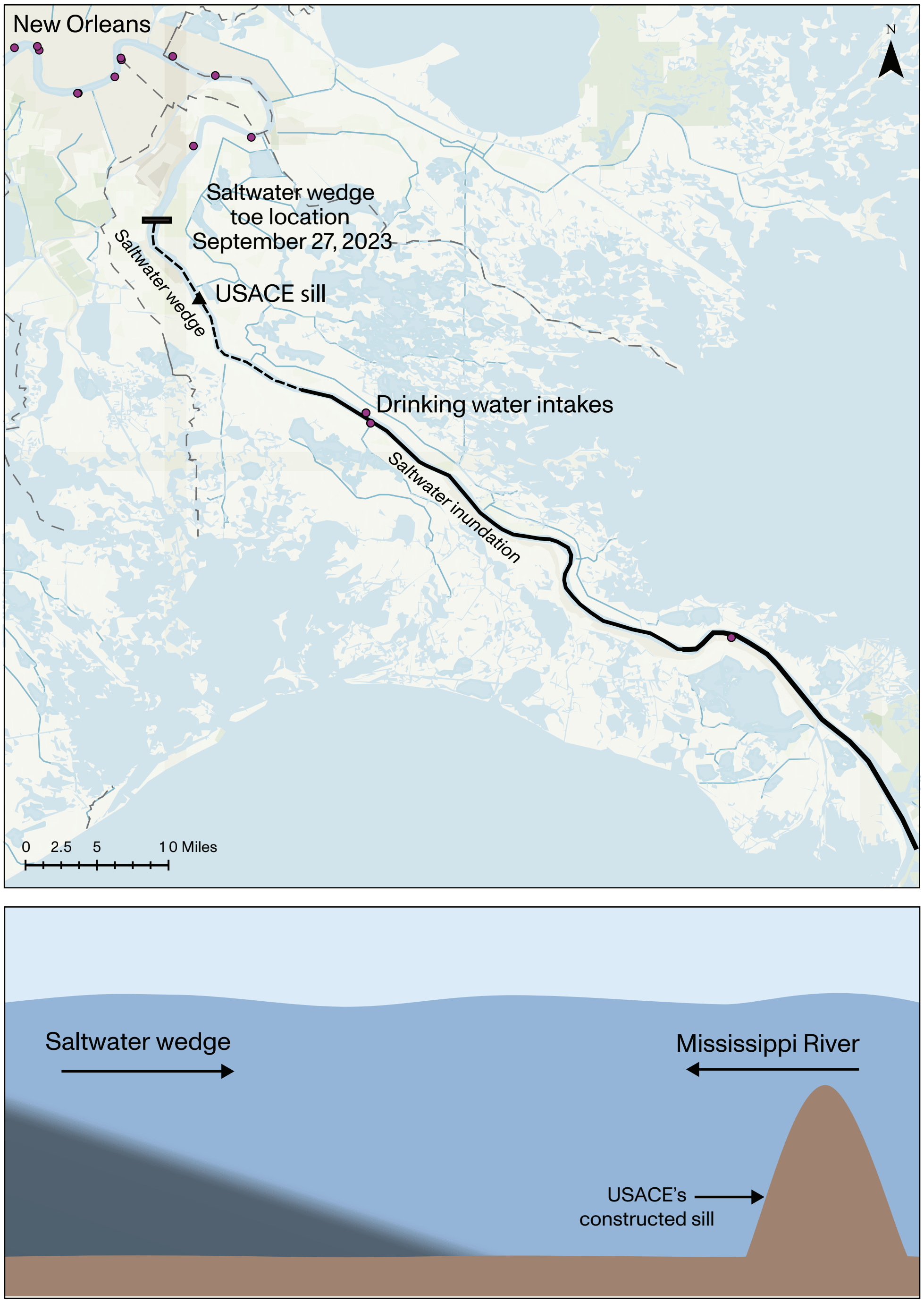
New Orleans has made investments with its limited resources but with trade-offs:

- investments in stormwater management and flooding mitigation
- few investments in an already strained drinking water system

Saltwater intrusion events reaching a New Orleans drinking water intake would stress an already strained drinking water system: The drinking water treatment facility was last renovated in 1959. The city has four drinking water intakes (two on the east bank and two on the west bank of the Mississippi River), of which one on the west bank has not worked in 34 years. If the other west bank intake breaks, then 50,000 people will be out of water within 24 hours. The two east bank intakes were damaged in 2016 and 2021 and not repaired because of a lack of funding and/or lengthy legal processes.[50] The city has been investing its limited resources in stormwater management and flooding mitigation at the expense of the drinking water system. Saltwater intrusion events will likely occur more frequently because climate change is increasing the intensity and duration of droughts in the greater Mississippi watershed, so New Orleans will have to prepare for future high salinity events.

FIGURE 5

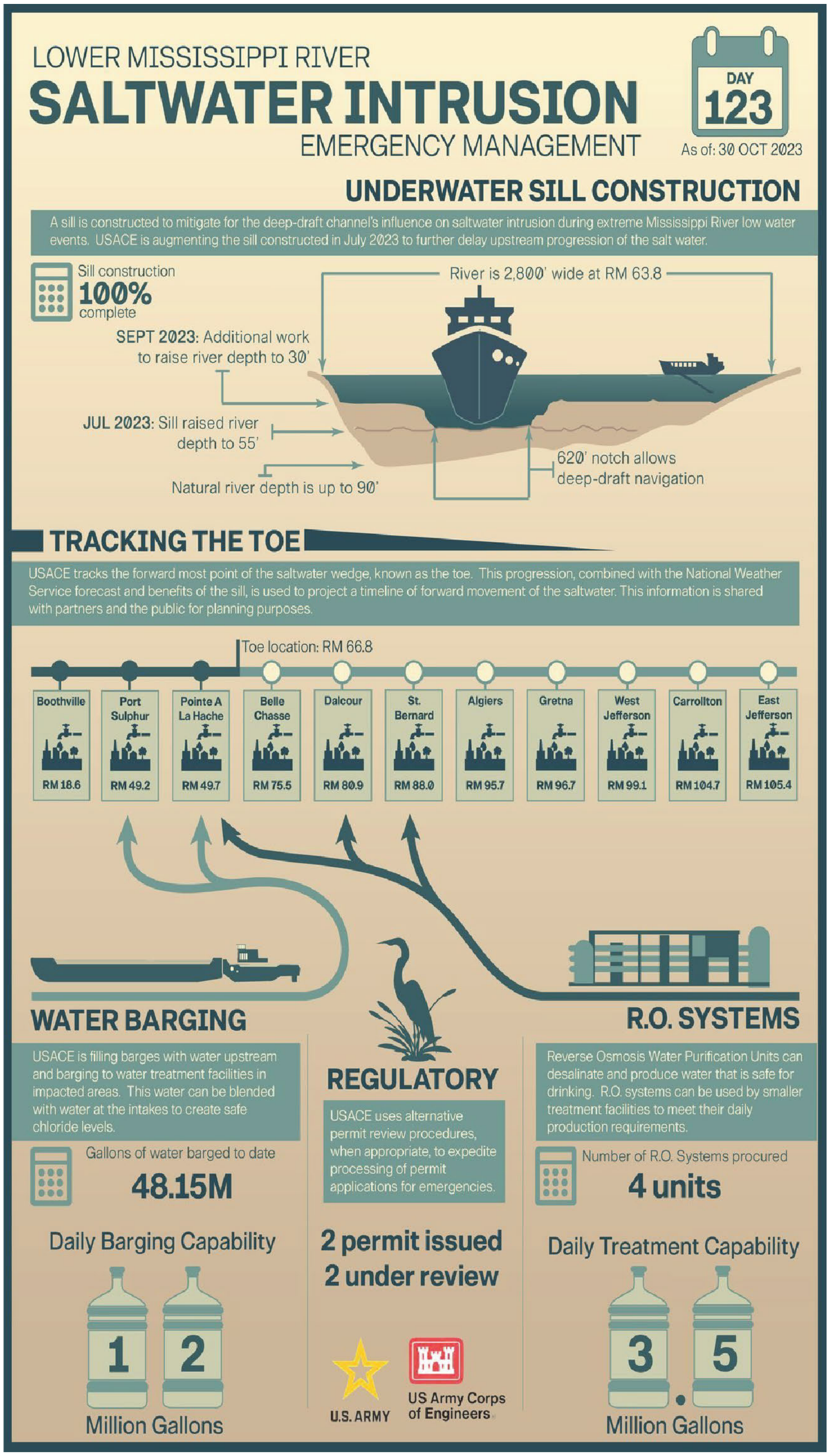
Map of September 2023 Saltwater Intrusion Event and Conceptual Diagram of a Saltwater Intrusion Event and a U.S. Army Corps of Engineers Constructed Sill



SOURCE: Adapted from USACE, undated.

FIGURE 6

U.S. Army Corps of Engineers Communication Materials for Lower Mississippi River Saltwater Intrusion Emergency Management, as of October 30, 2023



SOURCE: Reproduced from Lyla Klein, "2023 Saltwater Intrusion: Understanding the Impact on Plaquemines Parish," Water Collaborative, July 15, 2024. Original image from the USACE.

Melbourne

Aerial view of the Victorian Desalination Plant.

Melbourne has been growing rapidly for several decades, its population expanding from 3.2 million in 2001 to 4.6 million people in 2024.[51] The beginning and middle of this period was marked by the Millennium Drought, which started in 1996 and ended in 2010. Successive less-than-typical rainfalls during the cool season led to increasingly dire hydrologic implications, such as the drying of vegetation and draining of groundwater resources. Storage volumes dropped from effectively full in 1996 to nearly one-third by 2010, leaving only one year's water supply in storage.[52]

The city took a consultative approach to drought response and never issued any fines.[53] Instead, in 2008, the city adopted the Target 155 campaign to drop per capita consumption to 155 L per day (41 gal per day) compared with an Australian national average consumption of 340 L per day (90 gal per day).[54] The campaign resulted in per capita consumption dropping 40 percent over the past two years of the drought and yielding a net daily consumption rate of 22 percent less than in the 1990s.[55] These conservation efforts almost certainly prevented the city from running out of water (see Figure 7).[56]

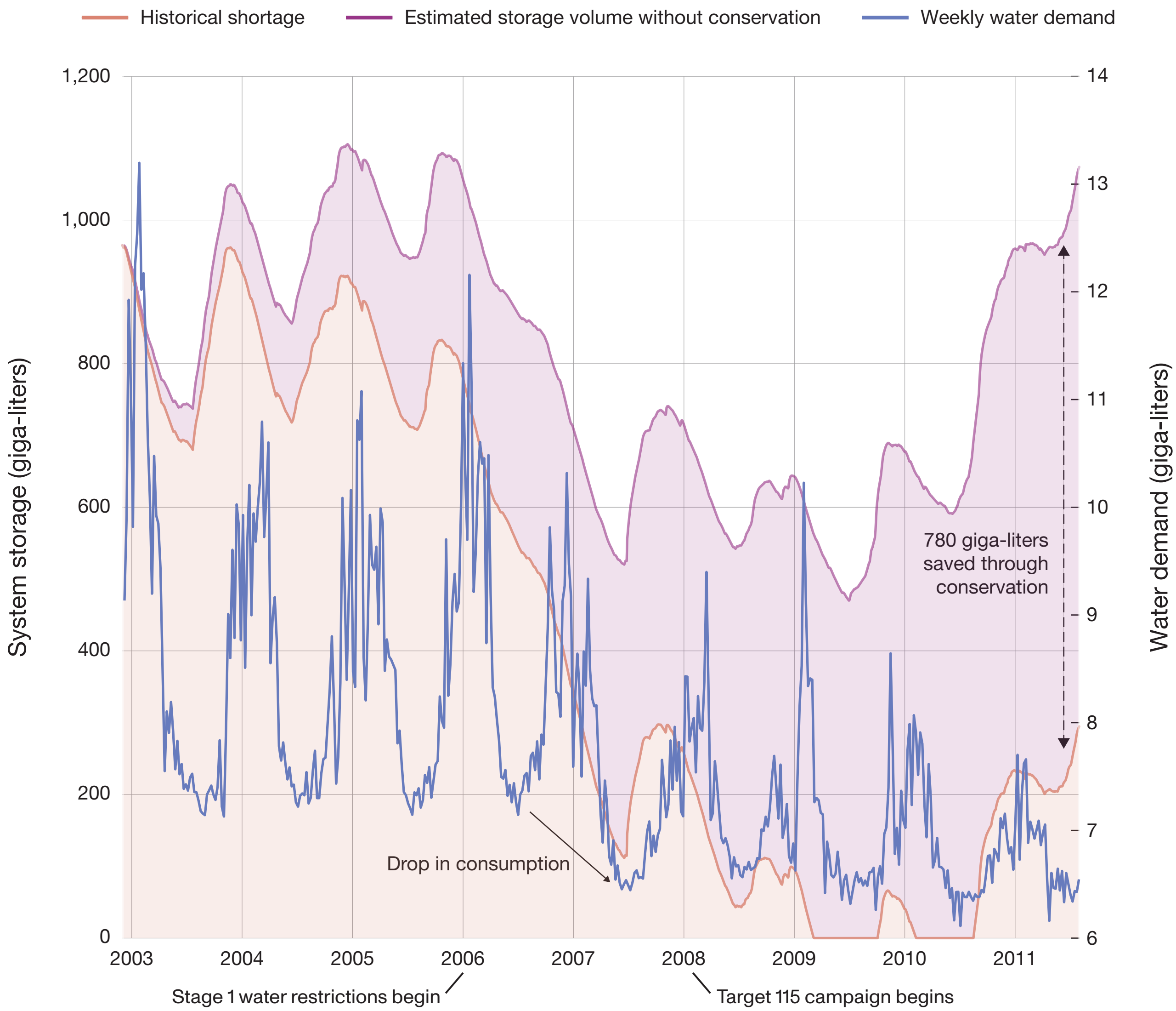
The government of Victoria, Australia, launched:

- a variety of educational campaigns
- efficiency rebate incentives
- free shower timer devices

The city also built new infrastructure. For example, construction began in 2009 on a seawater desalination plant, and in 2010, the 70 km North-South Pipeline from the Goulburn River was completed. The $3.1 billion desalination plant came online in 2012 but did not receive its first order to provide water until 2017. With the desalination plant and Goulburn River water pipeline, Melbourne can now provide one-half of its water needs.[57] In 2015, rainwater tanks became compulsory in new homes, reducing laundry, toilet, and garden water reliance by 40 percent. The government of Victoria, Australia, also launched a variety of educational campaigns, efficiency rebate incentives, and free shower timer devices.[58] In addition, Melbourne Water provides copious monitoring data to keep the public informed.

FIGURE 7

Melbourne's Estimated Storage With and Without Conservation Efforts



SOURCE: Features information from Melbourne Water, "Melbourne Water Open Data Hub," webpage, undated.

Overall, these efforts led to per capita water use being cut in half by 2018, but net annual water use increased 10.7 percent from 2019 to 2024, in part because of population growth.[59] This trend is expected to continue, with the population increasing to 6 million in the region by 2030 and up to 8 million projected by 2070.[60] Meeting water security needs, however, will be increasingly challenging for the city; researchers have found that streamflow into storage reservoirs still has not returned to pre-drought levels because of landscape level changes in vegetation and groundwater dynamics.[61]

The 1,100-km long Tietê River in the state of São Paulo, Brazil, is crucial for potable water, irrigation, and energy production in southeastern Brazil.

Findings

Drivers of Crisis

Across the cases, the key driver of the crises was sustained drought outside typical, but not unforeseen, planning parameters. This external stress, however, was then exacerbated by population growth or other socioeconomic shifts since the initial design (or recent expansion) of the water supply system. For Las Vegas, aridification of the Colorado River Basin combined with rapid population growth drove the region into megadrought starting in the early 2000s. For Melbourne, episodic droughts prompted the city to search for new water sources, typically by damming catchments or even establishing interbasin transfers. This approach, however, had run its course by 1983, and despite a decade of turning to technological and efficiency-based demand reduction through building codes and voluntary efforts, the Millennium Drought was so severe that there were no more available opportunities to expand surface water or groundwater resources, requiring a paradigm shift in the city's response.

Supply crises in several cities were also driven by a state of poor infrastructure repair or other management shortcomings.[62] For example, when the drought hit São Paulo, its water distribution system was already losing about 30 percent of supply to leaks. New Orleans's crisis was exacerbated by both near- and long-term management issues. USACE miscalculated the sill height for a high-salinity event in New Orleans, which led to delayed action despite similar conditions that occurred in 1988, 1999, 2012, and 2022. At the same time, heightened media attention on New Orleans's drinking water system brought to light the Sewerage and Water Board of New Orleans's (SWBNO's) lack of resources to address supply and drainage challenges. Similarly, Cape Town's crisis was deepened by insufficient investment in operations to maintain its infrastructure and the good intentions of addressing inequality and providing greater access. The attempt to thoughtfully design pricing and subsidies to support lower-income neighborhoods was unsuccessful because of the lack of proper administrative oversight, resulting in more-affluent areas also benefiting from these plans.

Water quality concerns can exacerbate existing supply challenges and worsen already critical conditions. In Australia, bushfires increased during the Millennial Drought.[63] Reduced vegetation following fires can lead to an increase in runoff and sediment loads in surface water sources, which can strain water treatment systems.[64] Wildfires are more likely during extreme heat and drought conditions, making this a compounding stressor on limited water supplies. Climate change exacerbates water quality risk by increasing the likelihood of fire conditions. Climate-induced extreme precipitation following wildfires increases the risk of landslides, sending even greater sediment loads into surface water supplies. In New Orleans, a saltwater wedge driven up the Mississippi River threatens water treatment systems, and at some point, the increase in salinity from the saltwater wedge combined with low river flows could make the water untreatable for periods of time.[65] Furthermore, as sea levels rise, these saltwater intrusion events will be more frequent and compound low river flows associated with drought conditions and over-withdrawals.[66] Last, in São Paulo, if more surface waters in and around the city were of higher quality, the impact of low water quantity could have been diminished. The poor quality of water in and around the city also had a disproportionate impact on lower-income communities, which were more likely to be without running tap water during pressure reductions.[67]

Catalysts of Response

We found that the catalysts of response were varied as cities sought to balance equity with efficiency concerns, address conflict between urban and rural consumptive uses, navigate political dynamics, or sustain environmental flows. In part, this variation was because of different technical, policymaking, or governance challenges underlying larger-scale basin strategic planning principles. Table 2 summarizes strategic responses from the cases.

Cities' primary response strategy was undertaking some sort of capital improvement, varying from infrastructure repairs to building new supply sources, despite these efforts often being costly or arriving too late. For example, by the time Melbourne's desalination plant was planned, permitted, and constructed, the drought had broken, making the project seem like poorly spent funds because of high capital and energy costs. Furthermore, because of the operating expense, some desalination plants have been taken offline to reduce costs; bringing these assets back online in the future will be logistically challenging because of the complexity of the equipment and staffing expertise required.

Another common response was changing behavior through incremental conservation and implementing demand reduction innovations. For example, in Cape Town, Level 2 water restrictions (of 6 levels) were implemented on January 1, 2016, when dam levels were at 52 percent. Additional restrictions followed a poor rainy season in 2016. When dam levels dropped to 20 percent, a new strategy was needed, leading to the development of a disaster plan with criteria for Day Zero. Level 5 restrictions were imposed on September 3, 2016, and planning for Day Zero became urgent. If dam levels reached 13.5 percent, water would be restricted and residents would be required to fetch water from public points of distribution. Political disagreements sometimes delayed responses, but early and steadily increased restrictions, alongside pressure management and flow regulators, were crucial. Similarly in São Paulo, water utility SABESP began frequent pressure reductions in 2014 when the crisis was apparent. It implemented a discount for below-average water use in February 2014 and a surcharge for above-average use in February 2015. These strategies evolved to manage demand without resorting to outright rationing, which could have had political repercussions. Although demand management often provides the biggest benefit for the cost, it can be publicly unpopular and, therefore, politically difficult to implement, particularly in extreme cases when severe restrictions on water use are necessary. As a result, expensive infrastructure solutions may get more political backing.

A third common response was improving communication and outreach by establishing key signals and triggers for action to undergird long-term planning to shape future investment. For example, midway through the São Paulo water crisis, SABESP provided web tools that could be used by the public to check reservoir levels.[68] Another approach was SNWA educating stakeholders in Las Vegas about the true risks and potential impacts of water supply challenges. Engaging diverse community groups helped build consensus and support for necessary actions, even before they are required. Decisions

TABLE 2

Primary Strategic Responses of Cities to Water Supply Crisis

Primary Strategic Response	Cape Town	Melbourne	Las Vegas	São Paulo	New Orleans
Improve infrastructure					
Repair leaks	✖		✖	✖	
Dam operations			✖		✖
Build pipeline		✖		✖	✖
Change behavior					
Voluntary targets		✖	✖		
Demand pricing	✖		✖	✖	
Water restrictions or pressure reductions	✖		✖	✖	
New approaches to supply and demand					
Flow regulators	✖	✖	✖		
Building codes		✖	✖		
Desalination		✖			(✖)
Communication and outreach					
Real-time dashboard	✖	✖			✖
Outreach campaign	✖		✖	✖	

NOTE: (✖) = temporary response.

were typically driven by well-presented facts and trade-offs, ensuring that elected officials comprehended the implications and costs of various options. In the example of the construction of a new low lake–level water intake, this project was perhaps uniquely driven by the stakes of spending more than $1 billion on infrastructure that may not deliver benefits as promised nor do so in a timely fashion. A benefit of this type of process, as realized by New Orleans, is that it can delay a decision so that action does not need to be taken. For example, the SWBNO has discussed short-term plans for infrastructure investments at water intakes, as well as long-term plans for a pipeline that would bring freshwater to New Orleans from upstream the Mississippi River, but it is unclear if or when these solutions would be implemented.[69]

Considerations and Constraints for Decisionmakers

When decisionmakers are responding to a water supply crisis, they are operating under conditions of imperfect information, if not deep uncertainty. The challenges these conditions present for identifying, implementing, and communicating crises responses were very clear in our case studies. For example, knowing the location and movement of the saltwater wedge in New Orleans was critical to planning a response; however, because of the size of the watershed and complex dynamics, early predictions about New Orleans running out of freshwater in late October 2023 were incorrect because of rainfall in the Midwest. In Cape Town, decisionmakers learned as they went along the extent to which conservation measures would result in meaningful reductions in urban water demand.[70]

A further constraint on decisionmaking are solutions that require long implementation timelines, such as new capital infrastructure, meaning investment has to start well before there is a crisis.

A further constraint on decisionmaking are solutions that require long implementation timelines, such as new capital infrastructure, meaning investment has to start well before there is a crisis. As one interviewee noted, “It’s hard to talk about [drought measures] when it’s raining outside.”[71] Justifying and financing large capital investments often require rigorous cost benefit analyses and political support, and both can be challenging to mobilize under conditions of uncertainty. In New Orleans, SWBNO faces financial and political barriers to securing the resources needed for a more resilient system, forcing the utility to choose between short-term and relatively cheaper options of adding a charcoal system to help with filtration or long-term and more expensive options of building a new treatment plant, canal, or groundwater wells. Decisionmakers in Cape Town have struggled with the desirability and feasibility of building desalination facilities. Such supplies that are resilient to climate change come at great expense and must be economically justified to be prioritized above other needed investments. One interviewee said,

> When people go through something traumatic, they want to blame someone. There was a fear in government that they could be excused for a new threat, but if a similar drought came two years later and they hadn’t made sufficient investment, there’s no excusing it. They have been fretting about how much investment is enough, knowing the public or even water interest groups might not understand what was given up to make that investment.[72]

Most of the case study cities pushed demand reduction or other conservation strategies to their limits. At the micro level, water demand management devices in Cape Town’s township areas—introduced prior to the drought—had to be peer enforced at the household level. At the middle level, water pressure reductions in São Paulo were implemented by SABESP in place of outright rationing. This exposed inequities in the system as poorer communities, which lacked water towers, were disproportionately affected, and the reduced water pressure allowed for pathogens to enter pipes in these communities.[73] As one interviewee stated, “The way water management is done is super politicized and it’s politicized in a way that has these . . . very grave impacts on inequality.” [74] With a state governor’s election approaching, there were potential political ramifications from encouraging the public to reduce their water use. This greatly reduced SABESP’s ability to proactively push conservation initiatives and communicate the magnitude of the drought, and the government was incentivized to minimize the severity of the crisis. As one interviewee stated,

> At the end of 2013, there were already signals of this problem because it didn’t rain and during this summer it didn’t rain either. There was a double problem to be addressed. There was no panicking by the government. And no communication

> [of the drought] to the population. There was also an issue of elections and the governor who was hoping to be reelected. They took measures much later than they should have done because of this.[75]

At the macro level, Las Vegas relied on its three pillars of conservation: reducing demand through incentives, education, and regulation. Incentives encourage community participation in water-saving measures, such as turf removal and the adoption of efficient technologies. Indoor conservation is less emphasized because much of this water is treated and returned to Lake Mead. Education initiatives aim to raise awareness about the importance of water conservation, while regulations establish guidelines to ensure sustainable water use practices across the region. For example,

> early in [SNWA's] conservation program, a lot of the education was centered around showing people that desert landscapes were beautiful. . . . [SNWA] published a calendar, and we sent it to every home and it had pictures of beautiful landscape conversions. . . . A part of that education campaign was sort of dispelling some of the myths.[76]

Last, SNWA strategically focused its regulatory powers on reducing demand by targeting outdoor water use (e.g., building codes that prevent new non-functional turf), which constitutes a major portion of consumption because of landscape irrigation and evaporative cooling.

Confronting Governance Hurdles

Ultimately, the responses of these cities in crisis were shaped by the institutional dynamics governing their relationship with other levels of government. For example, in New Orleans, coordination among the Federal Emergency Management Agency, USACE, and state partners helped ensure that parishes had resources to mitigate the evolving and ever-looming disaster. Although this ad-hoc arrangement worked relatively well in New Orleans, in Cape Town, according to an interviewee, the "driving reason for Day Zero was delayed planning for a local dam, lack of clear communication between levels of government delayed seizing the nature of the crisis as it was evolving. This could have spurred construction of the dam and had it come online in time."[77] The city slowly learned about the cross-scale dynamics between neighborhood, city, province, and national interests and how to keep data flowing. In this case, the city and province were closely aligned, but building relationships with neighborhoods was the hardest.

São Paulo had a similar experience of being hamstrung by bureaucracy. Despite clear indications that a new approach was needed, by February 2014, SABESP did not start putting water pricing measures—aimed at reducing consumption—into place until October 2014. This delay was entirely due to political reasons to downplay the drought as elections for the state governor and president took place in October 2014. In fact, again due to political reasons and the timing of the elections, a drought was not declared for São Paulo until August 2015. The drought declaration finally allowed SABESP to implement further drought measures and financial solutions, and state agencies could implement solutions, such as supply augmentation through interbasin water transfers.[78] One interviewee described these circumstances as the main issue in the water crisis: "The issue with the consumers is that SABESP is a state-run entity and is governed by a board that effectively answers to the governor while the governor was in a tough reelection race. So, the governor did not want to admit that there was a drought."[79] Another interviewee stated how this caused the utility to underplay the crisis: "But comparatively, I think it was much more about minimizing the crisis and about giving you a sense of normalcy throughout. The sense was that the crisis was a technical problem being managed by SABESP."[80] This issue highlights how the relationships between governance levels and politicized actions have the potential to negatively affect local and regional responses to water crises.

In contrast to these crisis-born arrangements, SNWA in Las Vegas has existed as a joint powers authority since 1991. It includes seven municipalities in Southern Nevada, each responsible for water and wastewater functions, and is governed by a board of directors made up of elected officials from each municipality. Any new policy, such as turf restrictions, must be approved not only by the SNWA board but also by each municipality's governing body. This requires substantial buy-in from multiple stakeholders, which can constrain rapid response because of the need for extensive coordination. Although this process can slow decisionmaking, it ensures that policies are uniformly codified across the region, generating broad support and fostering a unified strategy in water management. According to Pat Mulroy, the formal SNWA general manager, "If the SNWA hadn't been created, there never would have been a conservation plan, and Nevada could not have negotiated the agreements on the Colorado River that have become essential to the area's survival."[81]

For cities that are diversifying supply, the actual process can be complex and even introduce new constraints downstream that are amplified by population growth. SNWA, for example, collaborated with the Center for Business and Economic Research at the University of Nevada–Las Vegas to develop population projections using economic models to inform demand forecasts.[82] They analyzed various scenarios, including changes in population growth and conservation achievements, to understand potential impacts and guide decisionmaking for the third intake and low lake–level pumping station at Lake Mead, ensuring access to water even under challenging conditions. In Melbourne's case, introducing desalination as a part of the drought toolkit has irreversibly altered its, and much of Australia's, municipal water security strategy. After the plant's first decade, there is talk of expansion, illustrated in the extreme by Perth's near dependence on desalination and new energy and technology.[83]

After the Crisis

Among our case study cities, some are better positioned after their crisis but not all changes were systemic, and some cities are still quite vulnerable to future droughts. For example, Cape Town and São Paulo saw rebounds in their per capita water use as demand management techniques were lifted. In contrast, Las Vegas and Melbourne have continued to reduce their overall water use, although their improvements are at least partially offset by population growth. Most cities have maintained enhanced monitoring and data collection or have continued to strengthen institutional processes and infrastructure repairs and delivery. New Orleans appears to be an exception and has struggled to make major long-term changes to its drinking water system. Whether it is because of limited resources, political tensions, or compounding issues that New Orleans's drinking water systems are already facing (aging infrastructure, hurricanes, and emerging contaminants, to name a few), it is uncertain whether the city has the capacity to make major changes.

Two of the best examples of how cities improved their monitoring and evaluation come from Cape Town and Las Vegas. Cape Town continues to monitor and publicize dam levels and water outlooks, as well as implement a more diversified supply that includes groundwater, reuse, and desalination. Its sophisticated monitoring system, influenced by World Bank best practices, tracks water stored in major dams and use trends. Because national regulations restrict access to international infrastructure or climate adaptation financing, the city must focus on demand management and rely on its own limited budget (customer charges have a not-to-exceed threshold), with water competing against other essential services like electricity, waste, and roads. Similarly, Las Vegas monitors consump-

Aerial view of a water treatment plant in Cape Town, adjacent to wetlands and river. New facilities are being constructed to increase purification capabilities. Settlement ponds can be seen in the foreground.

tion and conservation on an ongoing basis, using advanced metering infrastructure (AMI) to closely track water demand across different sectors, which aids in rapid leak identification and refining conservation programs. SNWA also conducts studies to validate water savings from such initiatives as landscape conversions and smart irrigation controllers.

Perhaps unsurprisingly, therefore, Cape Town and Las Vegas are also two examples of how crises changed thinking about long-term approaches to infrastructure centered on resilience. During the drought, Cape Town developed tools and techniques to reduce demand and communicate the urgency of water security more effectively. Similarly, for Las Vegas, SNWA has endeavored to embed conservation into the community's fabric, ensuring that efficiency becomes a permanent aspect of water management. This strategy not only addresses immediate shortages but also prepares the region for continued droughts while supporting sustainable growth and economic stability. The city's 50-year water resource plan relies on state-of-the-art climate and population growth models and is updated annually to adapt to changing conditions and ensure long-term water supply resilience.

Learning from Crises to Build Urban Water Security

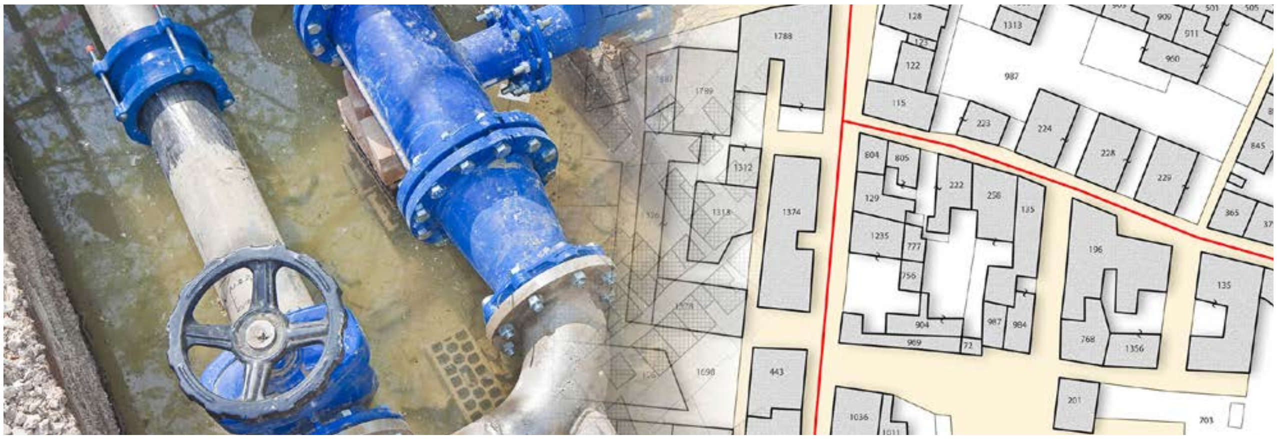
The experiences of these cities with water supply crises provide insights into how such events came to be and, conversely, how they might be avoided. Indeed, our interviewees were asked this question directly, and many sources in our environmental scan of the literature approached these events from a similar perspective. In reviewing our findings, there were five lessons or strategies that stood out as particularly important and universal across the cases:

- Plan and invest proactively.
- Build capacity for taking a systems approach.
- Strengthen intergovernmental collaboration.
- Embrace innovation.
- Build trust and effective communication.

The relevance and examples of each of these lessons are discussed in greater detail below.

LESSON 1

Plan and Invest Proactively



A metal hydraulic system for drinking water and installation plans.

The cities in our study were chosen in part because of their relatively recent experiences with a water supply crisis; by definition, they were confronting or had confronted a threat that required a short-term response. Their experiences show that proactive planning and investing help build urban water security in three ways: (1) lack of prior planning and investment contribute to the occurrence of the crisis in the first place, (2) any prior planning was usually useful for responding to the crisis, and (3) decisions made quickly during a crisis can be long lasting.

Urban water supply crises are often the result of a lack of prior planning and investment because of insufficient funding or technical capacity, competing priorities, a lack of leadership or political support, or a failure to monitor the relevant indicators. For example, although New Orleans had been aware that saltwater intrusion was a potential risk to the city's drinking water supplies, very little forethought had been given to how and when the city would take steps to avoid a contamination event because the city was already combating other water quality and quantity issues with limited resources. Similarly, Cape Town had been undertaking supply forecasting and demand management ahead of the 2015 drought, but officials had stalled on a new dam project, so the city had not diversified its supplies. Politics and public perceptions can also play a role in proactive actions. For example, in São Paulo, SABESP delayed taking any actions to reduce demand early in the crisis due to the potential political ramifications of the upcoming governor's election. Many water systems also have competing priorities, such as replacing aging infrastructure or addressing new emerging contaminants, which are prioritized over increasing resilience to future water supply risks through such projects as expanding dam capacity or building desalination treatment. Finding better ways to balance these competing priorities is critical for cities.

Conversely, Las Vegas credits its water resilience to proactive planning and investment. SNWA updates its 50-year plan annually, integrating new climate and population projections and state-of-the art modeling techniques to develop various future supply and demand scenarios to ensure that it is prepared for a variety of futures:

> [L]ong range planning allows us to take action to adapt and deal with changing circumstances, and it keeps our elected officials, our board of directors, informed about the conditions in our

water supply and demands and allows us to take different paths depending on changing conditions.[84]

To enable such frequent long-term planning, SNWA has invested in significant staff capacity and technical expertise to understand the models that inform the plan. The authority has built trust in its governance process and approach, leading to management and stakeholder acceptance of this technical analysis. However, significant uncertainty remains about future water supply, especially concerning the Colorado River Basin. Ongoing discussions are focused on the renegotiation of current river water use agreements, some of which are set to expire in 2026: "My biggest concern about Las Vegas is future water supply. . . . What's climate change gonna take away? . . . What are upper basin entities going to take away from the river?"[85] The uncertainty described in these questions reiterates the need for robust approaches to decisionmaking that account for a variety of possible scenarios and give decisionmakers the tools to adapt their plans over time as conditions clarify.

The experiences of the cities in our study also showed that any prior planning that had been done, even if it had not been comprehensive or specific to their particular circumstances, was useful during a crisis event. For example, in Cape Town, some cross-departmental planning exercises done prior to the drought made it easier for departments to work together to address the water supply crisis; decisionmakers reflected, "If we hadn't built the muscles through strenuous projects prior to the drought, we wouldn't have been able to come together in a room the way we did," and "Investments in transversal capabilities are never wasted—that's your disaster response team."[86] As Cape Town experienced, any planning and decisionmaking tools also need to include a diverse set of stakeholders to ensure that planning includes decisionmakers across city governments.

Finally, these experiences of urban water crisis reveal the pitfalls of making what can be long-lasting and very influential decisions about water infrastructure, billing and tariffs, communication, and investments on a short timeline and in a high-pressure context. Decisions under these conditions are made quickly and, therefore, are likely to lack the evaluation and community engagement that are needed for truly effective and resilient investments. It can be difficult to mobilize the resources and engagement that are needed without adequate time for deliberation and relationship building. For example, in Cape Town, the city lacked a plan for a major drought event that would have provided a road map for officials to follow when one occurred; therefore, officials had to quickly develop a cross-departmental response.[87] Also, "good quality international technical assistance would have been good; we didn't have a network to pull on."[88] The Day Zero construct turned out to be a useful tool for communication and mobilization but, ultimately, is akin to a government shutdown or running up against the debt limit—an artificially constructed moment in time when an accumulating crisis is estimated to peak. Used by decisionmakers to force debate or the media to heighten awareness, the brinksmanship of the Day Zero construct belies the underlying policy failure. In Cape Town's case, the narrative also brought unwanted international media attention that was harmful to a developing economy relying on tourism and international investment.

The lesson from these cases is that there is value in refining and improving emergency or crisis response models, but the more cities can work to avoid a crisis, the better. This requires rigorous monitoring, planning, and proactive investment. Scenario planning in particular would have value for helping envision and plan for a major supply disruption event before it occurs. Proactive planning and investment also help build the experience and relationships that strengthen crisis response and can help ensure important programs and investments are made with the support of the community and with the input of all relevant data and expertise.

LESSON 2

Build Capacity for Taking a Systems Approach to Urban Water Security

Trees for reforestation.

Scholarship on urban water security has emphasized the importance of a systems approach and a shift in thinking from a single emphasis on supply augmentation to a broader view of sustainable and adequate water availability.[89] The value of a shift to a more systems-based approach is also a lesson many of our case study cities learned during their water supply crisis, specifically the importance of collaborating across departments and sectors, building data systems and technical capacities, and ensuring financial resilience.

Cross-sector collaboration is particularly valuable to building urban water security. Engaging departments as diverse as land and watershed management, infrastructure and public works, public health, economic development and financing, and planning is needed to develop and implement the strategies that support urban water security. In São Paulo, planned efforts of reforestation in watersheds feeding the reservoir systems are designed to boost water supply in the region and mitigate pollution of the water supply. There has been significant push by SABESP, and state and national governments, for this as it benefits the water supply system overall. Improved ecosystem integrity will enable cleaner water to more gradually runoff into rivers and reservoirs, which allows for more flexibility in managing the reservoir system and more efficient water treatment. Cape Town sees its water security challenge as effectively balancing and coordinating equity concerns, financial resilience, infrastructure management, and supply diversification which implies a nearly whole-of-city approach. It can be challenging to effectively work across departments on a new or shared goal, however, as there is a need to balance respect for domain expertise with the reality of new, cross-cutting objectives.

Cross-sector collaboration can extend beyond city government. Las Vegas has cultivated a culture of conservation by engaging diverse stakeholders and implementing strategic water management practices. SNWA has developed a three-pronged approach involving regulations, incentives, and education to effectively manage water resources. This approach includes stakeholders from such sectors as commercial and residential real estate, resorts on the Las Vegas Strip, golf courses, and nongovernmental organizations. The city conducts in-depth educational sessions with these groups to explain proposed actions and gather feedback: "If you can get the right cross-section of people, that's powerful in your community. . . . {I]t sets you up

A 2007 meeting and press conference hosted by Secretary of the Interior Dirk Kempthorne on water issues arising from the drought affecting the southeastern United States. The Secretary is joined by Alabama Governor Bob Riley, Georgia Governor Sonny Perdue, Florida Governor Charlie Crist, White House Council on Environmental Quality Chairman James Connaughton, and the Commander of the U.S. Army Corps of Engineers Lieutenant General Robert Van Antwerp.

for success."[90] Although not all suggestions are adopted, the process ensures transparency and understanding. By securing the support of influential community groups, such as the Resorts Association and local commercial real estate chapters, Las Vegas strengthens its position when presenting proposals to decisionmaking boards. This inclusive strategy fosters collaboration and equitable outcomes and enhances the likelihood of successful policy implementation.

Part of the systems approach to urban water security is focusing or refocusing on elements that are critical to success. In our case study cities, two elements that stood out as particularly important but often overlooked before a crisis are building data systems (and the technical capacities to support them) and building financial resilience. Cape Town found that, prior to the drought, the city did not have a good sense for who used how much water or how much conservation could be achieved in the system. Through the drought, city officials learned where those opportunities are (people with gardens and pools) largely through tracking billing data. The city is still learning how best to interpret metrics and challenge assumptions and emphasizes the value of human resources to collect and interpret data for decisionmaking. Good financial management can also provide the cushion or flexibility needed to make investments while ensuring equity and minimizing impacts on low-income and vulnerable populations. Cape Town continually grapples with balancing its equity goals and commitment to the human right to water with the realities of water supply planning and investment. The city's commitment to baseline water allocations put them in a precarious financial position that has made it challenging to make needed investments, particularly when combined with a relative lack of federal and provincial resources. In New Orleans, financial resilience is a major barrier to the city's ability to counter elevated salinity levels at drinking water intakes. Although USACE has the data to inform New Orleans of an impending crisis by tracking the movement of saltwater wedges, that information is not helpful if New Orleans does not have the financial resilience to invest in solutions. With greater resources, the city could invest in reverse osmosis systems, repair damaged intakes, and update its water treatment plant to better prepare for future saltwater intrusion events.

LESSON 3

Strengthen Intergovernmental Collaboration

The Grand Coulee Dam on the Columbia River. The Columbia River Treaty, an international agreement between the United States and Canada, coordinates flood control, electrical energy production, and the development and operation of the Columbia River Basin.

Urban water security and effective crisis response require financing, regulation, and technical resources that are often best provided by other levels of government. National and subnational governments often have a strong stake in the development and resilience of urban water systems and the long-term sustainability of urban areas. For Melbourne and other cities, especially in southern Australia, the Millennium Drought brought about the 2007 national Water Act because of over-allocation and environmental degradation in the Murray-Darling Basin. The act formed a federal authority that, through a multistate community consultation process, developed a legally enforceable management plan in 2013. Urban water security cannot be achieved by local governments alone, and political and administrative tensions between levels of government can inhibit collaboration and slow decisionmaking processes down. Furthermore, local governments are likely to be more susceptible to public pressure against water restrictions, yet demand curtailment is one of the most cost-effective and immediately implementable solutions to address a water crisis. Creating multistate water authorities and empowering them with the authority to make these hard decisions is critical in times of crisis.

The importance of intergovernmental collaboration for effective crisis response and broader efforts to build urban water security was clear in our case study cities. In both Cape Town and São Paulo, political tensions between local, state, and federal governments delayed needed investments and responses. In São Paulo, this tension manifested as constraints on SABESP's ability to implement water pricing and other drought response measures toward the beginning of the crisis. This issue was reflected in public sentiment and in SABESP's overall response. As one interviewee stated,

> [There was a] sense that the state was keeping it [the water crisis] very much behind closed doors and that had to do with the specifics of the kind of electoral process as it was happening. . . . It was clear that water was lacking throughout the city, that people were kind of dealing with water shortages, and you were like watching the kind of reservoirs and that sort of thing. But, you know, my sense was that there was a really delayed response. So, it's basically a delayed process of kind of admitting the crisis. And it came, I

think, after the governor elections. And then you had a switch, where suddenly there was more attention being paid to it.[91]

In Cape Town, tensions and poor communication with the provincial water agency created delays in a dam project that would have helped mitigate the effects of the 2015 drought. Instead, the dam's incompletion led to delays in responding to the drought once it hit. The city recognized this shortcoming and, following the crisis, has made investments and improvements in its relationship with provincial authorities and the Western Cape Water Supply System in particular. Making inroads with the national government has proven more challenging.

Although investing in large-scale conveyance, storage, and municipal water infrastructure can build resilience to future droughts, these adaptations only reach their full potential if managed optimally. For SABESP, municipal water supply investments have included improvements to pumping stations, leak repairs, and expanded water treatment capacity, all of which must be managed effectively to work in tandem. For Brazil and São Paulo, the expansion of interbasin conveyance capacity for water transfers has involved improving models, scenario analysis, and careful operational planning. The effective management of new infrastructure owned by different actors thus involves coordination across local, state, and national governments and agencies. The optimal management of this water infrastructure as a holistic system helps dampen the effects of drought, the major driver of the water crisis.

In Las Vegas, a regional approach has made it easier to achieve water efficiency and supply security goals, even when federal support was not forthcoming. SNWA highlights the critical importance of regional water management in ensuring water security and cost containment. By establishing a governance structure that coordinates efforts across multiple jurisdictions, SNWA can implement comprehensive strategies that address both immediate and long-term water challenges. This collaborative approach helps manage costs effectively because investments in infrastructure and conservation are shared, reducing financial burdens on individual communities. Additionally, regional management enhances water security by creating a unified response to fluctuations in supply, ensuring resilience against future uncertainties:

> In many instances, you can achieve greater cost efficiencies if the facilities benefit various areas, all of whom share in the cost; you spread the costs over a larger constituency. In southern Nevada, we built $5 billion of water infrastructure without a single dime of federal money, but we were only able to do it all ourselves because we spread the cost out.[92]

The governance structure of SNWA is designed to require significant buy-in from multiple stakeholders. SNWA operates as a joint powers authority, encompassing seven municipalities with water and wastewater functions in Southern Nevada and a board of directors made up of elected officials representing those seven municipalities. This structure necessitates coordination and agreement across various jurisdictions. For instance, when SNWA proposes a new policy, such as restrictions on turf, it must be approved not only by the SNWA board but also by each municipality's governing body: "So, it takes a ton of coordination to get something uniformly codified in Clark County, and [SNWA has] been really successful at it."[93] Additionally,

> [t]he SNWA developed the blueprint regarding what conservation measures had to be taken. Those required every entity to rewrite its regulations, ordinances, and water rate structures and to implement and enforce the same measures across the board. That saved southern Nevada. Southern Nevada would not be what it is today had the SNWA not been formed and had we not set aside decades of war between the various jurisdictions.[94]

LESSON 4

Embrace Innovation

Approaching urban water security in a new way and adapting to new challenges will require new ways of doing things. This might mean adopting new technologies or ways of communicating, collaborating, planning, and financing. Innovation, and the creativity behind it, is a central component of building urban water security and responding effectively to water supply crises. Conversely, continuing to do things the same way even as conditions change is likely to erode urban water security in the long run.

The importance of innovation and experimenting with new ways of doing things was a central lesson from our case study cities. Las Vegas has implemented a variety of solutions to manage its long-term water shortage challenges based on its water supply and use profile. For decades, the city has embraced innovative water reuse strategies and has been able to recycle 40 percent of its water delivery through wastewater treatment and return, extending its water supply by about 75 percent. Infrastructure solutions to maintain water access under drought conditions included major investments in large infrastructure projects that required multiple years to put in service: SNWA spent $1 billion, funded entirely by rate payers, to construct Intake 3 and a low lake–level pumping station on Lake Mead to maintain access to water even if water levels are reduced to dead pool, or the point at which reservoir levels are so low that downstream flow ceases. Before the projects were completed in 2020, lake levels had never been so low that these solutions would have been needed, but they were almost immediately necessary when Lake Mead hit critical depth in 2022.

Innovative, smaller-scale infrastructure projects to maintain a resilient water supply included solutions to improve water treatment efficiency (e.g., aerating reservoirs to prevent trihalomethane formation, modifying filter pathing at treatment plants) and using new predictive tools (e.g., a new three-dimensional water quality model) to understand how rising temperatures from climate change might affect water quality at intakes. Las Vegas also relies heavily on AMI to identify leaks to reduce water loss throughout the system, sending an automated text alert or phone call to customers when unusually high water use is detected.[95]

The El Prat Desalination Plant, a seawater reverse osmosis facility near Barcelona, Spain.

Cape Town's experience with Day Zero prompted experimentation with new approaches and has helped foster a broader culture of innovation. Success with system pressure upgrades and improved pressure management during the crisis led to new investments in sensor technologies, "an 'internet of things' kind of investment."[96] Similarly, the water dashboard that helped the city track key metrics and raise community awareness of water availability has continued to be used. Initial commitments to diversify water supplies via desalination, however, were met with the financial realities of high capital costs and limited support from higher levels of government. City officials were not confident they could invest in desalination and maintain affordability and their commitment to free baseline water services. This has led the city to double down on alternative ways of diversifying supply, including through groundwater development, wastewater reuse, and managing demand.

LESSON 5

Build Trust and Effective Communication

A mural promoting water conservation efforts on a retaining wall at Cape Town's harbor.

Perhaps the most common—and challenging—lesson learned from cities' experiences with water supply crises is the importance of building trust and effective communication with city residents. Many cities grappled with how and when to communicate about a water supply crisis and the planned response. Mistakes at this stage often made it more difficult for decisionmakers to take the steps needed to address the crisis; a breakdown in trust impedes crisis response and can make it more difficult for the city to take necessary steps. Conversely, effective communication campaigns were often critical to reducing water demand during a supply crisis. Building trust in the water system and the people who make decisions about the system facilitates needed investments and helps ensure support for mitigation efforts.

We found in our case studies that decisionmakers often struggle with the need to be straightforward and honest with residents about the condition of the water system, the threats the system faces, and the investments and changes that are needed to ensure water security. Decisionmakers and observers reflected that there is often fear that this kind of honesty will have political, economic, or regulatory consequences or that, if they get things wrong, the public will lose trust. But the experiences of our case studies also show that the opposite is more likely: A failure to communicate and engage is a common cause of mistrust. It takes political courage to communicate clearly and accurately about water supply challenges, and urban water suppliers do not often have a lot of experience with public engagement and communication. It is a complex communication challenge that requires a balance of conveying the uncertainty and seriousness of the threat with fostering trust that the situation will be addressed. It also requires city officials and possibly engineers to interface and engage with lower-income communities, which can require different skillsets. Unlike a more traditional disaster, people might have to be convinced that water supplies are a priority, especially in places where this is a more unusual event.

In São Paulo, although SABESP did implement fiscal incentives to limit household water use, community involvement and communication was notably lacking by the utility. Effective community outreach was needed to decrease overall water demand, another driver of the water crisis. There was a significant breakdown in trust

Aerial view of the city of São Paulo.

between SABESP and several lower-income communities in São Paulo because of inequities that were amplified by the crisis. These communities already had less-robust water connections and inadequate sanitation infrastructure provided by the company, and these inequities were amplified by the pressure reductions. One interviewee described these preexisting inequities as follows:

> And, so, I think it's hard to kind of disentangle the water system from these broader inequalities that shaped the city. And I, you know, I mentioned that in terms of sanitation and sewerage. But, like, there's lots of other ways you can kind of think about that. Where people have, you know, this kind of proximity to where they polluted water, but then at the same time, their connections to drinking water are really tricky.[97]

These communities were typically located on the outskirts of the city at high elevations. The pressure reductions by SEBESP had a disproportionate effect on these communities because lower pressure led to even less water supplied to higher elevations, which did not have water towers to manage issues associated with lower water pressure. Lack of water, in addition to pathogens that entered the low-pressure water supply, led to the breakdown in trust between these communities and SABESP, while wealthier housing experienced less of an impact.[98] The breakdown in trust could have implications for future water crises in the region. Had SABESP implemented a more equitable solution, such as selective rationing based on timing or better incentives for water reuse, the breakdown in trust may not have occurred. As SABESP continues its outreach efforts, it should further improve the resilience of the system by building the capacity of communities to reduce water demands during times of drought.

Cape Town has prioritized communication during and after the water supply crisis. One principle the city continues to emphasize with the public is that "we are doing everything we can to ensure you get access to water safely and quickly to ensure you can meet your basic needs."[99] The effectiveness of this strategy rests on trust in the city, and, therefore, "Building trust with residents is also a bankable investment. It's all money in the bank for when a crisis arises."[100] Similarly, in New Orleans, the need to build good communication was one of the biggest lessons learned from the 2023 crisis. Day to day, the city's drinking water infrastructure is not very resilient, and the public sees that in the form of drinking water boil advisories. To help rebuild trust and increase communication, stakeholders learned to release data early, transparently, and often. SWBNO also acknowledged that ensuring diverse thoughts and voices are involved in the hazard planning process is necessary to think more creatively.

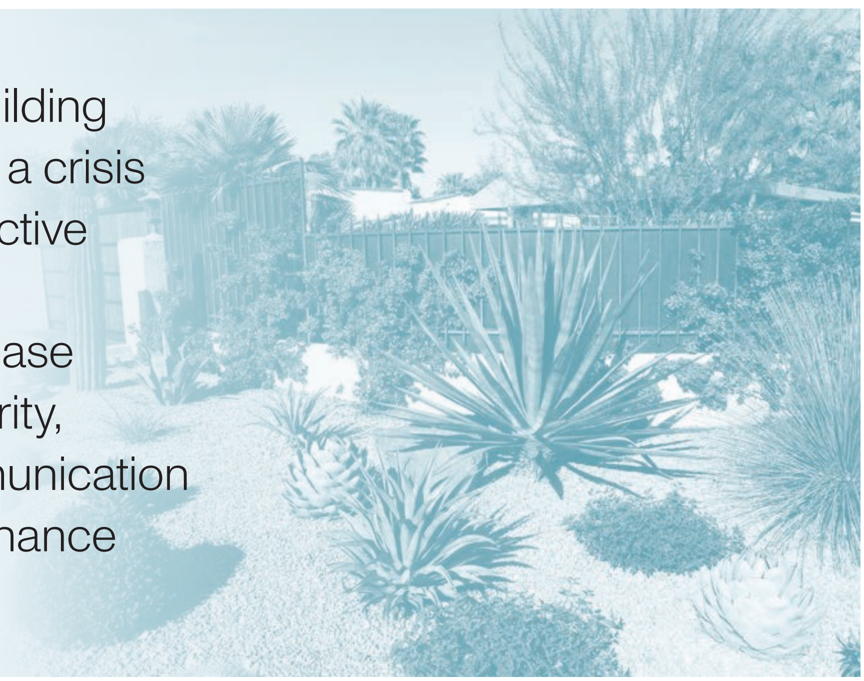
Various cities have experimented with different strategies for building trust and improving communication. SNWA exemplifies good governance by fostering transparency and building confidence in its decisions through rigorous, science-based planning. SNWA's commitment to developing a 50-year water resource plan annually ensures that its strategies are informed by robust data and long-term projections. This approach keeps elected officials and the community informed and prepared to adapt to changing conditions. "Brutal honesty is one of the key things,"[101] said one interviewee, highlighting the importance of clear communication and education in decisionmaking. By engaging diverse stakeholders and maintaining open dialogue, SNWA effectively bridges the gap between science and policy, ensuring resilient water management practices. Cape Town has found success in partnering with local politicians with strong social media presences. By taking a proactive approach to education and outreach, residents and politicians are water literate. This approach is enforced by Melbourne Water's requirement to give the state minister a recommendation every year on how much water should be ordered from the desalination plant. Through this evidence-based decision, there is not only accountability (the cost of desalination is transparently reflected in water bills) but also political protection against what might be unpopular or inequitable rate hikes.

Research has shown persistently declining trust in drinking water and drinking water providers, particularly in the United States.[102] Building and rebuilding this trust ahead of a crisis can support proactive and collaborative strategies to increase urban water security, strengthen communication channels, and enhance crisis response.

Pathways to Urban Water Security

Although the aim of building urban water security can be seen as universal, it is clear that *how* this aim will be achieved is unique to particular places. Even for our case studies, cities had unique starting points, risk factors, infrastructure configurations, capacities, and demand patterns. These unique features must be navigated and integrated into a tailored pathway to urban water security.

Building and rebuilding . . . trust ahead of a crisis can support proactive and collaborative strategies to increase urban water security, strengthen communication channels, and enhance crisis response.

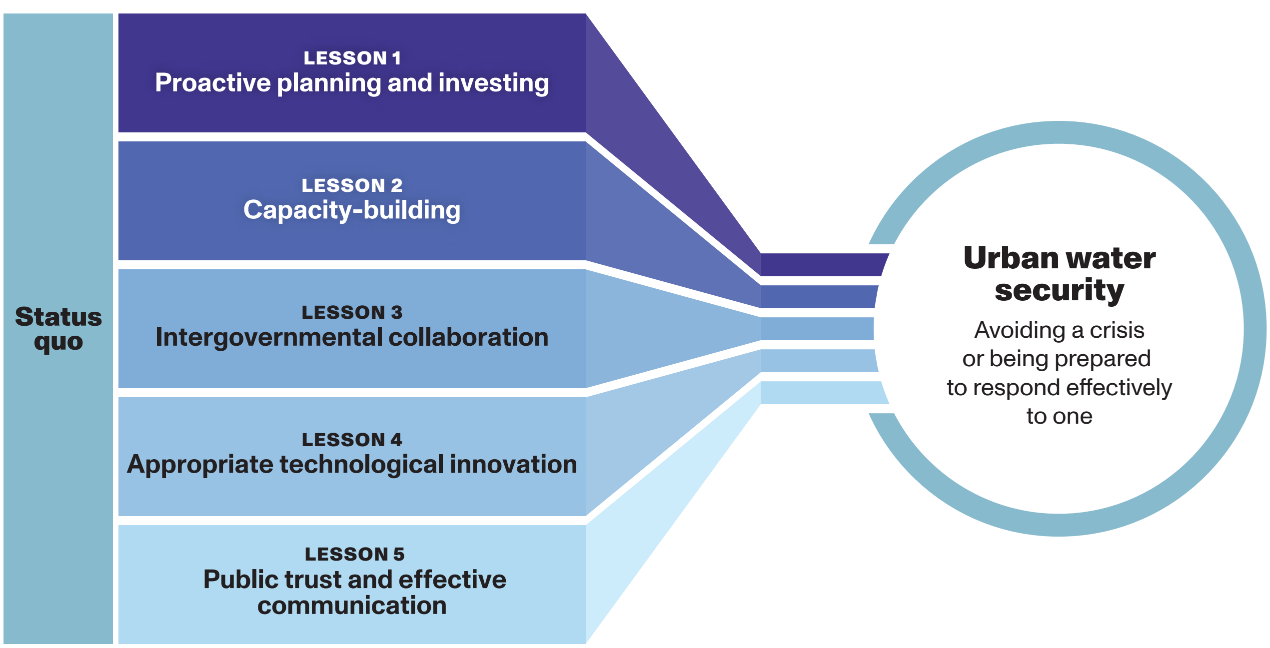


This challenge of building and traversing unique pathways to urban water security is illustrated in Figure 8. Insights from our cases studies tell us that moving from the status quo to a condition of urban water security will require proactive planning and investment, capacity-building, intergovernmental collaboration, technological innovation, and the establishment of trust and communication. All of these elements contribute to and are needed for building urban water security, but the importance of each element will vary from city to city depending on its starting point. These elements will also take different forms and require different levels of effort depending on the specific features of a city's context: the physical system (local hydrology); the infrastructural system and available technologies; financial constraints and opportunities; political constraints and opportunities; and the social context, including existing cultures of conservation and engagement.

This idea was underscored by our Las Vegas interviewees, who pointed out that understanding local water use patterns is crucial when designing effective water supply solutions. Each community has unique characteristics that influence how water is consumed and conserved. For instance, although Nevada's removal of nonfunctional turf is a sensible measure because of its arid climate, such an approach may not be necessary in such places as Denver, Colorado, where natural rainfall supports turf growth without irrigation. Additionally, water management strategies must consider how water is returned to the system. In Las Vegas, water is returned to Lake Mead, whereas in Southern California, much of the water is discharged into the ocean. Consequently, Southern California might prioritize water reuse over residential conservation measures. The maxim of "understand where your community is using water and what your low hanging fruit is"[103] allows for tailored solutions that maximize efficiency and sustainability. One São Paulo interviewee suggested a socio-hydrologic approach along the same lines. The interviewee noted how addressing the social issues around water supply

FIGURE 8

Five Lessons from Case Studies on Building Urban Water Security, Informed by Context-Specific Risks and Opportunities



A woman fills a watering can with water from rain barrels.

can lead to better decisionmaking and that people should be part of the solution:

> The only solution is to be very aware, careful, and transparent. And make the people become not the victims but the collaborators, putting things into place as to reduce to a maximum the effects of a larger drought. The solutions [to drought] are basically social-technical. No, they're not purely technical. There has to be more rationality in terms of reducing the consumption of water.[104]

The constraints and opportunities provided by the different physical, infrastructural, financial, and social and political contexts also generate the need to make trade-offs, which one interviewee identified as the hardest decisions cities have to make. Large infrastructure projects, such as desalination or reservoirs, increase water security and resilience against drought conditions, but these projects are very expensive and may require large rate increases or make it less feasible for a city to maintain existing infrastructure or invest in other technologies, leaving the system less resilient in other ways. Decisionmakers will need to prioritize among a set of influential projects depending on current and longer-term needs. Investments in water security are also likely to be traded off against investments in other sectors and systems. Planning approaches that account for long timelines, a variety of alternative approaches, and inherent uncertainty are therefore critical to support decisionmakers trying to increase water security. Robust decisionmaking methods have been implemented in parts of the United States to great success.[105] These decisionmaking methods integrate adaptive planning with scenario planning to help decisionmakers understand the vulnerabilities within the existing system and the factors exacerbating those vulnerabilities, such that they can identify ways to adapt their planning and long-term investments over time and more nimbly pivot as climate and hydrologic conditions change. Through the use of scenarios, robust decisionmaking methods also allow groups of decisionmakers to better understand their trade-offs and discuss during the planning process their priorities and how those priorities would change under different water stress scenarios.

The Ivanhoe Reservoir portion of the Silver Lake Reservoir Complex, after being filled with shade balls.

Conclusions and Next Steps

Decisionmakers face the challenging task of building the capacities—as broadly defined—that are needed to avoid a water supply crisis and respond effectively to one. Lessons can be drawn from the experiences of cities that have recently confronted near-catastrophic water supply risk events. These water supply crises arose for a variety of reasons, including severe drought, population growth, and a lack of consistent investment and planning. These cities' experiences also reveal a set of strategies that can help decisionmakers proactively build urban water security. The ability to adopt these strategies and the value they bring to a particular place are going to be shaped by a city's particular physical, political, economic, and social constraints and opportunities.

The findings also help us understand why it is so important but difficult to proactively and holistically build and manage urban water systems that are robust against change and surprise. Water supplies and demand patterns are fundamentally uncertain, water system infrastructure is complex, and the costs and trade-offs required to prioritize water security make it easy to fall back into previous unsustainable practices, creating the potential for history to repeat itself. There are multiple interacting systems and dynamics at play, along with real political tensions and trade-offs. The signals of impending crisis can often be hidden and difficult to observe if policymakers are not looking for them explicitly. It is also very difficult to prioritize future problems in the context of challenging and immediate problems that require attention today.

In a review of crisis management broadly, Boin and colleagues write that

> even the richest and most competent government can never guarantee that major disruption will not occur. . . . Prevention is very difficult when it comes to the "unknowable" and "unimaginable" events at the heart of many crises. There is, in other words, no alternative to investing serious time and energy in thinking in a more generic sense about the "rude surprises" that will inevitably occur.[106]

- For **urban water managers**, this underscores the value of building generic capacities: conservation and efficiencies, climate-independent sources of supply, and the fiscal and organizational capabilities needed for collaborating and mobilizing a response. It also underscores the universal nature of the challenge as water managers and planners confront an increasingly uncertain and dynamic environment. Planning ahead and investing early, building capacity in government and the community, and promoting water literacy can not only help prevent catastrophic water supply risks but also strengthen

Aerial view of a new rural housing development being built on former quality food-producing farmland in Australia.

response capacity during a crisis event. Policies and programs must be tailored to the specific context and trade-offs that are relevant to particular places, which requires high-quality technical analysis. Engaging the public and accounting for the impacts on vulnerable populations is also critical and can be significantly strengthened through building trust.

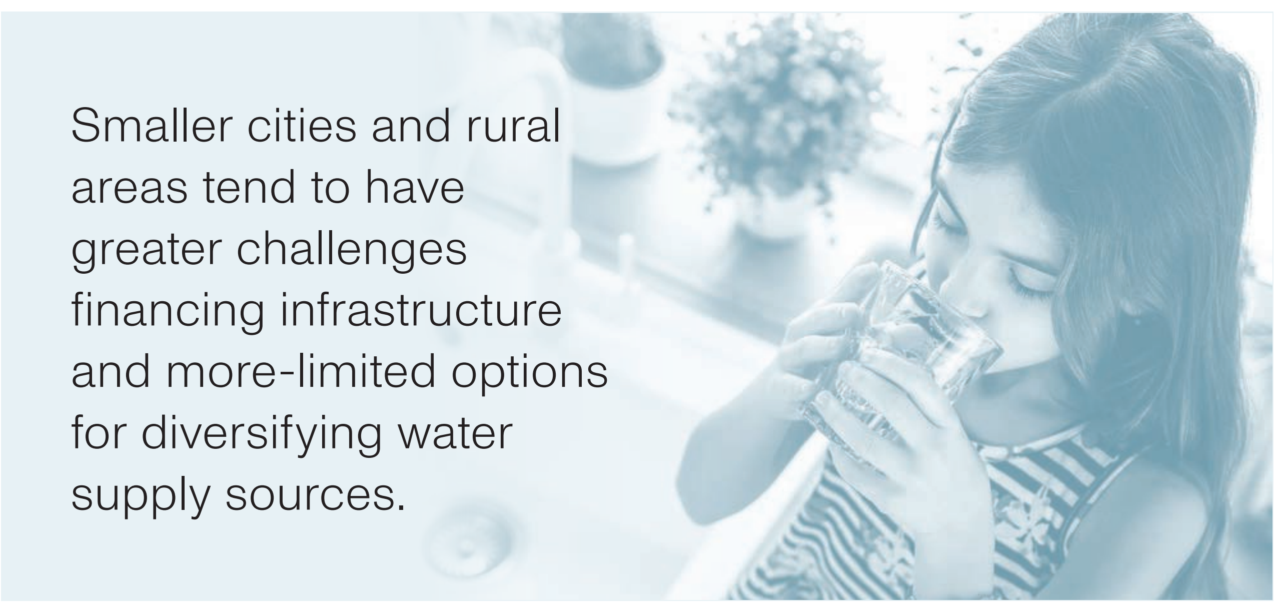
- For **city managers, planners, and urban developers**, our findings underscore the cross-sectoral nature of building urban water security. Coherent land use planning, housing strategies, and regulation of the built environment are critical to ensuring urban growth and development that is compatible with a resilient and secure water system. Managers, planners, and urban developers should be active participants in building urban water security and not viewed (by themselves or others) as outside the scope of building urban water security.
- It is critical that **national and subnational governments** act as partners in urban water security given the importance of intergovernmental collaboration and coordination. Partnership can include financing as well as technical assistance and supportive regulatory structures. Building and strengthening these relationships ahead of a crisis are critical for urban water security.
- For **nongovernmental organizations** (NGOs) focused on environmental sustainability and community resilience, prioritizing urban water security requires embracing innovation and building bridges between sectors, which NGOs may be uniquely positioned to do. Our work points to examples of such NGO-driven collaboration, either directing policy responses toward or diverting them away from alternative water sources and other key interventions. Building relationships with local governments and planners can be useful to achieve goals these groups share with official actors on such elements as ecological protection and building community water literacy.
- For **international development agencies and investors** that are interested in sustainable development goals related to water security, such as the United Nations and World Bank, our work illustrates the need to promote and encourage balanced capacity-building of all kinds—technical, fiscal, and social. It is these balanced pathways forward that show the most promise for urban water systems.

- For **researchers**, there are many promising areas for future work; this report presents a first step in understanding how decisionmakers—broadly construed—can best act now to prevent catastrophic climate risks in the future. First, the cities in our analysis are all relatively large. However, several of our interviewees pointed out that the challenges facing smaller cities and more-rural places can be quite distinct and challenging in their own way. Smaller cities and rural areas tend to have greater challenges financing infrastructure, as well as more-limited options for diversifying water supply sources. In Cape Town, it was also pointed out that outside major metro areas, it can be hard to retain staff with the appropriate skills or even engineering training. This makes it difficult to effectively plan for the future. During Australia's Millennium Drought, many small towns ran dry and trucked in water, which is not likely to be a solution for medium-sized communities.

The five lessons in this report also bear further investigation, individually and in relation to one another. It is one thing to understand the value of those lessons; it is another to gain insight into how they can be best applied. For example, under what conditions do cities act proactively to address water security concerns? What kinds of strategies or conditions best facilitate strong intergovernmental collaboration on these issues? How can water managers build trust and strengthen their communication abilities, particularly with vulnerable and marginalized communities? The insights presented here can serve as a starting point for more-intensive analysis for decision support and policy design.

Beyond these lessons, we see opportunities to explore additional questions that can benefit policymakers, specifically, (1) what monitoring strategies and metrics are most effective in anticipating a crisis or for evaluating and tracking progress on building urban water security, and (2) what are the most effective and equitable methods for assessing trade-offs and choosing among longer- and shorter-term solutions?

Learning from the past and building urban water security are critical challenges that are central to the climate resilience of cities in all parts of the world. Rigorous, engaged research can continue to support efforts to build urban water security and avoid the worst implications of catastrophic water supply risks.



Smaller cities and rural areas tend to have greater challenges financing infrastructure and more-limited options for diversifying water supply sources.

Left to right: Don Brown—Macomb County Board of Commissioners Chair, U.S. Representative John James, Candice Miller—Macomb County Public Works Commissioner, Barbara Zinner—Macomb County Commissioner, and Alyssa Eck—U.S. Army Engineer Research and Development Center Environmental Laboratory holding a harmful algal bloom sample collected from Lake St. Clair, Michigan, in 2023.

Appendix

Environmental Scan of Literature and Reports

We used a purposive sampling method to review literature under the project's short timeline. Prior publications, citation lists, and known works were collected. We used these initial works to categorize and summarize the literature along common lines: crisis definition, theory development, cases studied, focus on phases of the hazard cycle (prevention, prevention, response, or recovery), and production of water crisis management frameworks. Once the initial list was organized and summarized, targeted Google Scholar searches were used to fill gaps in each category.

To build the body of literature and fill in gaps, we also used the Elicit artificial intelligence tool to find additional peer-reviewed articles on post-event response, monitoring, and evaluation and pieces that identified specific water crisis management frameworks.[107] This tool searches more than 126 million academic papers from the Semantic Scholar corpus across all academic disciplines.[108] We conducted separate Elicit searches for each category. A team member reviewed the search results and chose the most relevant five to ten articles from each search and added them to the literature list, categorizing and summarizing them along the same lines previously used.

All sources in the literature list were reviewed and the content was summarized in an abstraction form along the dimensions described above.

Finally, the RANDChat artificial intelligence tool (based on the latest release of GPT-4o) was used to summarize key takeaways in each category from the collected literature, as documented in the abstraction form. We entered the content from each section of the abstraction form (e.g., crisis definition, theory development, water crisis management frameworks) into RANDChat and requested the tool produce a summary. The results were reviewed and summarized for accuracy and edited as needed, and they were distributed to the writing team for use in preparing interviews and drafting the final report. Summaries for each section and key references are found in the following sections.

Definition of Water Crisis

The reviewed literature does not provide a single, explicit definition of *water crisis*. Instead, it describes the concept through various lenses, including drought events, water scarcity, and water stress. For example, in California, a water crisis is framed around chronic water quantity and quality issues affecting marginalized communities, while in the Western Cape, water crisis is exemplified by the Day Zero scenario of critically low water reservoirs. The term is also linked with *urban water security*, defined as having adequate water for daily needs and freedom from water-related risks. Additionally, the literature highlights governance challenges, infrastructural problems, and the imbalance between water consumption and supply as critical components of a water crisis. Some articles focused more on describing the elements of governance crises than defining water crises, while other more-technical articles modeled current and future water shortage areas as likely to experience water crises because of water supply factors.

Theory or Conceptualization of Water Crises in General

The literature on water crises conceptualizes the issue through various theoretical lenses, including water resilience, water security, and the sociopolitical dimensions of water governance. Water crises are also framed as ongoing issues of water quality and quantity, particularly affecting socioeconomically marginalized communities, rather than isolated events. The concept of water security is explored across multiple dimensions—economic, environmental, and governance—emphasizing the interconnectedness of natural water systems and human social systems. Additionally, the literature discusses the impact of rapid urbanization, population growth, climate change, and aging infrastructure on urban water scarcity, stressing the need for proactive, long-term planning and IWRM.[109]

Elements of Preparation and Capacity-Building

Although many articles describe elements related to preparation and capacity-building, it was sometimes difficult to delineate between preparation and response strategies based on the crisis timescale—future or anticipated versus long-term conditions versus seasonal conditions versus acute challenges (e.g., because of infrastructure failure).

The literature outlines various elements of preparation and capacity-building for water crises, emphasizing both conceptual and practical approaches. Conceptually, resilience is defined with specific dimensions and characteristics to enhance water system robustness against crises. Practical elements include precrisis interventions, such as campaigns to decrease water use and plans for restrictions, tariffs, infrastructure improvements, and leak fixes. The articles identify global solutions to water stress and scarcity, including desalination, smart irrigation, digital solutions, and significant investments in infrastructure. The articles also emphasize the importance of governance, institutional arrangements, financial investments, technological and human resource capacity, and community engagement for effective water management. Additionally, the literature highlights proactive and strategic measures for drought risk management, regional coordination, and sustainable water management practices, stressing the need for long-term planning and stakeholder participation.[110]

Elements of Event Response

Fewer articles provide information on event response, but again, it was challenging to delineate preparation versus response activities based on the timescales of water crises that were described in the literature, as described previously.

Conceptually, resilience is a key theme with dimensions and characteristics tailored to immediate crisis management. Practical elements of response include planned measures, such as shutting off water delivery to specific areas, introducing large bottled-water supplies, and implementing water-limiting devices and policies. Case studies illustrate diverse responses, such as water rationing, public awareness campaigns, and infrastructure repairs. Behavioral interventions, such as public education campaigns, and technical solutions, such as desalination and groundwater abstraction, are also highlighted. Additionally, the literature discusses the importance of governance, emergency declarations, regulatory measures, and community engagement in ensuring effective and equitable crisis management. Some responses involve innovative technologies and the rapid mobilization of resources through public-private partnerships to address immediate water shortages and enhance long-term resilience.[111]

Elements of Postcrisis Monitoring and Evaluation

Very few articles describe postcrisis monitoring and evaluation, despite a targeted search for additional articles.

The literature on postcrisis monitoring and evaluation for water crises highlights the importance of continuous assessment and data-driven decisionmaking to inform and improve future responses. Conceptually, resilience includes dimensions that emphasize ongoing evaluation and adaptive management. Practical examples include the use of water dashboards and water maps in Cape Town to monitor water use, although the use of this data for monitoring and evaluation is not always clear. The literature calls for integrated water quality and ecosystem monitoring networks, regular data collection, and continuous risk assessment to track changes and make informed management decisions. Some case studies, such as those in São Paulo and the Nile River region, implemented new measurement regimes postcrisis using such technologies as artificial intelligence and smart city surveillance for monitoring and evaluation. Additionally, such frameworks as the OECD's Water Governance Indicator Framework and City Blueprint provide tools for self-assessment and continuous improvement in water governance.[112] However, specific postcrisis monitoring and evaluation practices are often recommended rather than described in detail, indicating a need for more rigorous and systematic approaches to evaluating the effectiveness of crisis response strategies.[113]

Frameworks for Drinking Water Supply Crisis Management

Few articles summarize or provide frameworks related to crisis management; some were more general or focused on broader water management issues. Key frameworks include the following:

- **IWRM:** This comprehensive approach includes such aspects as drinking water security, pollution control, wastewater treatment, solid waste management, climate change adaptation, and resource recovery. The City Blueprint approach is used to evaluate water management performance, incorporating the trends and pressures framework, the City Blueprint framework, and the governance capacity framework.
- **OECD frameworks:** These include the OECD's principles on water governance, the analytical framework for assessing water governance in cities, the three Ps framework (people, places, policies), and the OECD's Water Governance Indicator Framework. These frameworks emphasize governance, policy assessment, and stakeholder engagement.
- **City Blueprint:** A practical tool to assess and monitor IWRM performance, consisting of 25 indicators divided into seven categories: water quality, solid waste treatment, basic water services, wastewater treatment, infrastructure, climate robustness, and governance.
- **Urban water strategy maturity model:** This model outlines a progression from no strategy to efficiency, resilience, and abundance strategies, providing a roadmap for cities to enhance their water management capabilities.
- **Total water management:** An approach that examines urban water systems in an interconnected manner, focusing on reducing water demands, increasing water recycling and reuse, and achieving environmental goals through multipurpose, multi-benefit infrastructure.
- **Risk governance:** Offers a valuable framework for decisionmakers focused on water security because it accommodates the complex, multi-actor dynamics and nontechnical nature of climate change challenges while integrating decision support, iterative risk management, and varying degrees of transformative action.[114]

Abbreviations

AMI	advanced metering infrastructure
IWRM	integrated water resources management
OECD	Organisation for Economic Co-operation and Development
SABESP	Basic Sanitation Company of the State of São Paulo
SNWA	Southern Nevada Water Authority
SWBNO	Sewerage and Water Board of New Orleans
USACE	U.S. Army Corps of Engineers

Notes

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14 We tracked whether the articles dealt with a single crisis, defined a specific crisis versus a generalized conceptualization, described elements of preparation and capacity-building, addressed elements of response, provided elements of postcrisis monitoring and evaluation, or identified broader frameworks for crisis management. For an environmental scan of the literature, see the appendix.

15 The cities we considered were Baghdad, Bahrain, Bangalore, Beijing, Beirut, Bogota, Cairo, Canberra, Cape Town, Delhi, Istanbul, Jakarta, Johannesburg, Kuwait City, Lahore, Las Vegas, Limassol (Cyprus), London, Los Angeles, Melbourne, Mexico City, Miami, Montevideo, Moscow, Muscat (Oman), New Orleans, São Paulo, and Tokyo.

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About This Report

Researchers at the RAND Center for Climate and Energy Futures study emerging risks associated with the changing climate, society's responses to those risks, and the processes and conditions needed for policy implementation. This work includes understanding the actions that are required to transform systems and reverse historical inequities and risk management and mitigation options in the face of catastrophic risk.

A loss of available water supply is one of the catastrophic risks of climate change decisionmakers must confront. Cities around the world have already faced severe threats to their water supplies. In this report, we examine the experiences of five cities with severe or catastrophic water supply risks to identify steps that could be taken ahead of time to mitigate those risks and build urban water security. The case studies represent a variety of national and demographic contexts. Drawing on interviews with experts and decisionmakers and a review of available reports and journal articles, we identify the key drivers of these water supply crises and detail firsthand accounts of how these crises may have been avoided. The insights provide key lessons for preparing for and ultimately avoiding water supply crises in the future by building urban water security. We conclude by identifying opportunities and limits for applying these lessons and develop recommendations for water system managers, as well as policymakers, funders, and researchers working in this space.

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RAND Center for Climate and Energy Futures

The RAND Center for Climate and Energy Futures studies emerging risks associated with the changing climate, society's responses to those risks, and the processes and conditions needed for policy implementation. By working across disciplines and geographies large and small, center researchers endeavor to address persistent gaps in climate and energy research and analysis that have slowed the ability to respond rapidly, effectively, and equitably to the climate challenge.

The center is a collaboration between RAND Global and Emerging Risks and RAND Social and Economic Well-Being. For more information, email climate@rand.org.

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RAND SOCIAL AND ECONOMIC WELL-BEING

Reliable access to safe and affordable drinking water is a core service provided by city governments around the world. These services are critical to people's health and well-being, local and regional economies, and environmental sustainability. As the climate changes, infrastructure ages, and populations grow, many cities are—or will be—facing serious threats to their ability to maintain or enhance the level of service that they can provide and ensure the long-term resilience of their water supplies.

In this report, the authors examine the experiences of five cities—Cape Town, South Africa; Melbourne, Australia; São Paulo, Brazil; and Las Vegas, Nevada, and New Orleans, Louisiana, in the United States—facing severe or catastrophic water supply risks to identify steps that could be taken ahead of time to mitigate those risks and build urban water security. These case studies represent a variety of national and demographic contexts. Drawing on interviews with experts and decisionmakers and a review of reports and journal articles, the authors identify the key drivers of these water supply crises and detail firsthand accounts of how these crises could have been avoided. The authors identify the strategies available to decisionmakers—the people managing urban water systems and shaping the broader financial and regulatory environment in which they work—to proactively mitigate the possibility of catastrophic risk to urban water supplies. The insights provide key lessons for preparing for and ultimately avoiding water supply crises in the future by building urban water security.

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