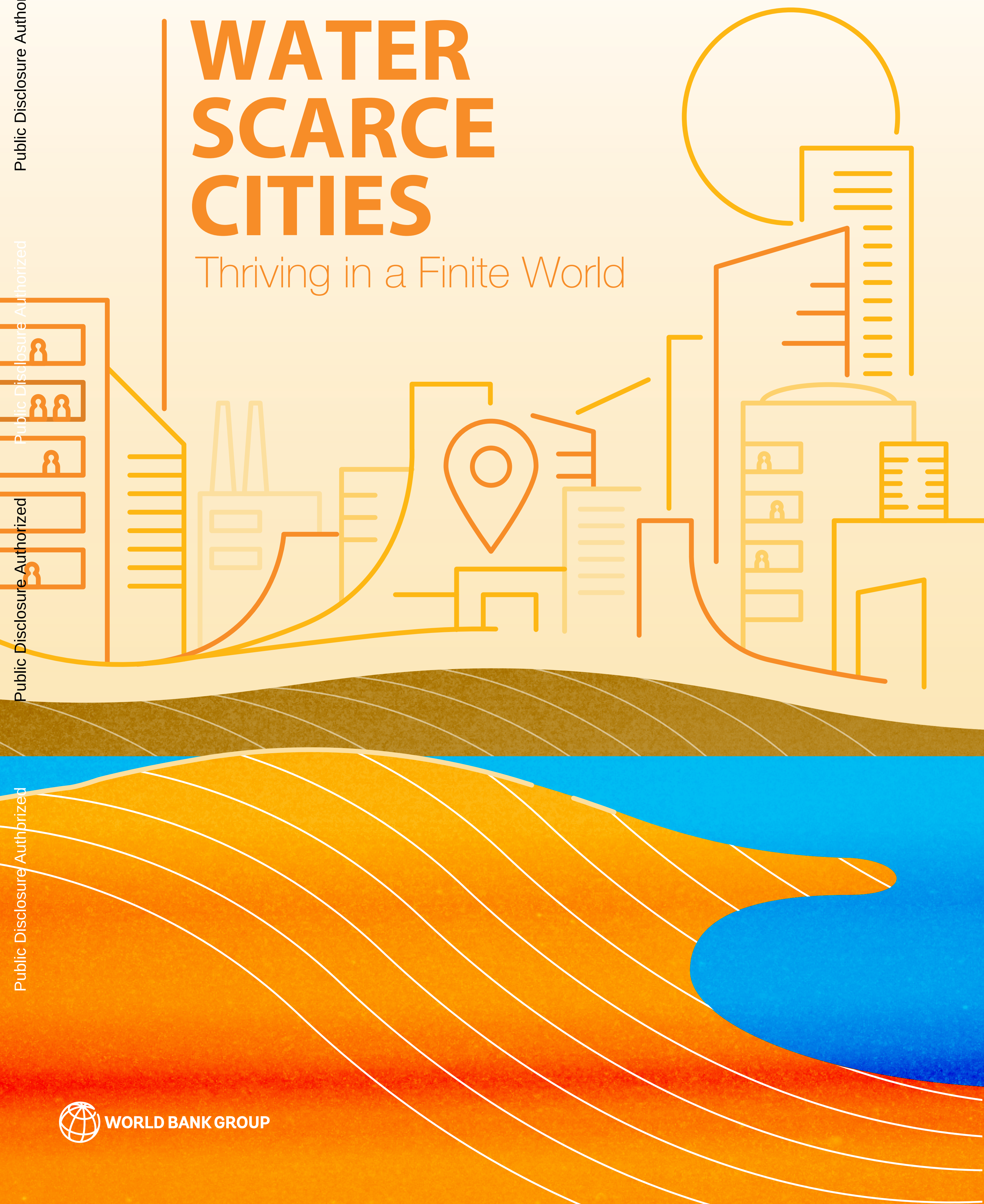
WATER SCARCE CITIES

Thriving in a Finite World



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Preface

In 2013, the Republic of Yemen was in an unprecedented situation. Because of the National Dialogue initiative, a reconciliation process backed by the United Nations, there was hope that Yemenis could build a better future after the turbulence that had swept the region a couple of years earlier. This hope, however, was tempered by anxiety that the country was on the verge of chaos. In Sana'a, the capital, Mayor Abdul-Qader Hilal, in particular, was actively concerned about the future of the city, especially its water supply. Hilal was keenly aware that his rain-deprived city was on the brink of running dry. Its centuries'-old aquifer was overpumped and dwindling. In addition, its water utility was underperforming and underserving his citizens, supplying only 48 percent of its 2.2 million inhabitants, while the rest turned to water tankers—spending at least five times more for water in peacetime, and up to 10 time more in periods of crisis. Hilal turned to the World Bank with a simple question: surely Sana'a is not the only water scarce city in the world; are other cities facing or have faced similar challenges, and which could he learn from?

Around the same time, water specialists from the World Bank were looking to U.S. cities that coped with water shortages. In the extremely dry southwest United States, cities faced with an alarming decrease in aquifer levels embarked on a decades-long comprehensive strategy to secure their water future. Las Vegas, Nevada, placed local utilities under a single authority to leverage their bargaining power and secure additional water credits through innovative market and regulatory mechanisms. Tucson, Arizona, recharged its aquifers with its unused Colorado River allocation, while developing water reclamation to materially offset municipal nondrinking uses. Both cities developed aggressive demand-management actions, such as targeted data-based awareness-raising, changes in land use planning, or stringently enforced water-consumption regulations, with many lessons learned from a decade of trial and error.

The World Bank saw an opportunity to connect cities and utilities that have taken innovative measures to manage their water resources more effectively.

Water managers in Tucson immediately understood Hilal's predicament, having pulled back from a similar crisis in the 1980s, when their aquifer vanished as the city rapidly expanded. Together, these water scarce cities could help ensure that water measures support inclusive economic growth, environmental progress, and societal well-being. At the 2015 Spring Meetings, the Bank hosted a number of leading voices from water scarce cities, including Ms. Pat Mulroy, who led the Las Vegas Valley Water District and the Southern Nevada Water Authority for over 15 years; and Mr. Muesse Kazapua, the mayor of water-stressed Windhoek, Namibia, and others. Hilal was invited as the guest of honor of the 2015 event. Unfortunately, he was unable to leave Sana'a due to conflict that had erupted in the Republic of Yemen in 2015, and he tragically lost his life in a bombing.

Yet Hilal's legacy as a water resource innovator lives on. The Bank recognized that there was a wealth of experience across the world that was not necessarily accessible to mostly decentralized and locally focused water managers, especially in the very urban and very dry Middle East North Africa (MENA) region. The Bank identified and compiled as part of the present study experiences from water scarce cities (as recent events in Rome, Italy, and Cape Town, South Africa, have proven)[1] that could inspire further innovation and change in the region. This quickly led to the establishment of a vibrant global network of utility managers, government officials, academics, and more. The Bank used this network to facilitate regularly scheduled knowledge exchange events (Marseille, France, December 2016; Casablanca, Morocco, May 2017; Beirut, Lebanon, September 2017) to initiate and support a new kind of dialogue with governments and utilities in Morocco (Al Hoceima, Marrakesh), Lebanon (Beirut, Tripoli), Jordan, Oman, and many others. This report tells the story of the Water Scarce Cities Initiative.

Note

1. Both cities have experienced, over the past year, significant water supply shortages as a result of extensive drought events.

Acknowledgments

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Abbreviations

AWBA	Arizona Water Banking Authority
CAPEX	capital expenditure
DPR	direct potable reuse
GCM	general circulation models
IDP	internally displaced persons
IPR	indirect potable reuse
IRWD	Irvine Ranch Water Department
MCT	Mancomunidad de Canales del Taibilla
O&M	operations and maintenance
OCSD	Orange County Sanitation District
OCWD	Orange County Water District
PPP	public-private partnerships
PUB	Public Utilities Board
SDCWA	San Diego County Water Authority
SNWA	Southern Nevada Water Authority
W&S	water and sanitation
WSC	Water Scarce Cities
WSS	water supply and sanitation

Ouarzazate, Morocco, at the edge of the Sahara Desert. © Arne Hoel/World Bank.

Chapter 1 Introduction

Water scarce cities face unprecedented challenges: rapid urbanization and growth have put pressure on dwindling resources, and cities are further stressed by climate change and conflict shocks. Most operate under unsustainable water management practices, based on linear, engineering-based approaches, yet government planners and others are unaware how this situation could lead to major water shortages. Therefore, this report, using information from the Water Scarce Cities Initiative, attempts to compile innovative approaches—based on cities' successfully responses to water scarcity—to inspire a new kind of urban water security.

Water sits at the center of a constellation of *unprecedented challenges* facing global cities. Changes such as rapid urbanization, economic growth, increasing populations, and evolving consumption patterns are individually and collectively stressing water supplies. Climate shocks are taking a toll on many urban centers and amplifying the unpredictability of freshwater availability. In addition, demands are piling higher among competing users. In some regions, urban water insecurity is exacerbated due to increasing numbers of prolonged droughts. Repeated water shortages create perceptions of government failure, deepen social inequalities, and intensify existing tensions. In some regions, the turmoil of conflict and forced displacement further weakens management of scarce water resources. Securing urban water supply is crucial, since the number of urban dwellers living with seasonable water shortages is expected to grow from close to 500 million people in 2000 to 1.9 billion in 2050 (McDonald et al. 2011).

Unsustainable water resources management has led to the depletion of strategic sources in many of the world's major water basins. Water authorities can share cautionary tales of water competition and conflict, contaminated water sources due to rampant pollution, and unsustainable consumption. Most common are examples of linear, engineering-based approaches in which wastewater and stormwater are swiftly channeled out of cities into receiving waterways, which lead to depleted groundwater resources due to excessive rates of abstraction without adequate replenishment. As local sources are depleted, utilities reach further away, increasing their dependence on imported waters outside of their control, and reducing their capacity to respond to resource shocks. From Malta to Namibia, and from India to Brazil, water authorities have faced either the prospect of zero-sum water, augmenting urban water supplies from finite sources to the detriment of other users, or they have embraced alternative water resource management solutions.

Although many cities understand the strategic importance of sound water management, many urban water utilities remain *unaware of these challenges*, mired in linear and narrow engineering approaches. Often, city water management models include limited use of sustainability considerations, inadequate coordination with multiple users, lost opportunities to develop local and more economical resources, and disconnection with the watershed. In addition, problems with poor water quality, low service coverage, and crumbling infrastructure loom. As a result, many cities underperform in their efforts to increase water supplies under scarcity. In São Paolo and Rome, for example, unprecedented water shortages have led managers to question the foundations of conventional, linear water management models.

Fast-growing cities increase pressure on scarce water resources. All urban dwellers are dependent on a safe and reliable source of water for even the most basic needs. If inadequately managed, these water challenges have the capacity to negatively impact quality of life, public health, and inclusive growth for urban spaces and their inhabitants, especially youth and women. Water shortages can have far-ranging consequences in the prosperity of urban areas, causing higher incidences of diarrheal diseases, including on young children, and harming economic activities. (World Bank 2016; Sadoff et al. 2017; Damania et al. 2017; Sadoff, Borgomeo, and de Waal 2017).

Extreme water scarcity in the Middle East and North Africa triggered a progressive exploration of a new mindset across progressive utilities around the world. In the Republic of Yemen, for example, city officials in Sanaa were acutely aware of the risks the city faced if it continued overdrawing its aquifer at alarming rates, and sought new ways of engaging the population to raise awareness to the extreme scarcity of water. Governments in Morocco and Lebanon looked to the World Bank for support after traditional approaches seemed to push them toward increasingly costly investment programs—with no sustainable solution to their structural water deficit.

The Water Scarce Cities Initiative has set out to compile, connect, and share these breakthrough projects for resource-strapped cities in extremely water scarce areas. For example, in the Southwest United States, Tucson, Arizona, Las Vegas, Nevada, and Orange County, California have pioneered sophisticated solutions across traditional silos of the water cycle. Singapore and Namibia have experimented with potable reuse of wastewater, and Australia has pushed through integrated, institutional innovations.

The Water Scarce Cities Initiative intends to magnify the successes of those urban areas and serve as a connective thread between global cities, their policy makers and, most important, the practitioners. It first seeks to shift predominant, outdated, mostly linear, and siloed thought patterns that sometimes lead to disjointed and costly investment decisions without necessarily providing protection against depleting resources or an increasingly adversarial climate. It then demystifies innovative urban water practices, including managing conventional resources such as aquifers more effectively, tapping new and nonconventional resources such as wastewater, controlling demand, or engaging differently (such as showing how the practices were done and what can be learned from them). The goal is to engage meaningfully with diverse water scarce cities to facilitate concrete engagement, product development, and technical assistance.

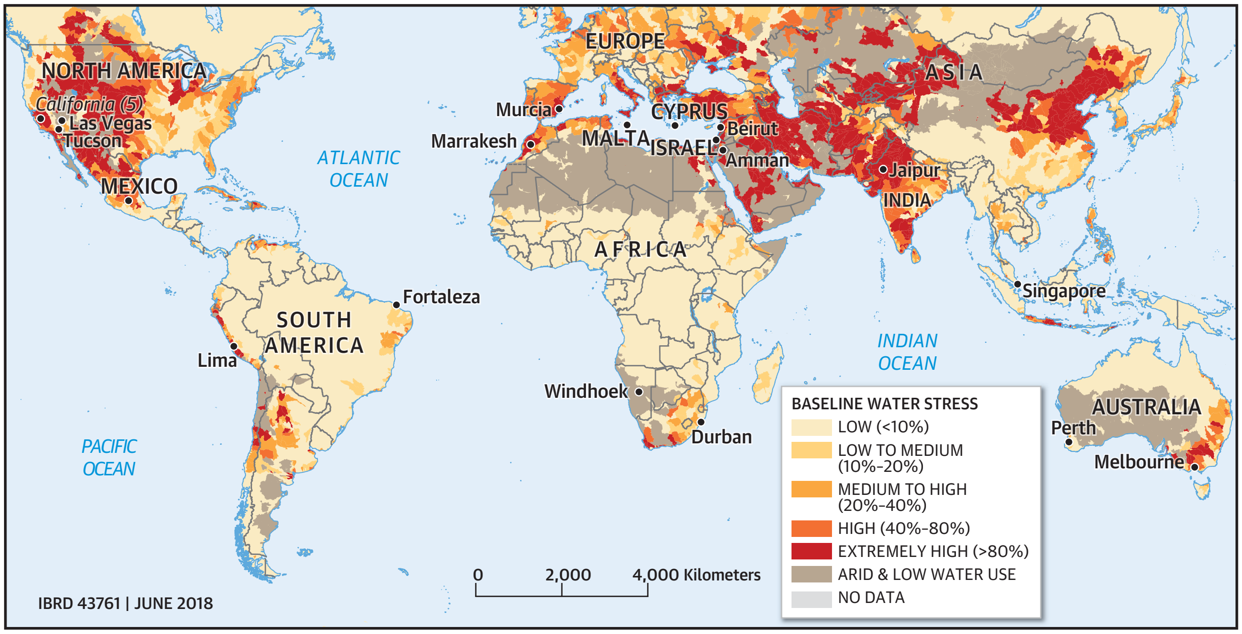
Water scarcity solutions that may be enigmatic or unfamiliar are illuminated through first-hand accounts to highlight paradigm shifts, emerging principles, and demystify innovative approaches. This report offers a first look at new pathways that cities, states, and regions facing water scarcity can explore, as well as recommendations for how they can unleash their potential through integrated and systemwide approaches that include technology, economic considerations, and inclusive outreach.

The Water Scarce Cities Initiative has developed this evidence-based advocacy piece to guide water security approaches with concrete examples and experiences. The report aims to promote successes, outline challenges and principles, and extract key lessons learned for future efforts. It shares the experiences of 19 water scarce cities and territories from five continents, which represent a diversity of situations and development levels, as identified in map 1.1. The selection of case studies is based on the expected relevance and diversity on cities' experience, and to a lesser extent reflecting geographic and income-level diversity.

Some cities and states have beaten water scarcity odds with new, integrated urban water management approaches. In sometimes surprising and often innovative ways, diverse urban spaces have been achieving inclusive and sustainable urban water services.

This report describes the emerging challenges and related water management principles that form a new paradigm ("Shifting the Paradigm"); presents and seeks to demystify key water scarcity management solutions ("Demystifying the Solutions"); and concludes with cross-cutting considerations relevant to policy

MAP 1.1. Case Studies and Other Key City Experiences in This Report



Source: World Resources Institute, Aqueduct Water Stress Projections Data, April 2015.
Note: Map depicts baseline water stress. Black text denotes cities in case studies for report. Brown text denotes other key locations.

makers of water scarce cities (“Cross-Cutting Considerations”). The report is not an exhaustive study of the issues, nor does it provide answers and tools to address the challenges that water scarce cities may face. Rather, it is an advocacy piece to raise awareness around the need to shift the typical way urban water has been managed and to share emerging principles and solutions that may improve urban water supply security in water scarce cities.

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Water level at historical low in 2016 in Nevada's Lake Mead supplying close to 20 million people. *Source:* U.S. Bureau of Reclamation.

Chapter 2
Shifting the Paradigm

In an era of looming water crises, water scarce utilities must shift the paradigm from linear urban water practices focused on achieving service standards in a financially sustainable way to an integrated water management mindset that can help water supply and sanitation (WSS) service providers secure reliable and sustainable water supplies. This report argues that WSS service providers, policy makers, and practitioners should look at their mandate and responsibilities in such a new light. Diverse experiences of the urban water management industry in water scarcity contexts[1] presented here can provide valuable insights into water security triumphs and challenges.

Emerging Threats to Urban Water Security

Water scarce utilities must deal with emerging threats to their water security. Increasing and changing population patterns, including large population displacement, drive sharp increases in urban water demand, as witnessed across the Middle East and North Africa region, including Marrakesh, Morocco, and Amman, Jordan. Windhoek, Namibia, Malta, and Tucson, Arizona, offer cautionary tales of progressive depletion and deterioration of water resources availability and quality. Perth, Australia, is actively facing down drastic changes in hydrology due to climate change. Large water importers in Orange County, California, and in Singapore are constantly exposed to shifting priorities of their historic water providers. Murcia, Spain, and Las Vegas, Nevada, illustrate how utilities have to maintain appropriate political leverage within a basin to secure their allocations, despite being priority users.

PHOTOGRAPH 2.1. Sitting Near a Well Collecting Water

Source: Tomas Sennett/World Bank.

The complicated world of urban water supply is marked by challenges such as aging infrastructure, evolving service standards, and urban expansion. To address these challenges, "business as usual" for WSS service providers is generally framed by the following questions:

- How much water is allocated to the city and in which quality?
- How to produce and distribute safe drinking water, and how to collect, treat, and discharge wastewater at the lowest cost?

Unpacking conventional problems in the urban WSS industry is complex. If a city's water services are caught in a vicious cycle combining poor services, insufficient cost recovery, obsolete infrastructure, and inadequate sector governance, then the priority is to address these fundamental institutional and operational issues. These questions are further complicated by five emerging challenges that increasingly affect many cities around the world, are among the most threatening events to water supply security, and require new ways of thinking:

- Sharp increases in urban water demand
- Depletion and deterioration of availability and quality of resources
- Climate change
- Changing priorities in historical sources
- Competition with other users

In the following sections, each emerging challenge is illustrated by examples of how the cities studied for this report have addressed them.

Sharp Increases in Urban Water Demand

Increasing and changing population patterns are an important worldwide reality that most WSS providers are facing. Marrakech and Amman provide stark illustrations of how social, political, and economic dynamics can exacerbate already tense water situations and lead to drastic changes in urban water demand. In Lebanon, Jordan, and Iraq, major population influxes of refugees and internally displaced persons (IDPs) strain already water scarce cities. In such context of fragility, water insecurity can precipitate violence and conflicts (Sadoff, Borgomeo, and de Waal 2017; World Bank 2016).

Marrakech

In the water scarce city of Marrakech—located 100 miles inland on the foothills of the Atlas Mountains—sudden increases in water demand outgrew traditional resource availability. Over the past few decades, Marrakech has become a luxury holiday destination with over 10 million tourists visiting every year. As part of the booming tourism industry, a mainstay of the Moroccan economy, proposals for more than a dozen golf resort development projects posed a difficult water balance equation. Increasingly water-strapped, Marrakech decided to depart from the "business as usual" approach of setting its sights on distant water sources to meet escalating demands. Instead, the city developed an untapped and innovative water resource (wastewater) to meet the touristic boom in a water-safe manner. This decision also allowed the city to reduce its discharge of treated wastewater to the receiving environment.

Amman

Jordan is one of the most water scarce countries in existence, with constant water stress and historically poor water availability. Amman, its largest city, has experienced a sharp population increase due to half a million refugees. The city struggles to provide safe and reliable water supplies; yet despite the diligent efforts of WSS service practitioners and agencies, the gap between supply and demand for water resources for the approximately 700,000 subscribers continues to increase. While local water conservation and reuse measures have helped mitigate the water deficit, Jordan is planning a major regional desalination and water conveyance infrastructure to overcome this exceptional challenge.

Progressive Depletion and Deterioration of Water Resources Availability and Quality

The progressive depletion and deterioration of available resources beyond usefulness is one of the most common new challenges facing many cities. Two cases illustrate the experiences and efficient response to this situation: Windhoek and Malta.

Windhoek

Challenged by a climate characterized by extremes, WSS service providers in Windhoek are familiar with water insecurity. With increasing water demands from rapid population growth and escalating water use from competing stakeholder groups, and a depleting aquifer (the traditional water source), the Namibian water sector has faced unique water challenges over the past decades. In addition, Windhoek experiences multiyear periods of very low rainfall, making it even more difficult to secure safe and reliable water sources. Confronted with concrete and immediate threats to its economic development, Windhoek had to rethink water supply approaches. The WSS service providers brought to this corner of the African continent innovative solutions, such as extensive reuse of treated wastewater and advanced management of its aquifers.

Malta

The water scarcity story of Malta echoes that of Windhoek in multiple respects. The island of Malta, located in the heart of the Mediterranean, is one of the most water-stressed countries in Europe. With its semiarid climate, Malta lacks (a) significant perennial surface water bodies, (b) summer rainfall, and (c) exploitable surface water sources, all compounded by increasing demands and escalating use. In addition, Malta's groundwater resources have been severely depleted due to years of overexploitation and their quality reduced by decades of pollution from nitrates and high salinity from seawater intrusion. Water supply challenges have persisted throughout the island's history. As a response, the Maltese WSS service provider has demonstrated the importance of water use efficiency and resource diversification including desalination and stormwater capture when most conventional solutions are exhausted.

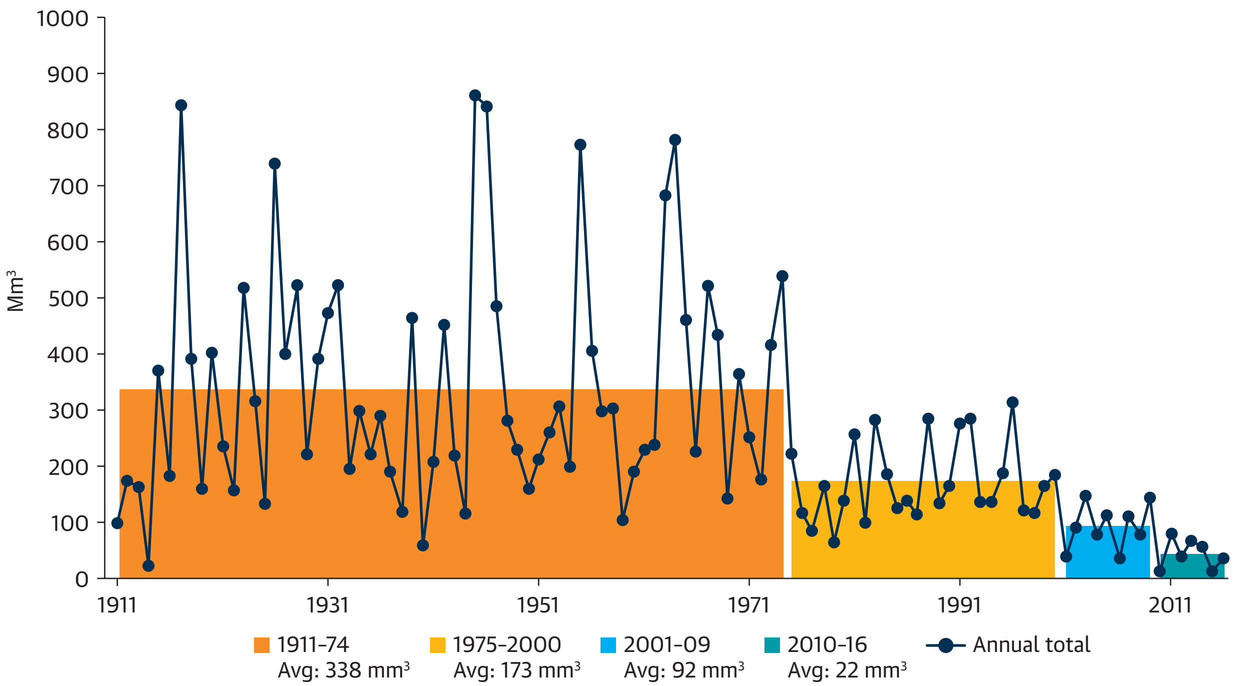
Drastic Changes in Hydrology Due to Climate Change

Traditional WSS service providers have found themselves at unanticipated setbacks in their development trajectory due to increasing climate change-related shocks and stresses.

Perth

Perth enjoys a Mediterranean climate with a population of more than 2 million people. Its location subjects it to an ongoing drying effect of declining rainfall

FIGURE 2.1. Streamflow into Perth's Reservoirs, 1911–2016



Source: Perth Water Corporation website (https://www.watercorporation.com.au/water-supply/rainfall-and-dams/streamflow/streamflowhistorical).

and reduced groundwater recharge. Perth has had a 20 percent reduction in annual rainfall as compared to the pre-1970 average, severely impacting its traditional sources of water (see figure 2.1). Further drastic reductions were experienced in the early 2000s and early 2010s, reducing streamflow into the city's reservoir to just 12 percent of pre-1970s' levels. In a climate that is hotter and dryer than ever before, WSS and water resources management agencies have been actively confronting the challenges approaches including policy responses, cooperation at different levels of government, and nontechnical innovation in water management.

Vulnerability When Historic Water Source Provider Shifts Priorities

Another vulnerability many cities face is when historic water providers shift priorities. Orange County and Singapore, for example, had to confront this issue with innovative responses and policy decisions.

Orange County

Orange County, with more than 3 million inhabitants in the arid southern edge of California, has relied since the 1960s on water transfers from Northern California to satisfy a large part of its water needs. When these historic source providers began to reconsider their allocations due to local emerging priorities, this dependence on distant water resources became a major risk to water security. In response, Orange County developed local programs to manage groundwater and stormwater, made possible due to changing technology and cultural drivers not possible half a century ago.

Singapore

In the early 1960s, the tropical city-state of Singapore signed two agreements with Johor, Malaysia, to ensure access to water resources. One of those agreements ended in 2011, and the other, which currently covers more than half of Singapore's water demand, expires in 2061.

The dependency of Singapore on Johor for its water supply has provided Malaysia with political leverage; in the past, there have been tensions over water. Driven by strong political leadership and a deep understanding of the island's reliance on water for its survival, Singapore is undertaking a profound transformation of its water sector and diversification of old and new sources, aimed at full self-sufficiency by 2060.

Power Play with Competitive Water Basin Users

The regional approach to water supply in Murcia illustrates shifting balances of power with competitive users in water basins. Despite often enjoying legal status as a priority user, cities such as Marcia can be subject to significant pressure from other politically powerful water users.

Murcia

Murcia is on the Mediterranean coast of southeastern Spain with a population of over 1.5 million. The irrigation sector plays a leading role in the region's hydropolitics. Water allocation from the primary local river has historically been granted to irrigators, prompting Murcia to search for water sources more than 200 kilometers away. In a context of increased water stress, the irrigation lobby has influenced the river basin authority to secure more water rights, leaving the urban sector with no option but to seek alternative water supply options. The city and other local urban centers responded by setting up an institution, the Mancomunidad de Canales del Taibilla, to help them garner political and financial support for infrastructure development and negotiations with irrigators under the auspices of the river basin agency.

Principles for Resilient Urban Water Scarcity Management

Water scarce utilities have to creatively adapt their practices despite a strong legacy of linear approaches and seemingly little leverage in complex water systems. Successful experiences point to five key principles. The priority must be to shift from a culture of abundant water to rationalized demand. Utilities should then hedge against a variety of risks through diversification of their resources. This includes securing local sources such as strategic aquifers, and increasing climate resilience by exploring desalination or wastewater reclamation—without precluding external recourses when needed. These principles come together in adaptive design and operations to cope with uncertainty and variability, as demonstrated by advanced approaches in Orange County.

Given present and future water challenges, and even more so in fragile or conflict-affected countries, urban WSS service providers now must creatively adapt urban water management approaches to changing environmental conditions and socioeconomic shifts. However, traditional WSS service providers may not have the culture and capacity to monitor, anticipate, and manage water insecurity, especially when its root causes lie far beyond city boundaries. To address these unchartered challenges, WSS service providers' first and most decisive step may be to internalize a broader set of guiding questions:

- How much water is needed for the city to thrive? How little water could it still thrive with?
- Are the current sources being used at a sustainable level? Are the current water allocations reliable on the long term, for how long?
- Is urban water supply resilient to climate shocks?[2]
- Do we consider these risks in our designs and have clear plans to anticipate and react to dry shocks?
- Are the mechanisms that govern water allocation to the city adequate and reliable? Is urban water supply vulnerable to increased pressure from competitive users?

In the face of the challenges faced by water scarce cities today, embracing these questions represents a shift in WSS service providers' water paradigm. This report draws from relevant experiences from around the world to describe how these questions were successfully addressed by water scarce cities and to extract several underlying principles to their strategies. Overarching these principles is the critical need for WSS service providers to have data on the fluxes of water inflows and outflows of a city and understanding their relative vulnerabilities. Such documentation of the urban water metabolism sets up the key principles[3] described in the following paragraphs.

Reducing City's Dependence on Abundant Water

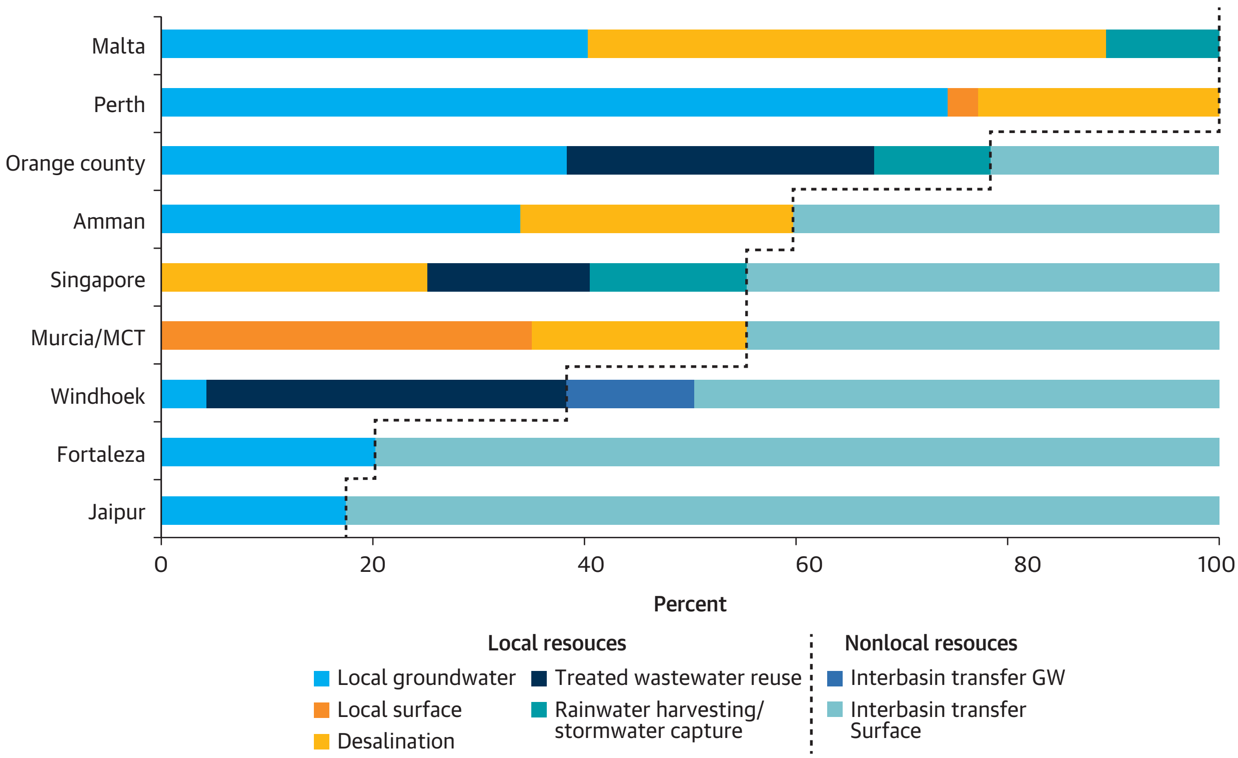
When cities facing water scarcity seek new water resources, demand management and improving system efficiency should be two of the potential sources to be tapped. Demand can be reduced through improvements in system efficiency and the reduction of losses, by incentivizing customers to reduce consumption, and changing consumption patterns or the source of water based on fit-for-purpose considerations. Droughts have provided key opportunities for such reductions, as shown by California's 25 percent statewide municipal water consumption decrease between 2014 and 2016, and Windhoek's ability to conserve 70 liters per capita per day (from 200 liters per capita per day to 130 liters per capita per day, respectively) during periods of severe restrictions. However, these efforts must go beyond drought response. Zaragoza, Spain, is an exemplar for demand management, with residential water use at 97 liters per capita per day in 2015 (overall consumption down 30 percent from 2000 levels). Other cities such as Málaga, Spain, Leipzig, Germany, or Tallinn, Estonia, have brought their water consumption down to below 100 liters per capita per day without reducing service quality, risking health, or negative reactions from their citizens. Efficiency measures further ensure a city is not wasting already scarce resources. Places like Singapore and Los Angeles, California, which depend on financially and politically expensive imported water, have reduced their nonrevenue water to lows of 5 percent. Politically, cities must also show good faith: the city of Fortaleza, Brazil, was asked by the river basin committee to show significant reductions in residential water demand and nonrevenue water before being allocated any water from other users.

Some cities have managed to grow and reduce residential water consumption at the same time. Since 1995, Singapore has reduced residential water use from 172 liters per capita per day to 148 liters per capita per day despite a tripling of its gross domestic product (GDP).

Hedging against Risks through Diversification

To bolster their resilience to shocks, cities must build diversified and dynamic water resource portfolios and make the best of available water sources through fit-for-purpose approaches that consider the needs of each type of water use. For instance, use of surface water and groundwater gives Windhoek flexibility since these sources respond to stress on different time scales. Singapore's four national taps and Murcia's multiple sources provide other good examples of balanced portfolios in which sources have different risk and cost profiles. Singapore's water supply system relies on a combine local catchment water, imported water, desalination, and wastewater reuse with the aim to become independent of imported water. In the Colorado River basin, Las Vegas has developed a robust portfolio that includes banked resources in three different states, which can be tapped if the city faces future shortages. Figure 2.2 illustrates the diversity of water resources portfolios adopted by a selection of water scarce cities covered in this study. This static representation does not reflect the contribution of the invisible resource, namely demand management, in cities such as Perth or Murcia. Nor does it illustrate the role that water reclamation for irrigation can play, unleashing additional surface water or groundwater allocations for

FIGURE 2.2. Water Resources in Several Water Scarce Cities, by Type



Source: Based on World Bank case studies.
Note: MCT = Mancomunidad de Canales del Taibilla; GW = groundwater.

the city (as in Amman and Malta). Economic models, such as the ones developed by the Cooperative Research Centre for Water Sensitive Cities (CRCWSC)[4] can help identify the optimal mix of resources in the portfolio, based on city resources and associated uncertainties.

Relying on Solutions that Are Not Vulnerable to Climate Change

In the face of climate uncertainty, cities can supplement other (local) sources with those whose availability is not subject to climate conditions. Due to overdraft and limited local recharge, Malta faced severe salinization of its aquifers in 1980, which led the water scarce island to invest in its desalination capacity. Today, up to 60 percent of Malta's normal consumption can come from desalination and is available no matter the drought conditions. Windhoek has responded to its arid climate and extreme interannual variability through investing in reclaimed wastewater. First implemented in 1968, it now supplies over 30 percent of its water use (potable and nonpotable). In the southwestern United States, wastewater reuse provides a resource that is, to some extent, climate-independent and is increasingly incorporated in cities' water portfolios for potable and nonpotable uses. Orange County recharges its aquifer with highly treated wastewater, thus improving groundwater quality and buffering low rainfall years. The West Basin Municipal Water District provides reclaimed wastewater to local parks and industries, which purchase it from the water district based on a menu of different levels of treatment.

Ring Fencing Water Systems from External Competition

Because cities often share their water resources with various stakeholders and sectors, their portfolios must include sources they can control without competition from other users. A starting point can be to view cities as water supply catchments—recognizing that water resources can, and should, be harnessed within the city boundary, including groundwater, reclaimed water, rainwater, and stormwater. Local, city-specific aquifers can be managed at the city level, which decreases vulnerability to other users' demands. In Windhoek and Perth, managed aquifer recharge is envisaged to stabilize and replenish groundwater levels while increasing autonomy. Tucson taps another generally underused local source: stormwater. Through rainwater harvesting infrastructure that mimics natural systems to promote infiltration, Tucson water managers ensure water can be collected and filtered for reuse, providing a locally controlled source for the city. Portfolio diversification with local sources has provided a similar respite for Singapore and San Diego, California, helping to free them from imported water in high demand from other users. In times of surplus, water banking schemes can allow a city to retain access to its full water rights while planning for future shortages. While cities should harness local sources within their span of control, they may also need to rely on external sources that involve large infrastructures or enter politically sensitive water-sharing arrangements between users.

Coping with Uncertainty and Variability through Adaptive Design and Operations

Many threats to urban water security identified in the previous section include unpredictability, stemming from political, economic, and—most acutely—climate factors. Infrastructure development programs that can perform well across a wide range of potential future conditions may be more advisable than solutions that are optimal in expected conditions but ineffective in conditions deviating from the expected (Ray and Brown 2015). Cities must therefore build scenario analysis and response into their water systems, so that they are equipped to deal with shortage situations before they escalate. While Perth draws about half of its potable supply from desalinated water, it leverages its network of dams to store excess water from desalination plants for use in higher demand periods or lower rainfall years, providing a fallback without increasing production excessively during dry years. Orange County manages its aquifer as a buffer in dry periods, leveraging stormwater, imported water, and reclaimed water for a diverse recharge strategy. In turn, water managers set allowances for their clients to pump water from the aquifer according to groundwater levels. However, all these principles cannot truly yield resilience if the city or county does not carry out drought planning to ensure there are planned responses—both structural and social—to different scenarios. In Spain, both Murcia and Barcelona have defined drought thresholds associated to different responses, such as changing the mix of sources used, restrictions, and emergency funding.

Notes

1. This report does not consider any strict definition of a water scarce city. It is broadly understood that it includes urban areas of any size subject to arid climate conditions and very limited freshwater availability per capita.
2. WSS service providers increasingly need to consider resilience to a broad array of shocks, including resilience to natural disasters, earthquakes, floods, and terrorist attacks.
3. Such fluxes overview framework can be open-ended to facilitate ongoing evolution in contemporary resources management within a city. Some cities have, for example, extended this framework to include water-energy nexus and water-food nexus.
4. See Water Sensitive Cities' website: https://watersensitivecities.org.au/content/hedging-supply-risks-an-optimal-urban-water-portfolio/.

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Piped water services brought to a periurban neighborhood near Meknès, Morocco. © Arne Hoel/World Bank.

Chapter 3
Demystifying the Solutions

To operationalize the principles outlined in previous chapters, water supply and sanitation (WSS) service providers can draw from a toolbox of technical, institutional and regulatory measures aiming at (a) stimulating water use efficiency and conservation practices; (b) making the best of existing surface and groundwater resources through innovative management schemes; (c) developing nonconventional water sources; (d) collaborating with other water users for an optimal allocation of available resources; and (e) adopting adaptive design and operation approaches. The following chapter offers examples and lessons from the implementation of such measures across water scarce cities identified through case studies prepared for this paper. These solutions are far more than technical in nature. Their adoption and implementation often require innovations at the policy, institutional, and regulatory levels and demand extensive consultation and communication efforts. The solutions are complementary and can be integrated for optimal results, as many of the case studies have shown.

Demand Management and Infrastructure Efficiency

Rationalizing water demand should target two potential problems: inefficient water networks that waste part of the water transported into leakages, and profligate water consumption. Utilities in Singapore and Malta use demand management as a pillar of their water security and have developed highly effective leakage reduction operations. Spain, Australia, and California have demonstrated that conjunctive conservation measures such as rules and restrictions, water pricing mechanisms, education, and public outreach can effectively dent high water consumption levels when appropriately designed and implemented.

Improving Water System Efficiency

Efficiency improves water supply reliability—in addition to reducing costs—through technological, infrastructure, and regulatory improvements. In conventional systems, efficiency measures that focus on reducing network leakages can stretch a finite water allocation to serve more users and avoid the need to expand the system or negotiate a larger water allocation. In the Spanish city of Zaragoza, investments in network renovation and infrastructure improvements reduced raw water use by almost 20 percent between 2001 and 2006. In Murcia, Spain, the WSS service provider has reduced leak detection and repair time to 2.5 days through hydraulic zoning and microsectorization. Nonrevenue water is now under 14 percent, compared to 40 percent in 1975.

A system's economic level of leakages, below which the marginal cost of reducing leakages outweighs associated economic benefits, is highly context-dependent. A long, iterative process is needed to identify its value and clarify the real scope for water savings. Nevertheless, in most cases, leakage reduction targets could be set well below 20 percent. Considering the current levels of nonrevenue water of 167 WSS service providers in water scarce areas as shown in figure 3.1 (and even if those figures often include a share of commercial losses), maximizing network efficiency appears as a priority option to bridge the gap between water supply and demand.

To be implemented successfully, such programs require technical and operational know-how, which knowledge exchanges between utilities have proven helpful to build. For example, in Lebanon, water savings are critical in summer when water resources are limited. Following an exchange between the Malta Water Corporation and the Beirut Mount Lebanon Water Establishment, a pilot program in Beirut led to massive water savings and achievement of 24/7 water service.[1] This pilot is now being expanded by the water establishment through a performance-based contract, which should bring additional utility expertise and allow the entire city to participate in a few years. A similar experience in Jaipur, India, proved that not only 24/7 supply can be achieved but also that nonrevenue water (here in particular physical losses) can be drastically reduced with limited resources.

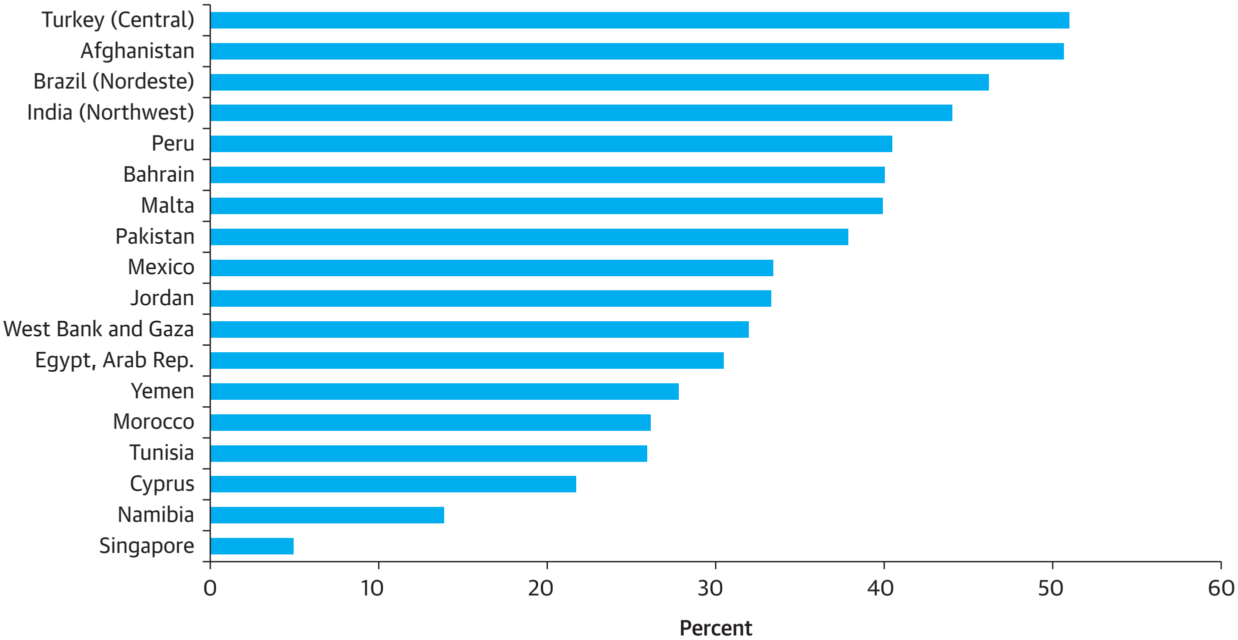
Promoting Water Conservation

As for network efficiency, inferring achievable water conservation targets can be challenging, but benchmarking with other cities can help, at least the residential dimension of water consumption. Out of 111 water scarce cities covered by the International Benchmarking Network (IBNET) or included in the present study, a majority shows residential consumption levels between 65 liters per capita per day and 125 per capita per day. Outliers include countries at both ends of the economic development spectrum, such as Singapore and the Republic of Yemen. They also include less predictable cities in Mexico, Pakistan, or Namibia, as shown in figure 3.2.

Conservation measures are typically mandatory or voluntary. Mandatory measures are rules and restrictions that water users must adhere to by law or be penalized, such as withdrawal limits and consumption rates. Voluntary measures encourage water users to reduce their water usage but do not legally bind them, and include education schemes, media campaigns, and monetary incentives. The following sections introduce these different types of instruments and examples of their application.

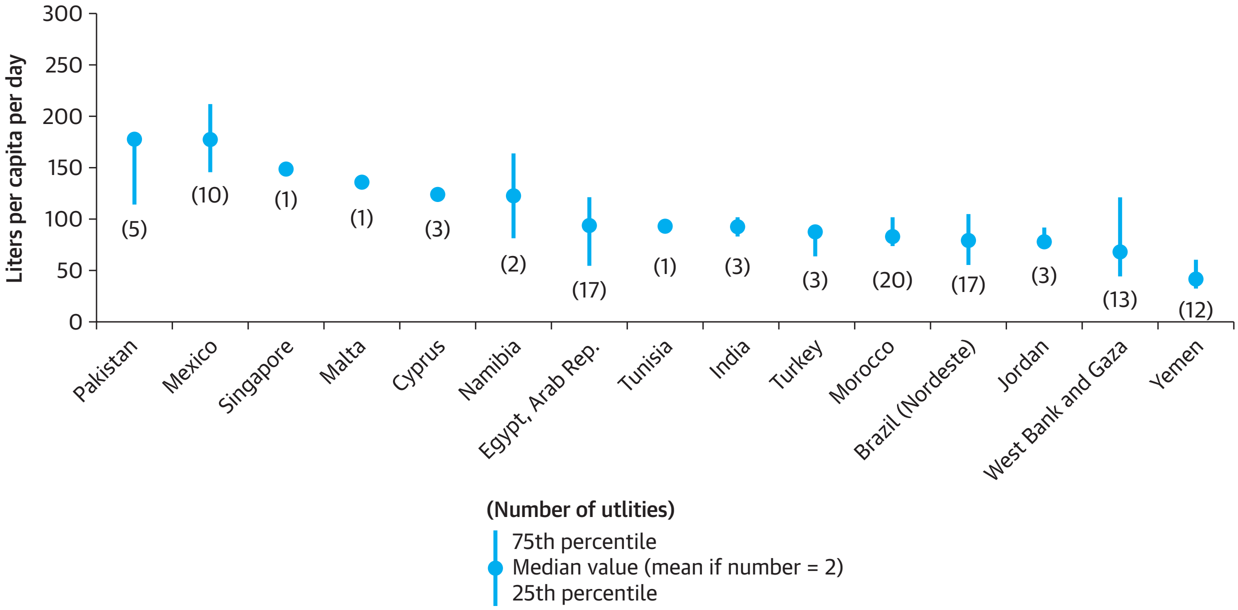
Rules and restrictions tend to be more effective tools in managing short-term supply shortages because they prompt immediate actions from customers.

FIGURE 3.1. Average Nonrevenue Water in 167 Urban WSS Utilities Aggregated in 18 Water Scarce Countries and Regions



Sources: IBNET; World Bank.
Note: These figures include both physical and commercial losses. WSS = water supply and sanitation.

FIGURE 3.2. Residential Water Consumption in 111 Water Scarce Cities



Source: IBNET.

In California, in response to a drought, Governor Brown mandated that the state achieve 25 percent conservation by 2016. The State Water Resources Control Board then allocated conservation responsibility among the state's water agencies to total 25 percent statewide conservation in municipal areas. Despite perceptions that the distribution of responsibility was not always fair, results were impressive with a cumulative 24.5 percent statewide reduction achieved compared to 2013 consumption levels. However, now that the mandatory conservation has been lifted and responsibilities for goal-setting has been shifted back to the water agencies, there is debate about whether these achievements will be maintained over time. Other examples, such as in Australia,[2] have shown that the elasticity of social norms have been broken and that a lower water consumption could be sustained following restriction.

One key to having the community accept of restriction programs and maintaining the responsible agency's standing with customers is the demonstration of agency fairness and equity. In Brisbane, Australia, where the community was suffering from restriction fatigue after two years of water restrictions, residents expressed that they could not save any more water. In addition, they were under the impression that businesses, not residents, were responsible for the largest consumption of water in the region. Due to this lack of belief that an individual could make a difference, opinion of the water agency was quite low when it proposed further restrictions. Regular communication about the ways in which the drought affected the city and what customers could do about it helped alleviate negative perceptions and tensions.

In the most successful cases, such as in Melbourne and Perth, Australia, well-designed restriction programs are eventually recognized by the community as good water use practices rather than as constraints.

In Perth, restrictions on fixed sprinkler systems have shown good results as part of emergency contingency planning. However, in response to concerns from the nursery, reticulation, and turf-growing industries on the potential damages of garden watering restrictions, the Water Corporation worked with these actors to devise a two day per week roster for garden watering by sprinkler systems. The roster system provided significant water savings while preventing more severe restrictions, without damaging gardens and lawns. It was accepted by the government and the customers and implemented as a "good watering practice." In Melbourne, an extensive public campaign based on detailed behavioral science principles helped halve per capita consumption compared to its early 1990s level (Melbourne Water 2017).

Incentives provide flexibility in that they invite the community to participate in conservation efforts through modifications in their own space and habits. In Las Vegas, Nevada, the successful Water Efficient Technologies program provides financial incentives to commercial and multifamily property owners to install water-efficient devices that save at least 250,000 gallons[3] annually (for example, through high-efficiency toilets and showers, lawn replacement for sport fields, or cooling system retrofits). Arizona's Tucson Water approaches the problem by offering households tax incentives and rebates to install rainwater-harvesting infrastructure in their homes. Customers are encouraged to shift part of their outdoor water use to from potable to rainwater, which offers a better fit for that type of water use. In California, drought-proof landscaping is now incentivized by most water districts through rebates on lawn replacements with gravel and succulents, as well as plant donations.

Water pricing is a very effective management tool to reduce water consumption. Numerous surveys and studies have shown the negative relationship between price and consumption, with increases in the price of water by 10 percent typically leading to declines in water consumption by less than 10 percent (Grafton 2010). Some studies, however, have suggested that demand may be more responsive to price in the long run, but that better short-term results in an emerging water crisis could be achieved with restrictions (O'Dea and Cooper 2008).

In Zaragoza, Spain, an increasing block tariff binomial structure is applied to communicate the value of water to their customers. For the first 6 m^3, the tariff is 50 percent below production costs, while for the highest consumption blocks it is five times higher than the lowest blocks. In addition, efficient water use is encouraged by reducing by 10 percent the price of water for those families that reduce their annual consumption by more than 10 percent.

One of the common arguments against using increasing block tariffs is that they impose a disproportionate burden on households with many members or on several households that share a common connection. To avoid equity issues, especially for larger households, Singapore introduced a four-tier approach, in which families with over two members have a higher volume in each tier, with rates for all tiers remaining the same. Similarly, Malta's first block volume is based on the number of persons registered as living in the household, with the second block being charged at a tariff five times larger than the first.

In Irvine, California, the Irvine Ranch Water Department (IRWD) has separated commodity (40 percent) and fixed (60 percent) service charges[4] to ensure that even when water demand declines, IRWD still recovers its costs. The commodity service charge is assessed through a customized monthly water budget for each customer account based on several factors, including landscape square footage of the property, number of residents, daily weather, and evapotranspiration. Water is sold to customers under a four-tiered structure adapted to their monthly water budget. As a result of the strong economic signal provided with the rate structure and the proactive customer outreach, water consumption has decreased significantly, and fewer than 3 percent of residential customers currently pay the highest tiers' charges. In general, pricing signals such as tiered-rate structures seem more efficient than traditional conservation measures (such as a state conservation mandate).

PHOTOGRAPH 3.1. Awareness Campaign in Las Vegas

Source: Las Vegas Valley Water District.

Such seasonal changes can help better reflect water availability during the year, but may have limited impact on long-term behavior change. In addition, changes in water prices must be communicated to consumers with some frequency, thus increasing transaction cost and the potential for confusion. During periods of drought, a drought surcharge can be applied, as was done in California in the recent drought and is foreseen in South Africa. In Los Angeles, California, shortage-year rates are implemented, during which the switch point between the first and second tiers is reduced to encourage additional water conservation and to offset any revenue losses resulting from lower consumption periods.

Another approach to convey water scarcity to customers is seasonal pricing, whereby regular increases and decreases in tariffs constantly remind consumers of the need for conservation, compared to constant conservation charges year-round.

Education and public outreach are a central part of any conservation campaign in a water scarce urban area: public communication efforts help ensure customers of all ages, as shown on photograph 3.1, understand the implications of water use in a dry area and secure community buy-in. They can make more draconian conservation measures seem socially responsible, and they may lead to behavioral changes that can result in long-term reductions. Furthermore, having an ongoing and evolving outreach effort with stakeholders provides a communication channel about conservation needs and decisions, a way to communicate to customers what they can do, receive feedback, and source ideas for new programs from stakeholders.

In Las Vegas, Nevada, a survey conducted prior to implementing conservation measures has found that people overwhelmingly supported the program, and that their main concern was that these changes be rolled out in an equitable manner. The Las Vegas water utility, Southern Nevada Water Authority (SNWA), hosts the annual WaterSmart Innovations Conference and Exposition—the world's largest water conservation-focused conference—which connects entrepreneurs to water agencies and potential partners. Through local partnerships, SNWA encourages businesses and other stakeholders to promote water conservation in the sector.[5] These platforms promote regular exchange between the SNWA and local water users and inform the evolution of their water conservation measures. Similarly, Zaragoza supported the creation of an association to connect industry players, researchers, and administrations to promote efficient water use. Stakeholders have supported this collaborative approach to the development, approval. and implementation of water-saving policies. Because of their detailed knowledge of the local water use portfolio, local agencies seem to be more effective and better placed than regional or state entities to implement conservation measures.

Water bills are another important communication tool to the customer for the success of any pricing mechanism in promoting water conservation. They bring attention to the link between water consumption and monthly expenditure, and they are a regular platform that links the service provider to customers. Zaragoza uses the bill to detail the efficiency-promoting tariff, and employs persuasive graphs and images to convey information on consumption levels and past trends and to encourage savings. Figure 3.3 shows the difference between bills for efficient and inefficient water use in IRWD, which enables a quick assessment of the benefits of conservation to customers.

Water authorities can use drought and dry periods as policy windows to implement new water conservation strategies. In Cyprus and Barcelona, Spain, the image of tanker boats delivering water to the harbors in times of water shortage are burned in the public's mind as symbols of drought impacts. Crises are important triggers for behavior change since they instill a sense of urgency and realization in citizens' minds. Since perception of the problem's importance is essential for customers to actively want to conserve water, cities should not let a good crisis "go to waste." Dynamic pricing (seasonal adjustments) can be a valuable tool for regulating demand during periods of high deficit. For instance, it is suggested (Grafton 2010) that Australia could have saved large sums of money wasted in idle desalination plants if it had used flexible pricing strategies that reflect supply conditions.

One challenge of using such policy windows is that once customers perceive that the situation has improved, their efforts may relax and consumption levels could

FIGURE 3.3. Residential Customer Bill Sample Comparison

Bill # 1 - The Inefficient Customer (55 m³)

Dates of Service	Meter Reading		Units Used
7/10/17 – 8/09/17	3550–3605		55 m^3
USAGE - LOW VOLUME	14	$0.48	$6.72
USAGE - BASE RATE	16	$0.60	$9.60
USAGE - INEFFICIENT	11	$1.44	$15.84
USAGE - WASTEFUL	14	$4.26	$59.64
WATER SERVICE CHARGE			$10.30
SEWER SERVICE CHARGE			$25.75
Your water budget for this bill	30 m^3		
Bill calculation based on	1214 m^2		
TOTAL WATER & SEWER CHARGES			$127.85

Bill # 2 - The Efficient Customer (30 m³)

Dates of Service	Meter Reading		Units Used
7/10/17 – 8/09/17	3550–3580		30 m^3
USAGE - LOW VOLUME	14	$0.48	$6.72
USAGE - BASE RATE	16	$0.60	$9.60
USAGE - INEFFICIENT	0	$1.44	$0.00
USAGE - WASTEFUL	0	$4.26	$0.00
WATER SERVICE CHARGE			$10.30
SEWER SERVICE CHARGE			$25.75
Your water budget for this bill	30 m^3		
Bill calculation based on	1214 m^2		
TOTAL WATER & SEWER CHARGES			$52.37

Source: Irvine Ranch Water Department.
Note: For a residential customer using 30 m^3 of water, the average monthly increase in the water and sewer bill is $1.05.

increase again. Windhoek, Namibia, officials have expressed that maintaining some of the savings realized during periods of intensive restrictions has been difficult, especially when followed by a period of good rains. Their approach includes constant media communication with customers to share the understanding that drought conditions continue despite short rain periods. Through wide political and social mobilization, they hope to achieve a lower overall average consumption, in the region of 150 liters per capita per day.

Conservation messages must recognize and align with what customers are already undertaking, and therefore must evolve as drought conditions prolong. In Queensland, Australia, while prior water restrictions focused on outdoor water use, the Target 140 campaign focused on indoor use, specifically the four-minute shower. By identifying one key consumer behavior to address and campaigning heavily around this change strategy, officials were able to personalize the problem and individualize the solution. Feedback to the community became an important feature of the campaign by providing information to households on their performance against the 140 target, congratulating them or encouraging them to try harder (Walton and Hume 2011).

Building on Conventional Approaches: Innovative Surface and Groundwater Management

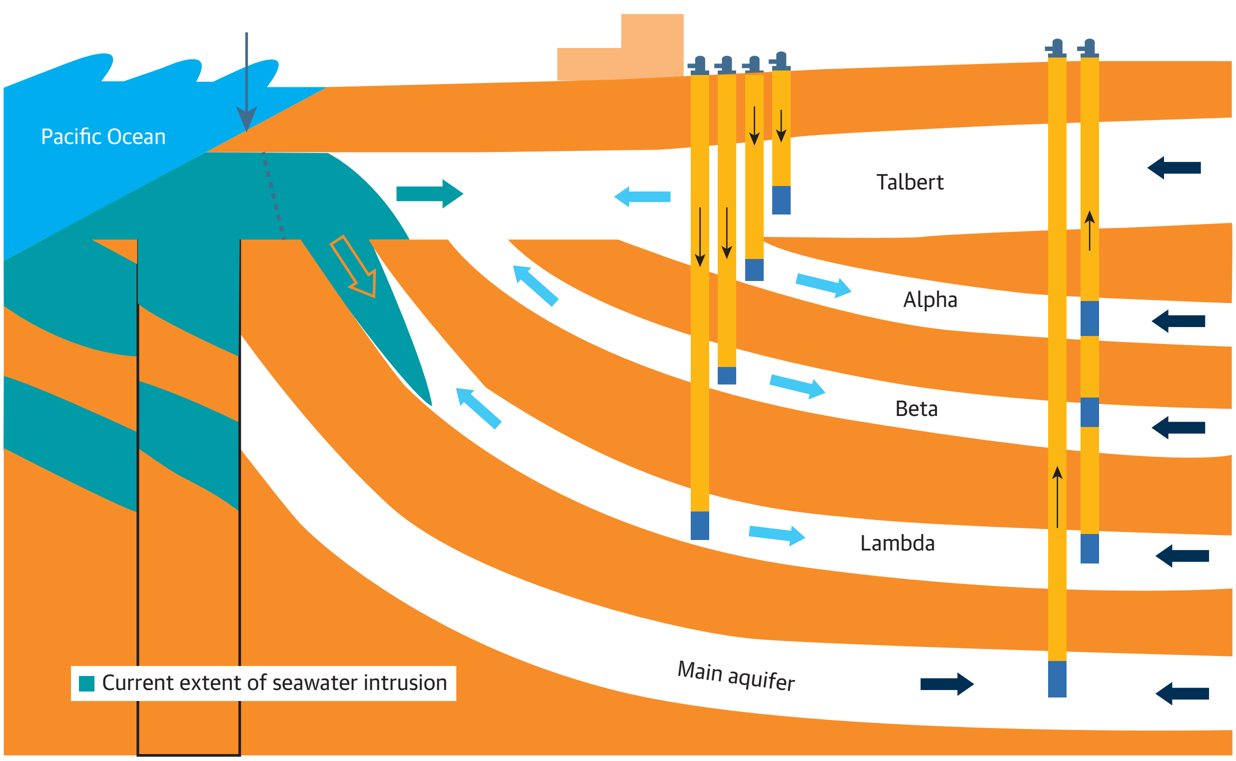
Conventional systems draw from the traditional water sources of surface water and groundwater. These are often seasonal and highly climate-dependent, and many show declining outputs over time. While cities move on to other resources once these are depleted, water scarce places such as Orange County, California, Tucson, and Windhoek have shown how diversifying resources can conjunctively replenish and optimize groundwater storage for long-term water security. Furthermore, cities in Nevada, California, and Arizona are pioneering water banking schemes and virtual water transfers that enable the optimization of ground and surface water storage and flows across complex large-scale water systems.

Optimizing Groundwater Management

While not present under all cities, aquifers are reemerging as the key element in developing an integrated approach to urban water security. A significant proportion of the cities in water scarce areas originally developed on the basis of extensive groundwater resources. However, over time these resources were overexploited or polluted, and with coastal cities, subject to seawater intrusion. As a result, cities became increasingly dependent on imported water provided from distant reservoirs through major conveyance infrastructure. Recently, a number of cities, including Windhoek, have recognized the threats to external supplies of water resulting from competition during drought years and, in some cases, threats to conveyance infrastructure from natural and human-made disasters. As a result, they have focused on rehabilitating their underlying aquifers. These aquifers serve as safe water storage, and when used with grey and green wastewater treatment infrastructure, become part of the water treatment and reuse cycle. Hence, the health of the underlying aquifer is often seen as an indicator of the health of the urban water management system.

The conjunctive use of surface and groundwater, including groundwater storage, has advantages under conditions of extreme variability: they respond to stress on a different time scale, and groundwater storage reduces evaporative losses. Leveraging aquifers' large storage capacity can provide an economical alternative to the expansion of water production capacity or surface storage infrastructure. The Orange County Water District (OCWD) provides an example of sound aquifer management along these lines: the utility operates the aquifer as a reservoir to withdraw or store water and buffer alternating periods of drought and water availability. The OCWD initially balanced natural recharge and injection of imported water to reduce costs and protect the aquifer from saline intrusion, as illustrated in figure 3.4. Now the water district has added new sources such as stormwater flow and highly

FIGURE 3.4. Aquifer Recharge to Protect Coastal Aquifers from Saline Intrusion and Increase Yield



Source: Orange County Water Department.

treated wastewater to that recharge portfolio, using innovative techniques to maximize infiltration as shown in photograph 3.2. A similar scheme using reclaimed water for local aquifer recharge and direct potable reuse is being implemented in Perth.

Unlike surface water shortages, declining groundwater levels are not immediately visible and require closer monitoring to avoid overdraft. Optimizing aquifer management should therefore occur with the development of a clear urban water metabolism framework to account for the stock and flows, and—in turn—sound groundwater governance and regulations. Malta's water company launched a program to register and measure all abstractions, going to the extreme of providing users with the meters and the management tools to monitor withdrawals. In Tucson, Arizona, pumping groundwater is regulated by permits, whose delivery is subject to strict conditions in terms of quantity and reason for use. In those cases, a strong monitoring and enforcement system needs to be in place. The Arizona Department of Water Resources even prohibits new developments unless sufficient and adequate supplies of water for 100 years are demonstrated. Orange County has

PHOTOGRAPH 3.2. Inflatable Rubber Dams Used to Maximize Groundwater Infiltration, Orange County, CA

Source: Orange County Water Department.

introduced financial incentives to encourage local WSS service providers to pump groundwater within a target range: OCWD establishes the percentage of each service provider's total water supply that should come from groundwater—the rest being purchased as imported water, which is more expensive. If water service providers pump above the defined percentage, they are charged a fee calculated so that the cost of groundwater production equals the cost of imported water.

Good local governance and strong coherence of water, energy, and food policies are key to the efficiency of these programs. In some cases, water sector and urban regulation, as well as traditional practices, can represent a major obstacle to their effective implementation. In Lima, Peru, the water utility cannot legally enter private properties to measure water usage and flow from wells located on owners' lands. As such, they cannot report groundwater use to the National Water Authority, and both entities lack the tools and legal backing to execute their regulatory mandates.

Finally, several experiences have shown that local governance, through the inclusion of all relevant stakeholders, can be an important tool to improve groundwater governance. For example, Morocco's groundwater management contracts, such as the Sous Massa contract, are established with a limited number of stakeholders, at a small scale, and promote participatory management of local groundwater (similar experiences have also been successfully implemented in the Republic of Yemen). The effectiveness of this approach depends on multiple factors including the existence of a governance system and the size of the contract, and requires upstream communication and awareness of the groundwater situation. Furthermore, stakeholders need to agree on water uses for the group and must rely on an adequate system to keep users involved, and adapt to new users or changes in the use of groundwater.

Water Banking and Virtual Transfers

Water banking has emerged as another solution to save unused allocations while ensuring availability for future drought years. Surplus water from one year can be stored locally—to avoid evaporative losses—in an unconfined aquifer, withdrawn in subsequent years by the "banker," and transferred to supplement the water resources of the "client," as illustrated in figure 3.5, panel a. Transfers can also be done through exchange deliveries, by which an entity upstream takes surface water from a reservoir or aqueduct and the water bank extracts and returns the same amount downstream, as schematized in figure 3.5, panel b. Most examples of this approach have evolved in southwestern United States: legal frameworks controlling water ownership and specific geological conditions and extensive infrastructure have allowed it, particularly in the Lower Colorado River basin, where storing water in a surplus year prevents holders of water rights from losing that apportionment in the future. The SNWA, for example, banks water in the Las Vegas Valley aquifer, in Arizona and in Southern California, for a total capacity of 2,220 million m^3 that it plans to keep available to respond quickly to future shortages.

Another tool is "virtual trading" or exchange of resources within a river basin. By spreading its banked water across three states of the Lower Colorado River basin, the SNWA has bolstered its resilience to localized droughts in the region and can choose where to withdraw water from in the future. Because the SNWA is upstream on the Colorado River from California and Arizona, these banking agreements can be considered as "virtual transfers," similar to the exchange delivery scheme but across state boundaries. When the SNWA decides the need to withdraw the banked resources, it notifies the Arizona Water Banking Authority (AWBA) and withdraws the water upstream from a reservoir on the Colorado River. Then AWBA pumps an equivalent amount out of its aquifer in Arizona and returns it to the canal for downstream use. The water isn't physically pumped back from Arizona to the SNWA; instead, a virtual transfer takes place along the river system. Such arrangements can help make innovative use of the large infrastructure and water rights systems in such areas. In Murcia, Spain, the river basin authority allows users in different points of the basin to exchange resources "not used" from the established allocation in drought periods. These can then be returned later to the system, without a physical

FIGURE 3.5. Water Banking Schemes

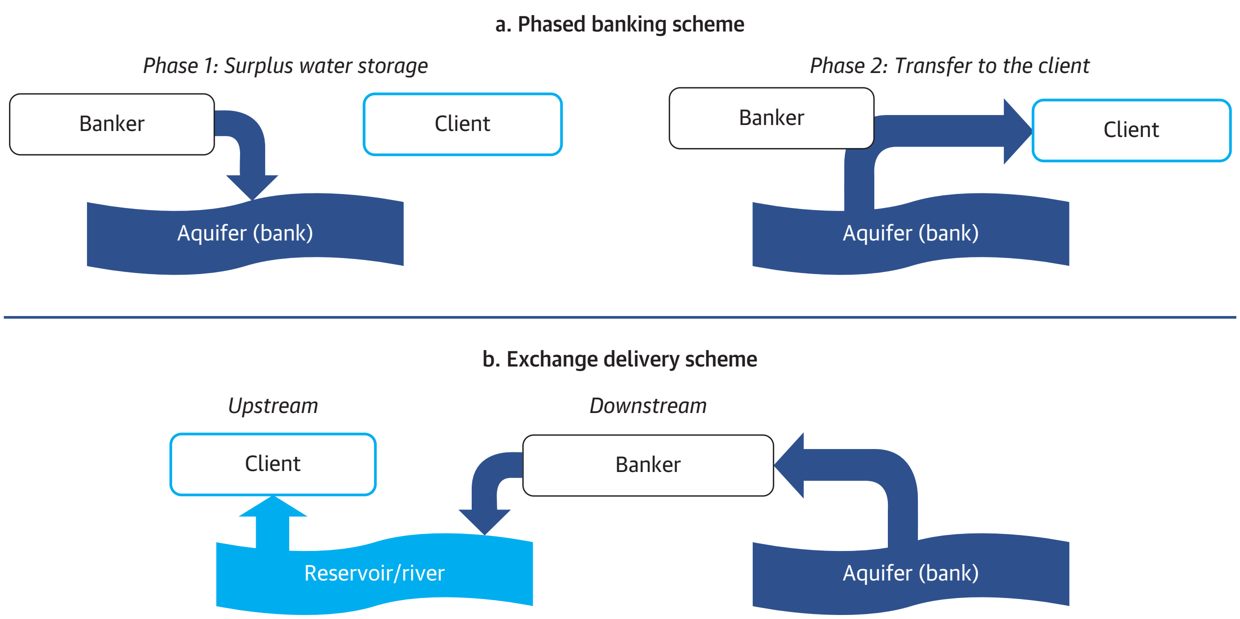
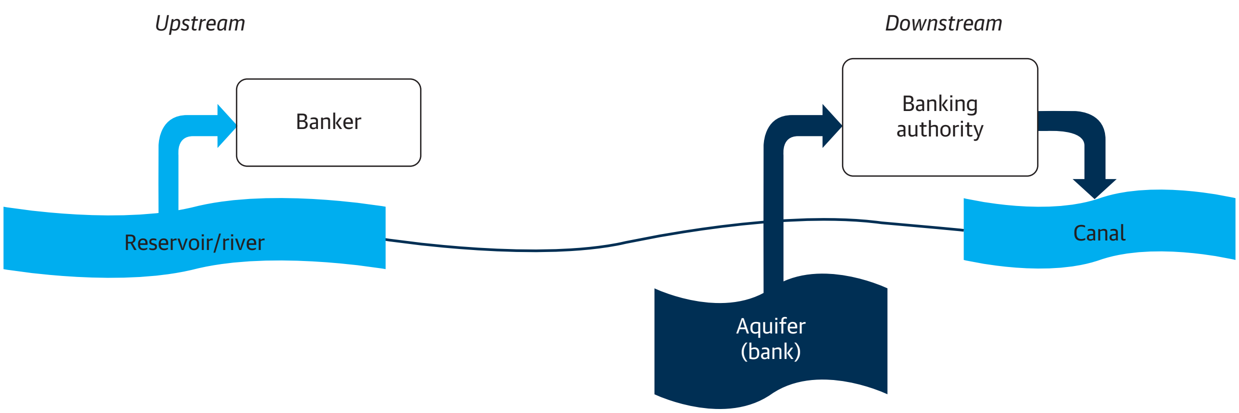


FIGURE 3.6. Virtual Transfer Scheme



link between them for such transfer, as illustrated on figure 3.6.

Experience from California and Murcia shows that stored water best comes from sources hydraulically disconnected from the banking area. When the two parties involved in a water banking agreement are in the same river basin, drought conditions are likely to enhance water demand from the client and the banker simultaneously. In Kern County, California, the water bank generally uses the market value of water to establish the stored water price. For third-party water users outside of the county, the cost increases depending on the local hydrological conditions. In contrast, the water banking agreement between the SNWA and the AWBA allows for a higher recovery (abstraction) rate during a declared shortage on the Colorado River. Similarly, Murcia's Mancomunidad de Canales del Taibilla (MCT) can tap reserve sources (aquifers on the upper basin) during drought periods and return these used resources by lowering its abstraction in more plentiful periods.

Nonconventional Water Resources: Waste, Storm, Sea

In the face of drought and increasingly scarce conventional water sources, several cities have begun to diversify their water portfolio by adding nonconventional sources. They are either incorporated by increased local capture, such as stormwater in Los Angeles or Tucson, or "sponge cities" in China (in which green infrastructure enables the management, filtering, and retention of stormwater), or are generated by new technological advances such as wastewater reuse and desalinated seawater. Indeed, advances in membrane filtration and energy recovery are increasing the attractiveness of indirect or even direct potable reuse, which are pioneered in places including Orange County, San Diego, Windhoek, Singapore, and India. These provide more flexibility, particularly in the face of climate change. Their optimal use can be supported by a fit-for-purpose use philosophy and corresponding infrastructure, which can promote energy efficient and low-cost local water sources for nonpotable uses.

Stormwater Management and Rainwater Harvesting

Urbanization and urban development have had significant impacts on the permeability of the surfaces of most cities and thus have generally increased runoff and reduced groundwater recharge in urban areas. Most cities have implemented separate drainage systems that convey stormwater runoff directly to a nearby water body. These systems try to avoid the problems faced by those that rely on combined sewer systems and experience overflows when strong rain events affect the area. In general, stormwater is perceived as a form of wastewater, to be disposed of, though it presents different quality characteristics from sewage. It does not include human waste and therefore generally requires less treatment to achieve the quality required before being used as an alternative water source.

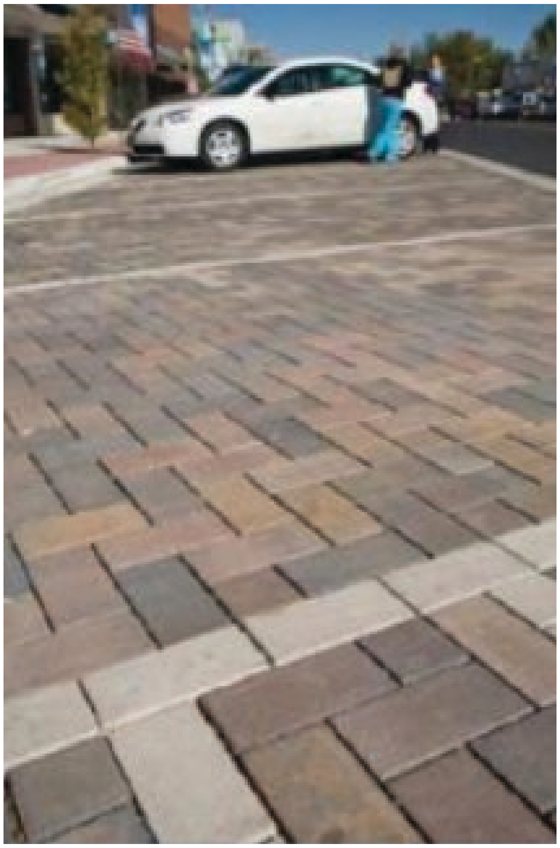
The southwest city of Los Angeles provides a good example of how the consideration of stormwater has changed. Flood mitigation was the only motivation behind Los Angeles' stormwater management efforts initiated as early as 1915. Through an elaborate system of concrete channels, storm basins, and drains, the rivers and creeks in the county's urban areas were contained with a straight path to the ocean and larger rivers, without consideration for the significant pollution loads of stormwater[6] or the value of these flows as a potential water resource. Recognizing and trying to mitigate the negative impacts of the pollution load of these runoffs on the environment, the California State Water Resources Control Board and the Los Angeles Regional Board developed in 1990 a stormwater permit system for different sectors, mandating that cities, industries, and farmers control pollution in runoff generated in their areas. Since runoff doesn't follow city boundaries, the 88 cities in Los Angeles County were given the option to carry out stormwater planning with other cities of the same watershed or with the county to maximize the impacts of their projects and pool funding. With the institutional setup provided by these plans and the treatment capacity installed to control pollution, the city and the county are now looking into the best ways to capture these resources through aquifer infiltration and other methods, closing the circle from flood mitigation to utilization of the resources.

Tucson has implemented two different approaches to improve stormwater management: low-impact development and green infrastructure. Low-impact development modifies land to mimic predevelopment hydrology and help maintain infiltration and drainage while reducing the runoff of pollutants into washes, rivers, and groundwater (Pima County, and City of Tucson 2015). Examples include swales and xeriscape (landscape that requires little or no irrigation); these are often incorporated as part of initial planning stages. In comparison, green infrastructure uses structural developments, such as cisterns and filters, to achieve the same objectives. These may include rain gardens or landscape designs that collect, distribute, retain, and filter water; rain barrels that hold harvested water for later use; or green streets that incorporate features of rain gardens along roadways (U.S. EPA 2009), as shown on photograph 3.3. These approaches allow for the capture and channeling of stormwater through natural systems, which avoids excess contamination while ensuring water can be collected and infiltrated for reuse.

Many cities faced with increasing water shortages have looked back to an old source: rainwater catchment and storage, generally referred to as "rainwater harvesting," for later use, normally implemented at the dwelling scale. Tucson has launched several such initiatives with mixed results despite substantial financial incentives. Singapore's water utility is considering making rainwater runoff capture mandatory from all new housing development. Jaipur has regulations that require rainwater capture for all buildings whose roof surfaces are more than 300 square meters. Malta building codes mandate the installation of rainwater collection and storage in all buildings to recycle this rainwater as greywater in the home (for toilet flushing) or to be used outside the home (such as for gardening), following an old tradition in the island (and most Mediterranean areas). In China, where over half of the cities are considered water scarce, the government has successfully launched the concept of "sponge cities," in which green infrastructure enables the management, filtering, and retention of stormwater, thus significantly reducing the impacts of recent floods in the pilot cities of Xiamen and Wuhan. In these examples, PHOTOGRAPH 3.3. **Green Infrastructure, Tucson, Arizona**

a. Xeriscaping to capture and infiltrate stormwater

b. Low-impact development of pervious pavement

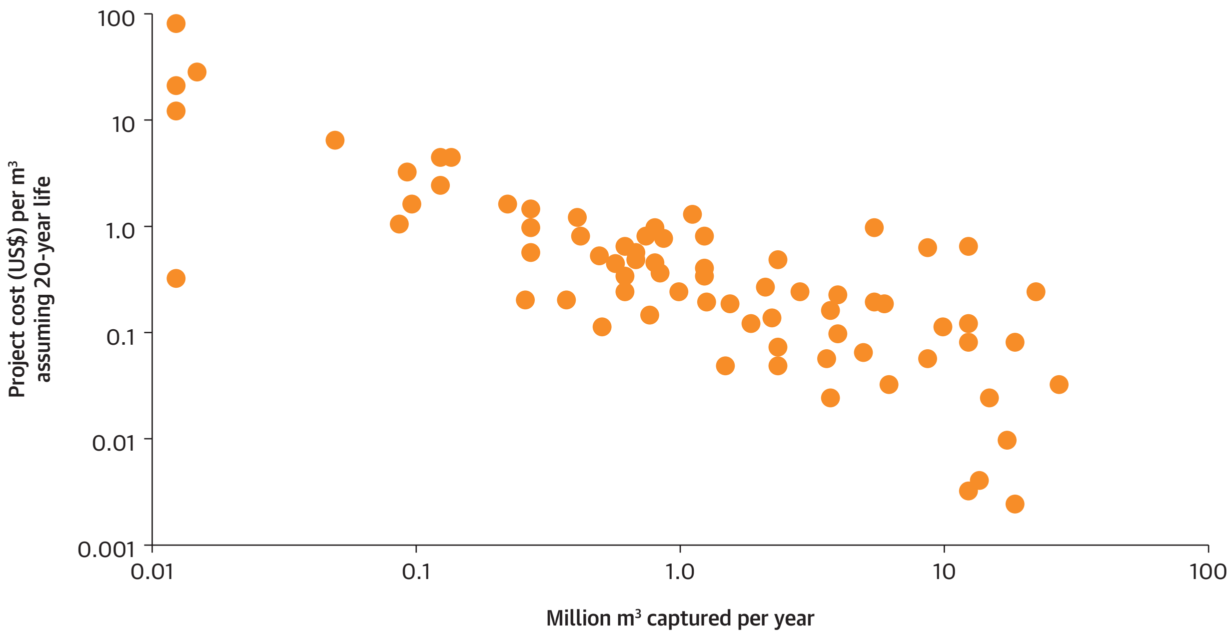


Source: City of Tucson.

rainwater is collected and treated to standards that allow its reuse instead of being dispatched to the ocean, evaporated, or polluted further once incorporated into surface runoff, with the added advantage of reducing runoff volumes and flooding.

The capital cost of such programs remains a barrier, and mixed results on cost-effectiveness have led to varying levels of political support. However, this barrier is largely attributed to current economic valuation of stormwater and rainwater harvesting projects being limited to the assessment of water as an undifferentiated commodity. Instead, the multiple benefits associated with distributed stormwater and rainwater harvesting systems, including property value capture and nonmarket values (such as enhancement of microclimate and resilience to increasing heat wave conditions, and reduction of sewage overflow), should be systematically included in its economic valuation. From a financial perspective, larger projects tend to yield better returns, with costs per m^3 over a 20-year life decreasing as the size of the system increases (with best results over 10 million m^3 captured per year), as illustrated on figure 3.7 (Atwater 2013). Further economic evaluation, including a broader inventory of projects benefits, would need to be carried out to confirm the comparative advantage of larger infrastructure projects.

FIGURE 3.7. Comparison of Unit Cost of Stormwater Capture Projects to Their Scale



Source: Atwater 2013.

Tucson's water utility experience illustrates the comparative advantages of active and passive rainwater harvesting programs: the net benefits of the active rainwater harvesting rebate program could not be shown to be demonstrably high, while in fact this program generates the greatest expense out of the eight water conservation rebate programs of this city (Davis 2014). Further, since the program is financed as part of the conservation fee, which grew by 40 percent in 2012 when rainwater harvesting was introduced, customers have expressed discontent regarding the overall fee increases and have questioned its cost-benefit balance. In contrast, passive approaches, including infiltration trenches, xeriscape swales, and water harvesting basins (often referred to as "groundworks"), have been shown to provide social and environmental benefits that outweigh more than 50 percent of their associated costs (Pima County and City of Tucson 2015). Indeed, passive approaches improve the area's tree canopy, which has been shown to reduce electric bills for cooling and the cost of irrigation, two critical household expenses in Tucson in the summer. These results indicate that passive approaches, with less participation by individuals and behavior change requirements, may be more cost-effective for cities to put in place.

As with other nonconventional sources, stormwater management and rainwater harvesting often lack an institutional home among city stakeholders, especially since these sources are intersect among the functions of local governments, public health agencies, water resource management agencies, and WSS service providers. This situation can undermine responsibility and ownership, as seen in Malta, where the Ministry of Infrastructure is in charge of stormwater management, while enforcement is with urban planning authorities. Even though Malta historically has depended on rainwater harvesting for water supply, this practice has been largely abandoned in recent decades. Legislation requiring all domestic and institutional buildings to be equipped with a rainwater collection cistern is not enforced systematically, and households rarely invest in the expensive double piping that would be required for greywater use. Malta's example shows the importance of clearly defining roles to (a) enable monitoring and enforcement of rainwater harvesting legislation, (b) make incentives more effective, and (c) bring about multiple benefits in water scarce urban environments, in terms of flood mitigation and a decrease in water demand.

Policies regarding stormwater management and rainwater harvesting, especially when they include clearly defined requirements for its reuse, help ensure that relevant entities are comfortable with this nonconventional source and can therefore be advocates for its implementation. Kalkallo in Melbourne, Australia, launched an innovative plan for potable reuse of stormwater that has lain idle due to regulatory barriers, lack of coordination and role definition, and the absence of clear procedures for quality assurance of stormwater capture and management of the projects, which have hindered institutions from taking ownership and moving the project forward (McCallum 2015).

By defining the rules early—including the need for additional regulation and the roles of all relevant stakeholders—cities can secure acceptance and momentum for nonconventional sources. In Tucson, demonstration sites of green streets throughout the city have helped secure community approval while serving as test beds and foundations for guidelines. Public acceptance remains a barrier to the widespread application of stormwater reuse, though support is generally higher for nonpotable applications, as discussed in "Importance of Inclusion and Good Communication" section in chapter 4.

Wastewater Reuse

Unplanned indirect potable reuse (IPR), or "de facto reuse," (Asano et al. 2007) has been an accepted practice for centuries, as the effluent from wastewater treatment plants and raw sewage is traditionally reintroduced into the environment through streams, rivers, or groundwater basins, and extracted again further downstream (Asano and Levine 2004; Bixio et al. 2008; NRC 2012). This reintroduction into the natural system serves as a buffer before consumption and has been considered acceptable to the public, especially since the effluent is carried downstream and goes out of sight—and therefore out of mind.

However, increasing freshwater scarcity and technology advancements have begged the question: why waste such a readily available source of freshwater when it could be reused at the point of production? For instance, Orange County produces recycled wastewater for injection into the aquifer, which uses half the energy of importing and a third of the energy required to desalinate that same amount of water. Cities and counties have begun to see wastewater as a strong ally in dealing with droughts while avoiding significant infrastructure costs; a previously untapped source, it is an important resource not to be thrown away.

The reuse market has focused on nonpotable reuse applications, such as landscape irrigation and industrial processes, or urban nonpotable purposes, such as toilet flushing and cleaning. These are initial steps in most reuse experiences because they demand lower levels of treatment. Such fit-for-purpose resource development approaches can be particularly relevant, especially in the low-income countries. In Lima, the regulation allowing for the reuse of water for the irrigation of green areas and parks in the city was established before the city's first wastewater treatment plant was even completed. In Cyprus, about 90 percent of the treated wastewater is reused, in majority for irrigation purposes, as illustrated on photograph 3.4. Jaipur has implemented a reuse program for urban landscape irrigation and Marrakech, Morocco, has mandated that all golf courses, which are strong contributors to local tourism, be watered with recycled wastewater. Demand for nonpotable reuse

The biggest barrier to such programs remains public acceptance, or the "yuck factor."

PHOTOGRAPH 3.4. Wastewater Treatment and Reuse for Irrigation, Cyprus

a. Limassol (moni) wastewater treatment plant

b. Wastewater reuse for irrigation

Source: Sewerage Board of Limassol - Amathous.

Source: Water Development Department, Government of Cyprus.

applications is increasing globally, and are expected to account for 97 percent of total reuse in 2022 (GWI 2017). This demand in turn is leading to more scrutiny on the part of regulators to maintain public and environmental health through proper guarantees and controls.

Proximity of an agricultural area to a city provides another opportunity for nonpotable reuse of the city's wastewater and may secure a portion of the farmers' potable quality water for municipal uses. City governments should be encouraged to work with higher tier authorities to secure a water partnership in which water resources diverted to support urban water demand is "returned" to the agricultural sector as reclaimed water following treatment. In Malta, the Water Services Corporation commissioned the first "new water" plant in 2017, making over 60 percent of the wastewater treated available for reuse to agricultural and industrial water users, with the objective of freeing a substantial amount of groundwater currently extracted for agriculture ("new water" users will be charged a tariff slightly lower than current groundwater pumping costs). In preparation, the Water Services Corporation carried out a sophisticated mapping exercise to identify the agricultural water users with the most water-thirsty and high-value crops, since they could pay for this service. In parallel, the Water Services Corporation and the Energy and Water Agency have launched an information and marketing campaign targeting the general public and consumers of agricultural products.

Two options are normally considered, direct and IPR. Direct potable reuse (DPR) is made after wastewater is subjected to advanced treatment to obtain a highly treated effluent, which is then reintroduced directly at the intake for potable water or into pipes. IPR requires that the highly treated effluent pass through an environmental buffer—usually an aquifer or a reservoir—before being pumped back out and treated with other future potable supply. Located in an extremely arid area, Windhoek has been reclaiming wastewater through DPR since the 1960s in response to worsening drought conditions. Today, reuse provides over 20 percent of the city's supply, both for potable purposes and urban greening.

Though uptake has been slower due to health and regulatory concerns, wastewater reuse for potable uses represents the next frontier to maximize the potential of wastewater in water scarce areas.

In Singapore, it covers up to 30 percent of the city's water demand. Orange County, too, uses IPR successfully.

The most successful cases of potable reuse have addressed community outreach through education and marketing. The Orange County Water District (OCWD) has conducted an aggressive outreach campaign that has sought to earn and maintain support for this unprecedented wastewater reuse project. Launched nearly 10 years prior to the project start-up, the extensive outreach campaign's success is demonstrated by the lack of organized opposition to date. Similarly, though the program has been ongoing for decades, Windhoek makes sure to engage regularly with the media so customers are aware that drought conditions are still in effect. In Singapore, outreach efforts focus on communicating the need to look at water as a renewable resource: to change the negative popular opinion toward recycled water, recycled wastewater was renamed as "NEWater," wastewater treatment plants were renamed as "water reclamation plants," and wastewater was renamed as "used water."

For both nonpotable reuse and IPR, infrastructure remains a challenge. Any type of wastewater reuse requires that wastewater be collected and treated, which poses a challenge in some low-income cities that lack wastewater management systems—and these represent a large capital investment. Kfouri, Mantovani, and Jeuland (2009) emphasize this as a significant limitation in the Middle East and North Africa region, for example. Nonpotable reuse has historically relied on the construction of extensive dual networks for distribution to avoid any chance of contamination, as is the case of the "purple pipes system" in California or Israel. In West Basin County, in the southwestern United States, using such a network to reach its recycled water customers is actually a hindrance to further growth of the reuse operations. Cost-benefit analyses have shown that it does not make economic sense for the West Basin County to further expand its purple pipe network to reach new customers, though it would have the capacity to produce more recycled water. On average, conveyance costs of nonpotable reuse projects are estimated to add \$0.55 per m^3 to \$0.80 per m^3 to the cost of treatment.

Similarly, there is an ongoing debate about the efficiency and unnecessary costs associated with the environmental buffers required for IPR. For San Diego, California, the cost of the pipeline that would bring highly treated wastewater to the San Vicente Reservoir (the environmental buffer required in this case for IPR) is motivating the city to look at DPR instead, and to become actively involved in the process of drafting regulations for DPR at the state level. San Diego and Windhoek have shown that the highly treated effluent from their advanced wastewater treatment plants is of better quality than the water bodies from which they draw water for potable use. In San Diego, modeling has shown that reservoir water quality would improve once reclaimed water were introduced. In this sense, cities need to consider whether it makes sense to treat this water twice before it makes to the tap and assess the feasibility of DPR.

When comparing desalination and wastewater reuse plants that use reverse osmosis, reuse remains less expensive due to the characteristics of the input water. The higher salinity of the ocean water requires more pressure to be applied in the reverse osmosis process, and advanced water treatment requires under a third of the energy needed for desalination.[7] In addition, for most cities, secondary treatment is a regulatory requirement. Though cost estimates for reuse often take the whole treatment train into account, the difference is in the incremental (tertiary and advanced) process. Currently, the cost of reusing reclaimed water for potable purposes through reverse osmosis ranges from \$0.60 per m^3 to \$1.62 per m^3 depending on conveyance (GWI 2017). When comparing the costs of different new sources of water for San Diego in

2013, the city estimated that, for IPR, \$0.8 per m^3 (about half of the estimated total water cost) could be saved in the form of wastewater and water quality credits from averted flows to the ocean and reduced salinity in the reservoirs.[8] Tertiary (toilet flushing, agriculture, and industrial) and triple barrier reuse combined are expected to overtake desalination by 2022. Triple barrier reuse (advanced treatment for potable uses) has been identified as the fastest growing type of reuse at 11.7 percent per year (GWI 2017).

Recycling wastewater close to where it is generated provides another approach to avoid the cost and infrastructure associated with transporting it to and from a centralized location. Such localized reuse is being implemented by San Francisco, California, through its Non-Potable Water Program, which allows for the collection, treatment, and use of alternate water sources for nonpotable purposes, such as toilet flushing and landscape irrigation. Alternate sources include greywater (bathroom sinks, showers, and clothes washers) and blackwater (toilet flush water). As of 2015, the San Francisco Health Code mandates onsite reuse for new buildings over 23,225 square meters. Though to date not enough systems have been put in place for conclusive cost analysis, current grants from the city seem to be insufficient to cover capital costs and operating expenses, which will likely need to be met through substantial increases in rental or condominium fees. As building scale systems remain an emerging practice, further research is ongoing to maximize efficiency at this scale and draw out lessons learned for wider application.

Industrial reuse represents another promising market: with increasing competition among uses, industries are seldom prioritized in water scarce areas, while they often have the resources to invest in the treatment systems needed for reuse. The West Basin Municipal Water District has a menu of options for customers to purchase reclaimed water at the quality requirements that meet their needs: irrigation, cooling towers, seawater barrier, and groundwater replenishment, and low- and high-pressure boil feed. Each demand requires a progressively higher treatment quality (and cost), and demonstrates the range of potential uses of recycled water. Costs are transparently passed on to customers for the amount of water purchased, while ensuring a drought-proof supply of water.

Finally, the SNWA has an extremely innovative wastewater use: it capitalizes on regulatory tools by applying the concept of "return flow credits," wherein wastewater is treated and returned to the Colorado River upstream of the city to increase its potential water use by 75 percent without additional allocation for the river. Any surplus water from its allocation is measured and stored in Lake Mead for future use. Another example of application of regulatory instruments is in China, where, since 2012, the government has limited freshwater abstraction for industries that do not reuse some of their wastewater streams (GWI 2017).

Seawater Desalination

Seawater desalination is an increasingly appealing water source for cities located on the coast[9] since it is climate independent and can mobilize unlimited resources, although at still higher costs than traditional sources. Also, seawater desalination can reduce the needs for conveyance and raw water storage compared to surface water solutions, which can be financially and politically attractive. Reports of desalination through distillation date back as early as Aristotle, who states sailors carried out "shipboard distillation" in the 1660s. Large desalination plants using distillation have been in operation in the Middle East since the 1930s (NRC 2008); now these have been replaced by membrane-based desalination, developed in the 1960s and continuously refined since.

Though seawater desalinization is too costly, with too many energy requirements for many cities, efficiency improvements and the increasing price of other sources have made this option more competitive.

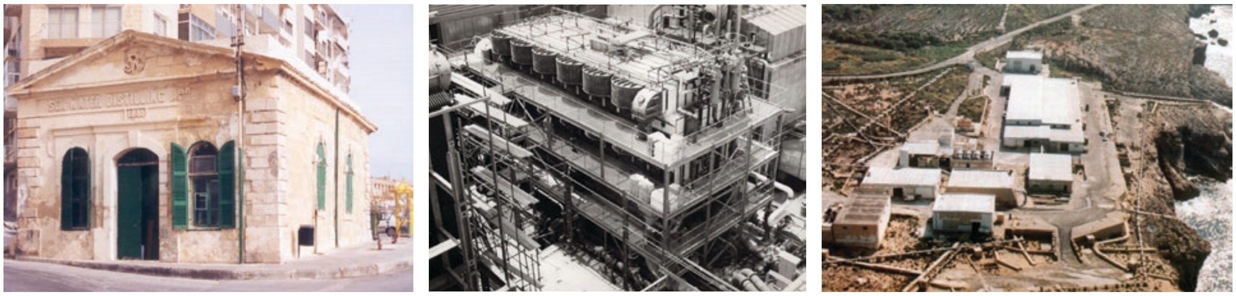
In many cities and countries, seawater desalination has thus become the only available option due to total, temporary, or increasing scarcity of other sources. In Malta, the absence of significant perennial surface water bodies, the lack of rainfall in the summer (the time of greatest demand), and the physical impossibility of imported interbasin transfers have led the country to develop desalination as early as the 1880s, as illustrated on photograph 3.5; today desalination meets about half of the country's supply needs. Singapore, in an effort to become independent from imported water, launched its "4th National Tap" with desalination in 2005, which can now supply 25 percent of the country's water. Israel, seeking independence from geopolitical tensions around water sources, today gets the majority of its water supply from desalination.

Due to its relatively high cost, desalination tends to function best as part of a portfolio of options; this gives cities flexibility in drawing from different sources based on drought conditions and climate vulnerability. In Perth, where about half of the potable supply comes from desalinated water, the Water Corporation uses its network of dams to store excess water from desalination plants for use in higher demand periods or lower rainfall years, which enables a fallback without increasing production excessively during dry years. In Murcia, desalination lends flexibility in dealing with varying demands. The bulk water provider Mancomunidad de Canales del Taibilla (MCT) seeks to contain water production costs by mixing water from different sources to minimize the use of desalination to the extent possible, while balancing water quality requirements, demand variability, and expected evolution in the availability of surface water resources.

High energy costs are one of the main barriers to the adoption of desalination and are the most volatile component in desalination costs. In Perth, groundwater replenishment with reclaimed water has replaced seawater desalination as the preferred new water source, due to its lower unit cost. Though both solutions will be needed to ensure Perth's future water security, price features prominently in prioritizing the development of new options. Technology advancements over the recent years have enabled significant energy recovery from the process, drastically reducing reverse osmosis's energy consumption through recirculation, as shown on figure 3.8. This has allowed a dramatic drop of desalinated water costs, from \$3.00 per m^3 in the late 1980s to an average cost of about \$1.00 per m^3 (GWI 2017) since 2000. For the largest plants, as low as \$0.60 per m^3 have been achieved, as illustrated on figure 3.9. Advances in renewable

PHOTOGRAPH 3.5. Three Generations of Desalination Plants in Malta

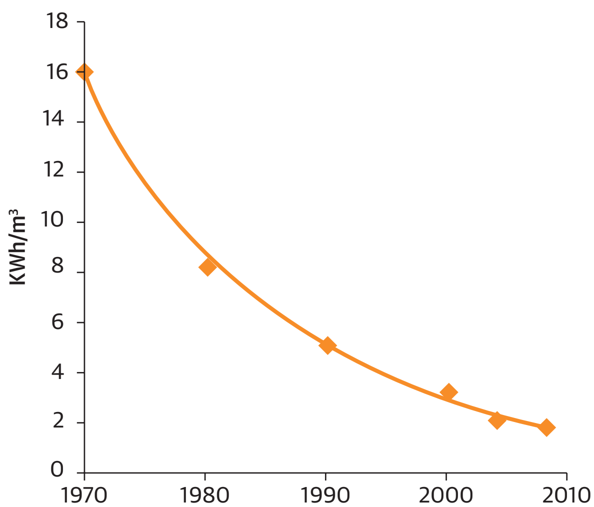
a. Distillation plant introduced in the 1880s | b. Multi-flash distillation in the 1960s | c. Large scale reverse osmosis in the 1980s



Source: Manuel Sapiano, Energy and Water Agency.

energy technologies also hold a huge promise in further decreasing desalination costs, with reductions in energy costs expected to represent about 40 percent in the next 10 years (IRENA 2016).

FIGURE 3.8. Reduction in Reverse Osmosis Power Consumption in Perth, Australia, 1970–2010

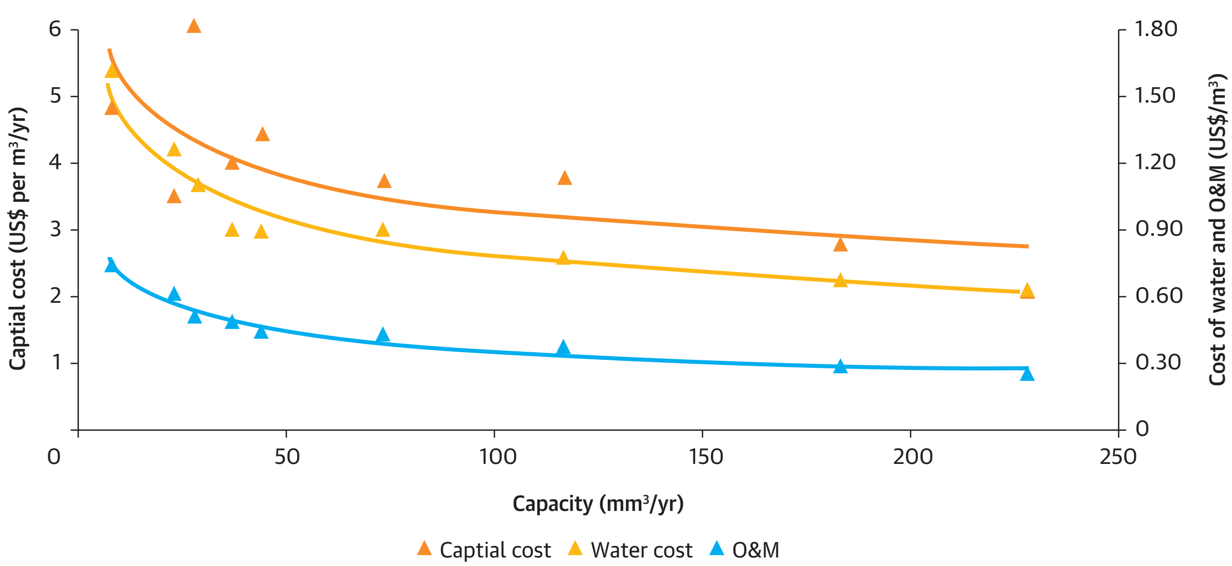


Source: Elimelech and Phillip 2011.

Although, desalination can enhance a city's water resources portfolio by providing an unlimited, climate independent water supply option, it does not yet outcompete most other sources from a financial standpoint. Because it draws directly from the ocean, desalination allows production to be close to the main consumers or peak users along the coastline who may need it in times of drought. It can be easily integrated into the existing network without much additional conveyance infrastructure, which enables coastal cities to easily maximize its potential.

The scale of desalination plants can easily be adapted depending on a city's or even a user's needs. Though economies of scale help lower the production cost of desalinated water, smaller systems have successfully to met lower localized demands. In Malta, since most hotels are along the coast, all major ones have invested in small reverse osmosis systems to produce desalinated water, which helps them meet higher seasonal water demand and relieves the utility of the pressure of peak demand. These units are sourced and serviced

FIGURE 3.9. Unit Cost Rates of Seawater Reverse Osmosis Desalination Plants on the Mediterranean Sea, 2016



Source: Debele forthcoming 2018.
Note: O&M = operations and maintenance.

by a subsidiary of the Water Services Corporation, thus ensuring proper operations and maintenance (O&M) and technical capacity.

Many cities have sought partnerships with the private sector to try and offset the high costs of desalination plants. In Cyprus, where desalination was implemented in 1997 to eliminate the dependency of the domestic water supply on increasingly variable rainfall, all desalination plants operate under build-own-operate-transfer (BOOT) contracts. The government is obligated to purchase a minimum amount of desalinated water each year until transfer, which provides the guarantee needed by the private sector to know it can recuperate its costs. The unit price for that water varies by plant and covers CAPEX (capital expenditure), O&M, energy, and standby O&M. This model has enabled the Government of Cyprus to leverage the private sectors' knowledge, experience, and financing capacity to improve the quantity and quality of public water services, while making sure that the cost of water at each plant reflects production expenses.

Desalinization is not without problems additional to its high cost and energy requirements. Public acceptance is a barrier for desalination as for other nonconventional sources, especially regarding environmental impacts. Groups that represent interests linked to coastal management, such as conservation in marine bays and surfers, are particularly vocal in their opposition. One main complaint is linked to existing efficiency levels, which require that about twice the amount of potable water produced needs to be withdrawn from the sea through intakes that "suck in" fish egg and larvae, disturbing and destroying marine wildlife. Another point of concern relevant for coastal impacts is brine discharge. Since the output from the reverse osmosis process is a concentrated brine, roughly twice as salty as the seawater that entered the plant, it is claimed it causes harm to marine life dwelling on the sea floor. Currently, the methods for estimating the actual impacts on wildlife are complicated and imprecise, so many regulators have resorted to encouraging ecosystem restoration elsewhere for "equivalent" mitigation. In Perth, in response to observed depleted dissolved oxygen levels near the plant outfall (Spigel 2008), a comprehensive environmental monitoring program to assess the seawater intake and brine outfall has become a condition of the plant's continued operation. A similar approach might be the best option to address similar concerns elsewhere.

Cooperation with Other Users

Surrounded by water users with different water needs and economic profiles, cities can seek optimized water allocations in times of enhanced water stress. This requires adequate mechanisms to manage water resources at the river or aquifer catchment basin level, institutional capacity to negotiate water transfers from low-value uses toward higher value uses and realize associated tradeoffs, but also in many cases large and costly infrastructure conveyance systems. Examples from Australia, Spain or South California have demonstrated the benefits of enhanced cooperation between users to improve urban water supply security.

Managing Water at Scale

Elevating the scale for water resource management to the level of the catchment basin serves to identify and assess competing interests and prioritize uses (and users) in times of drought. In Murcia, the integrated management of water resources at basin scale by the river basin agency—and the interconnection of water conveyance networks—provide flexibility and adaptive capacity, and facilitate the reallocation of resources between places, users, and periods of use in response to evolving needs. It also provides a potential opportunity to adjust demands to available resources.

Unless the water body's characteristics make abstraction practical across much of the basin, large infrastructure systems are required to share water resources at the basin scale and move water among users. Due to seasonal variation in water availability, conventional surface water systems depend on storage to ensure

PHOTOGRAPH 3.6. **Desalination Plant in Almería, Spain**

Source: RamblaMorales/Flickr.

supply during the dry seasons and tend to be heavy on infrastructure. For groundwater, exploitation requires an established network of wells to abstract water and monitor the quantity and quality of the resource over time. Ultimately, the costs of constructing or expanding conveyance infrastructure are often large enough to encourage cities to look to alternative and more local solutions. In Windhoek, the cost of artificial aquifer recharge is estimated at a third of the cost of securing more surface water through a new pipeline. These tradeoffs could deter users from actively engaging around river basin reallocations if there is no physical way to transfer water from one point of use to the other.

System efficiencies can be best identified and achieved when the water cycle is considered at basin or cross-basin level. The costs of inefficiencies upstream from the city—linked to water resource management and conveyance, for example—are often unfairly passed on from the water wholesaler to the service provider. In the supply of the coastal towns Safi and El Jadida, in Morocco, the current 80-kilometer long bulk water transfer from the reservoir entails losses representing almost half of the cities' demand. The planned implementation of local desalination plants will release corresponding volumes, including current losses, for the piped supply of Marrakesh from that same reservoir (Dahan and Grijsen 2017).

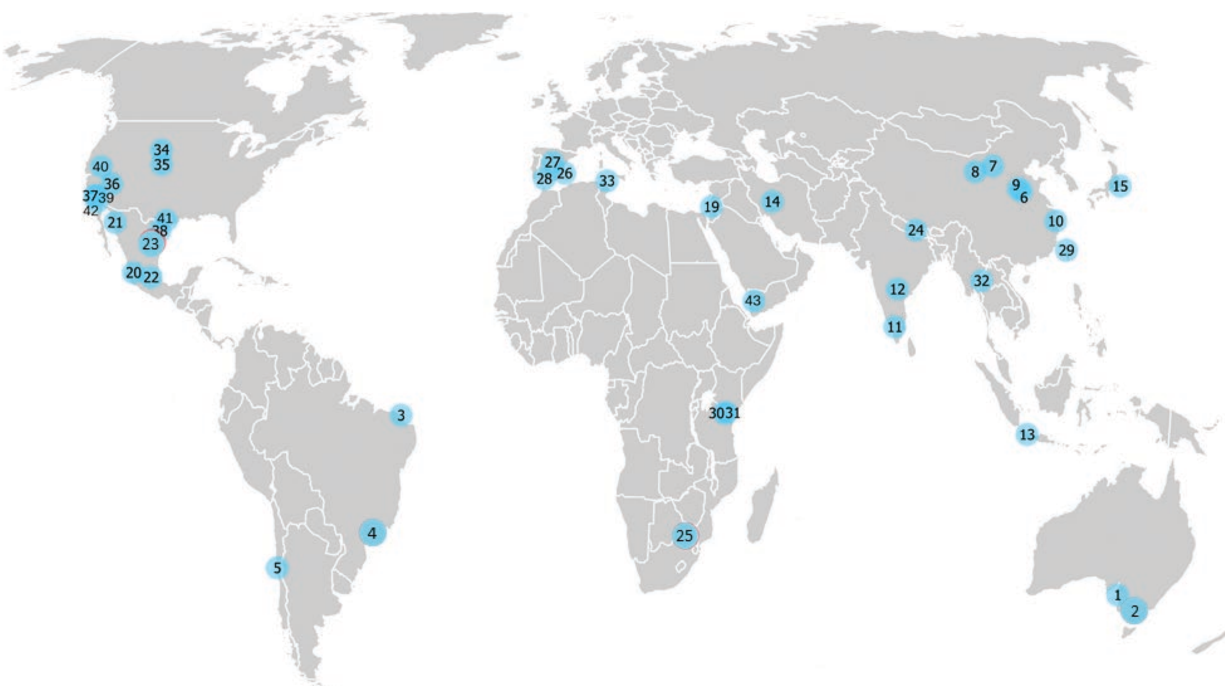
Limiting efficiency measures to the urban water supply network but not to upstream processes creates an institutional disincentive for the service provider. In Morocco, the water supply provider's mandate is limited to the distribution of water that has been abstracted, treated, and conveyed by the bulk national water service provider. Its financial incentives to reduce leakages extend only as far as associated distribution costs remain smaller than the benefits resulting from reduced water pumping. For Marrakesh, the launches in 2018 and 2030 of new interbasin transfers will entail, in addition to treatment costs, conveyance costs many times higher than distribution costs at city level (Dahan and Grijsen 2017). Institutional mechanisms incentivizing the reduction of all costs will be critical to achieve system water efficiency and water conservation to its full potential.

Cooperation for Optimized Allocations

Water markets, such as those operated in the Murray-Darling basin in Australia or in Reus, Spain, are an important tool to move water from low-value or low-priority uses toward higher value uses, especially where municipal demand has become difficult to fulfill and alternatives are costly. In Australia, water markets take advantage of having a variety of water users with different abilities to cope with shortages. Water transfers are a more formal and large-scale way to handle such reallocations, in which both parties legally agree to transfer a water right for a certain amount of time. In Malta, the service provider plans to provide about 60 percent of the agricultural sector's water through reclaimed wastewater, which would in turn free up water for municipal use.

Rural to urban water reallocation has attracted attention among policy makers across continents (as shown on map 3.1), motived by the premises that (a)

MAP 3.1. Overview of Rural to Urban Water Reallocation Projects, 2017



Australia
1 - Adelaide
2 - Melbourne

Brazil
3 - NE Brazil
4 - Sao Paulo

Chile
5 - Coquimbo

China
6 - Kaifeng
7 - Ordos City
8 - Wuzhong Prefecture
9 - Xinxiang
10 - Yiwu City

India
11 - Coimbatore
12 - Hyderabad

Indonesia
13 - Bandung

Iran
14 - Esfahan

Japan
15–18 - Saitama/Tokyo

Jordan
19 - Amman

Mexico
20 - Guadalajara
21 - Hermosillo
22 - Mexico City
23 - Monterrey

Nepal
24 - Kathmandu

South Africa
25 - Mokopane

Spain
26 - Alicante
27 - Guadalajara
28 - Seville

Taiwan
29 - Taiwan

Tanzania
30 - Arusha
31 - Moshi

Thailand
32 - Chiang Mai

Tunisia
33 - Tunis

United States
34 - Casper
35 - Denver
36 - Las Vegas
37 - Los Angeles

US Cont'd
38 - Lower Rio Grande
39 - Metropolitan Water District
40 - Reno
41 - San Antonio
42 - San Diego

Yemen, Rep.
43 - Sana'a

Source: Yu 2017.

agriculture uses most of the water, (b) low water use efficiency is prevalent in agriculture, and (c) the marginal productivity of water is often higher in urban areas than in agriculture. To achieve effective reallocation projects recognizing potential equity challenges for rural areas and addressing the political complexity of such urban-rural dialogue, it is essential to have institutional capacity and effective processes for negotiation and compensation for those who stand to lose (Yu 2017).

Cities must look beyond competition among users to identify opportunities based on the characteristics of different users' water needs and realize those tradeoffs.

In 2003, the San Diego County Water Authority (SDCWA) negotiated the largest transfer from agricultural to municipal use in the United States, securing up to 247 million m^3 per year for 75 years. The transfer requires the Imperial Irrigation District, which has one of the highest priority water rights on the Colorado River, to improve its water use efficiency and avoid what the State of California defined as "wasteful use." The water conserved is in turn sold to the SDCWA. This transfer is part of a larger agreement aiming to reduce California's use of Colorado River water and marks an important change in California water allocation: it prioritized municipal use and condemned water waste by agricultural users previously protected by the seniority of their water rights. It also indicates that, even in a case as seemingly overallocated as that of Southern California, there is flexibility in the system to accommodate changing needs and climatic conditions. As water management is rife with legal conflicts in California, it took over 15 years to reach this agreement, which points to the complicated nature of negotiations between agricultural and municipal water users.

Having an agricultural buffer (through nearby agricultural activity) enables urban municipal water managers to purchase water from agricultural interests in time of drought or shortage.

Such water transfers depend on available conveyance infrastructure to reach the new user. The SDCWA benefited from the existing water conveyance infrastructure to serve all the parties involved. In Perth, the Perth Water Corporation and Harvey Water (an irrigation water supplier) agreed to convert open irrigation channels to pipes to convey 17.1 million m^3 per year to the Water Corporation. Since 2006, this $58 million investment harvests water that would otherwise be lost through seepage and evaporation, while benefiting the irrigators through a pressurized pipe irrigation system that has enabled more controlled irrigation that suits higher value horticulture crops. As such, the project has received strong support from the local community. The formal nature of such water transfers can help ensure all parties are compensated appropriately and sets formal precedence for the priority of municipal use.

Water Trading

Water markets provide a flexible mechanism to reallocate water in time and space. Indeed, compared to water banking agreements or water transfers, which are set legal contracts over long periods of time, a water market transaction can allow a water user to increase revenue by leasing its water allocation to another user for whom that water has a higher value at the time, while not giving up access to that water in the future. Though most water markets remain informal and focus on irrigation water, experiences in Australia under the National Water Initiative, especially in the Murray-Darling basin, have shown good results in minimizing transaction costs and providing for urban water demand and environmental protection. Because having a variety of water users—with different abilities to cope with shortages—helps ensure that water trading is relevant to the area, this may prove a successful solution for cities dealing with various stakeholders and competing uses.

Reus, Spain, helped create such a system with farmers (Ruydecanyes, later expanded to include the valley of Siurana), which increased water resilience in the city through a market scheme since the early 1900s.

This regional market uses newly developed additional water. Transactions are transparent and regulated under simple norms for seasonal and permanent transfers. Though, as in the case of Reus, such market structures are informal, they require transparency and an agreed structure among stakeholders. These schemes may be present de facto in many places (for example, shadow trading of water with farmers or administrative allocations to them by a government agency), and they generally improve efficiency whether or not they are formalized. However, formalization may increase transaction costs compared to more informal mechanisms. Though in Reus resilience has been achieved through a much larger regional system with water conveyed from the Ebro River (the "big pipe" solution), water markets complement the diversity of sources and allow a flexible response for the city in scarcity. Challenges include the need to clearly define water entitlements and ensure good information flows between users.

Adaptive Design and Operations

Effective water resource and drought planning is the first stop in drought proofing conventional systems. If the resource is finite—whether for legal or environmental reasons—and subject to uncertainty, careful monitoring of its availability and protocols to deal with future scenarios can significantly build a city's resilience, even without additional sources. The key to effective drought planning is anticipation, which avoids costly emergency responses—both to the utility and to consumers.

Adaptive design starts with a detailed inventory of the city's water budget and corresponding vulnerabilities as baseline information for system planning and investments. When the 2008 drought hit Cyprus, water had to be shipped from Athens at the cost of \$8 per m^3, about five times the cost of desalinated water in that year (Sofroniou and Bishop 2014). When cities fail to provide an adequate water supply, users pay an even much higher price to water tankers. In Beirut, the cost jumped from \$20 per m^3 to more than \$50 per m^3 during the 2014 drought.[10]

Planning Water Systems under Uncertainty

Despite significant improvements in climate modeling and downscaling of general circulation models (GCMs), spatial and temporal precision remains usually insufficient to inform water resources planning at a city or basin level. Climate change therefore brings deep uncertainty in the programming infrastructure development.

Robust decision-making approaches assess the sensitivity of a proposed investment plan's performance to changing conditions, and accordingly adjusts the plan to minimize its vulnerability. These planning approaches strongly value no-regret measures, which can be implemented regardless of climate change uncertainty and still yield helpful results. This includes solutions with a high benefit-cost ratio regardless of climate forecasts, such as those aiming to address profligate water consumption, control network leakages, or improve allocation efficiency through improved cooperation with other users.

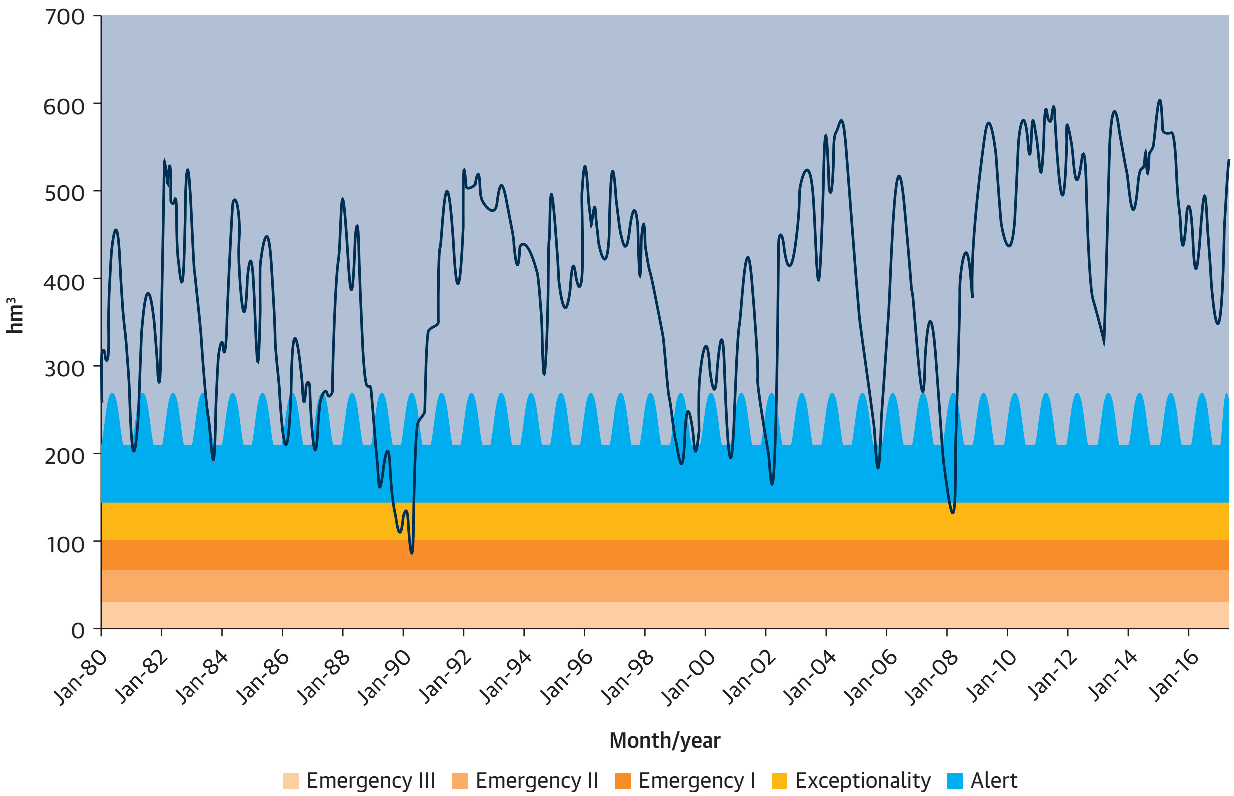
It assesses the relative performance and vulnerability of investment options across a wide range of potential climate impacts, and combines them into a web of adaptation pathways prompting policy actions at determined tipping points. Such approach was implemented in Lima (Kalra et al. 2015) to help define a step-by-step strategy for the development of water production capacity in a context of climate and water demand uncertainties.

Resilient Water Systems Operation

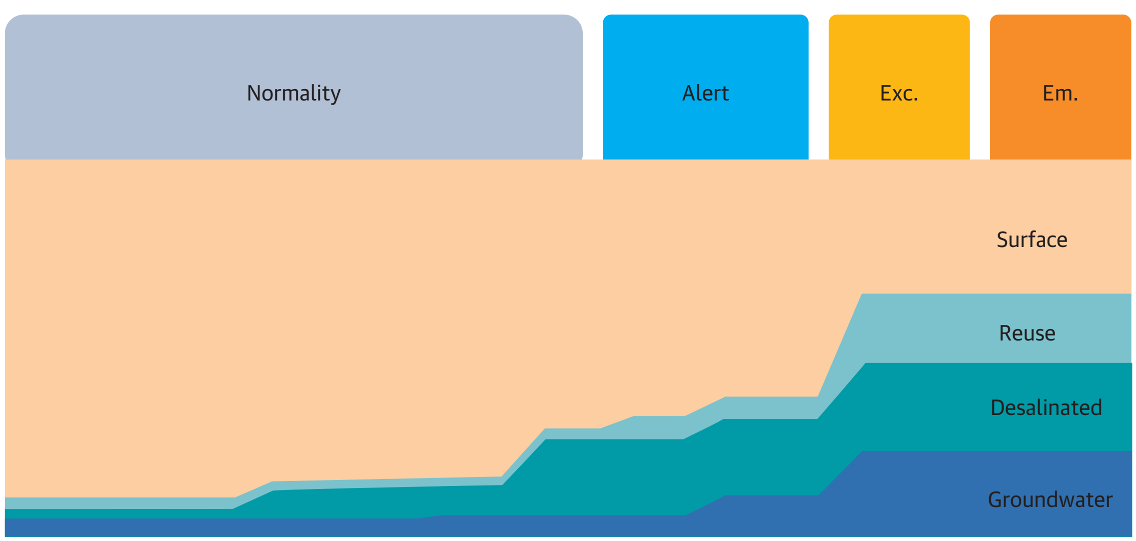
Resilient water system management should not only include response strategies to the current water availability conditions but also the definition of several stages of drought and associated actions to mitigate the risks of reaching more severe stages. For example, in Spain, Aigües de Barcelona's Drought Management Plan tracks key water system performance indicators and helps the utility respond through agreed measures to guarantee drinking water supply and mitigate economic impacts. Based on surface storage levels, the utility has defined drought thresholds (normal, alert, exceptionality, and emergency), which define what sources to draw from, as illustrated on

FIGURE 3.10. Drought Threshold Values and Water Source Mix, by Threshold, Barcelona, 1980–2016

a. Drought threshold values



b. Water source mix



Source: Creus 2017.

figure 3.10, panels a and b. According to a clearly defined decision tree, in a crisis, more expensive sources (reuse and desalination) would be used first; then strategic buffer sources (the aquifer); and finally, water normally used for environmental flows would be tapped (Creus 2017).

In Murcia, comparable plans to that of Barcelona have been developed for the city and the river basin. Each level triggers a set of measures that, in the case of urban water uses, can range from public outreach campaigns to imposing use restrictions. When the emergency level is reached, a legislative drought decree is approved by the central government, enabling the river basin authority to restrict or reallocate water rights, fast-track funding for emergency infrastructure works, and undertake other measures. Similarly, in the United States, the SNWA categorizes its water sources according to their availability and development strategy: permanent resources, available for use over the 50-year planning horizon; temporary resources, which can be used to meet potential short-term gaps between supply and demand; and future resources, which will be developed during the 50-year planning horizon. Though the SNWA has not exceeded its Colorado River allocation to date, its water resource planning embeds several fallback scenarios should a drought significantly reduce water availability.

Once a strategy has been defined institutionally, such preparedness requires the collection of reliable water information and its thorough analysis, which in turn is resource-intensive in terms of equipment, capacity, and finances. In Barcelona, where the basin is already heavily regulated with channels and floodgates, the electronic measurement of flow data was facilitated by the existing extensive infrastructure. However, in areas where infrastructure is not as developed, the installation of water data collection stations and the development of water information systems, with a trained team to operate and maintain them, need to be part of longer term planning processes. In such cases, the level of a key reservoir could be used as a proxy for more detailed water data and levels of emergency defined accordingly.

The decision tree framework (Ray and Brown 2015) provides planners with a flexible, cost-effective approach for guiding decision making.

Notes

1. Information directly collected from operational mission by World Bank in Beirut.
2. See Water Sensitive Cities' website: https://watersensitivecities.org.au/content/responding-millennium-drought-comparing-domestic-water-cultures-three-australian-cities-news/.
3. 946 m^3.
4. Fixed charges are the base charges to cover fixed costs such as infrastructures maintenance and fixed operation costs, whereas commodity service charges are the price per volume of water used and cover all variable costs.
5. For example, the Water Conservation Coalition, a group of local businesses and community leaders who promote water-efficient practices, or the Water Upon Request program, through which restaurants serve water only to those clients who request it.
6. Stormwater runoff, particularly in the early stages of the storm, contains a high load of heavy metals, suspended solids, and organic matter. These contaminants are accumulated on pavements, roofs, and other less permeable areas and then mobilized as part of the runoff.
7. Based on interviews and the website from IWA: http://www.iwa-network.org/from-seawater-to-tap-or-from-toilet-to-tap-joint-desalination-and-water-reuse-is-the-future-of-sustainable-water-management/.
8. After going through the reverse osmosis process, treated wastewater is remineralized but still has much lower salinity than imported water, which accumulates salts over its transportation due to evaporation.
9. When freshwater resources are very limited, such as on small islands, seawater can also be a useful resource even without desalination. Cities like Majuro in the Marshall Islands or Tarawa in Kiribati have developed seawater flushing systems to ensure adequate hydraulic conditions in sewerage systems while limiting the use of freshwater resources for potable water needs. With the need for dual piping systems, such option has an economic justification only in extreme water stress.
10. Information directly collected from population by World Bank in Beirut.

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Cape Town, South Africa. *Source:* https://pixabay.com/en/south-africa-cape-town-2267795/.

Chapter 4
Cross-Cutting Considerations

Though we often identify successful water scarce cities by the technological approaches they've applied to harness a specific source or maximize its use, the factors of success often lie beyond technology itself. Innovative water managers must expand their expertise from engineering to marketing and public relations. Sustained communications campaigns can demystify a city's decisions about water resource planning, and increase public trust in regulatory actors and stakeholders. Closer to decision makers' concerns, the systematic comparison of the economic costs and benefits of alternative solutions still seldom happens, mainly due to data availability, but also simply the difficulty of assessing "soft" options. Proper economic analysis can better underpin the development of innovative and diverse financing mechanisms, inspired by the myriad of experiences across some of the most successful water scarce cities. Finally, active involvement of water scarce utilities in managing their resources will require both a clear institutional framework within which it can operate, and in an integrated manner that works with institutional partners and stakeholders.

The experiences show that this paradigm exists and has developed organically, but also that scrutiny and comparison reveal the cross-cutting issues that form the backbone of these successes. This section outlines these key takeaways to inform the principles of a new water management paradigm.

The different cases presented in this report outline more than successful technological advances. In these success stories, the principles of a water resource management paradigm for cities begin to emerge.

Technology Is Not the Major Concern

Though we often identify successful water scarce cities by the technological approaches they've applied to harness a specific source or maximize its use, the factors of success often lie beyond technology. Though some approaches, such as aquifer recharge and wastewater reuse, require careful preparatory work from a technical standpoint, this seldom has to do with the technology and often is more of a planning, governance, or social acceptance issue. Furthermore, many good examples exist in both low-income and upper-middle-income countries, which create good opportunities for knowledge exchanges and mentorship. For example, an exchange program has been established between the Singapore Public Utilities Board (PUB) and California's Orange County Water District (OCWD) so that the two agencies continue to learn from each other's innovations in the field of reuse. In general, the technology is often tried and true, with research ongoing and closely supporting the validity of a given approach, but challenges lie in the way such results are communicated to the public and used in advancing the field.

The success of a technological solution, no matter how appropriate to the context of a city, relies on support from the public. In both San Diego and Los Angeles, California, proposed indirect potable reuse (IPR) projects were shut down in the 1990s due to public outcry and negative media portrayal of the projects as "toilet to tap." It took San Diego years of damage mitigation, through a strong public outreach campaign and a new demonstration project, to garner support from its customers again—despite the proposed technology's proven success in other places such as Orange County, Singapore, and Windhoek, Namibia. Therefore, innovative water managers must expand their expertise from engineering to marketing and public relations if they are to promote new solutions successfully.

Importance of Inclusion and Good Communication

Widespread communication efforts are stepping stones for social acceptance. Such communication campaigns demystify a city's decisions about water resource planning. They target the public's potential doubts early on, while offering a platform for consumers to ask questions and provide feedback. They also help secure public support and understanding of programs and investments that normally exceed the political cycle, thus avoiding drastic alterations when elections bring political changes before the projects are completed. One of the key success factors of the outreach campaign in the OCWD was its early launch, nearly 10 years prior to the IPR project startup, and its continuation throughout the project's life to maintain support through all accessible communication channels. Research from Singapore shows that public acceptance of wastewater reuse depends highly on public trust in regulatory actors and stakeholders, as well as their understanding of technology and potential impacts.

Though Windhoek's program has been ongoing for decades, the city still engages regularly with the media so customers are aware that drought conditions are still effective, leading to mindful water use.

When changes will impact customers' service or bills, this communication channel helps avoid dissatisfaction by promoting understanding and awareness of the changes early on. In Perth, Australia, a water policy unit was established in the early 2000s to support and coordinate the government policy response to the water crisis. The nursery, turf, and irrigation industries' initial resistance to proposed restrictions on domestic garden watering was overcome by genuine engagement through this unit. Such approaches can also warn customers of upcoming rate increases by justifying the reasons for changes (including new sources or technology, environmental remediation, or a new tax) and giving them the opportunity to speak out. Such participatory models can even be applied in the form of citizen juries convened to co-design water investments, shape services and prices, as is now the case in Yarra Valley, east of Melbourne, Australia (Yarra Valley Water 2017).

Involving constituents early in the process builds ownership over a city's water management decisions. Before infrastructure projects or significant changes in the water authority's practices are approved, the Southern Nevada Water Authority (SNWA) board of directors always appoints a citizen advisory committee to represent different stakeholders through the decision-making process. Their recommendations influence all important water management decisions, including the construction of new water management infrastructure, the development of new water resources, water quality measures, and rate increases. In several instances, these committees play the role that the court has played in other states by bringing all interested parties to the table before a decision is made and avoiding future lawsuits.

Inclusion promotes good governance by holding city decision makers to account. In Murcia, Spain, the Mancomunidad de Canales del Taibilla (MCT) incorporates local, regional, and national government representatives in decision-making bodies, facilitating trust and cooperation among different competent authorities. Such stakeholder involvement promotes transparency and limits future opposition by opening debate early in a collaborative discussion.

Good Economics Is Key

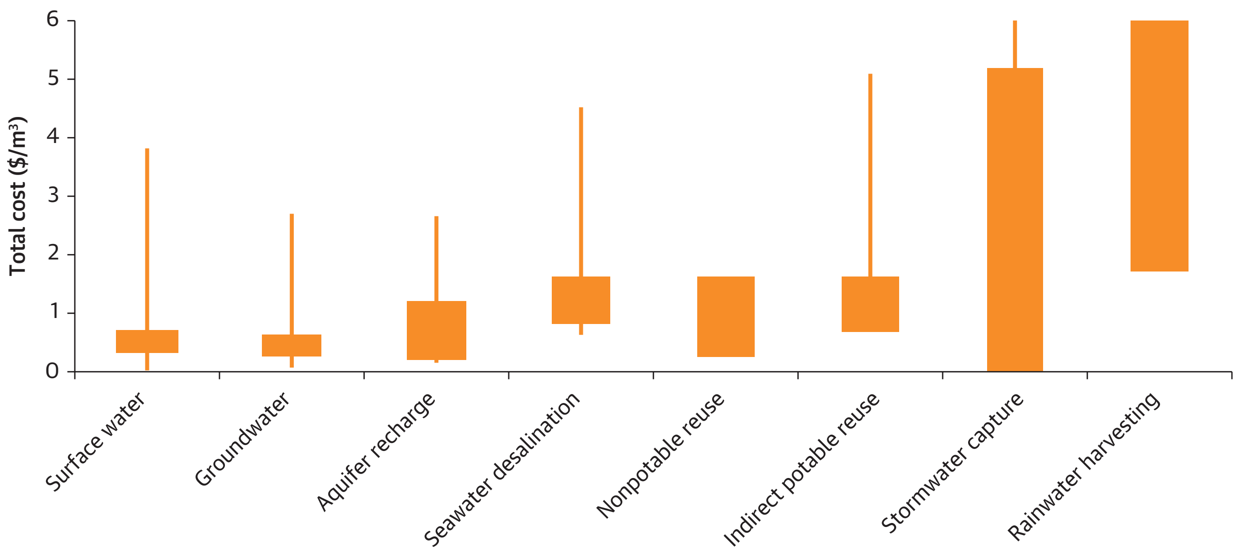
In many areas of the world, growing water scarcity impacts the availability of freshwater resources and shifting costs so that nonconventional solutions are becoming more affordable than the expansion of conventional ones. In the most water scarce provinces of China, freshwater withdrawal quotas are driving the price of freshwater up and rendering wastewater reuse much more interesting to industry and cities alike. Beijing now reuses 66 percent of its wastewater in non-potable applications, accounting for 22 percent of the capital's water supply, and has renamed all wastewater treatment plants (WWTPs) "water purification plants." (GWI 2017) Comparing the marginal cost of a variety of water supply options to close the 2030 water resources gap, projections show that traditional water supply sources would be costly, with many bearing a cost over \$10 per m^3 and steep marginal cost curves compared to efficiency solutions (2030 Water Resources Group 2009). Similarly, the construction of pipelines for long-distance water transfers is eclipsing the costs of developing local water supplies, especially as competition over that water increases.

The costs of most solutions vary dramatically across regions and cities, rendering direct comparisons hazardous. Beyond direct costs for water abstraction or collection and treatment, factors may include the need for complex intake systems (including river dams) and the scale of conveyance systems. Zhou and Tol (2005) suggest, as a rule of thumb, to adopt a cost of \$0.08 per m^3, for 100 kilometers of horizontal transport and \$0.06 per 100 meters of vertical transport, on the basis of a 100 million m^3 per year conveyance.[1] The variability of electricity prices, driven by power generation technologies and levels of subsidies, further complicate comparisons. Discussions in this chapter attempt to capture orders of magnitude of the different solutions, as illustrated in figure 4.1.

Identifying the relevant stakeholders early and having them communicate regularly with the public contributes to acceptance of a new approach and helps sustain certain behaviors.

For *surface water solutions*, conventional water treatment plants typically cost in the order of \$10 million per 100,000 people, resulting in a total cost (capital expenses [CAPEX] plus operating expenses [OPEX]) of \$0.30 cents per m^3. Exceptions abound

FIGURE 4.1. Total Cost of Water Production for Various Solutions



Source: World Bank.
Note: Vertical bars capture common scheme values; vertical lines span extreme values identified in the present research. Total cost includes capital expenses and operating expenses.

however: in the city of Erevan, Armenia, where water can be supplied by gravity from a high-quality water spring, costs are as low as $0.01 per m³.[2] By contrast, in Windhoek, total costs with water conveyance of inter-basin water supply from the Okavango River are estimated at $3.8 per m³. For *groundwater supply* solutions costs, commonly span between $0.1 and $0.4 per m³, but can exceed $2.0 per m³ with deep and distant aquifers, such as in the proposed Tsumeb supply scheme in Windhoek.

Reverse osmosis is the most competitive *seawater desalination* technology where salinity is low. Thermal desalination is costlier in terms of capital investments, but it is better adapted to high salinity sources and has the highest economy of scale for megaprojects (Cosin 2016). Costs typically range between $0.6 per m³ (achieved in Israel with a production capacity above 600 million liters per day) and more than $2.0 per m³ for smaller units, generally below 30 million liters per day. These costs do not include conveyance needs.

Reuse schemes have experienced significant reductions in costs, benefiting from advances in energy efficiency technology and from the development of membrane bioreactors (MBRs). IPR projects have higher CAPEX than nonpotable reuse due to more advanced treatment costs, which are estimated to be at 10 percent to 15 percent more than nonpotable water reuse (GWI 2017). With direct nonpotable water supply applications, specific, "purple" conveyance and distribution infrastructure needs to be factored in the cost of the solution. Costs have been found between $0.25 per m³ in California (GWI 2017) and $5.1 per m³ in Australia (Moran 2008), with most common costs being found between $0.60 per m³ and $2.20 per m³ (GWI 2017).

Stormwater capture has seen significant developments in California, where stormwater capture schemes have been found to cost in the range of $0.01 per m³ to more than $10 per m³, depending largely on the scale (Atwater 2013; Dillon and Australia NWC 2009). The needs for water treatment and conveyance also contribute to cost variability. When stormwater capture is combined with *managed aquifer recharge*, costs include infiltration and underground storage, which are highly heterogeneous. Stormwater capture and recharge schemes range between \$0.06 per m^3 in Marrakesh, Morocco (Dahan and Grijsen 2017), and \$2.67 per m^3 in Australia (Ross and Hasnain 2018).

Costs for *rainwater harvesting* depend on the types of roofs and storage solutions. Rainwater harvesting has been priced (CAPEX plus OPEX) in cities in Australia and the Pacific region between \$1.75 per m^3 and \$10.75 per m^3 (Moran 2008), which is consistent with the range of costs reported in arid areas by Gould and Nissen Petersen (1999), as updated by IRC authors Batchelor, Fonseca, and Smits (2011).

Systematic comparisons of the economic costs and benefits of alternative solutions seldom happen, despite being critical to optimize the use of water and financial resources. Data availability, if not tackled early in the planning process, constrains decision makers' ability to conduct a thorough economic analysis, and policy windows tend to dictate water resources choices more than cost-benefit justifications. Including data gathering activities in upstream planning can bolster decision making with key economic information. However, even in the largest water systems, economic analysis methodologies incorporating multiple objectives and complex factors such as tradeoffs between urban and nonurban water users, environmental externalities, and climatic and other uncertainties can effectively guide long-term planning. This is happening, for example, in the Valley of Mexico, where an integrated water security and resilience strategy is being developed to improve the reliability, robustness, resilience, and sustainability of the water system, which supplies 22 million inhabitants in the Mexico City metropolitan area.[3]

The lack of information on the costs and benefits of demand management and infrastructure efficiency interventions further complicates economic efficiency analysis. Because reducing network losses and conservation measures rely on soft components implemented over the long term, they are difficult to isolate as specific budget line items. For example, though the Las Vegas, Nevada, water utility has reduced per capita water consumption by close to 40 percent since 2002 through a mix of water pricing, regulation, incentives, and education, the portion of savings attributable to each and the associated costs distribution are difficult to ascertain. Since demand management and infrastructure efficiency represent "untapped reservoirs" for cities and can significantly extend the use of existing conventional resources, there is strong incentive to creatively think about how to economically evaluate such interventions.

Diversifying Sector Financing Strategies

Innovative applications of wastewater reuse can also help bridge water resources gaps at an optimized price.

Before considering costly infrastructure development options for supply augmentation, increasing sector efficiencies through improved water management often yields economic and financial efficiencies. In 2006, it was estimated that reducing nonrevenue water levels by half in low-income countries could generate an additional \$2.9 billion in cash every year for the water sector, from both increased revenues and reduced costs (Kingdom, Liemberger, and Marin 2006). Similarly, Southern California service providers include nonrevenue water and demand management as "additional" future sources: the water saved from efficiency improvements and reduced consumption is water that can serve users without increasing the city's allocation.

California's West Basin Municipal Water District provides a menu of five types of water, wherein clients can purchase reclaimed water at different quality levels, based on the use it will be put to (for example, irrigation, general industry, groundwater replenishment, cooling towers, boiler-feed water). The uses require varying treatment intensities and the tariff is adjusted accordingly, providing a secure and tailored water source for nearby municipalities and industries. In Durban, South Africa, the concession of a recycled water treatment plant for industrial reuse has provided local industries such as Mondi Paper with a stable water source cheaper than potable water (eThekwini W&S 2011). This project has ensured industries would not leave the area due to lack of water, thus safeguarding the local economy and jobs depending on these industries. In addition, it has enabled eThekwini Water and Sanitation (W&S) to reallocate freshwater resources to unserved areas and avoided the construction of a costly marine outfall (Bhagwan 2012). Through the concession model, eThekwini W&S has also secured a source of revenue from efficiencies initiated by the private sector.

Private finance is a large untapped source that could help fill the water sector infrastructure financing gap in many cities. Vendor-based financing, through build-own-transfer schemes (BOT), for example, have been crucial in mobilizing the necessary financing for many desalination facilities, and for some wastewater recycling plants. Public-private partnerships (PPPs) have been a key feature of the Israeli water reform, in particular to finance CAPEX and improve overall performance. The seawater desalination program was financed through BOT schemes, raising $1,300 million in private investment. Mekorot, the national water company, and the corporatized regional utilities are now financed through commercial debt with private banks or bond issuances, without sovereign guarantees. Finally, subcontracting by water utilities is encouraged to improve operational performance and reduce costs; today, private contractors perform a large portion of the tasks of the most-advanced Israeli water utilities.

Singapore has also relied on the private financing to improve services. PUB purchases desalinated water from the private sector, which built and now operates the desalination plant. Similarly, though the first three NEWater plants were owned and operated by PUB, the fourth and fifth plants were built under a design-build-own-operate (DBOO) model. The main motivation to involve the private sector was to develop a water industry that would provide quality and cost-effective services and to encourage greater efficiency and innovation in the sector.

Vendor-based finance for the development of desalination or wastewater treatment facilities is still relatively limited outside of industrialized or resource-rich nations, with the notable exceptions of China, Mexico, and Brazil (GWI 2017). Across the Middle East and North Africa region, the practice is already well established in Algeria and is emerging in Morocco, Tunisia, and Jordan. The water sector has historically relied on public financing, which is now largely outstripped by investment needs. A common obstacle to the development of vendor-based finance is the lack of predictable and sufficient tariff-based revenues to cover water production costs. In such case, the tax payer is expected to make up the difference, which entails a significant political risk for any private investment project. More generally, to access private financing capital (including, but not limited to, vendor-based finance), actions that improve sector governance and efficiency should be prioritized to improve service providers' creditworthiness.

Sector Institutions Need to Adapt to These New Challenges

A proper institutional setup that defines roles and responsibilities is essential for the management of scarcity situations and for emergency responses. Following the same criteria used to justify a change in the paradigm and the need for management techniques and approaches different from what has been the "business as usual" of a city's water utility and services, this paper argues that the institutional setup under which these services are delivered needs to adapt to the new realities and challenges presented by water scarcity situations.

Three of the principles for action provide the main elements for the setting and framework for the institutional setup: (a) the need to look beyond the city limits; (b) demand management and infrastructure efficiency as key elements of preparedness and response; and (c) diversification of sources. The following paragraphs present options for city managers to consider in this respect, as well as relevant experiences. From these experiences a logical approach would be to propose creating three focal points of responsibility within the management structure of the utility, to be in charge, respectively, of (a) resource mobilization and external relations; (b) demand management and infrastructure efficiency; and (c) resource augmentation and diversification.

The need to look beyond the city limits to address scarcity situations and respond to emergencies is obvious. However, it presents special complications, since, in most cases, it involves responsibilities and jurisdictions that exceed the authorities normally vested on city officials and institutions. The Singapore Public Utilities Board (PUB), the single agency responsible for all aspects of supply and sanitation—from source management to reuse—is an exception to the general situation, which is better illustrated by one in which one agency is responsible for water resource management and allocation, often at the scale of the river basin, while the city is one among many users of the same resources. Malta, despite its small size and high degree of urbanization, divides the roles of resource management and allocation, retained at the level of a government agency, from those of service delivery. Service delivery is assigned to the Water Services Corporation, a public entity responsible for the complete drinking and waste water cycle in the Maltese Islands. It produces and distributes potable water and collects and treats the wastewater of over 250,000 households, businesses, industries, hotels, and so on, serving over 420,000 people. In Murcia, the responsibility for water resource management and allocation among different users is clearly assigned to the river basin agency (Confederacion Hidrografica del Segura). Its regional perspective was developed one step further with the creation of the Mancomunidad de Canales del Taibilla (MCT), a regional agency entrusted with producing and delivering potable water in bulk to the numerous municipalities in the region, which are distributed by their respective water utility. The common elements in these two cases and several other similar ones, notably in the United States, are the existence of (a) a strong and unified voice to present and defend the needs and position of urban users (the cities) versus other users (notably agriculture); (b) a negotiating table at a river basin authority in which allocations and resource management decisions are taken; and (c) established and transparent rules for the allocation (and trading) and management of resources. For this purpose, at the utility level, the traditional roles of the units responsible for bulk supply need to be expanded to carry out the external relations with other users and river basin agencies, incorporating new functions such as negotiating for additional transfers, water trading, or overall management and monitoring of shared resources, therefore establishing a responsible focal point that coordinates internally these areas and represents externally the utility.

To a great extent, actions that contribute to the efficient functioning of the network (such as loss reduction, sectorization, and pressure management) are part of accepted practice for a well-run utility, which need to be scaled up in cases of scarcity, even if the opportunity cost of the additional supply saved through these actions is lower than the existing tariffs. However, many other elements, particularly those aimed at reducing consumption, require techniques (such as public campaigns, flow limitators, and economic incentives) that are not part of what has been

Demand management and infrastructure efficiency have been highlighted as key elements of response to scarcity situations.

"business as usual." These added techniques could have significant negative impacts on the utilities' financial situation by discouraging consumption, particularly among the highest users, which are normally those that contribute the most to revenues (and which are subjected to the highest tariff blocks). Examples abound, however, of utilities that have been successful in drastically reducing their consumption while retaining financial viability and quality of service for consumers (Zaragoza, Spain, is one example to watch). Utilities need to adapt their institutional structure to incorporate and coordinate the seemingly contradictory initiatives of demand management and maintain the utilities' profitability, beyond the traditional functions of network management, metering, and billing. The creation of a point of focal responsibility in the utility's management structure for the functions of demand management and infrastructure efficiency seems to be an efficient approach to address the many issues involved and plan and implement demand management and infrastructure efficiency actions in a coordinated and efficient manner. Linked to these, tariff structure issues and service delivery standards and objectives should be part of the responsibilities assigned to this focal point.

Whether it is part of a medium-term resilience plan aimed to adapt the city to growing water scarcity or an emergency response, augmentation of available resources, but especially diversification, are among the main tools in the hands of the utility managers. Many of the alternatives considered (aquifer management and recharge, storm water capture, desalinization of sea water, reuse of treated wastewater) involve new technologies that go beyond the traditional engineering practices used in most cities. Additionally, because of the innovative nature of these technologies and the reduced number of suppliers available, these investments have specific procurement requirements if efficiency is to be achieved. Therefore, it is good practice to designate a focal point of responsibility in the management structure of the utility for the planning and implementation of the investment programs associated to resource augmentation and diversification. The Malta Water Services Corporation combines several different sources (desalinization, groundwater, wastewater reuse) to guarantee supply and has adopted a plan to further increase the contributions from desalinization and wastewater reuse. Singapore has adopted the policy of "four national taps," aimed to achieve flexibility in the supply and allow PUB management the possibility of using the option that better responds to particular situations and offers lower costs. Responsibility for resource augmentation and diversification should thus go beyond the investment phase and into the actual management of which combination of sources to use with those objectives in mind, as well as into the planning for future scenarios and potential emergencies.

Integration Is a Critical Enabler

Dependence on resources shared at the basin scale means water resource management must take the river basin scale into account, which requires specific institutional structures. To thrive as a stakeholder within a river basin, a city needs to secure municipal demand in the face of other interests. Through river basin organizations, all users have access to a platform where their interests can be considered and uses prioritized according to the corresponding value of the water and, often, the political clout of each user. The organizations provide flexibility and adaptive capacity, facilitating the reallocation of resources between places, users, and periods of use in response to evolving needs, and the potential to adjust demands to available resources.

A successful institutional setup for the management of water scarcity situations requires effective management of water resources by a river basin agency and involvement by a water supply and sanitation (WSS) service provider to ensure available resources are adequate and secure. Where different uses are competing for finite resources, this structure contributes to define and enforce equitable and efficient allocations, and to maintain checks and balances between users. Murcia provides a good example of such a paradigm, with the regional bulk water supplier, MCT, representing the interests of all urban water service providers to the river basin agency. The creation of this strong regional public entity was critical not only to garner public and political support in water allocation processes but also to mobilize sufficient funding to undertake costly infrastructure investments. Such integrated models and metropolitan-wide approaches can be particularly relevant in urban areas composed of multiple jurisdictions and WSS service providers.

Because wastewater management is handled by a regional sanitation company, the benefits of pollution control are linked to the river basin scale at which they are accrued. In Malta, the size of the country encourages the centralization of service provision responsibilities—from abstraction to wastewater treatment—under the Water Services Corporation, though all decisions are checked by the Energy and Water Agency, the de facto water resource management entity.

When water use is dominated by one main municipal user, the same entity may manage service and resource allocation, and thus have incentive to manage water resources efficiently. Such models exist in Singapore and Las Vegas where creating a unified front in water negotiations with other countries or states, respectively, has been critical, motivating the integration of services and resource management under the same entity. If scale allows, these arrangements streamline allocation negotiations—with all interests centralized in one agency—and promote transparency.

Integrating municipal water management with other services can identify synergies and promote a circular economy. In Orange County, joint planning between the OCWD (in charge of bulk water supply) and the Orange County Sanitation District (OCSD) helped identify wastewater reuse as a key cost saver for the water district—by securing a new drought-proof source of water—and for the sanitation district—due to avoided seawater outfall costs. In Brazil, aligning stormwater drainage and solid waste management investments has helped with wastewater treatment by controlling the inflow of trash and stormwater entering the WWTP system (Tucci 2017). Planning for urban development can also facilitate future service provision. Windhoek wants to promote the decentralization of industrial growth to alleviate pressure on water resources in certain concentrated zones of its service area. By contrast, the Singapore PUB is one of the few agencies in the world that manages all aspects of water resources, which facilitates decisions about water source diversification and urban service planning.

Beyond a change in contractual mandates, water scarcity management principles need to be reflected in the service providers' internal organization, processes and incentives, and corporate culture. Water service providers have traditionally been dominated by urban hydraulics engineering and planning functions, with a linear management focus on obtaining, treating, delivering, collecting, and retreating water in a financially sustainable way. Key performance indicators and corporate efforts have been geared toward direct service-related targets and processes, leaving broader sustainability and resilience aspects as secondary considerations under the diluted responsibility of water sector and urban management agencies. A detailed review of this transformational process among effective service providers of water scarce cities will provide valuable insights to support the paradigm shift outlined in chapter 2.

Finally, because an integrated approach to urban water management likely requires institutional changes and reforms, political will and champions are needed to catalyze and sustain the right enabling environment. In recognition of the strategic importance of the water crisis in Perth, a water policy unit was established in the Department of Premier and Cabinet of the State of Western Australia in the early 2000s to support and coordinate the government policy response. Singapore leadership elevated water security as a top strategic priority for the country, which facilitated the planning and implementation of its broad sector reforms.

Notes

1. Costs for vertical transport would be the least impacted by economies of scale in terms of transported volumes.
2. World Bank calculation.
3. Project information document describing the project available at the following URL: http://documents.worldbank.org/curated/en/736711516302537958/pdf/Project-Information-Document-Integrated-Safeguards-Data-Sheet.pdf.

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Centuries-old cistern in Hababa, Yemen. © Bill Lyons/World Bank.

Chapter 5
Conclusion

Skyscrapers, urban populations, and temperatures are rising faster than ever. Up close, Earth's cities buzz with activity and growth, while urban lights boldly shine from space. Although human societies are growing and thriving, water scarcity is a persistent problem that plagues cities worldwide. Effectively managing water scarce cities has been a notoriously challenging puzzle through the ages and is increasingly difficult.

Global metropolises have been struggling for their very survival against water scarcity. Headlines documenting drought and water shortages are ubiquitous. From Rome, Italy, to Cape Town, South Africa, stories of deficient water supplies abound, while Brisbane, Australia, is on the edge of a severe drought. Although an abundance of water can boost economic prospects and public health, lack of water can be debilitating.

Despite the daunting challenges outlined, this report does not set out to evoke feelings of doom and gloom. Rather, it shows the successful approaches many cities have followed to shape a water secure future, less vulnerable to the vagaries of rainfall, the likely effects of climate change, and ever-increasing water demands.

Sometimes the most difficult problems have simple solutions; addressing urban water scarcity does not rest solely on costlier infrastructure and complex technologies. Efficiency gains at all levels (including water demand, allocations, and infrastructure), improved cooperation with other water users, or optimized groundwater management can go a long way. Major gains in the cost reductions of nonconventional sources such as desalination and reuse are game changers. Many solutions for water scarce cities are already accessible and less costly than traditional infrastructure approaches.

There has been an explosion of innovation and knowledge in water scarce cities, and the opportunity is ripe to unleash the potential for their replications. Water utility managers need to move away from a passive reliance on historical water allocations and take responsibility to generate "new water" through appropriate and innovative measures. They must become active players in the water resource management debate, seek synergies with other sectors and users, and master communication with the public to spur broad acceptance of water management decisions.

Research focusing on the shifts undertaken in terms of service providers' contractual mandate and performance obligations, internal organization, processes and incentives, and corporate culture will be most useful to help guide water scarce cities toward water security. This shift to more integrated and better incentivized utilities will add support to dialogue on credit worthiness and access to private financing (local market) to finance infrastructure development needs.

If we pay close attention, water shares many lessons. Water cooperates. Water nourishes. Water is persistent as it carves into seemingly impenetrable surfaces over millennia. Water adapts to its environment, as it flows effortlessly beyond obstacles in its pathway. Through the lens of water, the Water Scarce Cities (WSC) Initiative seeks to shed light on effective water management strategies in a changing world, to emulate knowledge exchange between cities, and to encourage water utilities to become the empowered agents of change needed to challenge cities' water scarce destiny.

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