FULL REPORT

# WATER SCARCE CITIES

## Thriving in a Finite World

WORLD BANK GROUP

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*Cover design:* Taylor Crisdale, JESS3.

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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

This report was prepared by a team of water specialists led by Stephane Dahan and comprising Clementine Stip, Manuel Marino, Richard Abdulnour, Amal Talbi, and Lauren Core.

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Contributions from many experts and partners have been critical in the preparation of the case studies: Australian Water Partnership (Perth), Emily Virginia Bell (Tucson), Florian Heiser (Fortaleza), Ghazi Abdul Razzaq Abu Rumman (Amman), Gregory Pierce (West Basin, California, and Southwest United States chapter introduction), Joost Buurman, Cecilia Tortajada, and Prof. Asit K. Biswas (Singapore), Kara Nelson (San Francisco), Madelyn Glickfeld (Los Angeles), Meleesa Naughton (Malta), Mike Muller (Windhoek), Nour Khater (Orange County, California), Nuria Hernandez-Mora (Murcia, Spain), Philippe Marin (Cyprus and Israel), Richard Luthy (Kern County, California), Srinidhi Sampath Kumar (literature review) and Subhash Verma (Jaipur). Collaboration with a broad range of institutional partners and other stakeholders in the water sector has been essential throughout the preparation of this study, with a special mention to ReNUWIt and UCLA for their technical guidance and support.

Finally, the team is grateful to the Water Partnership Program (WPP) for its support to the achievement of this work.

# Abbreviations

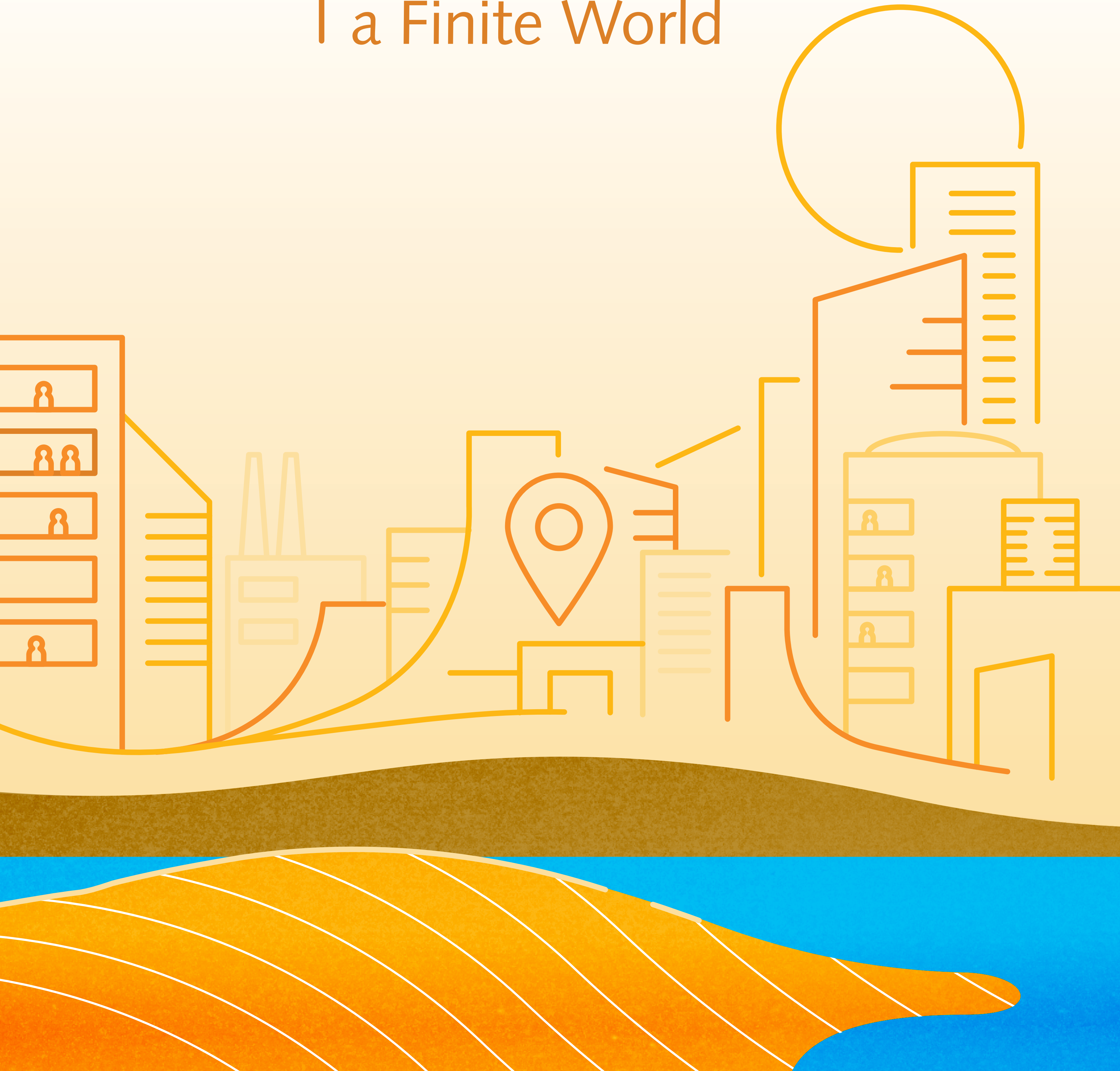
| | |
|---|---|
| ADOA | Arizona Department of Administration |
| ADWR | Arizona Department of Water Resources |
| AFY | acre-feet per year |
| AMA | active management area |
| AWBA | Arizona Water Banking Authority |
| AWS | Assured Water Supply (Program) |
| AWTF | advanced water treatment facility |
| BEA | Basin Equity Assessment |
| BMP | best management practice |
| BPP | Basin Production Percentage |
| CalEPA | California Environmental Protection Agency |
| CAP | Central Arizona Project |
| CAWCD | Central Arizona Water Conservation District |
| CDWR | California Department of Water Resources |
| CSIBP | Coastal Seawater Intrusion Barrier Project |
| CVWD | Coachella Valley Water District |
| CWCB | Central and West Coast Groundwater Basins |
| EPA | Environmental Protection Agency (U.S.) |
| EWMP | Enhanced Watershed Management Plan |
| GI | green infrastructure |
| GMA | Groundwater Management Act (Arizona) |
| GRIP | Groundwater Reliability Improvement Project |
| GWRS | Groundwater Replenishment System |
| ICS | Intentionally Created Surplus |
| IID | Imperial Irrigation District |
| IRWD | Irvine Ranch Water District |
| LACFCD | Los Angeles County Flood Control District |
| LADPW | Los Angeles Department of Public Works |
| LARWQCB | Los Angeles Regional Water Quality Control Board |
| LID | low-impact development |
| LVVWD | Las Vegas Valley Water District |
| lpcd | liters per capita per day |
| lpd | liters per person per day |
| MAF | million acre-feet |
| MWD | Metropolitan Water District of Southern California |
| MWDOC | Municipal Water District of Orange County |
| NOAA | National Oceanic and Atmospheric Administration |
| NWP | Nonpotable Water Program (San Francisco) |

| | |
|---|---|
| OCSD | Orange County Sanitation District |
| OCWD | Orange County Water District |
| PAG | Pima Association of Governments |
| QSA | Quantification Settlement Agreement |
| RA | replenishment assessment |
| RFC | return-flow credit |
| RWH | rainwater harvesting |
| SCAG | Southern California Association of Governments |
| SDCWA | San Diego County Water Authority |
| SFDBI | San Francisco Department of Building Inspection |
| SFDPH | San Francisco Department of Public Health |
| SFDPW | San Francisco Department of Public Works |
| SFPUC | San Francisco Public Utilities Commission |
| SERI | Sonoran Environmental Research Institute |
| SNWA | Southern Nevada Water Authority |
| SWP | State Water Project (California) |
| SWRCB | State Water Resources Control Board (California) |
| TDS | total dissolved solids |
| US EPA | United States Environmental Protection Agency |
| WIN | Water Independence Now |
| WRD | Water Replenishment District of Southern California |
| WRF | water reclamation facility |

All monetary amounts are U.S. dollars unless otherwise indicated.

# Part I

## Thriving in a Finite World



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.

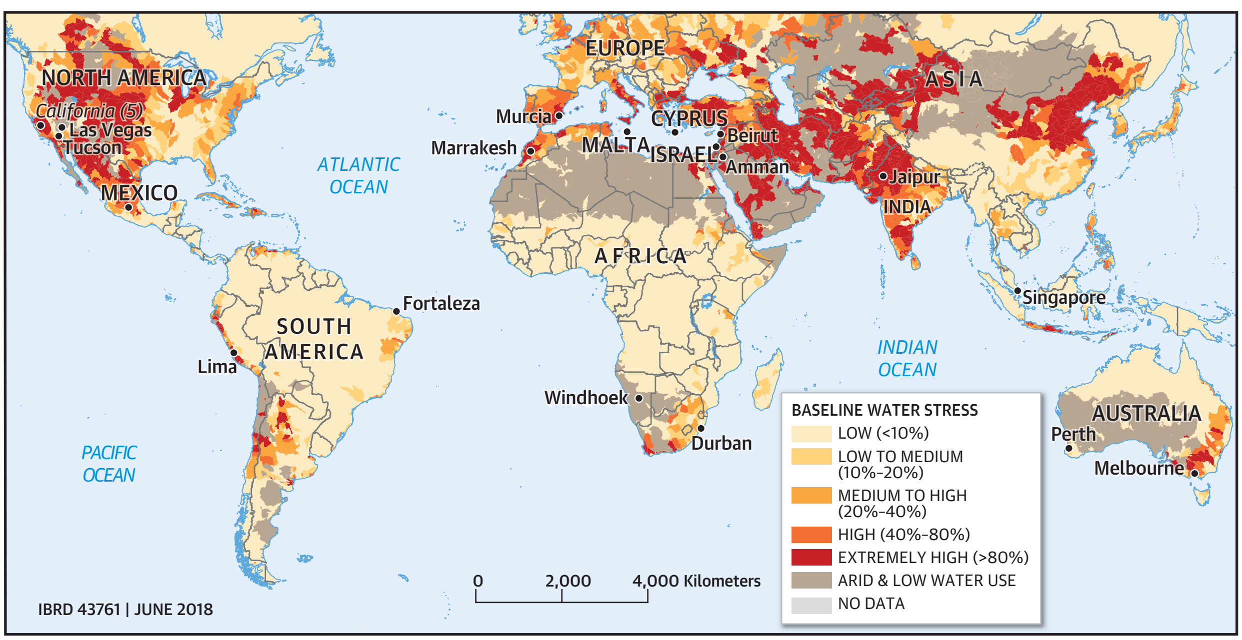
Water scarcity solutions that may be enigmatic or unfamiliar are illuminated through first-hand accounts to highlight paradigm shifts, emerging principles, and demystify innovative approaches. This report offers a first look at new pathways that cities, states, and regions facing water scarcity can explore, 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.

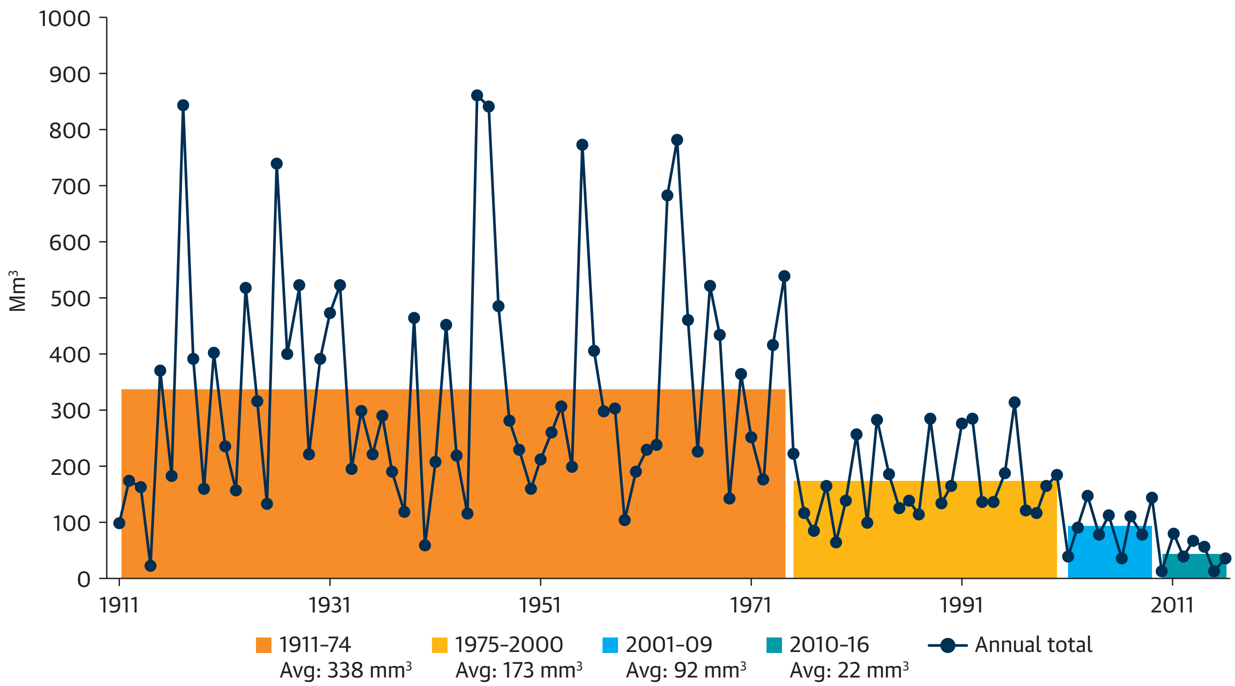
### Drastic Changes in Hydrology Due to Climate Change

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

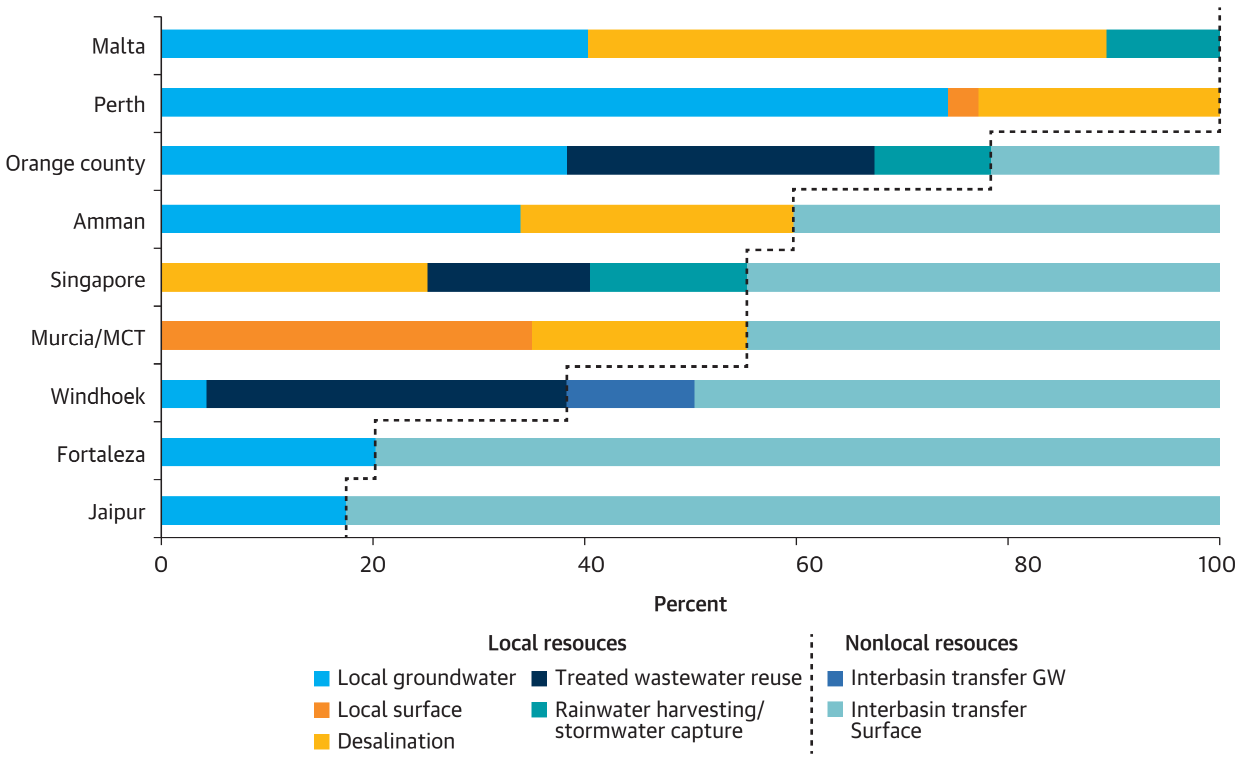
When cities facing water scarcity seek new water resources, demand management and improving system efficiency should be two of the potential sources to be tapped. Demand can be reduced through improvements in system efficiency and the reduction of losses, by incentivizing customers to reduce consumption, 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.

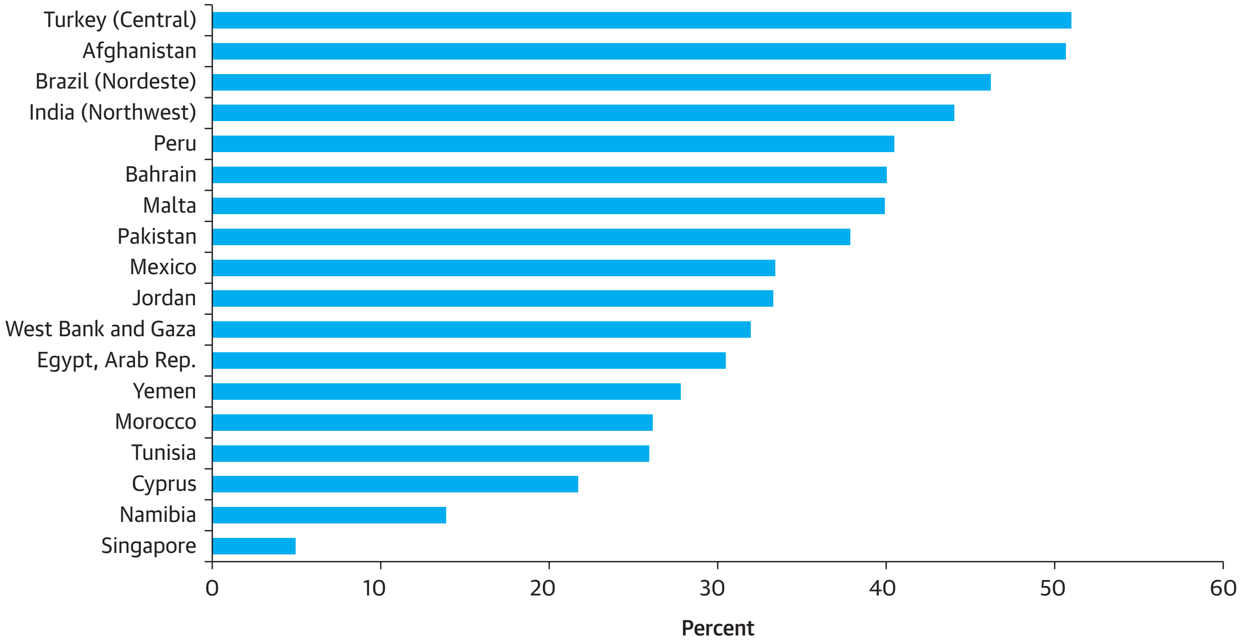
### Promoting Water Conservation

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.

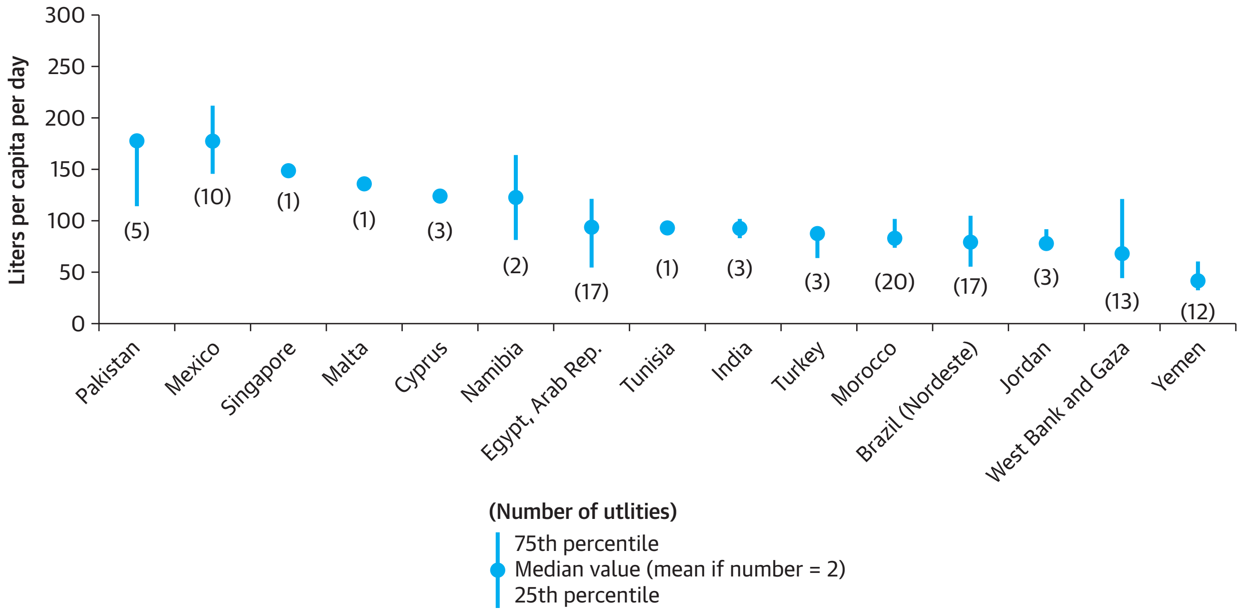
*Rules and restrictions* tend to be more effective tools in managing short-term supply shortages because they prompt immediate actions from customers.

**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

**PHOTOGRAPH 3.1. Awareness Campaign in Las Vegas**

*Source:* Las Vegas Valley Water District.

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).

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

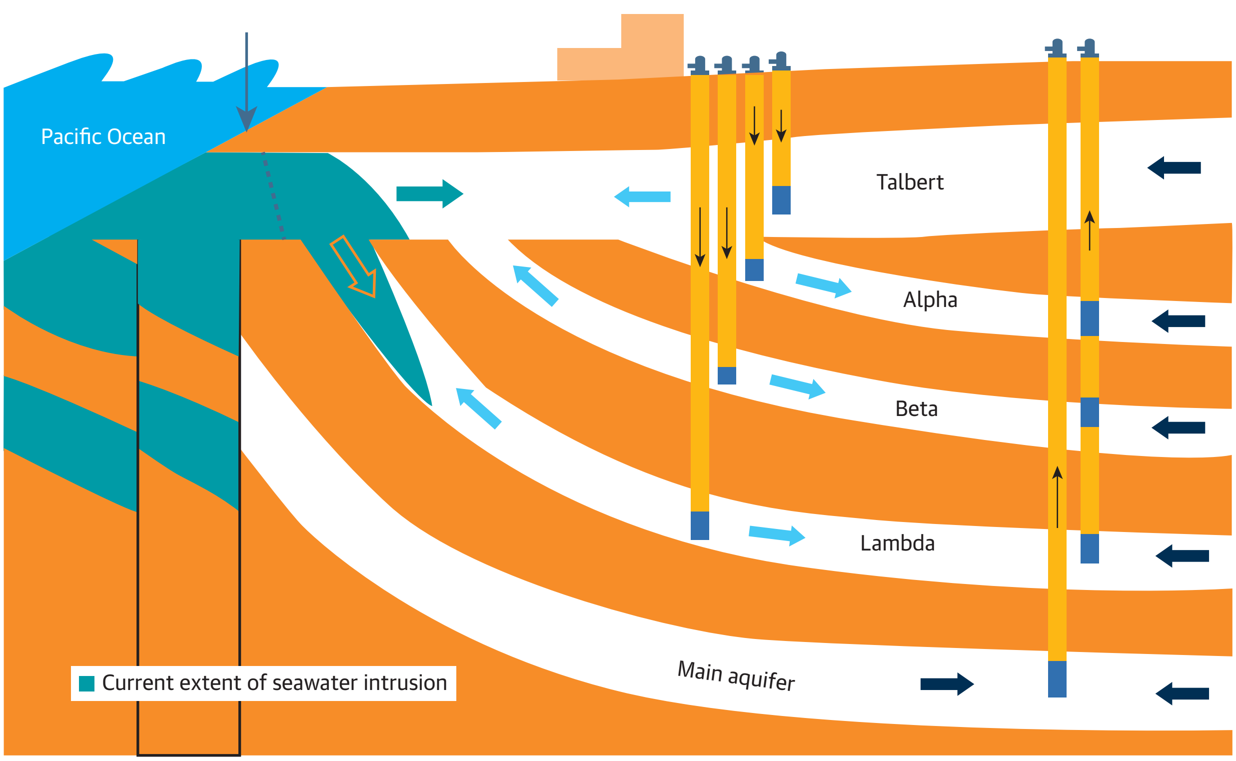
Conventional systems draw from the traditional water sources of surface water and groundwater. These are often seasonal and highly climate-dependent, and many show declining outputs over time. While cities move on to other resources once these are depleted, water scarce places such as Orange County, 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 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.

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

*Source:* Orange County Water Department.

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**

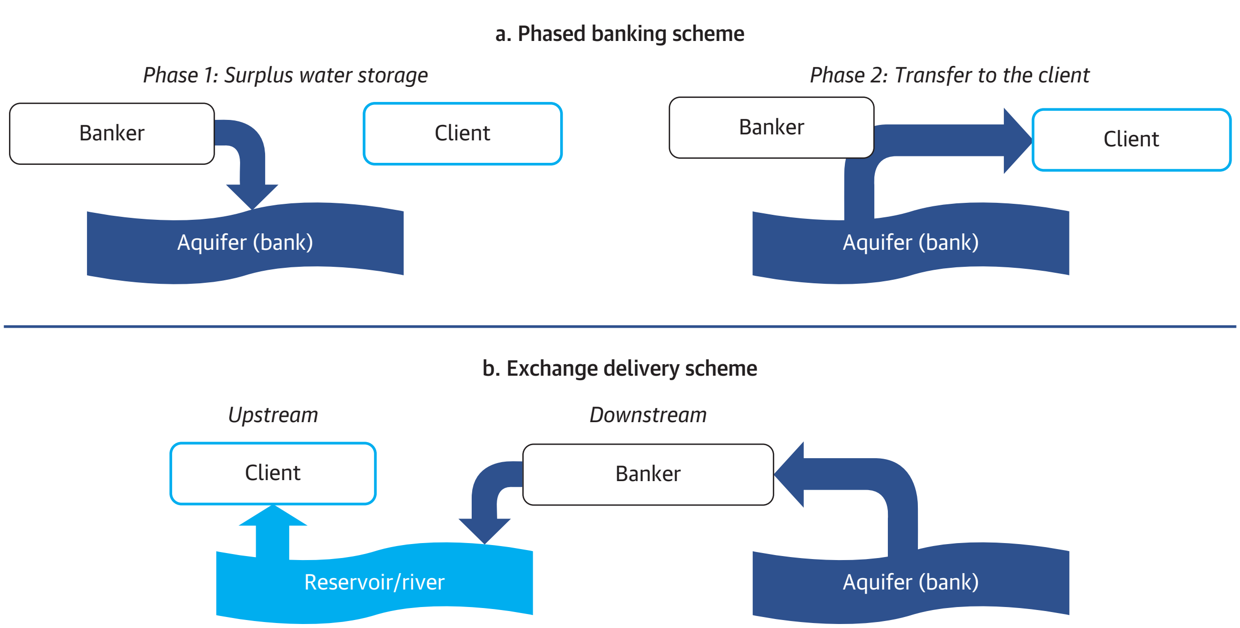
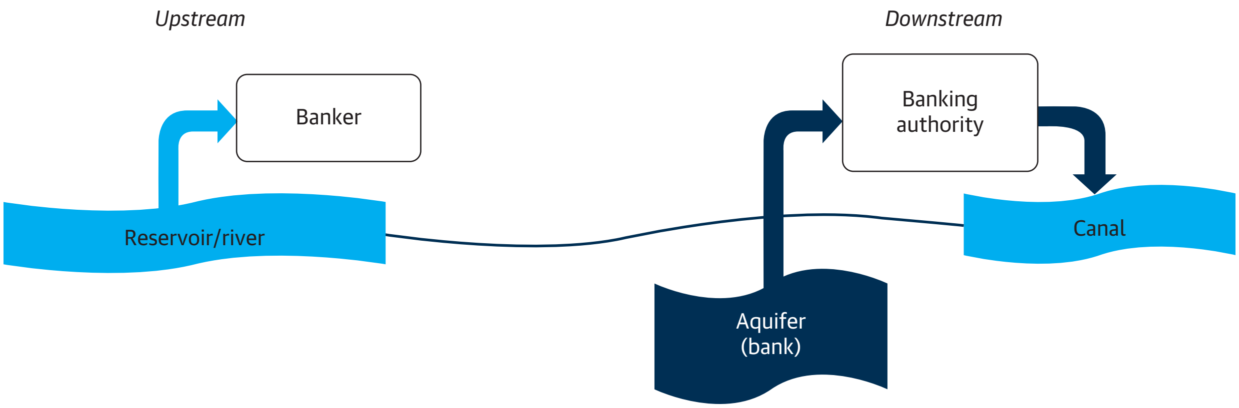


**FIGURE 3.6. Virtual Transfer Scheme**




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.

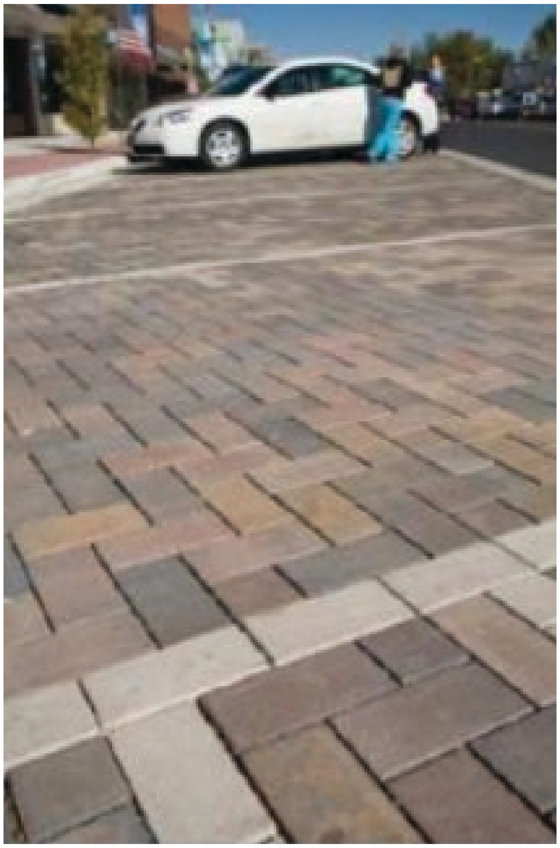
Tucson has implemented two different approaches to improve stormwater management: low-impact development and green infrastructure. Low-impact development modifies land to mimic predevelopment hydrology and help maintain infiltration and drainage while reducing the runoff of pollutants into washes, rivers, 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

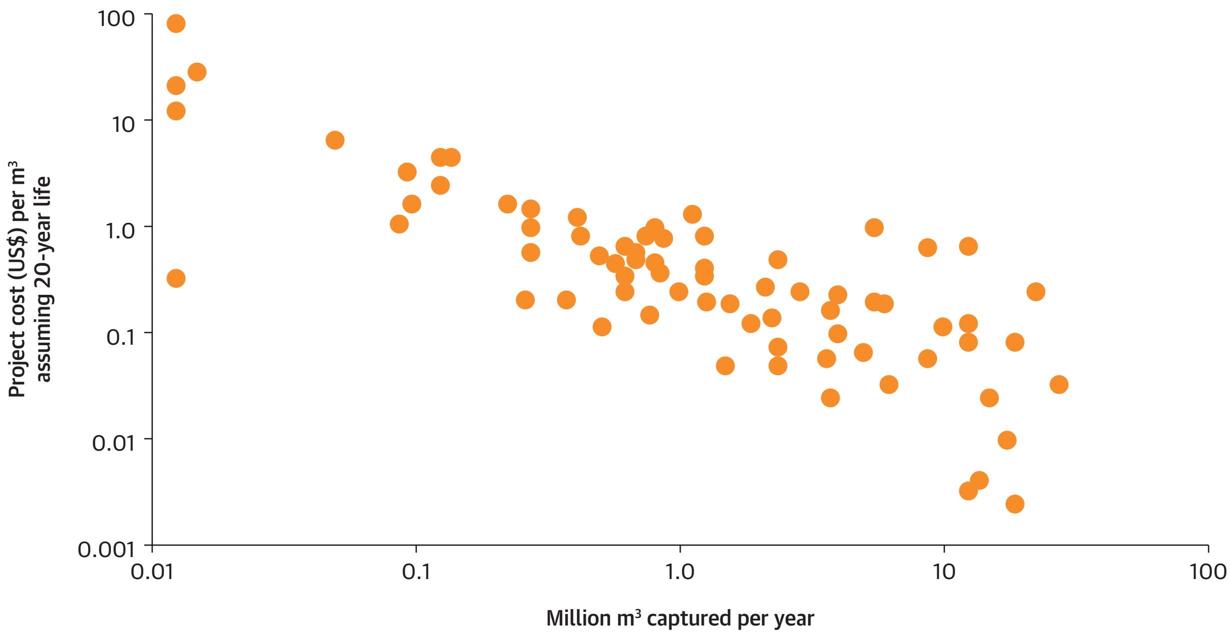


*Source:* City of Tucson.

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

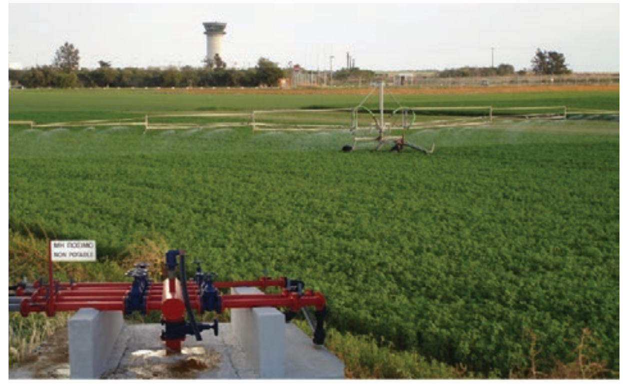
**The biggest barrier to such programs remains public acceptance, or the "yuck factor."**

**PHOTOGRAPH 3.4.** **Wastewater Treatment and Reuse for Irrigation, Cyprus**

a. Limassol (moni) wastewater treatment plant

*Source:* Sewerage Board of Limassol - Amathous.

b. Wastewater reuse for irrigation



*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.

**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.**

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.

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.

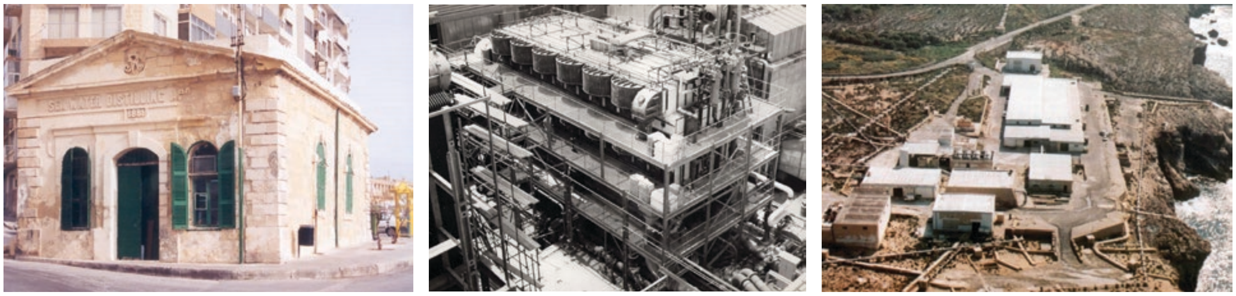
High energy costs are one of the main barriers to the adoption of desalination and are the most volatile component in desalination costs. In Perth, groundwater replenishment with reclaimed water has replaced seawater desalination as the preferred new water source, due to its lower unit cost. Though both 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 m³ in the late 1980s to an average cost of about \$1.00 per m³ (GWI 2017) since 2000. For the largest plants, as low as \$0.60 per m³ 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

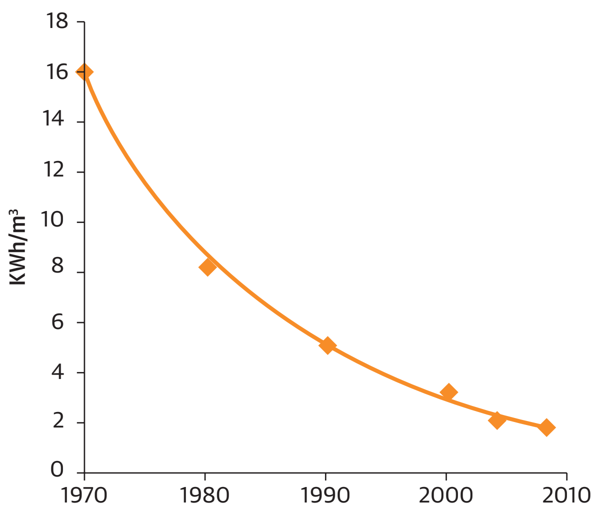
c. Large scale reverse osmosis in the 1980s



*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**

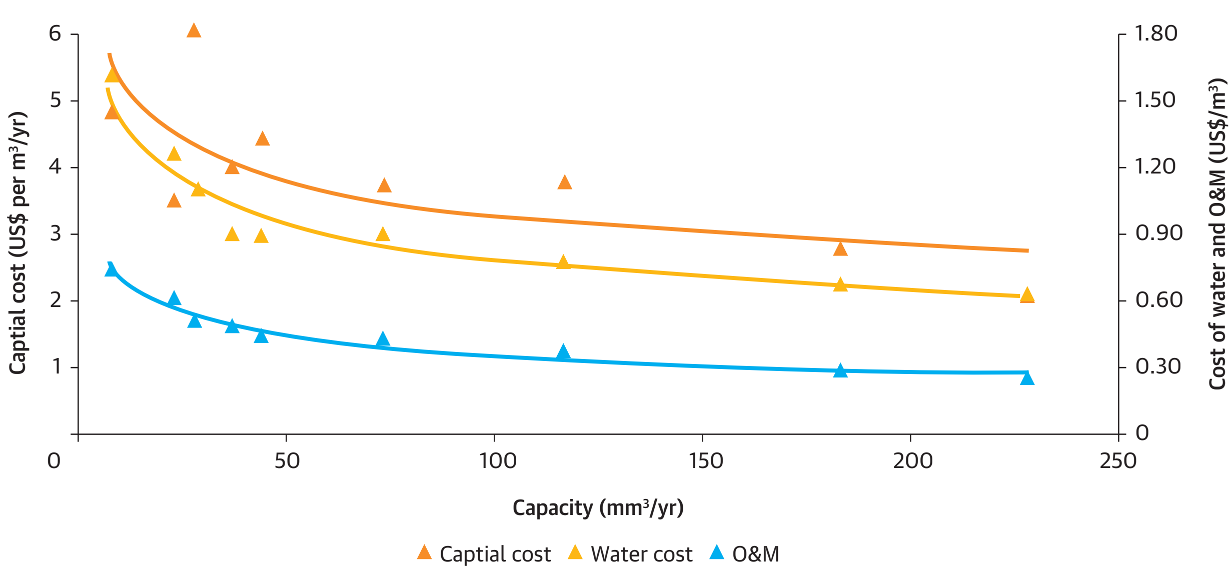



*Source:* Elimelech and Phillip 2011.

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).

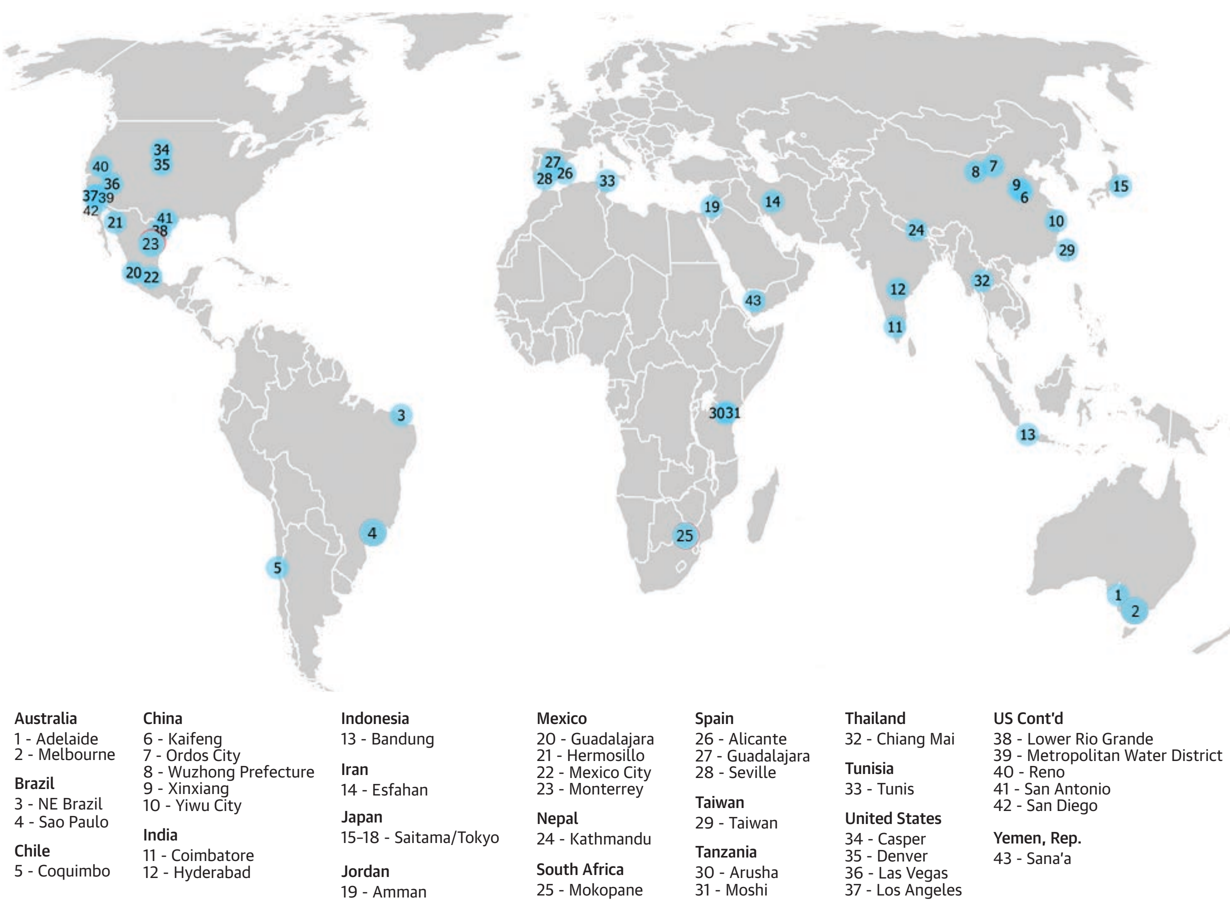
Limiting efficiency measures to the urban water supply network but not to upstream processes creates an institutional disincentive for the service provider. In Morocco, the water supply provider's mandate is limited to the distribution of water that has been abstracted, treated, and conveyed by the bulk 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**




*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 m³ 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 m³ 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.

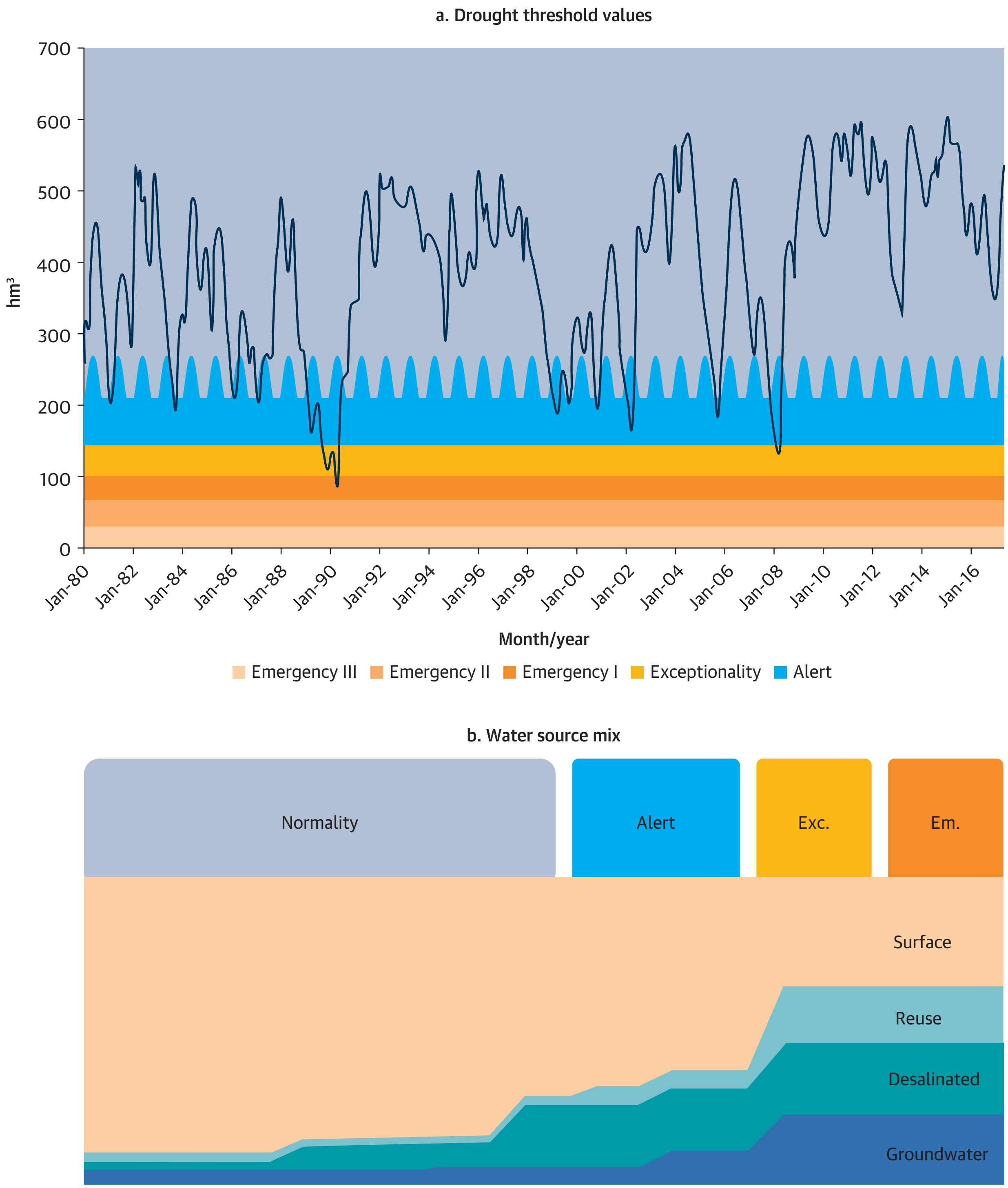
Robust decision-making approaches assess the sensitivity of a proposed investment plan's performance to changing conditions, and accordingly adjusts the plan to minimize its vulnerability. These planning approaches strongly value no-regret measures, which can be implemented regardless of climate change 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**




*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

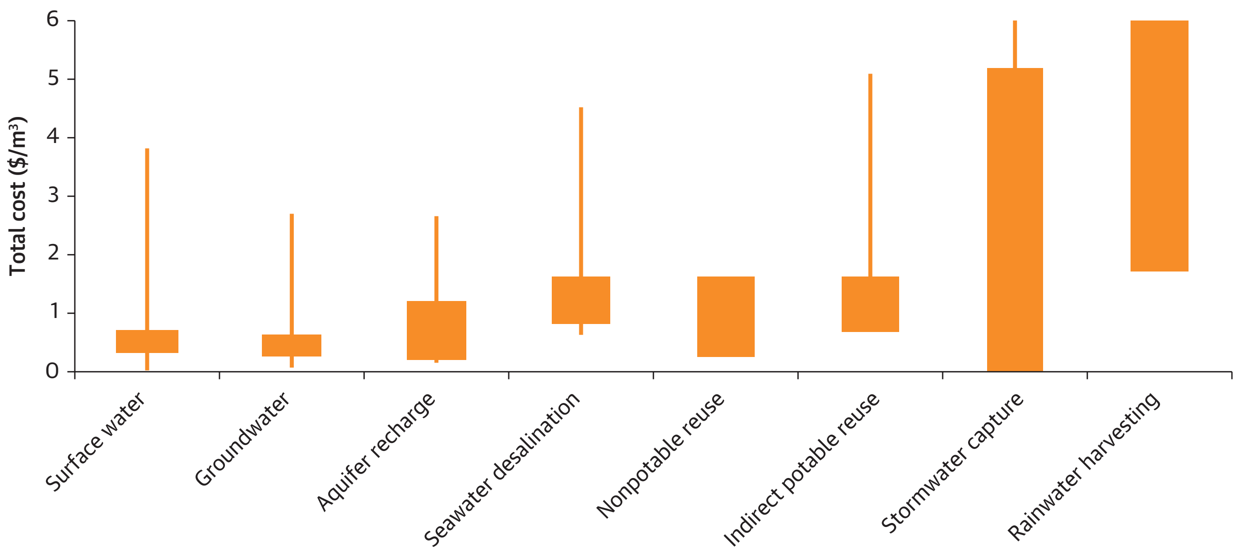
In many areas of the world, growing water scarcity impacts the availability of freshwater resources and shifting costs so that nonconventional solutions are becoming more affordable than the expansion of conventional ones. In the most water scarce provinces of China, freshwater withdrawal quotas are 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 $0.01 per m$^3$.[2] By contrast, in Windhoek, total costs with water conveyance of inter-basin water supply from the Okavango River are estimated at $3.8 per m$^3$. For *groundwater supply* solutions costs, commonly span between $0.1 and $0.4 per m$^3$, but can exceed $2.0 per m$^3$ 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 $0.6 per m$^3$ (achieved in Israel with a production capacity above 600 million liters per day) and more than $2.0 per m$^3$ 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 $0.25 per m$^3$ in California (GWI 2017) and $5.1 per m$^3$ in Australia (Moran 2008), with most common costs being found between $0.60 per m$^3$ and $2.20 per m$^3$ (GWI 2017).

*Stormwater capture* has seen significant developments in California, where stormwater capture schemes have been found to cost in the range of $0.01 per m$^3$ to more than $10 per m$^3$, 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.

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

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 "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.

# Part II
## Case Studies

Malecon, Havana, Cuba. (c) Dorte Verner.

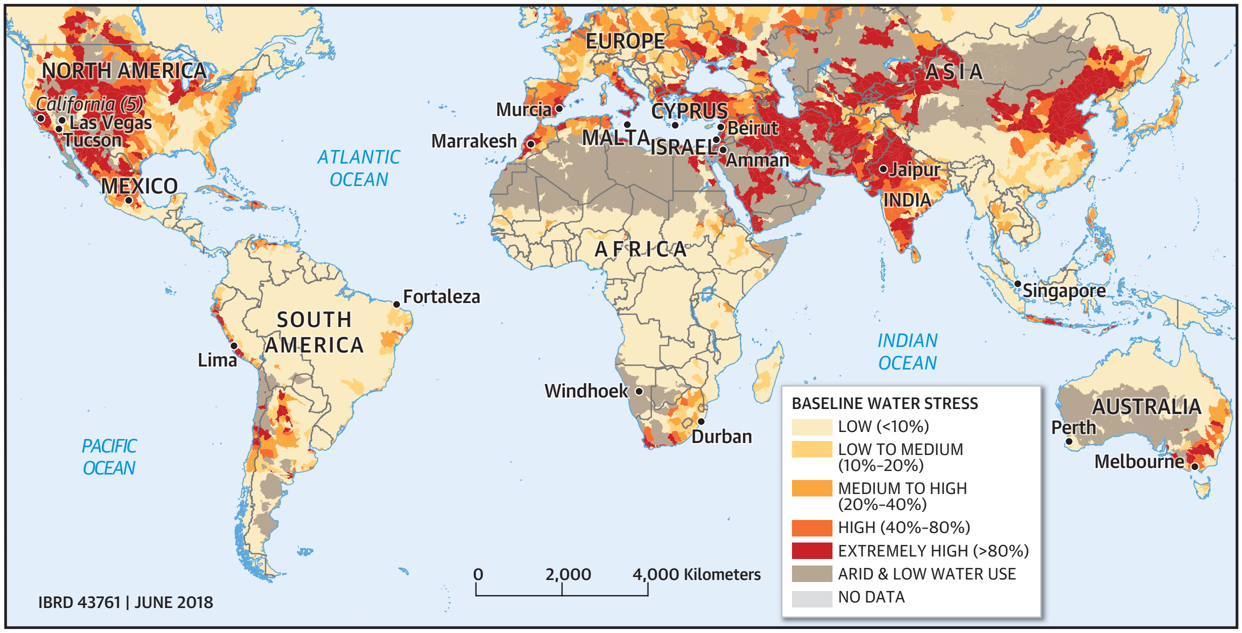
# Chapter 6
# Introduction to Part II: Case Studies

Part II compiles case studies from the Water Scarce Cities Initiative. These case studies were included to document and showcase the experiences and best practices from cities that have instituted effective solutions to tackle scarcity challenges.

Each case study follows a similar structure: a brief description of climate and hydrology and institutional context, followed by a review of past and future water use, to put in perspective a discussion on the city's water balance. This then leads to a presentation of the policy, institutional and technical solutions implemented by the city, and, when possible the political economy around their adoption and the drivers of change. The case studies conclude with a discussion on lessons applicable to other cities. Part II B, which is dedicated to cities from the Southwest United States, provides background discussions on the institutional framework, water resources and use in a common introduction to avoid repeating many of the features shared by these cities.

The case studies were selected considering the severity of the physical water scarcity challenge, and the desire to illustrate a broad range of institutional and technical solutions, addressing a variety of contexts and challenges.

**MAP 6.1. 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.

# Part II A

## Global Case Studies

*Source:* https://pixabay.com/en/malta-travel-tourism-europe-island-485321/.

# Chapter 7 Malta

Located in the Mediterranean at the crossroads of Europe and Africa, the Maltese Archipelago is composed of three islands (Malta, Gozo, and Comino), covering a total land area of approximately 316 square kilometers, with a coastline of 140 kilometers. Malta, the largest of the three islands, has an area of 245 square kilometers; Gozo and Comino have an area of 67 square kilometers and 3 square kilometers, respectively.

Malta has been inhabited since prehistorical times; its strategic location gave it prominence as a military and naval outpost in the Middle Ages, along the route to the Holy Land. From 1530 to 1798, it was ruled by the Order of the Knights of St. John as a vassal state of the Kingdom of Sicily and resisted the advances of the Ottoman Empire. After a brief period of Napoleonic rule, Malta became a British colony in 1800. Malta gained independence from the United Kingdom in 1964, became a republic in 1974, attained its freedom from the presence of British military troops in 1979, and became a member of the European Union (EU) in 2004, joining the euro area in 2008.

The Maltese archipelago is home to 450,000 inhabitants, making it one of the most densely populated countries in the world; approximately 95 percent of the territory is classified as urban. It is a popular tourist destination, particularly during the summer. The annual number of tourists in Malta equals five times the number of Maltese residents.

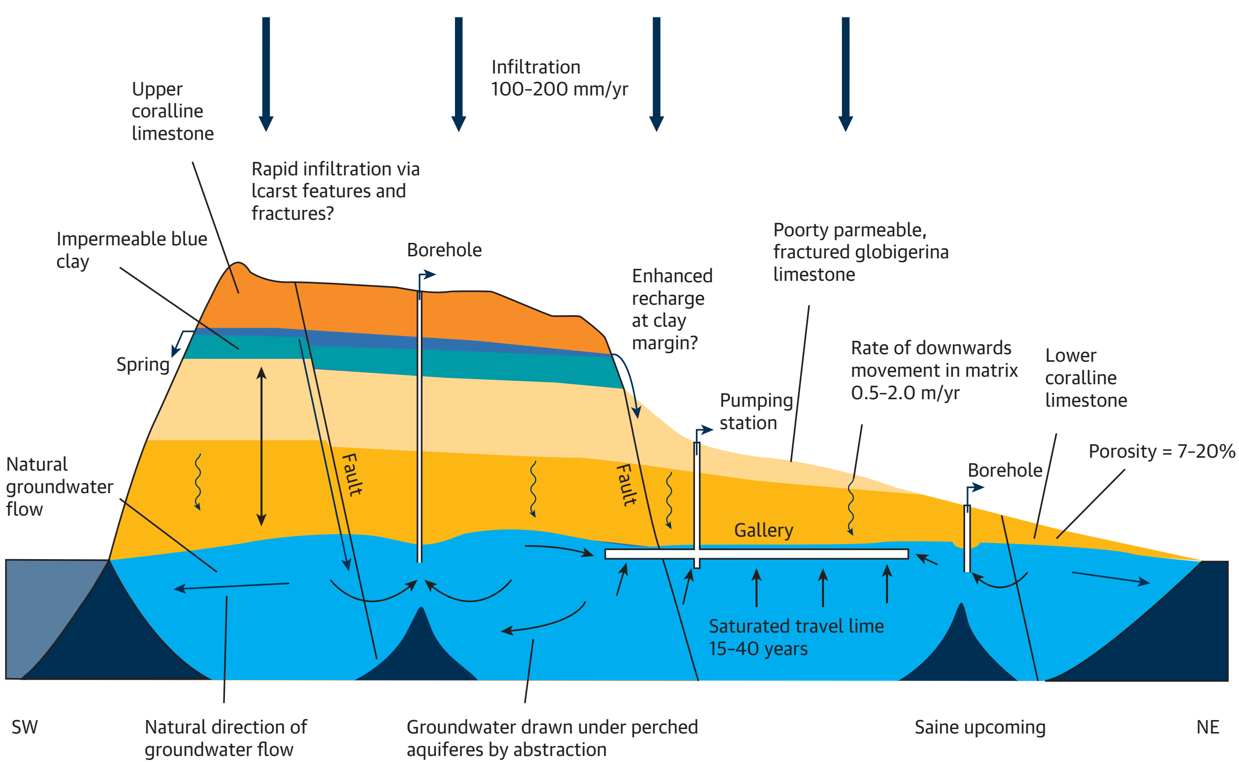
Water supply is a challenge for the country, due to the absence of significant perennial surface water bodies and the lack of rainfall in the summer, which coincides with the time of greatest demand. Malta was historically dependent on groundwater, abstracted from a system of water tunnels and boreholes, and rainwater harvesting; the population suffered from water rationing and intermittent supply from the 1970s through the late 1980s and early 1990s, when desalination was developed at scale. Desalinated water currently accounts for more than half of the domestic water supply. Groundwater still supplies about half of the domestic water supply and most of the water used for irrigation.

## Climate and Hydrology

With an estimated water availability of 80-120 square meters per capita per year, Malta is one of the most highly water-stressed countries in Europe (Energy and Water Agency 2015). Its climate is considered to be semiarid, with mild wet winters and hot dry summers and an annual average precipitation of 560 millimeters per year. There are no exploitable surface water sources or watercourses in Malta. By far the largest underground water storage capacity, yielding about 80 percent of groundwater abstracted in the country, is provided by the mean sea-level aquifers of the islands of Malta and Gozo. The rest of the groundwater available comes from the shallower "perched aquifers," which are separated from the mean sea-level aquifers by a layer of clay (figure 7.1) (Malta Resources Authority and FAO 2004). Desalination, which currently provides around 60 percent of the domestic drinking water supply, has been practiced for decades in Malta—the first seawater distiller was built in 1881 in Valetta, and the three plants currently in operation were built in the 1980s.

Desalinated water has become the main source of drinking water supply, supplemented by groundwater. Currently, the drinking water distributed by the utility, Water Services Corporation (WSC), is a blend of

**FIGURE 7.1. Schematic Cross-Section of Malta's Aquifer System, Showing the "Perched" and Mean Sea-Level Aquifers**




*Source:* BGS 2017. Reproduced with the permission of the British Geological Survey ©NERC. All rights reserved.

desalinated seawater produced by reverse osmosis (RO), and groundwater from the mean sea-level aquifers. Because the quality of the groundwater no longer meets potable drinking water standards, drinking water is blended in the reservoirs at a ratio of approximately 60 percent desalinated seawater and 40 percent groundwater. Large-scale exploitation of the mean sea-level aquifers of Malta and Gozo began in the 1950s and increased to meet the national potable water demand. Those aquifers are currently tapped by the WSC as well as by thousands of private (registered and unregistered) boreholes owners, mainly for agricultural use. It is estimated that private users abstract about the same amount annually from the aquifers as the WSC, with some variation between wet and dry years (abstracting more than WSC in dry years). A significant part of the abstraction from the private sector is from the perched aquifers, where the quality of the water is low due to nitrate pollution and increasing salinity; many springs, that tap into these aquifers have been abandoned over the years for public water supply, although they are still used for agricultural purposes (Malta Resources Authority and FAO 2004).

There is also some limited rainwater capture in urban and rural areas and self-supply from groundwater. A small number of residents living in small hamlets rely on the traditional spieri (private wells). Water reuse is also being developed, with the commissioning of the first New Water plant in the spring of 2017 by WSC.

### Water Resource Use Strategy

Desalination offers more than just an additional source of water for Malta. The blending of groundwater with desalinated water is vital to reaching drinking water standards. On its own, the quality of the groundwater is now too low to be used for drinking water, mostly due to pollution from nitrates and high salinity. The three desalination plants are located in areas of high population, and Malta has developed a system of transfer pipelines between them that enables managers to be flexible in meeting demand.

Storage capacity is supplemented by private residents' tanks. Current storage capacity allows for a total of three days' supply of desalinated water in Malta, so the flexibility allowed by interplant transfers is essential to ensure security of supply. After experiencing water shortages in the 1980s, all private residents also have small water tanks on the roofs of their houses.

There is a diversification of water sources on the smaller inhabited island of Gozo. The main source of water in Gozo is groundwater from the mean sea-level aquifer system of the island. During periods of high demand, it is supplemented by a water transfer from the Cirkewwa desalination plant, through a submarine pipeline. The utility is planning for a new desalination plant in Gozo as the submarine pipeline can malfunction and be difficult to repair when the seas are rough. This happened in January 2017, and the island was cut off from water supply for a number of weeks. Because this occurred during the low season, demand for water was relatively modest in Gozo, but were this to happen during the high season, the challenge for WSC would be much greater.

Nonconventional water sources being developed include wastewater reuse, which is currently being scaled up by WSC (three polishing plants are to be commissioned that will produce a total of 7 million cubic meters by the end of 2017), and rainwater harvesting (including initiatives to promote rainwater harvesting and double piping with households). Stormwater capture and greywater recycling are being piloted on a much smaller scale.

The benefits of desalinated water outweigh the costs in Malta, because of the need to ensure that groundwater abstraction remains sustainable. For total costs, groundwater remains the cheapest resource (0.28 euros per cubic meter), followed by desalinated seawater (0.72 euros per cubic meter). Polishing or treating wastewater for reuse is more expensive. There have been some pilot demonstration initiatives on greywater recycling, most notably by Global Water Partnership-Mediterranean (GWP-Med) (box 7.1) and private hotels, but WSC has no

**BOX 7.1. The Global Water Partnership-Mediterranean Nonconventional Water Resources Program**

The Nonconventional Water Resources (NCWR) Program in Malta, also known as Alter Aqua, is a multistakeholder program that brings together the GWP-Med, the Energy and Water Agency under the Prime Minister's Office, the Ministry for Gozo (MGOZ), the Eco-Gozo Project, and the Coca-Cola System in Malta (Coca-Cola Malta and General Soft Drinks Co. Ltd). It commenced its activities in November 2011 and is primarily funded by a Coca-Cola Foundation grant and cofunded by MGOZ. It is part of the regional NCWR Programme in the Mediterranean, also implemented in Cyprus, Greece, and Italy.

The NCWR Programme mobilizes NCWR as a sustainable solution for water security and climate change adaptation in the Maltese Islands by showcasing smart, innovative, and cost-effective NCWR solutions through small- and medium-scale demonstration projects, focusing on rainwater harvesting and greywater recycling. Activities are complemented with technical workshops for local technicians to enhance expertise in NCWR technologies; capacity-building workshops for local authorities to advance NCWR management; an educational program for students and teachers with specially developed educational materials; knowledge and sharing of experiences at the local, national, and regional levels; and raising the awareness of the general public on sustainable water use and domestic NCWR solutions.

The NCWR Program in Malta installs new and rehabilitates existing NCWR rainwater harvesting and greywater recycling systems, mainly in selected public buildings and areas on Gozo and Malta. These are fully functional and demonstrate different technologies and various applications in diverse facilities (schools, public buildings, historical buildings, universities, and sports facilities). Possible secondary uses of harvested rainwater and recycled greywater are also showcased, such as toilet flushing, landscaping (including green roofs), irrigation, and aquifer replenishment.

By 2017, four rainwater harvesting systems were installed and seven systems rehabilitated in schools, public areas, and buildings in Gozo and Malta. A storm water retention application was being implemented in Ramla Valley, Gozo. Greywater recycling systems have been installed in the Helen Keller Resource School; Gozo Football Stadium; Malta College of Arts, Science and Technology; and the National Swimming Pool. The Alter Aqua educational program has reached out to more than 13,300 students with hands-on activities and trained more than 1,200 school teachers, in cooperation with Nature Trust Malta and the Mediterranean Information Office for Environment Culture and Sustainable Development.

The Program has also contributed to the development of a new National Water Resources Management Strategy for the Maltese Islands through a national consultation on the theme. The new strategy highlights the potential use of NCWR at the domestic and community levels for secondary uses to alleviate the pressure on limited fresh water resources and close the supply-demand gap.

*Source:* Global Water Partnership-Mediterranean, Nonconventional Global Resources Program, http://www.gwp.org/en/NCWR/ncwr-programme/NCWR-Programme-Mediterranean/.

plans to scale them up in the short-term. Stormwater capture is perhaps the least economically and financially feasible option (2.10–5.10 euros per cubic meter for agricultural use)—land is costly and rain events are relatively infrequent and unpredictable in Malta, which would lead to the equipment being used only for a limited period during the year (JASPERS 2008).

### Precipitation Variability and Consequences to Hydrology

The Maltese climate is typically Mediterranean, with mild, rainy winters and dry, hot summers. The mean monthly temperature for the summer season was 35°C over the past century, while the lowest monthly average temperature was 11°C in January and February. The average annual precipitation stands at approximately 560 millimeters. During the past century, the average monthly rainfall was highest in December (at approximately 94 millimeters), with the highest precipitation rates occurring between November and February, and lowest in July (with practically no rain at all). Humidity tends to be high on the Maltese Islands, with little seasonal variation (Malta Resources Authority 2017).

Rainfall patterns over the Maltese Islands are characterized by relatively high spatial and temporal variability. Even the average wettest months can be very dry in some years. During the rainy season, the increasing number of days with thunderstorms implies that heavy precipitation events of short duration are on the rise, while precipitation on average has decreased over the same period (Malta Resources Authority 2017). Forecasts for the Southern Mediterranean indicate higher temperatures and reduced average precipitation (Malta Resources Authority 2017).

### Risks to Resource Quality

The main aquifer in Malta consists of a freshwater lens floating over seawater; competition for groundwater resources has depleted the aquifer over the years. The quantity and quality of groundwater is currently monitored in accordance with the EU Water Framework Directive (WFD). Eighty-seven percent of Malta's groundwater bodies contain nitrate or chloride levels that exceed EU drinking water standards as a result of nitrate contamination of rainwater in soil used for agriculture (Heaton et al. 2012). Furthermore, overabstraction of groundwater over the past decades has led to seawater intrusion, which further degrades groundwater. Maps 7.1 and 7.2 show the quantitative and qualitative status of the groundwater bodies of Malta as reported under the EU WFD in 2015.

Groundwater resources are at risk of further degradation from expected changes in rainfall patterns and recharge. Following the WFD, Malta is taking steps to prevent deterioration and restore the qualitative and quantitative status of groundwater by 2015 or, under some circumstances, by 2021 and 2027, through a dedicated Program of Measures, including the New Water program, which is expected to provide an alternative source of water for agricultural use (Energy and Water Agency 2015).

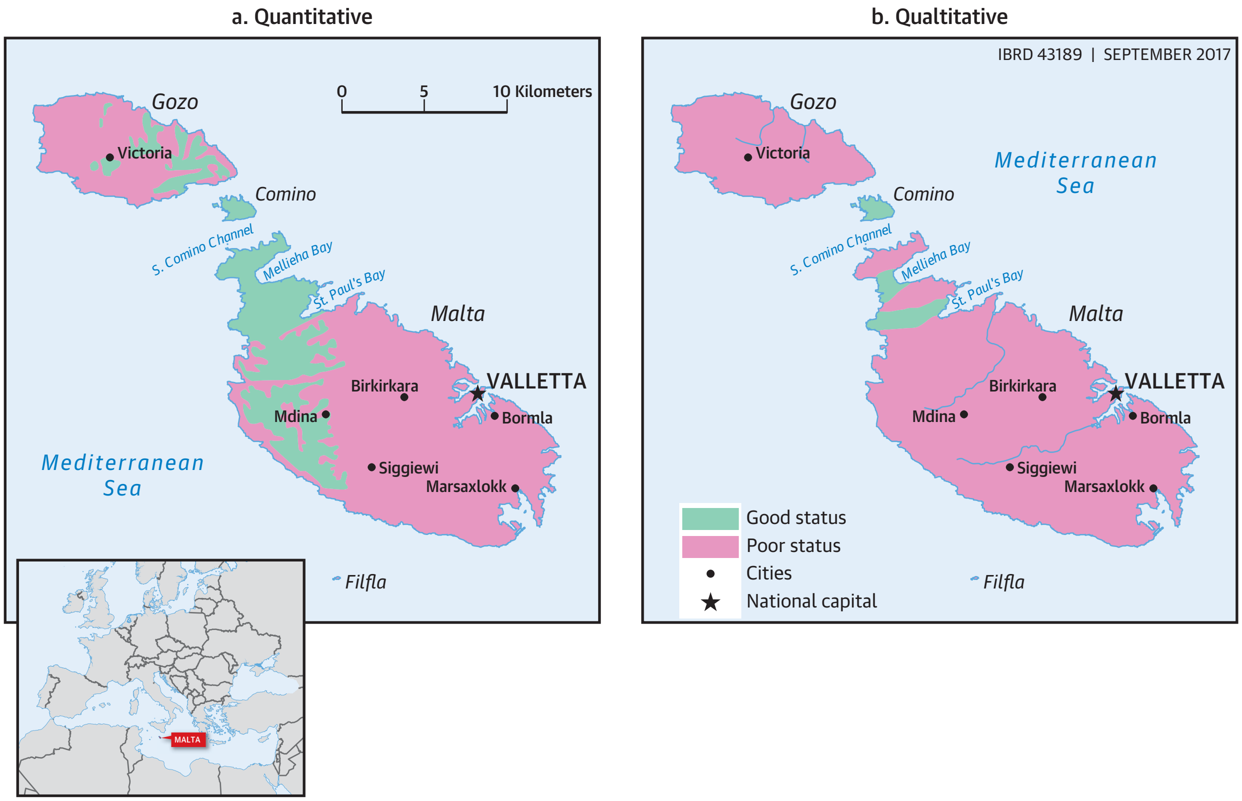
## Water Use

### Brief Overview of WSS Framework

The Energy and Water Agency is tasked with formulating and implementing the government's national policies for the water sector to ensure the security, sustainability and affordability of water and sanitation services in Malta. The Ministry of Transport and Infrastructure is responsible for stormwater and valley management, which includes flood protection. The Ministry of Transport recently implemented the €56 million National Flood Relief Project (NFRP), which has been described as the largest engineering project ever implemented in Malta.

A recent change in the structure of the water supply and sanitation (WSS) framework has separates the role of policy making from that of regulation. The Environment and Resources Authority is now the national environmental regulator for water resources,

**MAP 7.1. Quantitatve and Qualitative Status of Groundwater in Malta, 2015**




*Source:* Energy and Water Agency 2015.

and the Regulator for Energy and Water Services, established recently through the Regulator for Energy and Water Services Act of 2015, is the financial regulator for water and sanitation services.

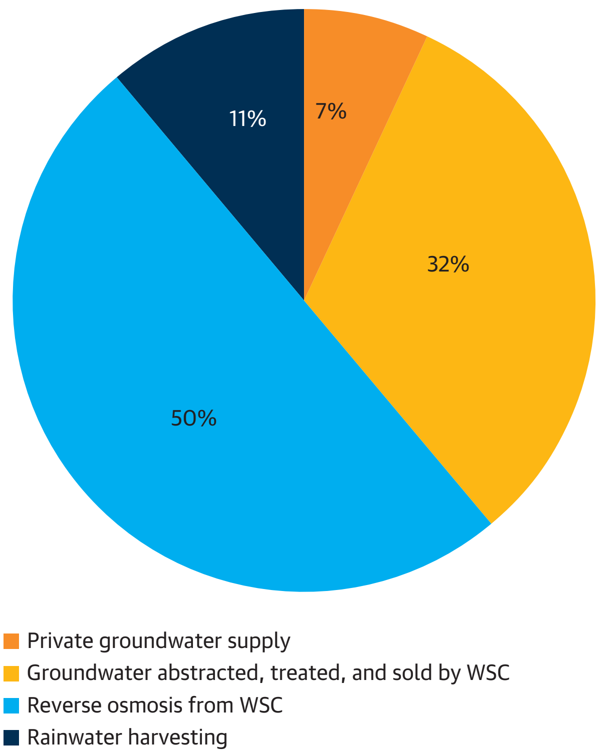
Provision of water and sanitation services, including wastewater collection, treatment, and reuse is under the authority of the WSC. The WSC produces and distributes potable water and collects and treats the wastewater of over 250,000 households, businesses, industries, and hotels serving over 420,000 people. The WSC operates RO, sewage treatment and polishing plants, pumping stations, reservoirs, and boreholes all over the country.

The WFD has been incorporated into national law as under the Water Policy Framework Regulations of 2004. The WFD and the Water Policy Framework Regulations are implemented through the Water Catchment Management Plan (WCMP) for the Maltese Islands; it is the strategic policy document guiding water resources management for the country.

## Coverage

Maltese residents have universal access to reliable water and sanitation services. Residential water is supplied primarily by WSC (estimated at 82 percent of total domestic water use). Sources of self-supply include (1) rainwater harvesting (estimated at 11 percent); and (2) private groundwater use particularly from old hand-dug wells, locally known as spieri (estimated at 7 percent) (figure 7.2). For sanitation, Malta embarked on a large investment program in wastewater collection and treatment in the 2000s, and 100 percent of

**FIGURE 7.2. Water Sources for Domestic Water Supply in Malta, 2013**




*Source:* Energy and Water Agency 2015.
*Note:* WSC = Water Services Corporation.

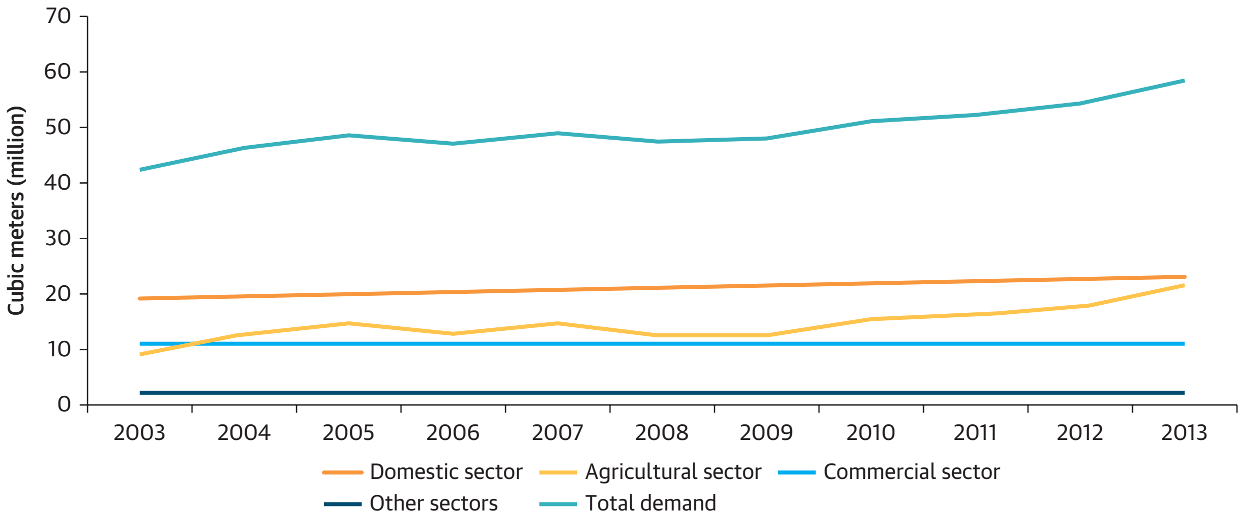
wastewater is collected and treated to secondary treatment by the WSC, either by connection to the sewerage system or cesspit waste removal. From 2017 on, approximately 30 percent of the wastewater treated will be made available for reuse to agricultural and industrial water users.

## Urban Water Use

Unlike many cities and countries, and because of the high level of urbanization and small size of the country, Malta's domestic sector uses the highest average share of water, followed closely by agricultural water use for irrigation. On average, domestic water use is estimated at approximately 20 million cubic meters per year or 40 percent of the national water consumption (figure 7.3). Agricultural water use is highly dependent on climate variability.

Domestic water consumption in the Maltese Islands is estimated to be about 110 liters of water per person per day (Sapiano 2015), below the rate of consumption of other European countries. Surveys on household water use show that about 50 liters are used for cooking, drinking, and personal hygiene; the remaining amount

**FIGURE 7.3. Trends in National Water Demand in Malta, by Sector, 2003–13**




*Source:* Energy and Water Agency 2015.

is used for various domestic purposes such as flushing toilets and doing laundry.

### Economic Dependence on Water Intensive Sectors

Maltese residents still remember vividly the impact of potable water rationing and intermittent supply in the 1970s, 1980s, and early 1990s, which drove the rapid development of desalination facilities. Malta views the provision of good services and infrastructure as vital to attracting foreign investment and developing the tourism industry, which accounts for 25 percent of its gross domestic product (GDP). Desalinated water production coupled with network efficiency improvements have avoided disruptions in drinking water supply in the past decades. Although per capita water consumption remains one of the lowest in the EU, population growth, tourism, and economic development have contributed to an increase in residential water consumption, with limited demand-management efforts until recently.

By contrast, water shortages have caused farmers to shift toward practices and irrigation systems that make more efficient use of water resources. The agricultural sector has had to work with groundwater that is less plentiful and of an inferior quality, supplied either through farmers' own boreholes or by bowsers (legally registered water tankers, delivering groundwater from private boreholes for resale at any time, not only in emergencies); desalination has not been an option for them. Levels of abstraction from private and registered boreholes are monitored by WSC.

The tourism industry is a heavy consumer of water and sanitation services during peak season in summer, when resources are most scarce, but it has adapted by investing in its own water supply sources. All major hotels, located mostly along the coastline, have invested in small RO units (most of which are sourced and serviced by a subsidiary of WSC) to produce desalinated water, which helps them meet higher seasonal water demand and relieves WSC of the pressure of peak demand.

There is no specific institutional framework that governs allocation, drought, or emergencies. WSC decides whether to increase or decrease the proportion of desalinated seawater in the water supply based on the quality of the groundwater and the ensuing blend in the reservoirs. Should groundwater use be prohibited for drinking purposes, desalinated seawater could supply a maximum capacity of 67,000 cubic meters per day, which is less than the peak demand of 93,000 cubic meters per day in summer.

## Water Balance for Current Situation without Additional Resources or Actions

Groundwater abstraction for domestic and agricultural water use remains unsustainable, particularly for the mean sea-level aquifers. Table 7.1 presents the groundwater balance for the largest aquifer, the Malta Mean Sea-Level Aquifer System. Abstraction volumes may vary year to year.

Water quality is one of the main challenges for water resources management. Groundwater, which had supplied all of Malta's water, can no longer be considered a primary source for drinking water, which needs to be combined with water from another source (such as desalinated water) to meet quality standards. However, groundwater still contributes most of Malta's water supply, especially for agriculture (figure 7.4). Agricultural users account for almost 80 percent of abstractions in the perched aquifer systems but less than 40 percent for the mean sea-level aquifer systems, which are also tapped by WSC (which accounts for 47 percent of abstracted water on average).

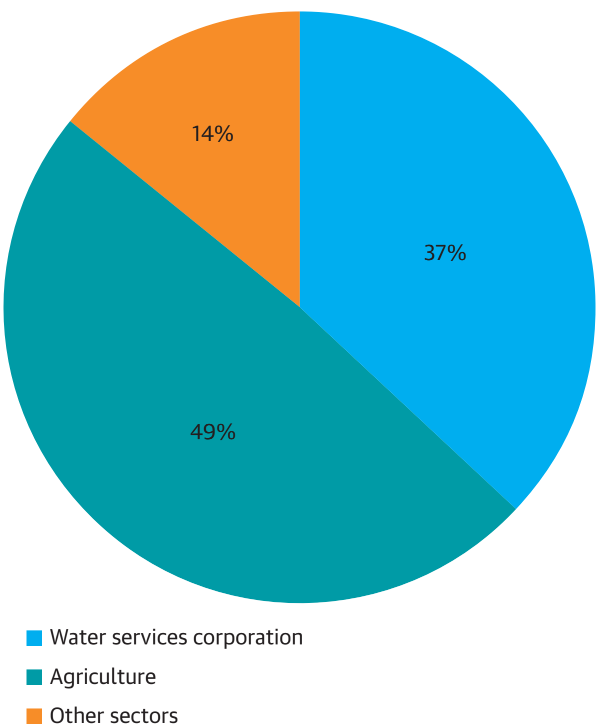
Total water use has remained stable over the past decade. Desalinated water production is close to 19 million cubic meters per year. The most notable change for municipal water supply was a tenfold reduction in real losses, which were cut from 4,000 cubic meters per hour in 1995 to cubic meters per hour in 2005. Since then, water supplied by WSC for municipal use has remained stable, at between 30 and 33 million cubic meters per year.

**TABLE 7.1. Groundwater Balance for the Malta Mean Sea-Level Aquifer System, 2015**

| Cubic meters (millions) | | |
|---|---|---|
| Groundwater recharge | Natural recharge | 28.8 |
| | Recharge from perched aquifers | 1.4 |
| | Artificial recharge (leakage from municipal networks and return flow from irrigation) | 6.25 |
| Groundwater extraction | Municipal | 11.2 |
| | Agricultural | 7.5 |
| | Other abstraction | 3 |
| | Natural subsurface discharge | 18 |
| **Groundwater deficit** | | **−3.45** |

*Source:* Energy and Water Agency 2015.

**FIGURE 7.4. Annual Average Groundwater Abstraction in Malta, by Sector**




*Source:* Energy and Water Agency 2015.

## Solutions

Malta has long used RO to remedy the decline in the quantity and quality of groundwater. From the mid-1990s on, as its desalination production capacity increased, WSC started to invest in reducing nonrevenue water (NRW). WSC is now developing programs for water reuse in agriculture as an alternative to groundwater abstraction, along with increasing rainwater harvesting and managing demand. These solutions are detailed below.

### Desalination

RO plant operation was identified as a strategic alternative in the late 1970s as a result of the intensive borehole-drilling campaign in the1960s and 1970s, which sought to increase groundwater production from the mean sea-level aquifers (FAO 2006). Although overall groundwater production figures increased, the quality of the groundwater suffered as a result. In 1980, salinity had doubled in less than 1 year, and yet domestic demand still could not be met; the population was subject to intermittent water rationing. It had become evident that the aquifers could no longer meet the growing domestic and agricultural demand. The first seawater RO plant started production in 1982 with a capacity of 20,000 cubic meters per day—one of the largest in the region at that time. Since then, desalination plants have been constructed in Pembroke, Cirkewwa, and Lapsi. Today, these plants produce about 60 percent of the total drinking water supply in Malta.

Management and operation of desalination plants is under the exclusive control of WSC. Desalination facilities were initially built with foreign investment and expertise and then transferred to the WSC, which now manages them. A fourth seawater desalination plant is currently being planned for Gozo Island. Desalination developments from 2004 onward benefited from EU funding and incentives. In anticipation of Malta joining the EU (which meant that the energy used to power the desalination plants would no longer be subsidized), WSC invested heavily in reducing energy consumption at the desalination plants. The current total cost of producing desalinated water is 0.72 euros per cubic meter, while the cost of producing groundwater is close to 0.28 euros per cubic meter. Energy accounts for about three-quarters of the cost of desalination (the proportion is similar for groundwater).

Hotels are also equipped with their own mini-RO systems, the total capacity of which exceeds 1 million cubic meters (FAO 2006). A WSC subsidiary sells and services these RO units, controlling about 80 percent of the hotel RO market in Malta. The hotels are also connected to the WSC mains. The water tariff charged by WSC for drinking water to the hotels is higher than that for residential use (2.20 euros per cubic meter compared to 1.40 euros for the first band of the residential tariff). The fixed costs of connection are recovered through an annual charge. Desalinated water is currently not used in the agricultural sector.

### Non Revenue Water Reduction

At the start of the 1990s, WSC had increased its capacity to provide water through the construction of a number of desalination plants; yet the population still suffered from intermittent and poor quality water supply, because of the poor quality of the network and the high level of NRW, which was estimated at 60–70 percent at the time. From 1995 on (with funding from the EU Structural and Cohesion Funds), WSC invested in leakage reduction and in upgrading the water distribution networks. These actions played an important role in the decrease of total system demand between 1995 and the mid-2000s, and notable results have been obtained in the leakage management program, where real losses decreased by a factor of 10, from 4,000 cubic meters per hour in 1995 to 380 cubic meters per hour in 2017.

However, apparent losses remain a challenge. NRW remains at 40 percent, substantially because some meters cannot detect the small trickles of water used to fill up water cisterns, which are estimated to account for up to 20 percent of NRW. Billing anomalies are responsible for another 8 percent. Immediate next steps are to focus on improving billing to reduce NRW further.

### Demand Management

From the mid-2000s on, tariffs were increased to ensure cost recovery for water services provision. (Sanitation services, which are under the WSC, are partly subsidized by the government.) Tariffs are approved by the Regulator for Energy and Water Services. Currently, there is one domestic tariff rate for consumption of less than 33 cubic meters per person per year (1.40 euros per cubic meter); for consumption over that amount, the tariff jumps to 5.14 euros per cubic meter. Nonresidential customers, including the tourism industry, pay 2.18 euros per cubic meter for consumption of less 33 cubic meters per year, and 5.14 euros per cubic meter in excess.

There is a strong impetus at the policy level to work further on demand management. WSC has put in place an online system, which allows customers to monitor in real time their domestic water consumption. Next steps include a National Water Awareness Campaign run by the Energy and Water Agency, which will target both residential and agricultural water users.

### Rainwater Harvesting

In 2003, rainwater harvesting was estimated to have a potential capacity of about 2 million cubic meters in Malta (FAO 2006). However, rainwater harvesting is not as widespread as it used to be, or rather as it should be, even though legislation requires all domestic and institutional buildings to be equipped with a rainwater collection cistern. This practice was widespread prior to the World War II; with the advent of modern water supply practices, it was quickly abandoned, although the legislation remained. As a result, most building are not equipped with rainwater collection tanks. Since 2003, new legislation has called for the reintroduction of this practice; the collected rainwater could be recycled as greywater in the home (for toilet flushing) or outside the home (for gardening). Informant interviews revealed that, although most new institutional buildings (such as schools and hospitals) abide by this legislation, households rarely invest in the expensive double-piping that would be required for greywater use, and domestic rainwater harvesting remains below its potential (Cardona 2006).

The low level of enforcement of rainwater harvesting in the domestic water sector can perhaps be attributed to the absence of an institutional home, even though it would bring multiple benefits such as the potential for flood mitigation and a decrease in water demand. The Ministry of Infrastructure is in charge of stormwater management, which includes rainwater harvesting, but enforcement for domestic lies with the urban planning authorities; rainwater harvesting is not part of WSC's core business.

The agricultural sector makes use of harvested rainwater. The agricultural census of 2001 registered about 9,000 agricultural cisterns (FAO 2006). In addition, there are approximately 100 small dams and 200 small reservoirs filled by rainwater (the storage capacity of the largest units is on the order of 2,000 cubic meters). They are owned by the government, managed by the Ministry of Infrastructure, and represent an estimated combined potential storage volume of 150,000 cubic meters. These can be used by neighboring farmers, and no charges are applied for water abstraction. The Ministry of Infrastructure is currently using Lidar to map existing storage capacity more precisely and aims to put a series of measures in place to optimize the management of small dams. It is also investing in a pilot Sustainable Urban Drainage Systems (SUDS) to try and catch as much rainwater as possible upstream of the valleys.

### New Water

Wastewater treatment capacity was developed at scale in Malta in the 2000s; currently, all of the wastewater produced is collected and treated by WSC, up to secondary treatment. Some of the treated effluent has been made directly available to agricultural water users since the 1980s (about 1 million cubic meters per year). The idea of treating sewage effluent up to a higher standard for reuse had been considered for many decades; funding from the EU enabled WSC to invest in the construction of New Water polishing facilities, which bring the quality of treated effluent almost up to drinking water standards. WSC had been championing this idea for decades, to provide an alternative to groundwater abstraction for agricultural and industrial water users.

Three New Water polishing plants with a combined capacity of 7 million cubic meters have been built under the first program of measures under the WFD (2010–15) and will be commissioned gradually in 2017. A small distribution system already exists and will be further developed under the next phase (2015–21), with networks designed to supply an estimated 1,250 h. Agricultural water users represent the bulk of the expected users of New Water. A sophisticated mapping exercise was done by WSC to estimate the agricultural water users with the most water-thirsty and high-value crops who could pay for this service. In parallel, WSC will also run an information and marketing campaign, which will target not only farmers but also consumers of agricultural products and the public at large. Tariffs will be subsidized by the government for the first years to provide an incentive for agricultural users to test and try New Water: It will be given for free for the first 3 years (while the distribution network is being expanded), with tariffs to be considered afterward.

Managed aquifer recharge is also being considered as part of this scheme, but with strict conditions and monitoring so as not to affect the part of the aquifer which is being used for groundwater abstraction for drinking water supply; a master plan for aquifer recharge will be developed. planned Artificial recharge will be conducted in the winter, when demand for New Water from agricultural water users will be the lowest, and production of New Water should outstrip demand.

## Conclusion

Malta has made tremendous progress in managing water scarcity in the past decades by developing a two-pronged strategy of diversifying and augmenting water supply sources. Domestic demand management has lagged but is now the focus of policy makers, although it remains to be seen whether this will bring about the expected reductions in residential water use. Now that the population no longer suffers from water cuts, there is a perception that water is available in abundance and behavior will be difficult to change.

Although risks remain to achieving water security, they are known at the political and the service delivery level. The New Water program is currently in its inception, and there is a risk that agricultural water users may still prefer to use their boreholes; however, this is something WSC is fully aware of, and they are investing heavily in marketing and promoting New Water to encourage behavior change at the agricultural producer and consumer levels. Malta has become reliant on desalination for drinking water supply. For the past 35 years, desalination plants have been managed very competently by WSC, but with very little breathing room for additional production or storage capacity. WSC benefits from the tourism sector's investment in RO production capacity to help the country face peak demand in summer. The economics of the tariff have helped, as hotels are charged a higher fee than residential customers. Malta has reduced the energy demands of desalination, but is still dependent on affordable energy for the production of drinking water. The country is entirely dependent on energy imports, either from natural gas or through the Malta-Sicily interconnector, which allows imports from the European electricity market. The progress made should therefore be nuanced, considering the following risks for the future: (1) increasing reliance on RO for the next decades (and therefore on sustainable and affordable energy) and (2) that behavior change does not lead to the expected outcomes for rainwater harvesting, domestic demand management, and New Water use for agriculture.

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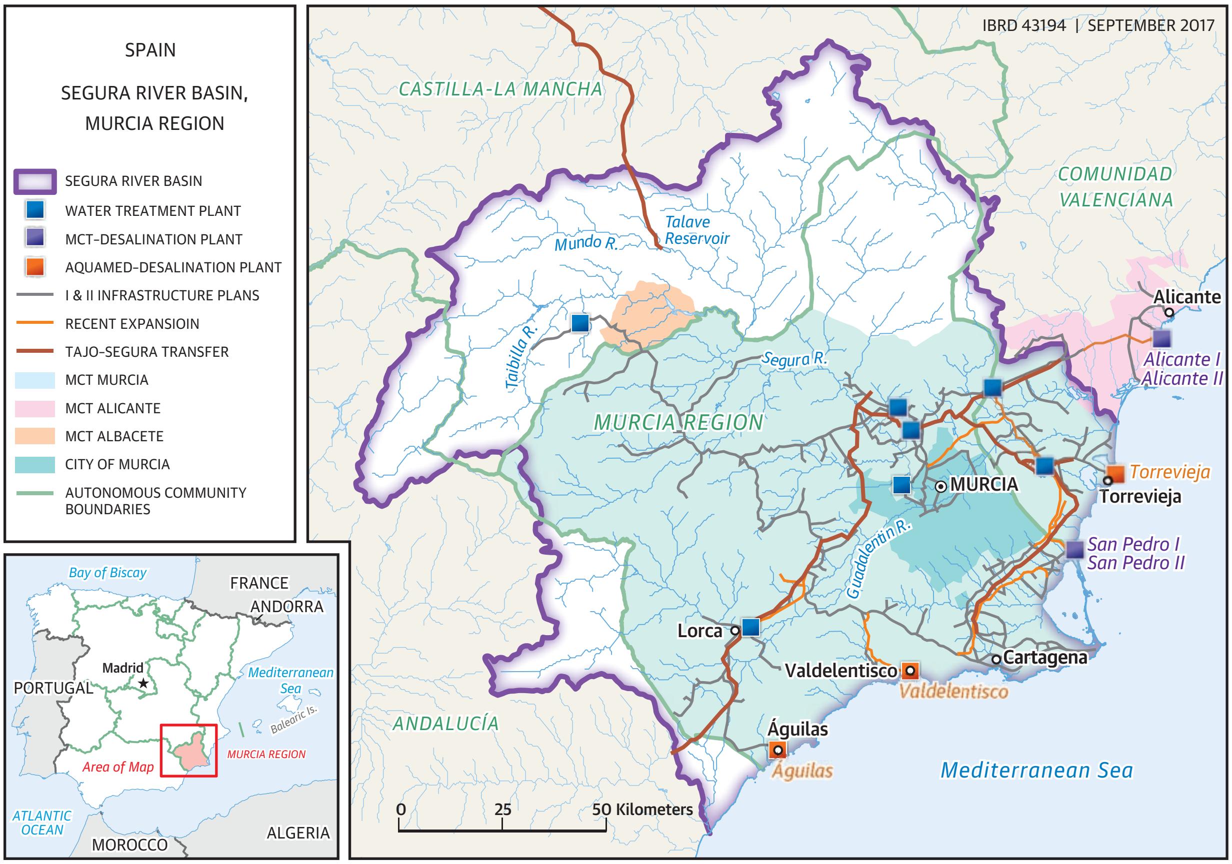
Murcia Valley of Ricote. Source: https://pixabay.com/en/murcia-valley-valley-of-ricote-2354219/.

# Chapter 8
# Murcia, Spain

This case study presents the experience of the Mancomunidad de Canales del Taibilla (MCT), a regional authority that has successfully guaranteed urban water supply in a context of strong competition for scarce water resources in southeastern Spain. Given Spain's multilevel and polycentric approach to water resource management, the case study focuses on four overlapping geographical and institutional scales: the Segura River Basin Authority (RBA), or Confederación Hidrográfica del Segura, which allocates raw water to the MCT and other users in the basin; and the MCT, which provides treated water to most municipalities in Murcia, the region of Murcia, and its capital, the city of Murcia (map 8.1). This multiscale approach is necessary to understand urban water supply in a context of scarcity in Murcia.

The region of Murcia is located on the Mediterranean coast in southeastern Spain. It has almost 1.5 million inhabitants, distributed over 11,000 square kilometers. Over a third of the population is concentrated in the main cities and towns. The region has a gross domestic product (GDP) of over US$36,000 per capita. The regional economy rests on four pillars (INE 2017): (a) the service sector (including tourism), which generates 69 percent of regional GDP; (b) agriculture, which generates 13 percent of employment and 4 percent of regional GDP; (c) the industrial sector, which generates 12 percent of employment and 17 percent of GDP; and (d) the construction sector, largely related to tourism, which generates 5 percent of GDP and regional employment.

**MAP 8.1. Segura River Basin, Murcia Region, and Mancomunidad de Canales del Taibilla Hydrographic and Hydraulic Network**




*Source:* Elaboration by M. Ballesteros with GIS layers and data from MCT, Segura RBA, and other public agencies.
*Note:* MCT = Mancomunidad de Canales del Taibilla.

The city of Murcia has about 440,000 inhabitants (30 percent of the region's population) and is the political and economic capital of the region. The city was historically an important agricultural exporter, with the traditional Huerta de Murcia producing irrigated horticultural products and supporting a strong agroindustrial sector. The city has grown over the historic Huerta, creating a complex landscape of independent but overlapping water supply networks for irrigation and urban water supply.

Guaranteeing access to water resources for drinking, irrigation, and other economic activities has been an ongoing political and social priority in Murcia. With average annual precipitation at about 380 millimeters per year and intense water demand, the water exploitation index plus (WEI+) for the region exceeds 100 percent, indicating unsustainable patterns of water use. Irrigated agriculture consumes 86 percent of available resources and dominates water policy and management. The regional approach to urban water supply that the MCT represents is a key element for guaranteeing high-quality drinking water for Murcia residents.

## Climate and Hydrology

Murcia has a typical Mediterranean climate with high spatial and temporal variability. Precipitation in the region ranges from over 1,000 millimeters per year in the northwestern headwater sierras to 200 millimeters per year in the southeastern coast, with average annual precipitations at 385 millimeters per year. Rainfall concentrates in the fall and spring, with an extended dry and hot summer season, when water demand for irrigation and tourism in coastal towns is greatest. Like the rest of Mediterranean Spain, Murcia suffers periodic droughts, with the more recent dry periods occurring in the 1980s, early 1990s, and mid-2000s, and a dry period starting in 2016.

A significant reduction in available water resources when comparing the long-term hydrologic series (1940-2016) versus shorter series (1980-2016) has been termed as the "1980s' effect" in Spanish water management. In the case of the Segura basin, available regulated surface water resources have decreased by over 30 percent. Recent studies have estimated that, under different climate change and demand variability scenarios, available water resources may decrease by an additional 20 percent in the Segura River Basin by 2040 (CEH-CEDEX 2012).

## Institutional Context for Water Resource Management

Water policy and management authority in Spain is distributed among different tiers of government. RBAs that depend on the central government are responsible for water allocation, planning, and management in river basins that, like the Segura, cross two or more autonomous regions. Regional governments have authority over intraregional river basins.

Domestic water supply and sanitation (WSS) services are a municipal responsibility. Autonomous regional governments provide financial, technical, or administrative support to municipalities and often develop and implement regional water sanitation plans. In the region of Murcia, WSS services are regionally integrated and involve several institutions:

- The Segura RBA is responsible for river basin planning and management and raw water allocation and distribution to different users (urban supply, agriculture, industry, etc.).
- Aguas de las Cuencas Mediterráneas (ACUAMED) is a state company that develops hydraulic infrastructures in the Mediterranean basins of Spain. It has been responsible for the construction and management of 13 desalination plants on the Mediterranean coast with funding from the central government, the European Union (EU), and, in some cases, from the end users.

The MCT, a public agency under the central ministry in charge of water affairs, supplies bulk potable water to the regions of Murcia, Alicante, and Albacete. In Murcia it supplies 43 municipalities and 96 percent of the population through an intricate infrastructure system including two dams on the Taibilla River, six water treatment plants, four desalination plants, and over 1,000 kilometers of primary canals.

Municipalities in the region are responsible for distribution and sanitation services within municipal boundaries. EMUASA (Empresa Municipal de Aguas y Saneamiento de Murcia S.A.) manages WSS services for the city of Murcia and 54 villages. EMUASA is owned by the Municipality of Murcia (51 percent) and HIDROGEA (49 percent), a subsidiary of AGBAR (Suez Environment). Map 8.1 illustrates the different scales of analysis presented in this case study: Segura River Basin district; the area supplied by the MCT differentiating between the part that falls in the autonomous regions of Murcia, Valencia, or Castilla-La Mancha; the region of Murcia; and the area supplied by EMUASA.

The General Water Directorate of the Regional Government of Murcia developed the 2,000 regional Sanitation and Treatment Plan and created a regional public company, ESAMUR (Entidad Regional de Saneamiento y Depuración de Aguas Residuales), to manage its implementation. ESAMUR operates wastewater treatment plants through agreements subscribed with municipalities.

## Water Resources

Given the strong temporal and interannual variability in water resource availability, the region of Murcia has expanded and diversified its water portfolio as demand has increased. Today, it relies on five primary sources: surface and groundwater resources from the Segura River Basin, imported water from the Tajo River Basin, desalinated water, and reclaimed water.

Surface water resources from the Segura River Basin are mostly allocated to historical irrigation districts. The primary exception is the Taibilla River, a tributary of the Segura to the north of the basin (see map 8.1), which is fully allocated to the MCT for urban water supply. The Segura RBA manages five major and 28 minor reservoirs with a combined storage capacity of 1,140 million cubic meters. The implementation of the regional Sanitation Plan (2001-10) has dramatically improved surface water quality in the Segura River. Challenges remain as a result of high salinity and nutrient-rich return flows from irrigation in the lower parts of the basin (Martínez-Fernández 2016).

Groundwater is a strategic resource. Cities relied on groundwater before their incorporation to the MCT service area. Out of a total demand of 244.6 million cubic meters for urban water use in the Segura River Basin, on average 5.5 million cubic meters are covered with groundwater resources. In times of drought this amount can increase significantly: the Segura RBA operates over 145 drought wells designed to temporarily pump water above renewable levels. During the 2005-08 drought, the Segura RBA pumped 480 million cubic meters from these drought wells, with 80 million cubic meters allocated to MCT and the rest to irrigation (Custodio 2016). The 2015 Segura Basin management plan has determined that 70 percent of groundwater aquifers had water quality problems, deriving primarily from nitrate and pesticide diffuse pollution from agriculture, salinization from irrigation return flows, and seawater intrusion.

The Tajo-Segura interbasin transfer (Tajo-Segura Water Transfer, or TTS), transfers water from the headwaters of the Tajo River through a 300-kilometer canal to the Talave reservoir on the Mundo River (map 8.1). The transfer's economic and management rules establish maximum transfers of 600 million cubic meters per year (110 of which is allocated for the MCT and 400 of which is for irrigation) and estimates 15 percent (90 million cubic meters) of evaporation losses. In reality, lack of resources in the Tajo have limited transfers to an average 350 million cubic meters per year, of which 106 million cubic meters have been allocated for the MCT.

Desalinated water is produced in five plants in the region of Murcia: two owned by the MCT and three by the publicly owned company ACUAMED (map 8.1). Total desalination installed capacity is 332 million cubic meters per year, but only 158 million cubic meters were being produced in 2016, 61 percent of which by the MCT. Desalinated water use is expected to increase to over 190 million cubic meters for the 2021 planning horizon (CHS 2015). Higher prices for desalinated water make it less desirable for users.

Treated wastewater became an important additional resource since the implementation of the sanitation plan in 2001. Ninety-nine percent of wastewater in the region is treated, and over 60 percent of the 88 wastewater treatment plants apply tertiary treatment. Competition for this new resource has been significant: irrigators have obtained 80 percent of the 147 water permits granted by the Segura RBA for wastewater reuse. The other

20 percent have been allocated to municipalities for public uses. Treated wastewater cannot be legally used for domestic water supply.

In summary, MCT relies on three primary sources of water: the Taibilla River (€0.02 per cubic meter); Tajo water through the TTS (€0.01 per cubic meter); and when these resources are insufficient (in particular during the peak summer months), desalinated water from MCT plants (€0.57 per cubic meter to €0.72 per cubic meter) and if necessary purchased from ACUAMED-owned plants (€0.29 per cubic meter).[1] The use of desalinated water year round has also become important to meet water quality standards during times of low surface water flows, and after national legal reforms in 2013 reduced TTS allocation to the MCT. The increasing weight of desalination is compensating decreasing resources from the Taibilla. Groundwater (€0.17 per cubic meter) and other Segura surface water resources are almost fully allocated to irrigation.

At the level of the city of Murcia, EMUASA holds a 6.6 million cubic meter surface water allocation from the Segura RBA (€0.01 per cubic meter), which covers approximately 20 percent of its water needs and is being fully used before MCT water is purchased (€0.69 per cubic meter). The municipality of Murcia also holds rights to about 1 million cubic meter of groundwater sources (€0.17 per cubic meter) and is considering a request for additional resources from treated wastewater and groundwater for nondomestic uses.

## Water Use

Urban water represents 11 percent of all water demands in the Segura River Basin. Piped water supply reaches 100 percent of the population in both the region and the city of Murcia. Demand peaks in the summer months, when the permanent resident population of 2.5 million increases by over 0.5 million and water consumption increases by over 30 percent.

Over the past decade, the combined impacts of the 2005-08 drought, the economic crisis that started in 2008, changes in consumer behavior, and improvements in service efficiency have resulted in a decline in overall demand both within EMUASA and MCT service areas. This trend is expected to continue, despite an anticipated increase in nondomestic public uses for development of new green spaces.

Irrigated agriculture is the primary water user in the Segura River Basin, demanding 86.2 percent of all available water resources. It is a culturally and politically strategic sector, even though it generates only 4 percent of GDP in the region of Murcia. In the Segura River Basin, irrigation gross annual demand is 1,518 million cubic meters, exceeding the total estimated average annual resources of 1516 million cubic meters from all water sources. The TTS-supplied irrigators are grouped in the Tajo-Segura Aqueduct Central Irrigators Syndicate (SCRATS), a powerful player in regional and national water politics. SCRATS encompasses 80 irrigator associations—in Murcia, Alicante, and Almería—representing 80,000 irrigators. For the most part these are highly profitable intensive irrigation operations.

## Solutions

### Overview

The Segura River Basin presents a classical example of basin closure, in which resources have been fully allocated and only nontraditional resources are available for allocation. Agricultural water use dominates the region both quantitatively and politically. The temporal variability of water resources, the historical allocation of most conventional water resources to irrigation, and the deterioration of water quality in the Segura River throughout the 20th century presented important challenges for urban water supply. The success of the region's efforts to guarantee domestic supply despite these challenges rests on five pillars:

- The creation of the MCT as a public entity dependent of the ministry in charge of water affairs, making it a powerful player both politically as well as financially,

since it guaranteed public funding and strong commitment for infrastructure development.
- The interconnection of different sources of water to improve resilience.
- The implementation of the regional sanitation plan (2001-10), publicly funded and managed (supported with EU cohesion and European Regional Development Fund [ERDF] funds), and the implementation of a water sanitation levy payable by all residents and industries through their water bills.
- Efficiency improvements and citizen behavioral changes that have led to a remarkable decrease in urban water demand, a phenomenon common to other Spanish urban areas.
- The integrated management of water resources at basin scale by the Segura RBA, providing flexibility and adaptive capacity, facilitating the reallocation of resources between places, users, and periods of use.

The city of Murcia's connection to the MCT water supply network in 1956 ended a decades-old search for a reliable and safe source of drinking water. The implementation of the regional sanitation plan has improved water quality in the Segura River, which crosses the heart of the city, transforming it into a valuable open space resource for its citizens, and regenerating important resources in the form of treated wastewater.

The key to the success of the system, however, is the MCT, which became a public entity in 1946 and is directly dependent on the central government to facilitate funding for necessary infrastructures. Its history shows continuous efforts to seek new sources of water to address emerging water deficits and increase resilience to droughts.

At every stage, the MCT has successfully dealt with the political dominance of irrigation in the region, constantly seeking alternative resources to guarantee supply. The core canal system was initially expected to supply the cities of Cartagena, Murcia, Alicante, and 47 other municipalities from the Taibilla River. By the late 1960s, the Taibilla River proved insufficient to meet growing demand so the system was connected to the TTS project, allowing further expansion of MCT service area. The 1990s drought severely affected both the Segura and the Tajo rivers and signaled the vulnerability that resulted from dependence on TTS transfers. This prompted the construction of two desalination plants in 2003 and the setup of framework contracts with ACUAMED, securing up to 63 million cubic meters from its desalination plants, greatly diminishing scarcity risks. Since 2013, changes in TTS management rules through national legislation in 2013 have reduced transfers and reallocated TTS waters to irrigation, increasing MCT's dependence on desalination resources.

Effective drought planning has been instrumental in minimizing drought-related risks. Drought management plans, such as the 2007 Segura River Basin Drought Management Plan and the 2013 Drought Emergency Plan for the City of Murcia, have been approved in compliance with national legal requirements These plans use an indicator system to calculate an index that defines four risk levels: normal, prealert, alert, and emergency. 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 an alert level is reached, a legislative drought decree is usually approved by the central government, enabling the RBA to restrict or reallocate water rights and undertake other measures.

### Mancomunidad de Canales del Taibilla: Diversifying Resources

The severe socioeconomic impacts of the 1990s' drought triggered a transition from drought emergency response to drought risk management in Spain. In the MCT service area, domestic and urban water use restrictions were imposed in 1995 and 1996. The drought showed the vulnerability of a water distribution system that relied heavily on interbasin water transfers from another basin, the Tajo, that was subject to similar patterns of climatic variability, and where domestic supply had to compete with more powerful irrigation interests (in spite of the legal priority of drinking water uses). The MCT looked at desalination as a preferable and more resilient alternative to drought-proofing its urban water supply system. Production of desalinated water could also be easily adapted to seasonal variations in demand, which is significant in the case of the MCT.

The MCT encouraged municipalities within their service area to implement conservation measures and efficiency improvements starting in the late 1990s, but demand was expected to keep growing due to urban and tourism development plans throughout the region. Following standard procedures for other infrastructure investments, the MCT designed the projects for the original desalination plants and planned to develop and finance them. The construction and operation of the desalination plants were outsourced through a public tendering process issued in 2000. The plants were partly funded through EU cohesion funds (85 percent of construction cost) and a 15-year concession to a consortium of private companies that built the plant under MCT direction. MCT purchases the plants' output and the price covers both amortization and production costs.

In 2004, a new political change in the national government resulted in the cancellation of a key element of the 2001 National Hydrologic Plan: the construction of a large interbasin water transfer from the Ebro River to the southeastern Mediterranean Coast, including the Segura River Basin. The cancellation responded to environmental and economic viability concerns, as well as strong social and political opposition from the donor regions (Font and Subirats 2010). As an alternative, the incoming administration developed the Actions for Water Management and Use Programme (A.G.U.A.), a comprehensive plan to (a) increase water use efficiency through water infrastructure renovation and agricultural modernization plans; (b) improve water quality through the construction of wastewater treatment facilities; and (c) augment water supply with desalination and wastewater reuse as alternative resources. The A.G.U.A. Programme was partially funded by EU Cohesion and ERDF funds.

In the MCT service area, the A.G.U.A. Programme included several projects that increased MCT's desalination capacity and built additional desalination plants developed and operated by ACUAMED.

In the case of MCT, desalination was implemented without controversy. The 2005-08 drought arrived after three years of exceptionally low flows in the Taibilla River, and desalinated water was used as soon as it became available. In a context of drought, economic growth, and expectations of increased demand in multiple planning horizons, MCT signed framework contracts with ACUAMED for the purchase of additional desalinated resources (63 million cubic meters). Expected increases in demand did not materialize, and these framework contracts were not executed until 2015 and later, when the loss of TTS waters to irrigators and the decrease in TTS transfers required all available desalinated water to meet demand.

#### Main Challenges

A new distribution infrastructure was required to connect the coastal desalination plants with a distribution network to move water from the basin headwaters toward the city of Murcia and the coast, where urban demand is highest. Much of the inland part of the MCT service area is still supplied by Taibilla and TTS resources. The use of desalinated water closer to the coast allows the release of Taibilla and TTS resources for other regions.

The incorporation of desalinated water into the MCT mix has affected production costs and thus water prices, as illustrated in figure 8.2. MCT tries 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.

The MCT water rate is designed to cover its operational, maintenance, and investment costs, as well as the cost of external water sources. Periodic rate reviews are approved by the MCT board of directors. Given the participation of all municipal representatives in the board and decision-making process, and the direct correlation between production costs and rates, the revision of the rates mostly avoids conflicts.

Irrigation interests are powerful players in the region's hydropolitics, limiting the options available for domestic water supply in spite of its legal status as a priority use. The historical allocation of most Segura River flows to irrigators is at the root of MCT's original search for sources of water in the Taibilla River Basin headwaters, over 200 kilometers away from the original destination, in the city of Cartagena. Reclaimed wastewater, which has become available through the publicly funded regional sanitation plan, has also been allocated to irrigation, making it challenging for municipalities to obtain concessions for public uses.

The most recent illustration of the political clout of irrigators can be seen in the negotiation over the reform of the TTS management rules, which has limited the amount of TTS water assigned to MCT. New water policy priorities derived from the implementation of the EU's Water Framework Directive resulted in the publication of a draft river basin management plan for the Tajo River in 2011, which limits transfers to the Segura River Basin to increase environmental flows and improve the Tajo's ecological health. Responding to pressures from the transfer recipient regions, a political agreement was reached between these regions, SCRATS, and the central government. The "Tajo Memorandum" commits the central government to undertaking the necessary legal reforms to guarantee the continuation of the TTS. These reforms were approved in 2013 and 2014, and have favored irrigation interests (MCT has lost the right to the "evaporation savings"). Furthermore, transferred volumes are now divided between MCT (25 percent) and SCRATS (75 percent), with a minimum of 7.5 million cubic meters of monthly transfers allocated to MCT. Prior to the reform, and given domestic uses legal priority, the entire MCT allocation (110 million cubic meters plus evaporation savings) was guaranteed if enough volumes were transferred. In the current context, MCT expects to receive on average 70 million cubic meters per year from TTS, a significant decrease from the historic average of 106 million cubic meters, with increased probability of not receiving any water in some months, as is the case in the summer of 2017.

In this new context, desalination has become a strategic resource for MCT, which expects to use the full production of its desalinated plants (approximately 80 million cubic meters). For instance, in May 2017, as TTS resources decreased, desalination covered up to 40 percent of all MCT water needs, double the average for the 2003-16 period. MCT is also negotiating individual purchasing agreements with irrigator associations and cities that have their own sources of water.

### EMUASA: Improving Efficiency

The case of EMUASA illustrates the improvements in efficiency and ongoing reduction in per capita consumption that characterize urban water uses in much of the MCT service area and in most Spanish cities. The case of MCT-associated municipalities is unique in that they are guaranteed supplies from MCT and are responsible only for water distribution and sanitation within municipal boundaries.

EMUASA focuses on the first three steps of the International Water Association's four-step program for efficiency improvements; the first three are (a) sectorization of the network, (b) pressure

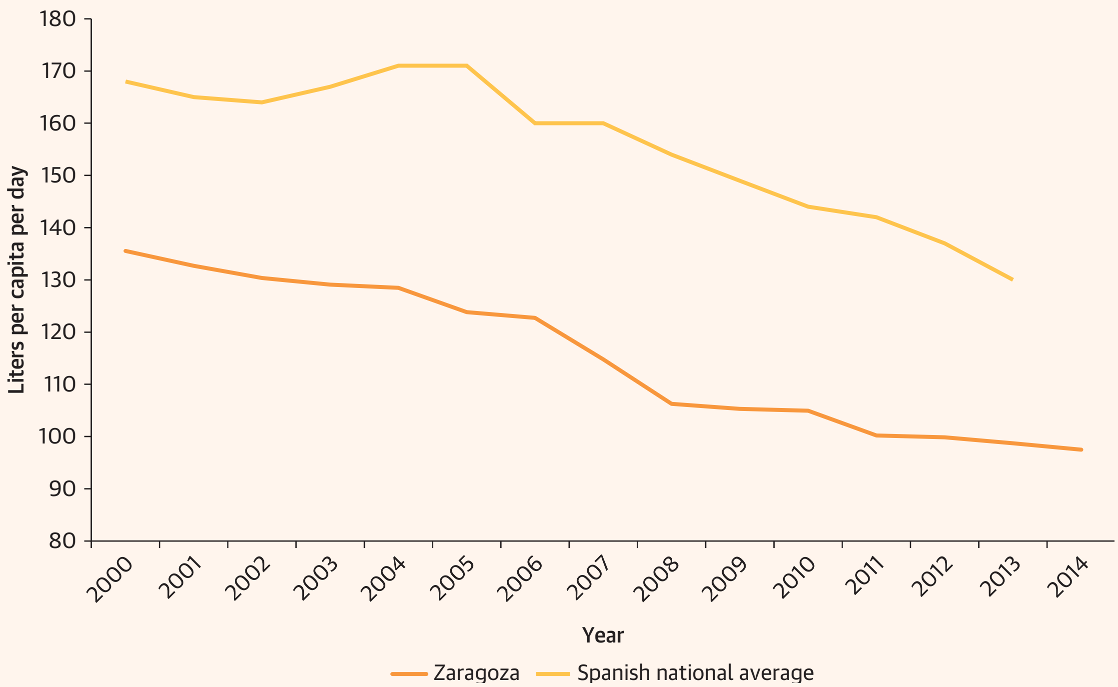
**BOX 8.1. Improving Efficiency in Zaragoza, Spain**

Zaragoza is a city of over 700,000 inhabitants located in central-northeastern Spain. The municipality has an area of over 970 $km^2$. Zaragoza has a continental Mediterranean climate and average precipitation of 340 mm per year.

Two water sources guarantee the quantity and quality of its water supply. First, water from the Ebro River reaches the city through the *Canal Imperial de Aragón*, an irrigation and navigation canal that runs parallel to the river and has historically been its main source of water. Second, the Yesa-Loteta reservoir system on the Aragon River has served as the primary source of water since 2010.

The municipality of Zaragoza manages the urban WSS services. Water is available to 99.7 percent of the population and sanitation to 98 percent. The water distribution network includes 1,288 kilometers of pipes, and the sanitation network includes 1,139 kilometers of pipes and nine pumping stations. In 2014, the city abstracted 58.8 million $m^3$, down from 107 million $m^3$ in 1979, when the city had only 400,000 inhabitants. Per capita consumption in Zaragoza is 99 liters per person per day (lpd), an almost a 30 percent decrease from consumption levels in the early 2000s (figure B8.1). Zaragoza's remarkable achievements are the result of a concerted effort, which started in the mid-1990s, to improve the efficiency of water use.

**FIGURE B8.1. Evolution of Daily per Capita Consumption in Zaragoza and Spain**




*box continues next page*

**BOX 8.1. Continued**

Public outreach and education campaigns, which targeted different groups, including public service institutions and the general population, were started in the mid-1990s through a local nonprofit, the Ecology and Development (ECODES) Foundation, with support from the European Union Life program the municipality of Zaragoza, and a variety of private and public partners.

The Water Quality and Management Improvement Plan the goal of reducing raw water use by 19.75 percent, from 80 million $m^3$ in 2001 to 65 million $m^3$ in 2006. This goal was achieved by investing in the renovation of the drinking water distribution network (€53 million), as well as by improving deposits and other infrastructures (€29 million). Twenty-one percent of the network has been renovated since 2002, and 3 percent continues to be renovated annually.

In Zaragoza, over 337,000 water meters monitor water consumption for domestic, commercial, and industrial users to facilitate the implementation of demand control policies.

In 2004, Zaragoza changed its water pricing and billing system in consultation with a wide array of interest groups and stakeholders. The current water tariff aims to cover investment and operating costs. It has a block tariff structure that favors lower income citizens and penalizes higher consumption levels: It promotes efficient water use by reducing by 10 percent the price of water for those families that reduce their annual consumption by more than 10 percent. The tariff for the first 6 cubic meters is 50 percent below production costs.

As part of the 2004 reforms, Zaragoza changed the way it billed its customers. Before 2004, 96 percent of citizens paid their water bills electronically through their banks and did not receive a paper bill at home. Now all residents receive a detailed monthly paper bill. Consumption is measured monthly so residents are billed for real consumption levels instead of estimates based on past consumption patterns. The bill itself serves as a communication tool to convey information on consumption levels and encourage savings.

Zaragoza promoted a collaborative approach to water saving policies through the creation of the Zaragoza Innova en Agua y Energía (ZINNAE) cluster, an association of the main economic agents for the efficient use of water. ZINNAE includes urban WSS companies, research centers, and local and regional public administrations. The city has also promoted the creation of Comisión 21, a group of social agents, neighborhood associations, and nonprofit associations that participate in municipal decision-making processes related to water. Finally, there is an internal commission within city hall that includes all municipal departments and is coordinated by the city's Agency for Environment and Sustainability. This commission is critical to the development of proposals, such as the recently approved Municipal Ordinance for Ecoefficiency and Quality in the Integrated water management (*Ordenanza municipal para la ecoeficiencia y la calidad de la gestión integral del agua)* that was approved in 2011.

Zaragoza aims to continue reducing both the demand of raw water as well as per capita consumption levels through a variety of measures that include: full implementation of the new water ordinance; development of new programs through collaboration with ZINNAE; and enhancement of network efficiency by substituting the current system of building connections to the city's distribution pipes.

regulation to minimize breaks and leaks, and (c) speed and quality of repairs. The fourth step, (d) an ambitious but very costly infrastructure replacement program, is not a priority for EMUASA, but small network replacements are annually undertaken in areas where breaks and leaks are recurrent.

EMUASA's most successful efforts to improve water use efficiency have focused on the microsectorization of the water distribution network and early detection and repair of leaks. This process has been conducted in two phases:

- Level 1: hydraulic zoning. Implemented in 1989, it subdivided the water distribution network into 102 hydraulic zones of 25 square kilometers in which bimonthly technical efficiency estimates serve to calculate nonregistered water and intervene in the most problematic sectors. Four hundred and sixty-four water meters were installed that allow daily measurement of production, distribution, and nighttime minimum flow.
- Level 2: dynamic microsectorization. Implemented in 2008–09, it has subdivided the network into 297 microsectors of 5 kilometers each. The system allows the isolation of the microsectors at night and the calculation and control of the minimum night flows without modifying normal distribution conditions.

Microsectorization allows for rapid detection of leaks, which are located with a leak detector and repaired within a maximum of 2.5 days. The implementation of the program has allowed EMUASA to improve reduce nonrevenue water (NRW) to less than 14 percent down from more than 40 percent in 1975, as illustrated in figure 8.3.

Water consumption in Murcia has decreased continuously since the 1980s, reaching 155 liters per capita per day, a 20 percent reduction from all-time highs in the 1990s, (although still exceeding the Spanish national average of 130 liters per person per day, and well above other cities such as Zaragoza, with consumption below 100 liters per person per day). EMUASA charges a water tariff of €2.7 per cubic meter to its users, including WSS services, higher than the Spanish national average of €1.27 per cubic meter, but below the tariffs charged in a number of other European cities.

### The Way Forward

The MCT is currently not considering alternative solutions, since existing desalination capacity both from MCT- and ACUAMED-owned plants covers current demands and possible future growth scenarios. Efficiency gains in municipalities within the MCT service area and the impacts of the economic crisis that started in 2008 have resulted in a continued decrease in water use production in the MCT starting in 2005 and until 2014, during which the downward trend seems to have stabilized. The crisis in Spain had a housing bubble component, which severely affected the MCT service area, where many residential development, resorts, and other leisure-related infrastructures were planned and built.

Given increasing reliance on desalinated water, future risks derive from the evolution of energy prices that will increasingly affect the evolution of the MCT rate. Further actions will need to advance in the interconnection of the different water sources to continue improving system resilience. However, there are technical and financial limitations to these interconnections, and some parts of the MCT service area will continue to depend on Taibilla and, currently, TTS waters. As TTS water becomes an increasingly unreliable resource, other alternatives will have to be considered.

## Conclusion

The experience of the MCT in the region of Murcia is an important example of a successful approach to guarantee urban water supply in arid regions and diminish vulnerability to droughts and expected climate change impacts. Irrigated agriculture dominates water resource policy in Murcia both quantitatively, by being the primary water consumer, and politically, by dominating regional discourses, policy initiatives, and demands over water. In this context, the institutional design of the MCT has proven to be resilient, effective, adaptive, and durable. The following points highlight the success of the urban water supply story in Murcia:

- The creation of a strong regional public entity, MCT, that can leverage political, financial, and physical resources to develop infrastructure, garner public and political support, and guarantee sufficient funding.
- The existence a solid institutional framework for water planning and management at the scale of the river basin.
- An effective governance structure for the MCT that (a) incorporates representatives from multiple levels of government in decision-making to facilitate trust and cooperation among competent authorities; (b) closely integrates the Segura RBA within the decision-making bodies, thus facilitating cooperation in the allocation and annual management of resources; and (c) creates effective financing mechanisms (the MCT rate) for financial stability.
- The increased diversification and interconnection of different sources of water to minimize vulnerability, increase flexibility, and maximize resilience.
- The availability of EU funding that has helped finance up to 80 percent of infrastructure development in the region in recent decades. Whether investments in nontraditional resources would have been possible without this funding in such a short period is in question.
- Urban utilities within the MCT service area, such as EMUASA, have invested in efficiency improvements, thus contributing to reduce overall demand and giving MCT the necessary flexibility to successfully tackle new scarcity situations.

The MCT experience faces challenges that will have to be addressed to guarantee the sustainability of the model. First, the political and discursive dominance of the irrigation lobby at the national and the regional levels effectively limits MCT's adaptability and forces it to rely on more costly and energy intensive sources of water. It may be necessary to reinforce the legal priority of domestic water supply and reduce irrigation's impact on the region's water quality and overall availability.

Second, the reliance on external resources from the Tajo River increases the vulnerability of the MCT water supply system. The Tajo experiences the same climatic variability as the Segura River Basin, and the transfer is subject to social and political controversies that exceed the control of the agency. As Tajo waters become less reliable, the MCT will have to increasingly rely on other water sources and will need the political and institutional support to make this possible.

Third, unrealistic demand growth expectations in the 1990s and early 2000s led to the investment in desalinated infrastructures that may not have been necessary, but that are proving crucial to compensate for the unreliability of TTS waters. As the water portfolio has become increasingly diversified, the MCT has created a water production and distribution network that is heavily energy dependent. Experience has shown that, as reliance on desalination has increased, so have MCT rates. This upward trend will continue in the foreseeable future, affecting water supply tariffs charged by municipal utilities. To manage production costs, MCT will have to develop ambitious energy management policies.

Acknowledging the success of the regional model for urban water supply that the MCT represents, and identifying the key elements of its success, will be first steps in guaranteeing its continuity in the future and effectively facing the challenges ahead.

## Note

1. The price corresponds only to production costs since MCT paid for part of plant construction.

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# Chapter 9
# Republic of Cyprus

The island of Cyprus is located in the eastern basin of the Mediterranean. The third largest Mediterranean island after Sicily and Sardinia, its total population is estimated at about 1.2 million people (2016). The Republic of Cyprus was established in 1960, when the island gained its independence from Great Britain. However, following ethnic strife and the invasion in 1974 of the northern part of the island by the Turkish Army, it has been separated along ethnic divides between the Greek Cypriot community (GCC) and the Turkish Cypriot community (TCC).

Currently, the Republic of Cyprus controls only the southern 60 percent of the island, which is home to the GCC. It is the only internationally recognized government of the island. In 2004, it became a member of the European Union (EU), and adopted the euro in 2008. The north of the island (about 37 percent of the territory) is home to the TCC and falls outside of government control.[1] The island division is materialized by a buffer zone, under the control of the United Nations (UN). Although many efforts have been made in the last decades under the auspices of the UN to settle the issue, the country remains divided.

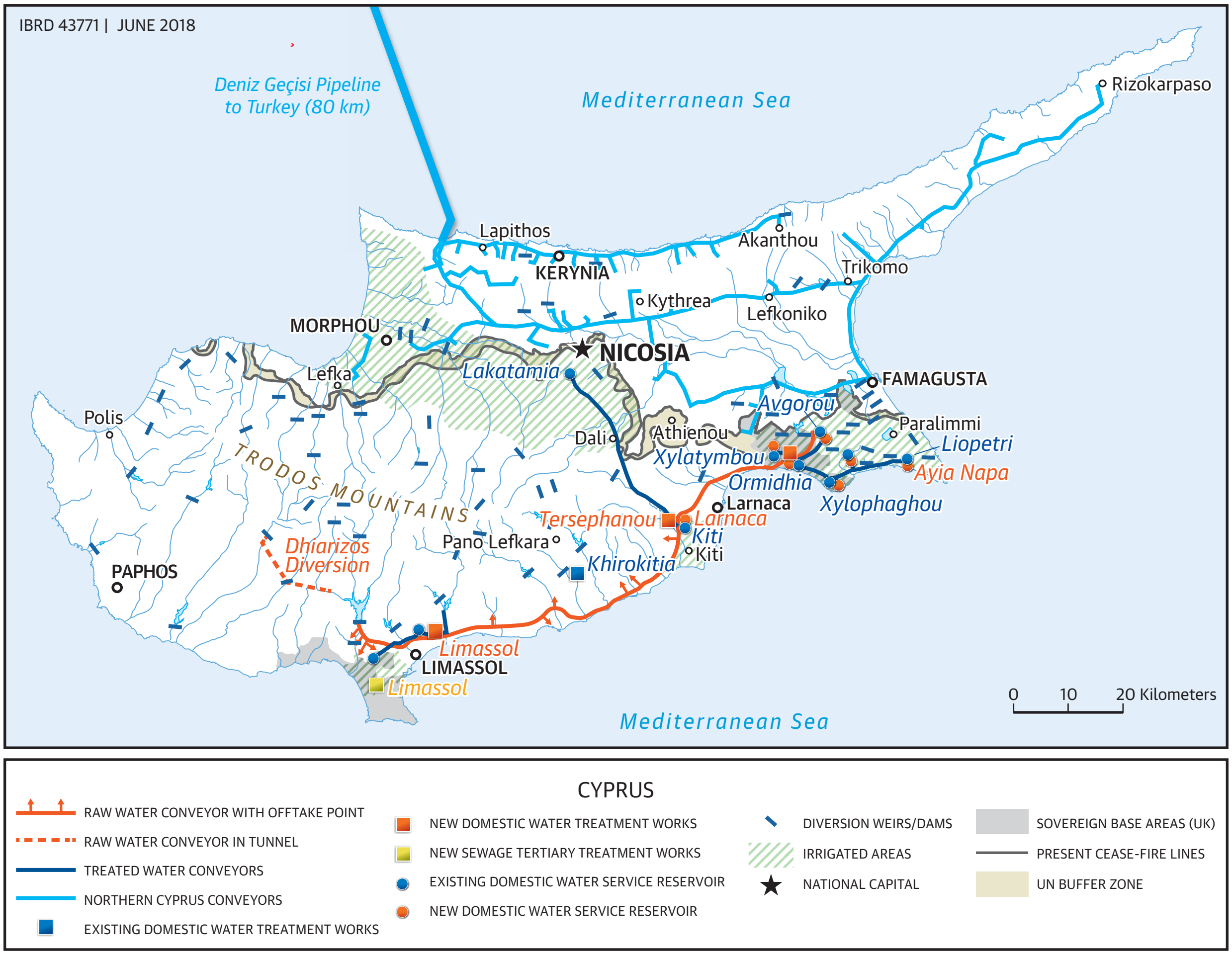
This case study focuses on the water management experience of the Republic of Cyprus; that is, the southern part of the island (GCC) (map 9.1). It has a permanent population of close to 950,000 plus almost 3 million tourist arrivals per year (2016).

## Climate and Hydrology

Cyprus and Malta are the two most water-stressed countries of the EU. Availability of renewable natural freshwater in Cyprus stands at only 390 cubic meters per capita per year in the government-controlled area,

This chapter is adapted from Marin, Philippe, Bambos Charalambous, and Thierry Davy. Forthcoming. "Securing Potable Water Supply under Extreme Scarcity: Lessons and Perspectives from the Republic of Cyprus." World Bank, Washington, DC.

**MAP 9.1. Large Water Infrastructure Operated by the Water Development Department**




which is well below the standard threshold for extreme water scarcity of 500 cubic meters per capita per year (the normally accepted threshold for scarcity being at 1,000 cubic meters per capita per year).[2] Because of its arid climate and limited size, Cyprus does not have any rivers with perennial flow. There are only a few streams, and these flow only during the winter rainy season; therefore, the island depends entirely on seasonal rainfalls for its natural water resources.

Because Cyprus lacks permanent superficial water bodies, the Cypriot population relied entirely on groundwater until the mid-twentieth century. As a result, at the time of independence in 1960, the aquifers were already overexploited, with growing salinization on the coastal aquifers. The situation became worse in the last decades due to continued population growth and increased demand from tourism.

After independence, the slogan "Not a Drop of Water to the Sea" was adopted by the Cypriot government and determined the national water policy for the ensuing decades. As a result, Cyprus embarked into a massive program of surface water and rainwater storage through dam construction, most of which were of the earth-fill type. The water storage capacity went up from a mere 6 million cubic meters in 1961 to about 332 million cubic meters in 2015. It is estimated that about 54 percent of the water from rainfalls is captured into the dams. Dams are used only for potable water supply, irrigation, and aquifer recharge.

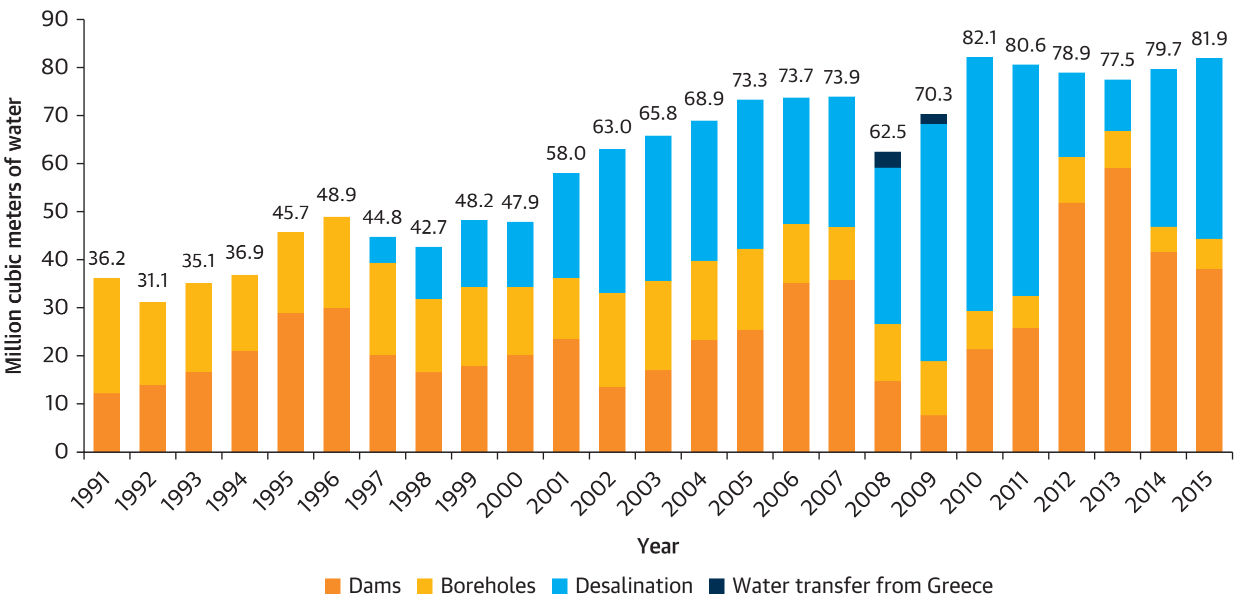
In spite of the development of surface water storage, the Cypriot government could not achieve water security due to the high variability of rainwater and the frequency of multiyear droughts. In the last two decades, Cyprus has turned to the development of nonconventional water resources, including desalination and wastewater reuse, to achieve water security.

### Water Resources Strategy

For many years before the desalination program went into full gear, potable water supply in Cyprus was subject to considerable pressures and uncertainties. At the end of each winter, a decision had to be made regarding the allocation of available water between domestic supply and irrigation. Policy makers had to consider demand from domestic users and agriculture and the target for the amount of water stored in the dams before the following rainy season. This latter element was particularly sensitive, because it involved taking a gamble on how much water would fall in the following rainy season. While demand for potable water is stable and therefore predictable, it worked the other way around for irrigation, since farmers would decide how much annual crops to grow based on how water they can get each year.

This decision-making framework is now evolving with desalination. While desalination could serve as a base load to supply most of domestic potable water needs, the annual allocation of raw water from dams for irrigation depended until now not just on rainfalls but also on short-term financial considerations. The capacity of the four large desalination plants supplying Larnaca, Limassol, and Nicosia (with a fifth plant to be constructed soon to supply the city of Paphos on the west coast) is now—since 2012—able to cover almost all the demand for domestic potable water in urban areas.[3] In theory, this means that all water stored in the dams could be allocated to irrigation. However, desalinated water is costly, and the 2012–14 period, when the two new desalination plants in Limassol and Vassilokos started to operate (and the Larnaca plant was rehabilitated and expanded), coincided with the 2012 financial crisis in Cyprus. Figure 9.1, which shows the sources of potable water for the distribution systems supplied in bulk by the Water Development Department (WDD) since 1991, including

**FIGURE 9.1. Potable Water Supply Sources in Cyprus, 1991–2015**




*Source:* WDD 2016.

dams, boreholes, desalination, and bulk water transfers from Greece during the drought, in 2008-09.

### Precipitation Variability and Consequences on Hydrology

The rainfall regime is characterized by extreme variability, both among parts of the island and between successive years. Cyprus is seriously affected by the impact of climate change. The effect started to be felt as early as the 1970s, with increasing rainfall variability and frequency of droughts. Statistical analysis shows a 20 percent drop in the mean annual precipitation since the early 1970s compared to precipitation records over the last 100 years. This reduction in rainfall has been accompanied by a parallel increase in average temperature, with parallel negative impact on evapotranspiration. Drought periods occur frequently, and it is not unusual to experience two or three or even up to six consecutive dry years. In the last two decades, three severe drought periods were observed, which severely affected the country.

The 2008-09 drought was the worst in Cyprus in modern history. In the preceding years, the large surface reserves had been gradually depleted through four consecutive dry years. Because of upcoming elections in 2008, the government was reluctant to impose water saving measures early on—betting on a return of the rains during the 2007 winter—but this did not happen. As a result, the dams were at critical level at the beginning of 2008. This provoked a major water crisis, forcing the government to take drastic measure to ensure potable water supply. Severe rationing measures were reintroduced in early 2008, making domestic water supply in most areas available only three times a week. Several small mobile desalination plants were installed in emergency. The most spectacular measure was to transport water from Athens via tankers: a total of 8.4 million cubic meters were supplied over an 8-month period at the prohibitive price of about €6.7 per cubic meter. The public irrigation perimeters depending on supply from surface water also suffered catastrophic losses.

### Risks to Resource Quality

A 2002 study carried out by the WDD and the Food and Agriculture Organization (FAO) concludes that the Cyprus aquifers were previously at very low levels, partially intruded by saline water, and were overexploited by 40 percent. Due to the combination of overpumping, saline intrusion, and nitrate contamination from agriculture, around 80 percent of the groundwater bodies were rated as being at risk of failing to achieve a "good status" according to the Water Framework Directive (WFD) in 2016. However, less than half (9 out 21) were assessed as being affected by increasing pollution, which suggested that some of the negative factors were starting to be better controlled and mitigated.

## Water Use: Water Supply and Sanitation Framework

The Ministry of Agriculture, Rural Development and Environment (MARDE) is responsible for the formulation of water policies. All decisions related to water policies—including tariff changes, or annual allocations of water from dams—are made at the level of the Council of Ministers of the Republic. The WDD, within MARDE, is responsible for both water policies and managing large water infrastructure (bulk water transfer, water production, etc.) for domestic potable and agriculture. The Ministry of the Interior oversees the water supply and sanitation (WSS) providers, such as the water boards, sewerage boards, and local water municipal services.

More than half of the population is served by the three water boards of Nicosia, Limassol, and Larnaca. These are ring-fenced public utilities with strong central government presence on the board of directors, covering several municipalities in the three largest urban centers on the island. There are nine municipal water supply departments, which provide service to about a quarter of the population in cities and towns not covered by the water boards. The remaining 29 percent of the population receives potable water through 146 community boards in small villages in rural and peri-urban areas. In both cases, the water services are not ring-fenced from the municipal budget, and tariff levels are set by local authorities and cover only a portion of operating costs.

### Coverage

There is 100 percent coverage for domestic potable water supply in Cyprus, with all consumers connected to the water supply network. The organization of sewerage services is different from potable water, with five urban sewerage boards covering 70 percent of Cyprus population in the urban areas of Nicosia, Limassol, Larnaca, Paphos, and Ayia Napa and Paralimni.

### Urban Water Use

The average demand between the different users is at about 60 percent for irrigation, 3 percent for livestock, 26 percent for domestic use, 4 percent for tourism (11 percent of all potable water), 3 percent for industries, and 4 percent for landscape irrigation. This breakdown is an estimate, because water allocated each year to agriculture varies greatly since irrigation is used as a buffer to compensate for rainfalls variability, and because the actual amount used in each year for irrigation comes from private boreholes from which amounts of abstraction are unknown. The two main users—domestic potable water and irrigated agriculture—both have significant seasonality that poses additional challenges in a context of extreme water scarcity for managing water resources during the dry summer months.

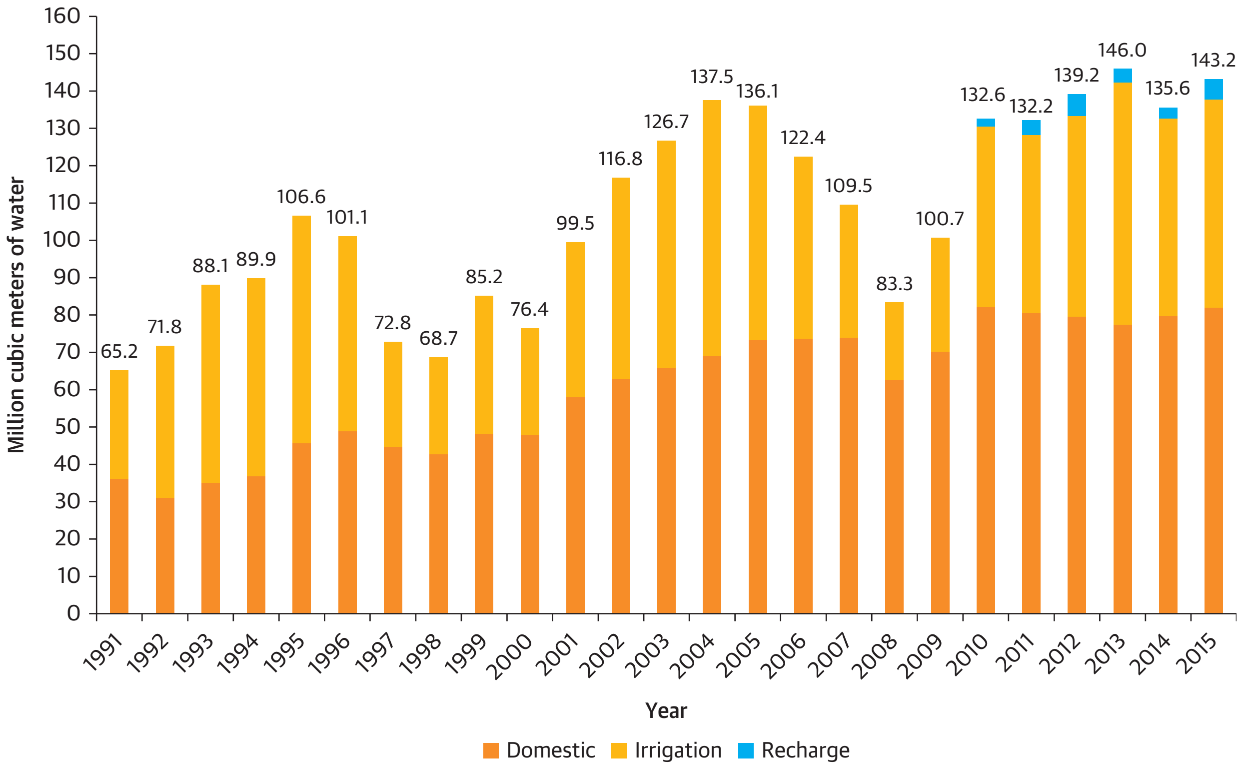
The domestic consumption per capita for the urban areas of Limassol, Nicosia, and Larnaca stands at 140 liters per day on average. This is broadly in line with per capita domestic consumption in other southern European countries such as Spain, France, Italy, Portugal, and Greece—but significantly more than in Israel (86 liters per day), which, like Cyprus, is another eastern Mediterranean country that has implemented major reforms to deal with extreme water scarcity. This consumption level of 140 liters per day includes a sizeable amount dedicated to gardening (no rainfalls for more than half of the year), though many private houses also have private wells. Water demand from the tourist industry is more than three times that of residential users, at 465 liters per day per capita (Savvides 2001). The total consumption of the tourist industry is estimated at about 20 percent of total urban consumption, or about 5 million cubic meters per year. While no data are available for the per capita domestic consumption in areas served by municipal departments and community boards, it is likely that the per capita consumption is higher, due to both lower tariff and much less strict metering practices.

### Water Balance without Additional Resources or Actions

The water balance of Cyprus is heavily influenced by rainfalls and is therefore highly variable. Out of the 2,670 million cubic meters that come from rainfall on average, only 370 million cubic meters are left available after evapotranspiration; 135 million cubic meters per year goes to replenish the aquifers, and 235 million cubic meters per year are available as surface water through seasonal streams. Groundwater abstraction represents on average an estimated 135 million cubic meters per year, bringing to the total usable amount to 370 million cubic meters. These figures are based on average rainfalls, and do not reflect the situation of acute scarcity that occurs during drought years.

The average total annual water demand has been estimated at 252 million cubic meters for 2011. The actual water demand of irrigated agriculture is difficult to estimate due to high interannual variability. Outside of public irrigation perimeters, there are many farmers who use unmetered boreholes for irrigation. The total water demand from irrigated agriculture was estimated to be based 174.4 million cubic meters, based on crops pattern on the island in the early 2000s and assuming no water shortage (Savvides 2001). However, the water demand regarding irrigation is rarely satisfied, and the actual water consumption in agriculture fluctuates around 150 million cubic meters per year, as shown in figure 9.2. During the past two decades, only 1 year (2004) saw no restrictions for irrigation.

**FIGURE 9.2. Water Development Department Water Allocation between Domestic, Irrigation, and Managed Aquifer Recharge, Cyprus, 1991–2015**




*Source:* WDD web site: http://www.moa.gov.cy.
*Note:* Data do not include private boreholes; domestic data include tourism. WDD = Water Development Department 2016.

## Solutions

Because of Cyprus's acute water scarcity and high variability of rainfalls, the Cypriot population has been forced since time immemorial to develop technologies and practices to manage water efficiently and deal with the lack of water. As population and demand grew, the government of Cyprus undertook various measures to enhance water security.

### Surface Water Management

To reduce the pressure on aquifers and satisfy growing demand, an ambitious dam construction program began in the 1960s. The water storage capacity went up from a mere 6 million cubic meters in 1961 to about 332 million cubic meters in 2015. Dams are used only for potable water supply, irrigation, and aquifer recharge. There are no hydroelectric dams in Cyprus, because extreme water scarcity has always made meeting demand for domestic supply and agriculture the unique priority. At present, Cyprus has over 100 dams, most of which are dedicated to supplying small to medium irrigation systems spread across the island. The recharge dams were constructed to mitigate overexploitation in the coastal aquifers. The four large dams dedicated for potable water supply represent 54 percent of the total storage capacity. Cyprus is unique within the world with the magnitude of dam development, with a ratio of 50 large dams for every 10,000 square kilometers. It is ranked first among European countries for its dams' density. It is considered that the dams' potential in Cyprus has been largely developed to its maximum.

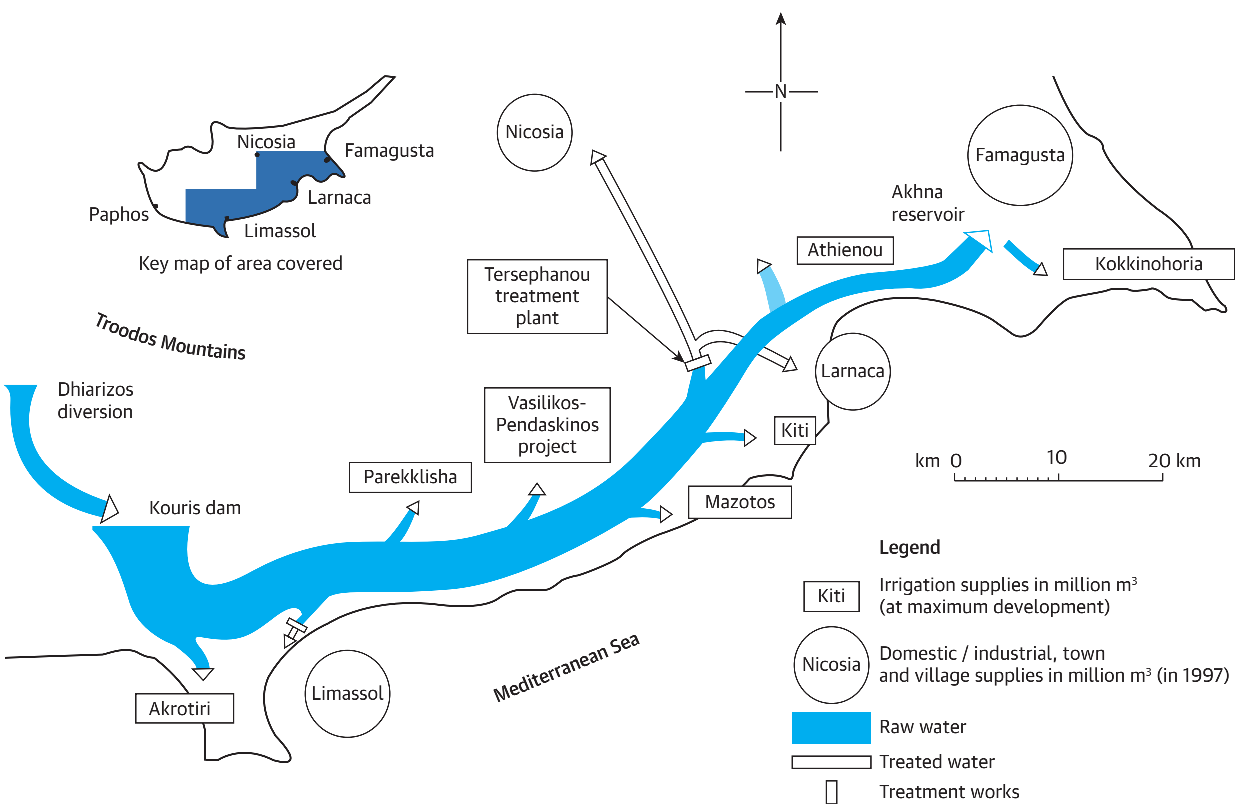
The average total volume of water stored in dams for the period 1988–2014 amounts to 100.4 million cubic meters, but there are considerable interannual variations: from as low as 20 million cubic meters during the worst drought years, to as much as 270 million cubic meters in wet years. The dam network is therefore largely insufficient to meet demand due to the overexploited aquifers and is insufficient to guarantee that potable water supply can meet demand during years of droughts.

## Bulk Water Conveyance

Along with the development of dam storage capacity, in 1984 a major bulk water transmission network began construction. The Southern Bulk Water Conveyor project interconnected the main dams to the largest urban centers and tourist areas on the island: Limassol; Larnaca; Nicosia, the capital; and the tourist area around Famagusta. In addition, the new bulk water conveyor allowed the development of a series of new public irrigation perimeters in the southern plain around Famagusta, where the coastal aquifer could not be used for agriculture due to saline intrusion. The schematics of the bulk water transmission system is represented in figure 9.3.

The Southern Conveyor allows raw water sources to be connected to the large dams dedicated mainly to domestic potable water, along with a series of other dams dedicated initially to irrigation. Bulk water is mixed in the transmission pipe and distributed between the three potable water treatment plants (WTPs) (serving Limassol, Larnaca, Nicosia, the

**FIGURE 9.3. Schematics of the Southern Bulk Water Conveyor**




*Source:* WDD.
*Note:* Schematics represent first and second phases. WDD = Water Development Department.

Akrotiri U.K. military base, and the Famagusta tourist area) and the various public irrigation perimeters developed along the conveyor. The WDD operates not only the dams and the entire conveyor transmission system but also the WTPs that provide water in bulk to the urban water boards and municipal water supply departments (which were built before the construction of the Southern Conveyor) and the public irrigation perimeters along the conveyors. Overall, 70 percent of the total dam storage capacity for potable water in Cyprus is interconnected with the Southern Conveyor.

### Desalination

As it became gradually evident that the massive development of dam storage capacity could not be sufficient to achieve potable water security and reduce pressure on overexploited aquifers, a program of massive development of nonconventional water resources—including desalination and treated wastewater—was implemented over the last two decades.

The catastrophic 2008-09 drought was a turning point, pushing the government's decision to embark on a massive desalination program to secure potable water supply. The three successive wet years of 2001-02, 2002-03, and 2003-04 were a false blessing, because they had given the misleading impression that the water shortage problem had been solved. Desalination plants had begun development in the early 2000s, but the development of additional desalination plants that had been agreed upon after the 2000 drought were postponed to save money, while a large portion of the water stored in the dams was freed for agriculture. The 2008-09 drought came as a brutal wake-up call, prompting the government to adopt a new water production strategy whereby virtually all urban residential water needs would be met by water generated from desalination plants. The aim was that (a) water supply for domestic, commercial, industrial, and tourist use could become independent of weather conditions; and (b) renewable freshwater from rainfall could become solely dedicated to the agricultural sector to gradually restore groundwater reserves.

The first large seawater desalination plants started operation in 1997 and 2001 to cover the urban centers of Larnaca and Nicosia plus the Famagusta resort area. Both were developed under a build-operate-transfer (BOT) approach, and with an initial 10-year operations and maintenance (O&M) period, followed by rehabilitate-operate-transfer (ROT) contracts for an O&M period of 20 and 25 years, respectively, which also involved the rehabilitation and expansion of the plant. The third large desalination plant started operation in 2012 near Limassol, following again the BOT contractual model, this time with a 20-year O&M period. A fourth permanent desalination plant started operation in the summer of 2013 to serve a wide area including Larnaca, Nicosia, the Famagusta resort area, and a number of the eastern villages of Lemesos. In this case the contractual WDD has a bulk water purchase contract with the off-taker (EAC) in a BOT contract with a private concessionaire. The BOT contract was awarded with a 20-year O&M period.

The total desalination capacity with the four seawater desalination plants under BOTs with private concessionaire now stands at 220,000 cubic meters per day. All the desalination plants are based on reverse osmosis. They are interconnected with the Southern Conveyor, allowing water to be transferred as required to Limassol, Larnaca, the Famagusta area, and Nicosia. The annual production capacity of 80 million cubic meters is broadly equivalent to the combined demand from the various domestic users (residential, commercial, industrial, and tourist). In practice, the desalination plants are never operated at full capacity during the whole year, first because some of this capacity is an operational cushion to be used only during the summer peak demand, and second because the WDD arbitrates each year for bulk water supply between desalination and treatment of raw water stored in the dams, depending on rainfalls so as to reduce water production costs. Desalination now supplies half of total domestic potable water on average, and the existing total capacity of the desalination plants provides enough cushion to guarantee that domestic demand can be met even during drought years.

### Nonrevenue Water Reduction

The WDD has provided no reliable estimate of the level of losses in the bulk water transmission systems. Access to nonrevenue water (NRW) data from service providers is a challenge in Cyprus. Estimates provided by World Bank (xxx) show that levels of NRW for the three water boards of Larnaca, Nicosia, and Limasol stand at 18 percent, 20 percent, and 28 percent, respectively. However, for the municipal water departments and the community boards, they are estimated to be much higher, at 35 percent and 40 percent, respectively.

The NRW performance of the Limassol Water Board is unsatisfactory, at 28 percent, and with an Infrastructure Leakage Index of 3.5 based on 2013 data. While water losses in Nicosia and Larnaca have been on a positive downward trend, this is not the case for Limassol, where water losses have been on the increase. During the 2008-09 drought, the Limassol utility was forced to impose rationing and adopt an intermittent distribution mode for 8 months. This considerably damaged the networks, due to the repetitive pressure surges, generating multiple breaks and leakages, most of them invisible. Once the drought was over and distribution restored to continuous 24/7 supply, the level of NRW had increased by about 9 percentage points compared to the predrought level. Since then, the Limassol Water Board seems to have been unable to restore the physical condition of its distribution network back to its pre-2008 condition. Another reason for the relatively poor performance has been the incorporation in 2013 of another peri-urban municipality in the Limassol Water Board, whose water network was in poor shape.

Private roof tanks generate significant meters' underregistration, which is a notable component of NRW in Cyprus. In Cyprus, although now a continuous 24/7 supply is guaranteed for all domestic customers thanks to the desalination program, most houses are still equipped with roof tanks (they are a legacy especially of the last major droughts in 1999-2002 and 2008-09). The problem is due to the ball valves in roof storage tanks, which cause meter underregistration, especially at the very low flows. Installing flow control devices (called unmeasured flow reducers, or UFRs) was an efficient solution to solving this common problem faced by water utilities in water scarce countries: a valuable lesson for countries in arid climates facing similar situations.

The level of water losses in the municipal water supply departments is much higher than for the three water boards: at an estimated average of 35 percent. NRW figures are reported for only a limited number of municipal water departments and vary between 28 percent and 45 percent, indicating relatively high water losses. Even though they represent a combined production volume comparable to that of the Nicosia Water Board, the volume of water losses is almost double, estimated at 6.4 million cubic meters in 2013. This is an issue of major concern—not only in terms of efficient water management under scarcity but also of financial sustainability—because almost all of the municipal water departments are supplied in bulk by the WDD, and most of the potable water comes from expensive desalination plants.

### Demand Management

To foster water conservation, water tariffs of water boards and municipal water supply departments are based on a progressive block structure, with all customers being metered. Customers are differentiated by categories, with commercial customers and hotels paying higher rates to cross-subsidize domestic customers. For domestic customers, the fixed charge is in the order of €3 to €5.5 per month. The first discounted consumption tranche typically covers the first 10 cubic meters per month. There are steep rate increases for large consumption above 21 cubic meters per month: between two and three times the rate of the first tranche. To ensure affordability for large families, special tariffs are available for households above six. Overall, urban WSS tariffs in Cyprus are lower than in most other European countries. Water tariffs tend to be lower in urban areas served by municipal departments, because water charges are set solely by local authorities, while for urban water boards the central government has significant power to push for water charges closer to full cost recovery.

With an average consumption of 140 liters per capita per day, households in Cyprus use water rather comfortably, considering that the island suffers from extreme water scarcity. This can be directly attributed to the fact that the rather low WSS tariffs are insufficient to foster much demand management. Still, several significant measures have been taken over the last decades to promote demand management. Communication campaigns are carried out by the WDD on a regular basis to educate the public on the need for water conservation, and were intensified during recent droughts. Since 1991, using piped potable water for washing cars and cleaning pavement has been banned, with fines imposed by the police. Even though WSS tariffs charged to hotels are considerably higher than for domestic customers, per capita water demand remains three times as high.

Since the early 2000s, the WDD has established subsidies for a series of water-saving measures at the household level. The two most important were for installation of a greywater recycling system (€3,000 per household), and for drilling of boreholes for watering gardens (€700, or about half of the cost of drilling plus pump installation). A total of 7,666 boreholes subsidies were granted between 1997 and 2010. Overall, the WDD estimated that these measures saved about 1.7 million cubic meters per year in domestic water demand, of which 1.38 million cubic meters per year came from the borehole subsidy and 0.27 million cubic meters per year from the connection of boreholes with toilets.[4] These subsidies were phased out in 2013 as part of the drastic budgetary cuts applied in the aftermath of the Cyprus financial crisis.

In retrospect and with the exception of greywater recycling, these subsidies measures were questionable in a context of already overexploited groundwater resources. They were not directed at reducing the total water consumption of households, but rather at switching water supply partly from the piped network to the aquifers. Furthermore, using shallow boreholes for toilets increased the salinity level of sewerage collected in coastal areas, which creates challenges for further reuse of treated wastewater in agriculture.

### Rainwater Harvesting

Little data are available on the uptake of domestic rainwater harvesting. As part of the Rural Development Program, farmers have received subsidies to implement on-farm rainwater harvesting through installing small-scale water reservoirs to prevent groundwater overexploitation. However, no data are available on its uptake.

### Wastewater Reuse

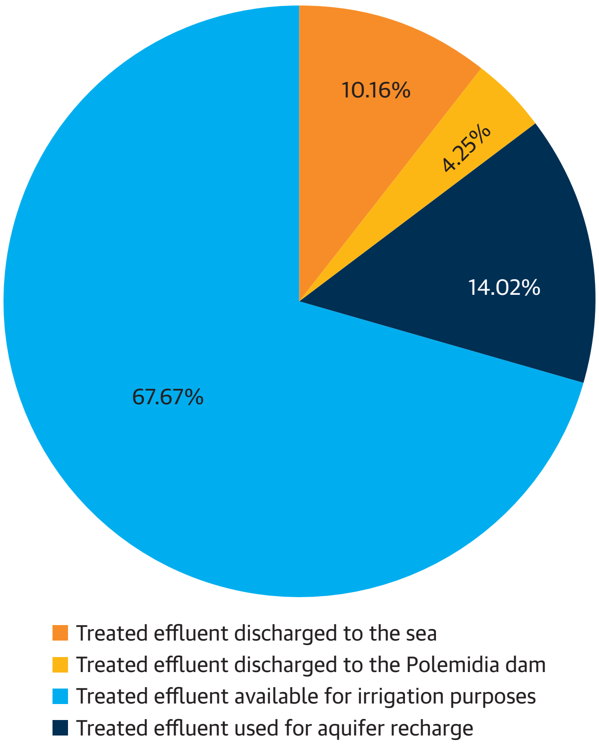
Since joining the EU in 2004, Cyprus has made considerable efforts to comply with the EU Urban Wastewater Treatment Directive (UWWTD). Coverage and wastewater treatment stands at 84 percent in the areas of the five urban sewerage boards. A key feature of the development of wastewater treatment plants (WWTPs) has been the widespread recourse to private-public partnerships (PPPs) following the design-build-operate (DBO) model.

The government decided to develop extensive wastewater treatment reuse for agriculture. A WWTP with tertiary treatment level entails complex technological processes, with significant risks of noncompliance with the more stringent effluent standards required for agriculture. Adopting the PPP approach for the development and O&M of the WWTPs has allowed risk to be transferred to private concessionaires, which are liable in case the treated effluents do not meet minimum standards. Under DBO schemes, and contrary to BOT schemes as adopted for desalination, the public developer and off-taker financed the new plants. The private sector remained responsible for the design, construction, and subsequent O&M of the plants. As such, each private concessionaire has strong incentives to design, build, and operate the plant efficiently. The first WWTP DBO in Cyprus started operation in 1990, and since then, seven other large WWTP DBOs for urban areas have been developed and are operating.

About 90 percent of the treated wastewater is now reused. Figure 9.4 shows the breakdown of usage for treated wastewater in 2015: 68 percent is used for irrigation; 14 percent, for aquifers recharge; and 4 percent, discharged into a dam. The yearly relative proportions of usage for treated wastewater have been relatively stable in recent years since the desalination capacity came into full gear.

The need to comply with the UWWTD as part of joining the EU was a crucial trigger for the development of wastewater reuse in Cyprus. The development of treated wastewater reuse required major investments in wastewater treatment and construction of dedicated pipelines to convey treated wastewater to irrigation perimeters[5] as well as large reservoirs for winter storage. While in other countries reuse for irrigation is often limited to lands nearby the WWTP, a large conveyance infrastructure was built in Cyprus to ensure that farmers receive all the volume of treated wastewater. Furthermore, treated wastewater must be stored during the winter months when there is low demand for irrigation.

**FIGURE 9.4. Reuse of Treated Wastewater in Cyprus, 2015**




*Source:* WDD.
*Note:* WDD = Water Development Department.

## Groundwater Management

Most aquifers in Cyprus are suffering from overabstraction, with a gradual lowering of the water table over the last five decades. Furthermore, the coastal aquifers have deteriorated due to seawater intrusion. The country has prepared two successive River Basin Management Plans (RBMPs), which allowed for the condition of the aquifers to be assessed in details. Due to the overpumping, saline intrusion, and nitrate contamination from agriculture, around 80 percent of the groundwater bodies was rated as being at risk of failing to achieve a “good status” according to the EU WFD.

To implement the WFD, a new Drilling and Abstraction Law was adopted in 2014, introducing drilling permits and requiring all wells and boreholes to become registered. Since then, about 50,000 extraction permits licenses have been issued, but about 35,000 owners of operating wells (mostly small ones, such as for household gardens) have not yet done so. Under the new law, each borehole owner must install a meter, but many have not yet done so, and the WDD anticipates this will be a long process. Starting in 2017, abstraction rates have been introduced, albeit at the modest level of only €0.01 per cubic meter for irrigation, and €0.05 per cubic meter for domestic use. Billing is based on metering or an estimate using the maximum volume recorded in the license.

The promotion of managed aquifer recharge (MAR) through reuse of treated wastewater has been another notable initiative for improving aquifers management in Cyprus. In 2016, about 14 percent of total treated wastewater volume produced was allocated to recharge coastal aquifers affected by saline intrusion. The recharge sites have been carefully selected based on hydrogeological conditions, availability and quality of wastewater, possible benefits, economic evaluation, and environmental considerations. Two recharge sites have been successfully operated since 2010.

Implementing the WFD was essential to put aquifers management on a path toward sustainability. Although it will take time to reverse decades of aquifer overabstraction, the first two RBMPs have led to these crucial steps: assessing the condition of the aquifers in detail, establishing a reliable monitoring system (piezometers), and establishing for the first time an obligation for private boreholes to be registered and measured—and for private users to start paying an abstraction fee. The legal obligation to comply by 2027 with the requirement of good status of underground water bodies—which must be translated in the RBMPs into practical actions—provides a strong incentive to take action and achieve results.

## Future and Limits of Adopted Solutions

Even though the island suffers from extreme water scarcity and rainfall variability, potable water security has now been achieved in Cyprus. There was no rationing of potable water supply during the summer of 2014, even though winter rainfalls were as low as during the 2008 drought. This was achieved thanks to the massive recourse to desalination, other investments, and three decades of policies to improve water management under extreme scarcity.

The widespread development of nonconventional water resources, as well as new policies for sustainable water management, are bringing much needed relief to overexploited aquifers. With desalination supplying most of the potable water needs, the water captured in the large dam storage infrastructure can now be allocated mostly to agriculture, thereby reducing the need for farmers to pump water from their private boreholes. The development of reuse of treated wastewater—whether for irrigation or for aquifer recharge—is also reducing the degradation of aquifers.

The successful development of nonconventional water resources—desalination and wastewater reuse—was achieved through recourse to well-designed PPPs with the private sector. The government recognized two decades ago that both desalination and wastewater reuse were complex and costly technologies, and that it would be beneficial to develop the new plants under PPP models (BOT schemes for desalination and DBO schemes for wastewater treatment). More than €250 million of private funds was raised for the four desalination plants since 1997.

The development of major water storage and transmission infrastructure has optimized water resource management. Concentrating the management of this large water infrastructure in the WDD—as the operational arm of the water sector in Cyprus—has been essential for optimizing the allocation of available water to various users.

Cyprus has succeeded in leveraging the implementation of EU water legislation to improve its water management under extreme scarcity. The country went beyond the requirement of the UWWTD by developing tertiary treatment and wastewater reuse for all its WWTPs, gradually phasing out all discharge of treated wastewater into the sea and effectively closing the urban water cycle (every cubic meter of desalinated water is used twice, first for domestic supply and then through treated wastewater reuse). Cyprus is taking advantage of the gradual implementation of the WFD to move toward sustainable aquifer management, and it will attempt to reverse over the next decade more than half a century of overpumping of groundwater.

However, potable water security has come at a price—not just financial but also environmental. The massive development of dams in the 1970 through 1990s—albeit an imperative at the time to meet demand in the face of severe aquifer depletion—has destroyed natural habitats in the seasonal rivers of the Troodos Mountains. The four desalination plants consume about 9 percent of the total electricity generated in the Republic of Cyprus, and represent an emission of carbon dioxide gases estimated at about 436 thousand tons per year. Furthermore, electricity production on the island is entirely dependent on expensive oil-fired plants, with the governmental budget having to absorb changes in oil prices. The discharge of brine into the sea has local negative impact (albeit marginal). However, with the recent discovery in the Cyprus's economic zone of significant gas reserves, it is hoped that in a few years it may become self-sufficient in gas energy, which would both reduce the cost of desalination and its environmental impact.

And despite these successes, there are still several remaining challenges for reforms and moving toward sustainable water management. While most the efforts have been concentrated so far in infrastructure development and the supply side of water policies, several aspects of water management remain to be optimized. With ever increasing rainfall variability and scarcity due to climate change, the country may not be able to cope unless the financial sustainability of the entire water sector is improved. This would require promoting more incentives for operational efficiency and a focus on demand management, including through tariffs. The social and economic contribution of irrigated agriculture should be considered now that most of the water captured in dams will be allocated for irrigation. Whether this will be sufficient for farmers to switch to higher value crops, considering the climate change risk, needs to be carefully considered. Policy makers should also consider further development of reuse of treated wastewater, as well as the need to reduce aquifer abstraction.

## Notes

1. Although a de facto divided country, the whole of Cyprus is considered EU territory. Turkish Cypriots (as opposed to settlers from Turkey who came after 1974) are considered EU citizens since they are citizens of an EU country—the Republic of Cyprus—even though they live in a part of Cyprus not under government control. See the EU Cyprus webpage at http://europa.eu/european-union/about-eu/countries/member-countries/cyprus_en.
2. Based on the World Business Council for Sustainable Development (2005): a country should have at least 1,700 cubic meters per capita per year to be water-sufficient. Between 1,000-1,700 cubic meters per capita per year means a country experiences water stress. Water scarcity starts below 1,000 cubic meters per capita per year, and less than 500 cubic meters per capita per year characterizes extreme water scarcity.
3. Domestic potable water supply in rural villages and settlements is still provided by boreholes and local springs. These are located mostly in the western coast and central Troodos Mountains.
4. Other subsidies included for the installation of a hot water recirculator (€220), and connection of a borehole with the toilet cisterns (€700). Other savings were minimal: 0.03 cubic megameters per year from the installation of recycling systems and 0.05 cubic megameters per year from hot water circulators (CLICO).
5. The treated wastewater networks are separate from the Southern Conveyor, which transports raw water from dams to both potable water plants and irrigation perimeters, since usage of treated wastewater is forbidden for crops consumed raw, crops for exporting, and ornamental plants.

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Amman, Jordan. *Source:* Flavia Lorenzon.

# Chapter 10
# Amman, Jordan

Amman is the capital and largest city in Jordan. Its 4 million inhabitants make up 42 percent of the country's total population, 94 percent of whom are urbanized. The population of Jordan has recently increased sharply because of the influx of about 1.6 million refugees, one-third of whom live in Amman (Ababsa 2013).

The 50-year mean annual rainfall in Amman is about 350 mm, but, with an average evaporation of about 90 percent (MWI 2015), estimated infiltration rates range from only 4 to 10 percent of precipitation (Al-Mahamid 1994). As a result, Jordan is categorized as one of the poorest countries in the world in terms of water availability (Raddad 2005).

## Institutional Framework

The roles and responsibilities for governing the water sector are defined in the country's legal framework as follows:

- The Ministry of Water and Irrigation (MWI) develops strategies and policies to increase the sector's resilience through improved efficiency and effectiveness of operations and investments. The most recent strategy was the National Water Strategy 2016–25, which is accompanied by a set of new policies, and a National Capital Investment Plan to prioritize investments (MWI 2016).
- The Water Authority of Jordan (WAJ) is responsible for ensuring that the quality of drinking water

distributed to consumers is safe and complies with Jordanian standards.

- Miyahuna, the service provider, is responsible for treating water and wastewater and delivering water that complies with the Jordanian regulations and standards. Water supply in Amman was privatized in 1999; however, in January 2007, the service was returned to a local government-owned company.

To meet the increasing demand for water during the refugee crisis, WAJ and Miyahuna studied and prepared water and wastewater master plans, implemented feasibility studies, and tendered documents for urgent upgrades to the existing infrastructure. These projects were derived from Jordan's National Water Strategy 2016–30 (which followed Water for Life—Jordan's Water Strategy 2008–22) and the National Strategic Wastewater Master Plan 2014, which call for all major cities and small towns in Jordan to be provided with adequate wastewater collection and treatment facilities by the year 2035. The estimated cost of the plan is $7.5 billion. The MWI, WAJ, and Miyahuna are the implementing agencies.

The National Water Strategy focuses on increasing water supply to meet the demand for Jordan and the Syrian refugees through the following: (a) optimization of surface water resources; (b) more widespread safe reuse of treated wastewater; (c) introduction of nonconventional water resources (including desalination); (d) decreasing of the level of groundwater exploitation; and (e) maintaining of the daily water per capita allocation despite the sudden increase in population.

A key pillar of the National Water Strategy is the addition of treated wastewater to the water budget for reuse, with priority given to agriculture for unrestricted irrigation. The main elements of this substitution policy are as follows: (a) achieving public acceptance; (b) suitability and adequacy of high-quality water; (c) sustainability; and (d) enforcement of laws. As a result, the use of treated wastewater to replace fresh water in irrigation has increased, while meeting the quality guidelines and standards of the World Health Organization (WHO) and the Food and Agriculture Organization of the United Nations (FAO). The use in industry of treated effluents has also been increasing.

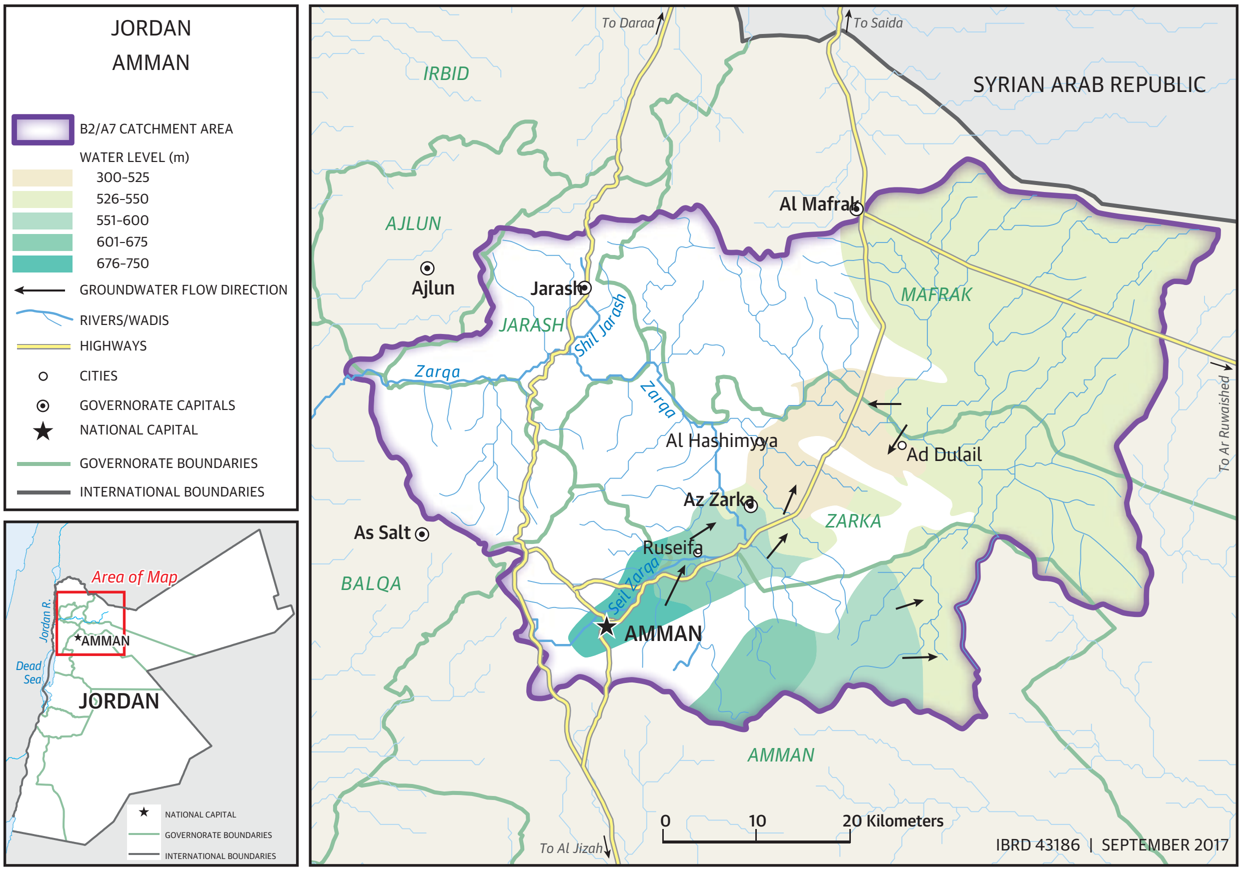
Another key pillar of the strategy has been the improvement in the efficiency of service providers. Nonrevenue water (NRW) in Amman causes physical, commercial, and administrative losses. The government put in place a management plan to reduce NRW to 45 percent, but achieved 36.7 percent by 2015. The National Water Strategy set as one of its goals to reduce NRW by the year 2022 to 25 percent, a target that seems achievable because recently implemented projects have reduced NRW to 28 percent in the Tareq area (Rothenberger 2009). Controlling illegal connections (3,832 cases in 2015), replacing water meters, and developing evaluation and monitoring programs have been instrumental in achieving these reductions in NRW.

The government has also embraced larger-scale private sector participation (PSP) modalities. In 2002, the government of Jordan signed a 25-year built-operate-transfer (BOT) agreement for the design, construction and operation of the As Samra wastewater treatment plant, which was the first public-private partnership in the financing and management of a public infrastructure project in the country. Two other BOT contracts have been successfully procured in Jordan's water sector. One BOT contract was signed in 2012 for the extension of the As Samra wastewater treatment plant's capacity from 267,000 to 365,000 (MWI 2012). The project will cost €150 million and involves a 3-year construction and a 22-year operational phase.

## Water Sources

Groundwater represents the main source of water in Amman. Most of the groundwater is being abstracted from the Basalt and B2/A7 layers (map 10.1). This area

**MAP 10.1. B2/A7 Aquifer, Amman**




includes the highest concentration of wells, which increased from 672 in 1995 to 955 in 2015, mainly to supply water to the growing population living in the Amman-Zarqa Basin as a result of the influx of refugees. Abstraction from the Amman-Zarqa basin started in the mid-1960s and increased from 8.46 million cubic meters per year to 119 million cubic meters per year in the late 1990s and 156.3 million cubic meters per year in 2013 (Goode and others 2013). The estimated annual recharge is approximately 70 million cubic hectometers per year and the safe yield is 87.5; current overuse is depleting the groundwater in the basin, where available resources and water quality have reached critical conditions.

Water supply to Amman is also obtained from surface water, nonrenewable ground water, desalinated brackish water, and treated municipal wastewater. Most important among these other sources are (a) Zai Water Treatment Plant, (b) Zara Desalination Plant, (c) other treatment plants, (d) King Abdullah Canal, and (e) the Disi fossil aquifer (Salameh, Alraggad, and Tarawneh 2014).

The new supply from Disi, which became operational in 2015, is probably the most important project undertaken to supply Amman. It allows Miyahuna to meet the increasing demand from the Syrian refugees. The project involves extracting 100 million cubic hectometers from the Disi aquifer and transporting it to Amman over 325 kilometers.

In 2016, the total volume of water produced from all sources was 238 million cubic hectometers , of which 191.7 million cubic hectometers were supplied to Amman and the rest was pumped to other cities—Zarqa, Madaba, and Balqa.

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

## Water Use

Domestic water use in Amman is approximately 376 million cubic meters per home per year. Per capita consumption is currently 69.7 liters per day, according to records for billed water in 2015. Quantities supplied by Miyahuna in 2014 are summarized in table 10.1.

Because of the increased demand for water, national water resources face growing pressures from overabstraction and the effects of climate change. The exponential rise in water demand has led to severe competition for resources among different socioeconomic sectors. The National Water Strategy gives priority to the domestic sector, followed by the tourism sector, which is growing. Third priority was given to the industrial sector.

**TABLE 10.1. Volume of Water Supplied by Miyahuna, 2014**

*Million cubic meters per year*

| Use | Volume of water |
|---|---|
| Domestic | 158 |
| Nondomestic[a] | 22 |
| Agriculture | 43.8 |
| Refugees | 21.5 |
| Industry | 1.72 |

*Source:* World Bank data, 2017.

a. Nondomestic includes commercial, small industries, and tourism.

## Demand Management initiatives

In Amman, the WAJ and Miyahuna have implemented a retrofit program that consists of an upgrade of plumbing fixtures to meet the flow rates recommended by the Jordan Standards and Metrology Organization standards and to comply with the water and sanitation plumbing code. The outcomes of the program indicated potential water savings of 48 percent using lavatory faucets with the standard flow of 4.5 liters per minute, 27 percent for kitchen faucets at 8.3 liters per minute, 21 percent for showerheads at 7.6 liters per minute, and 33 percent for the dual-flush toilets at 4.0 liters per flush. Currently, residential indoor water use for faucets, showers, toilets, clothes washers, dishwashers, and cleaning accounts on the average for approximately 97 percent of the total water use in the service areas of Miyahuna.

The payback period and benefit-cost ratio show that the retrofitting of faucets, showerheads, and toilets is a highly profitable measure to improve the efficiency of water use. Retrofitting costs are recovered in 21 days for a kitchen faucet, 2 months for a showerhead, 2 months for a lavatory faucet, and about 13 months for a toilet. The benefit-cost ratios are 68 to 1 for kitchen faucets, 25 to 1 for showerheads, 25 to 1 for lavatory faucets, and 3.7 to 1 for toilets. The overall payback period for the retrofitting of all fixtures is about 5 months.

To help in controlling NRW, the WAJ created a Master Plumber certification and enforces building and plumbing codes for tall buildings that set maximum water flow limits and minimum quality standards for plumbing fixtures. This approach is expected to save 10 percent of the water currently used in Amman each year.

Miyahuna also developed a Water-Use Efficiency Plan (WUE) to support the implementation of water conservation programs. These plans include a Residential Best Management Practices Checklist to assist users in auditing their day-to-day usage and conserving water. Bilateral agreements are also being developed to initiate Water Demand Management Plans across the city.

### Wastewater Reuse

Amman's wastewater is treated at the As-Samra Wastewater Treatment Plant, which is the largest wastewater treatment facility in Jordan. With a peak flow of 840,000 million cubic meters per day, As-Samra treats an average flow of 267,000 million cubic meters per day, serving a population of about 2.2 million people living in Amman and Zarqa. As-Samra provides safe, treated wastewater for reuse in irrigation.

As of 2014, wastewater collection and treatment services were being provided to about 63 percent of the population, producing about 137 million cubic hectometers per year of treated wastewater, of which 125 cubic hectometers per year is being reused, primarily in agriculture. Treated wastewater is discharged into the Zarqa river, which flows for 60 kilometers into the King Talal Dam, where it is blended with stored rainwater prior to its release into the Jordan Valley to be used for irrigation.

**PHOTO 10.1. Wastewater Plays an Important Role in Economic Development**

*Source:* Flavia Lorenzon.

With the increasing population and the country's social and economic development, the amount of wastewater is also increasing. It is estimated that by 2025, the volume of treated wastewater will be 240 cubic hectometers per day. As available freshwater resources become more limited, treated wastewater will play an increasingly important role in the country's development.

### Other Solutions for the Future

Despite these efforts, the gap between supply and demand for water resources for the approximately 700,000 subscribers in Amman is increasing. To address this challenge the WAJ is implementing several projects to explore new resources, with the objective of generating 187 cubic hectometers per year of additional fresh water and increasing the storage capacity of the country's dams by 25 percent, to around 400 cubic hectometers, from the current 325 cubic hectometers. Moreover, to increase the current supply for the city of Amman, the WAJ has identified two reservoirs 180 kilometers southwest of Amman with a storage capacity of 20 and 15 cubic hectometers, respectively, within phase 1, and potentially an additional 30 cubic hectometers for the following phases.

The MWI is also relying for its long-term solution on the Red Sea-Dead Sea Water Conveyance Project, which is expected to provide 30 cubic hectometers per year to supply Amman out of the 65 cubic hectometers per year of desalinated water it will produce through phase 1 (Abu Qdais 2008). Under this project, seawater will be pumped out from an intake located in the northern end of the Gulf of Aqaba and desalinated there. The project foresees the construction of a brine conveyance pipeline, lifting pump stations, hydropower plants, and discharge facilities at the Dead Sea, the implementation of which will occur between 2017 and 2021. This project is also expected to produce an additional 150 cubic hectometers per year under a second phase, which will be implemented between 2020 and 2025.

Finally, the government is considering further developments to address storm water drainage and to continue the rehabilitation, restructuring, and extension of Amman's water networks. It has been estimated that until the year 2020, about $1.5 billion will be needed adapt to the results of climate change, with an additional $5 billion needed by the year 2050.

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*Source:* Richard Abdulnour.

# Chapter 11 Israel

Israel is one of the most water scarce countries in the world. Located on the southeastern coast of the Mediterranean, most of the country has a semiarid climate, with annual rainfall varying from 600 millimeters in the north to less than 150 millimeters in the south. Extreme variations in precipitation between years are normal, and multiple years of drought not uncommon. According to the United Nations Development Programme (UNDP), the total renewable volume of water per capita stands at 276 cubic meters per year—about half of the "shortage red line" of 500 cubic meters per capita per year, which defines a situation of water shortage (Tropp and Jågerskog 2006).[1]

Israel is spread across four distinct regions: the Mediterranean coastal plain, the central hills (average altitude 600 meters), the Jordan Rift Valley (the Dead Sea in the rift, the lowest point on Earth at 400 meters below sea level), and the Negev Desert in the south. Since the creation of the State of Israel in 1948, the population had grown to over 8.5 million. Its population density is around 350 people per square kilometer, and jumps up to 980 people per square kilometer when the Negev Desert is not included.

Given the specificities of water management in Israel, this chapter focuses on the management of water in the country as a whole rather than on a particular city. It does not purport to present a comprehensive picture and analysis of the Israel water story. Rather, it focuses on identifying and presenting the elements of the Israeli water experience, which can be valuable for water scarce cities, in a global context of climate change

This chapter is adapted from Marin, Philippe, Shimon Tal, Joshua Yeres, and Klas Ringskog. 2017. "Water Management in Israel: Key Innovations and Lessons Learned for Water-Scarce Countries." World Bank, Washington, DC.

and increased water stress across all continents. As such, this chapter deliberately does not address some key aspects of the water management in Israel that are controversial and well known—such as conflicts on watersheds and aquifers sharing with neighboring countries, as well as restrictions imposed on the Palestinian population in the West Bank and Gaza.

## Institutional Context for Water Resources Management

Institutional transformation has occurred through crises. Until 2000, the Ministry of Agriculture managed the water sector through a conventional approach, relying on (and overpumping) natural water resources to meet all water demands, with agriculture being the main user. Shortages in some years saw reduced water supply to farmers during droughts. Tariffs were kept low for farmers, and domestic water and wastewater collection were also heavily subsidized. Increasing demand due to population growth made this approach unsustainable and kept the Israeli water sector in a permanent state of vulnerability.

Three major water crises in the 1980s and 1990s built gradual momentum for major reforms in the 2000s. They affected initially the agricultural sector the most until the 1998 drought, which culminated in severe water shortages and rationing in most Israeli cities. In 2000, the government of Israel changed the policy for water sector management and set up a Parliamentary Investigation Committee of the Water Sector, which led to the gradual establishment—over the last 15 years—of a modern institutional framework for water management. This required some difficult political decisions along the way—as with the sharp rise in domestic water tariff in the aftermath of another major drought, this time in 2008. the government also stimulated a series of innovations that succeeded in gradually restoring a sustainable water balance.

### Current Institutional Framework of the Water Sector

Since the 2000 reform, the Ministry of Energy and Water has been the line ministry in charge of formulating and enforcing policies in the water sector. It directly supervises the drainage and river basin authorities, the Israel Water Authority (IWA), and Mekorot, and indirectly supervises the water and sanitation providers through IWA. Mekorot is the national bulk water provider, managing most of bulk water production and transmission, which it delivers to municipal utilities and farmer associations. It was established in 1937 as a wholly owned government company and has become the operating arm of the water sector. It has approximately 2,200 employees and supplies 1,600 million cubic meters of water per year (2016)[2]—85 percent of Israel's domestic potable water consumed and 70 percent of Israel's total water consumed—through the operation of 3,000 installations and 12,000 kilometers of pipeline.[3]

The IWA is the national regulator for the whole water sector—covering the entire spectrum of potable water supply and wastewater services, irrigation services, and water resource management. It is in charge of planning overall investments, allocating and supervising water rights, and regulating tariffs and performance of services providers (including local water utilities). IWA combines the functions of both regulator and planning body. Its establishment in 2007 as an autonomous agency was essential to drawing a line between the political level, which is responsible for policy, and the professional level, which manages the water sector.[4]

### Legal and Regulatory Framework of the Israeli Water Sector

A codex of four laws was approved in the decade after the establishment of the State of Israel to establish the principles upon which the water sector was to be managed. The Law for Water Measurement (1955) establishes the crucial importance of metering water to enable water management and control of water flows and uses. The Law for Supervision of Water Drillings (1955) was passed to assert national control over the production of the water. The Law for Drainage and Flood Prevention (1957) was enacted to help reduce and prevent floods due to the rapid urbanization.

Finally, the Water Law (1959) is the cornerstone of Israel's legal water framework, setting the overall principles for managing the sector. It specifies that the state owns all water resources and the government manages them (there is no private ownership of water resources in Israel, even beneath privately owned land) and establishes the mechanisms for allocation of water rights. Other key legislations have been added in the last two decades, including the Municipal Water and Sewage Incorporation Law (2001), requiring local authorities and municipalities to establish public ring-fenced corporations to manage local water supply and sewage services, to improve performance and promote the agglomeration of services into regional utilities. Two public health regulations also set quality standards for reclaimed water (Sewage Effluents Quality Standards and Sewage Treatment Rules, 2010), and drinking water (Sanitary Quality of Drinking Water Law, 2013).

## Climate and Hydrology

Winter rainfall is characteristic of the Mediterranean climate, with 75 percent of annual precipitation falling within three months (December to February). The Sea of Galilee (Lake Kinneret), from which the Jordan River flows, is the only natural fresh surface water reservoir between the Jordan River and the Mediterranean. It provides approximately 20 percent to 30 percent of the state's fresh water supply and is the country's largest freshwater reservoir (at approximately 200 meters below sea level).

Most rainfall is lost to evapotranspiration (approximately 70 percent), and approximately 25 percent infiltrates to groundwater or remains in the soil to support vegetation and crops; only 5 percent flows as surface water. Floods are short and intense and contain up to 9 percent suspended solids, making it difficult to store and reuse flood flows.

## Water Resources

Despite a situation of acute water scarcity, Israel has managed to drastically reduce overexploitation of aquifers through increases in the volume of wastewater reuse (since 1998) and seawater desalination (since 2006). This is illustrated in figure 11.1, which summarizes the water resource data for 1958-2014.[5] Thanks to the measures taken over the last two decades, the total amount of water production in 2014 has been maintained at the 1985 level, despite a sharp drop in the natural water supplied. As a result, the recent major shortage of rainfall in 2014 (comparable with 1998) had no effect on users.

As of 2017, the availability of quality water in Israel is sufficient to meet all foreseeable needs of the country, even accounting for steady population growth and the foreseeable effect of climate change. Extreme changes in water yields between years have dictated the resource use strategy: balance average water demands so that average water resources ensure water storage capacity is sufficient to compensate for seasonal rainfall variability and multiyear droughts.

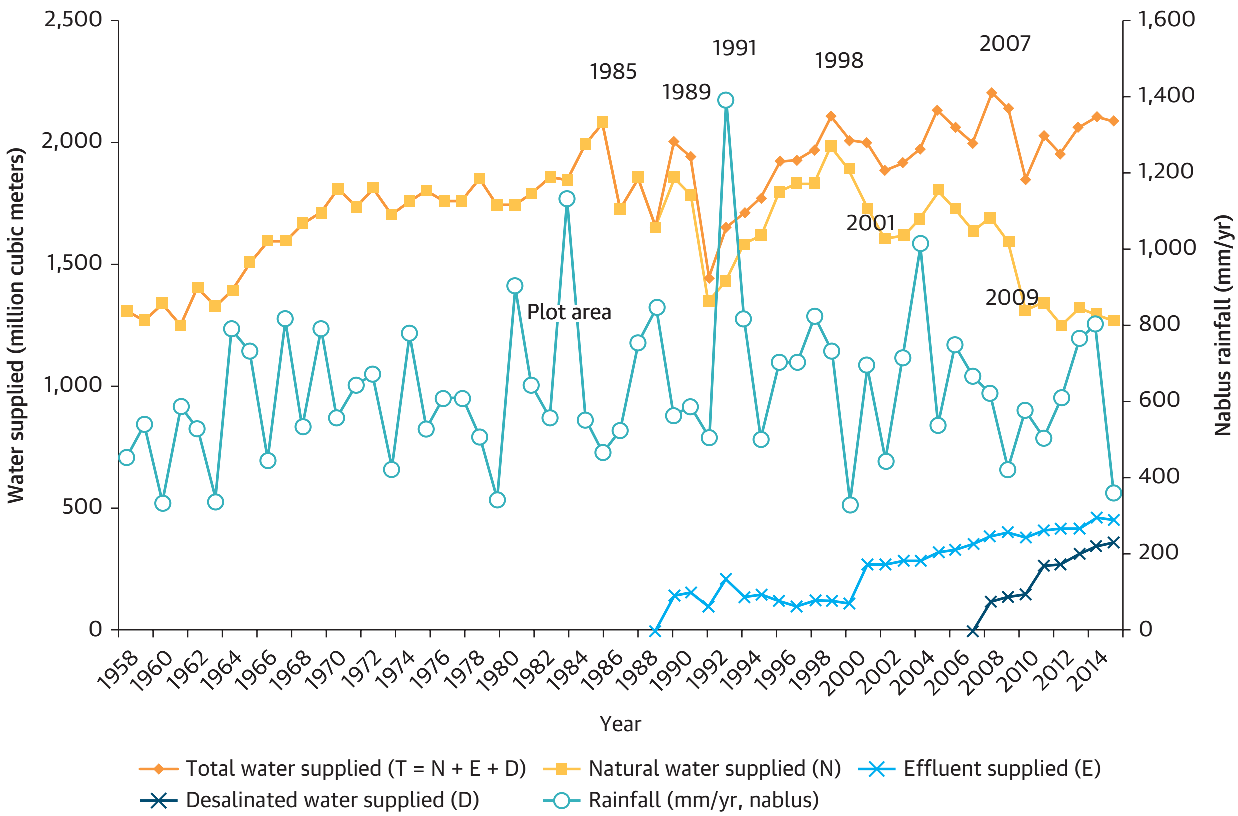
## Water Use

Shortly after the creation of the State of Israel, the government was faced with a fundamental trade-off of choosing between water security and food security since there was not enough water to meet the growing demands. A major strategic decision was made to increase food imports and reduce the country's reliance on domestic crops, effectively compensating for water scarcity by the import of "virtual water" imbedded in imported foods. Greater selectivity of food crops grown for export paralleled the displacement of food crops that could be more cheaply imported than grown domestically. Emphasis was placed on growing counterseasonal vegetables that could reach developed markets in the winter and fetch higher prices. The growth of counterseasonal crops is now largely done in green houses to reduce evapotranspiration.

## Solutions to Address Urban Water Scarcity

To maintain a reliable water supply, Israel has gradually implemented a policy that combines institutional

**FIGURE 11.1. Israel Water Resource Development, 1958–2014**




reforms and massive infrastructure investment that includes the following seven solutions:

- *Promoting demand management and public awareness* to control aquifers abstraction (water permits, metering), improve efficiency, reduce domestic consumption (potable water per capita), and shift water use to higher-value irrigated crops. Domestic per capita consumption of potable water now stands at approximately 90 cubic meters per capita per year, and farmers have switched to high-value production.
- *Reuse of treated wastewater for irrigation* to replace and release scarce freshwater for domestic uses and the environment. More than 87 percent of wastewater effluent is currently reused for agriculture, representing approximately half of total water that farmers use nationwide. A large proportion of wastewater receives tertiary treatment and can be used for any crops without restrictions.
- *Developing large-scale desalination of seawater* and brackish water, with 85 percent of all potable water distributed in the country is now desalinated water. This has allowed the government to achieve potable water security for the population, with domestic water supply becoming largely independent from rainfall and aquifers abstraction.
- *Developing a national bulk water conveyance infrastructure* to optimize the use and distribution of water from various sources (desalination, water treatment from Kinneret Lake, recycled water).
- *Using aquifers as strategic reservoirs* (in the absence of surface reservoirs and dams), with recharge of aquifers with treated wastewater during

low-demand months, capture of occasional flash floods, and monitoring and control of aquifers' levels and abstraction regime.

- *Institutional reforms to promote financial sustainability of the water sector as a whole, and to separate political decisions from infrastructure planning and operations.* Corporatization of service providers—and the establishment of a strong national regulator responsible for the whole water chain and setting tariffs across the whole spectrum of water users (abstraction, potable water for utilities, irrigated water, sanitation, and reuse)—have allowed full cost recovery through tariffs for most of the water infrastructure and services.
- *Creating an enabling environment for innovations* in the water sector.

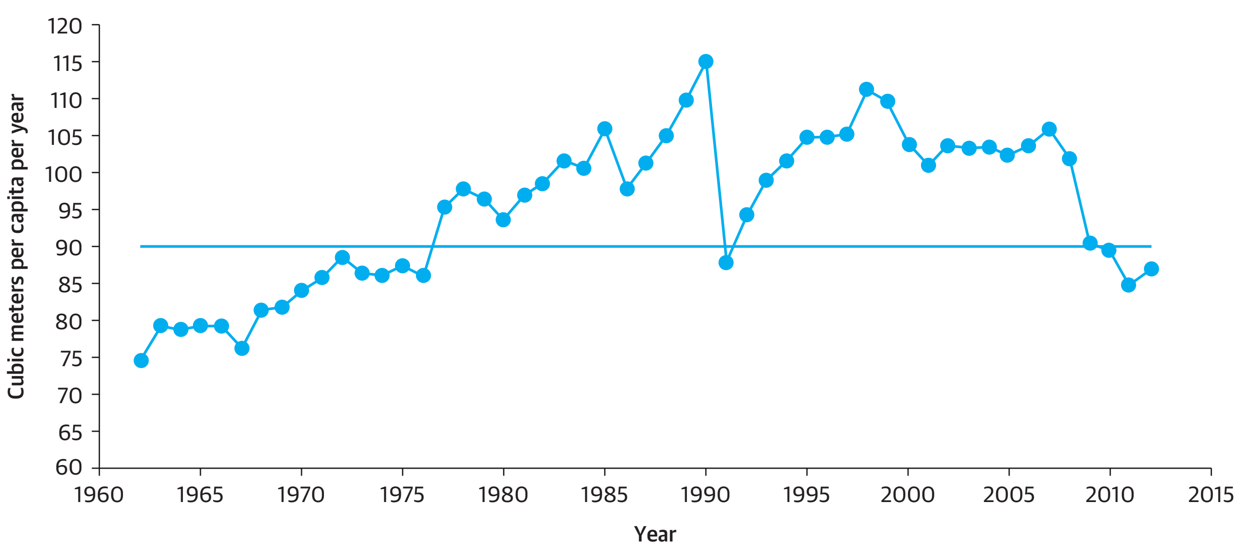
## Promoting Demand Management and Public Awareness for Domestic Water

Demand management has always been an important component of Israel's efforts to achieve water security. The higher price of water for irrigation has encouraged farmers to improve their water efficiency. In the urban utility sector, the two-tier tariff structure for potable water and sanitation services provides incentives for customers to conserve water.

This effort was expanded in 2008 when the government initiated a successful major water conservation campaign. It promoted the installation of water-saving devices (bathrooms, toilets, kitchens), reaching 55 percent of households and public buildings and government offices. In parallel, a media awareness campaign was implemented over an 18-month period from 2008 to 2010 to educate consumers about water use. The 2008 public awareness campaign has had a huge impact, and has proven a very cost-efficient initiative. Its total cost was approximately US$7.5 million and it is estimated that consumers reduced their consumption by 76 million cubic meters. The campaign freed up water for alternative uses at a cost of only US$0.10 per cubic meter, or a fraction of alternative supplies.

These steps and the near doubling of water tariffs that took place in 2008-09 were effective. Israel reduced urban water consumption per capita by 24 percent, to less than 100 liters per capita for domestic customers. Figure 11.2 demonstrates water consumption in Israel. It is estimated that 8 percent of the reduction was due

**FIGURE 11.2. Water Consumption in Israel, 1960–2015**



to educational activities and 16 percent to higher water tariffs and installation of water-saving devices.

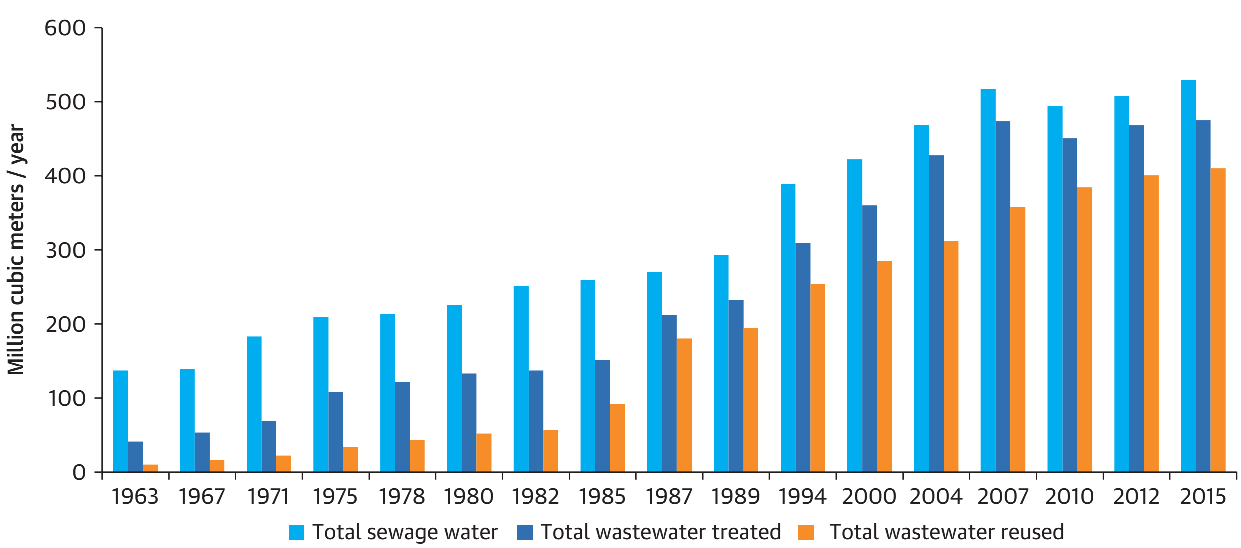
## Demand Management and Reuse of Treated Wastewater for Irrigation

Reclaimed wastewater has become a major source of water for farmers, supplying more than 40 percent of the country's needs for irrigation and more than 87 percent of wastewater being reused.[6] Figure 11.3 shows the evolution of wastewater reuse over time. As of 2015, 87 percent of 500 million cubic meters was recycled.

Today, the country has 67 large wastewater treatment plants (WWTPs) (greater than 1,500 cubic meters day), and the 10 largest WWTPs treat approximately 298.5 million cubic meters per year (56 percent of total volume), most of which were developed by local authorities using traditional construction contracts such as design-build (DB) or turnkey. Apart from the Shafdan plant in Tel Aviv, most are upgrading to tertiary treatment after the enactment of new wastewater reuse treatment standards in 2010. This will allow them to treat wastewater to be used for all types of agricultural uses, without restrictions.

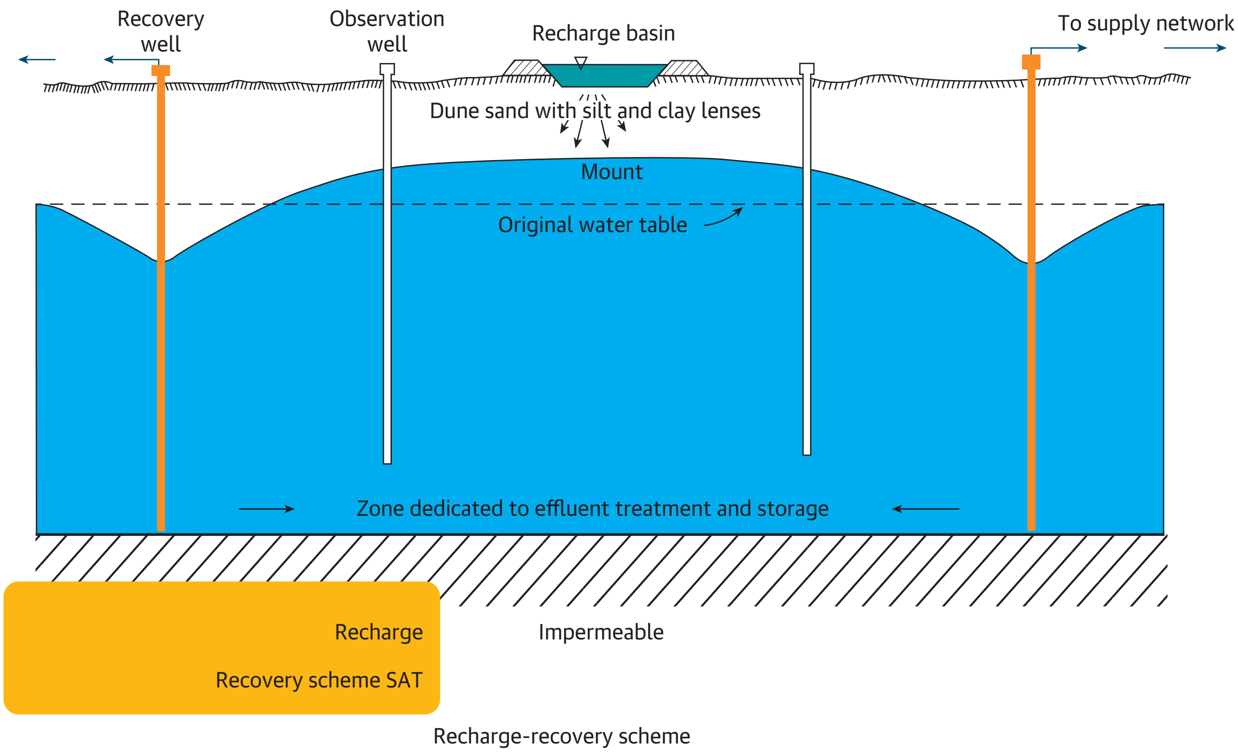
Since its commissioning in 1989, Israel's flagship project for effluent reuse for agricultural purposes has been the Shafdan WWTP and the Third Line to the Negev pipeline (figure 11.4). It supplies tertiary treated effluent from 140 million cubic meters of wastewater per year from Tel Aviv and seven neighboring towns (approximately 2.5 million people and some 70,000 factories). The Shafdan WWTP achieves tertiary treatment through an innovative aquifer recharge method called soil aquifer treatment. Wastewater treated to a secondary level is injected into specially designated recharge basins, where it naturally filtrates through the sand. To avoid contamination, there is complete separation between the reclaimed effluents introduced and the aquifer water, which is achieved by creating a hydrologic trough that prevents the reclaimed water from spreading. The treated water is later collected in peripheral reclamation wells after six to 12 months and pumped to the Negev. In dry months, Mekorot abstracts treated water from the aquifer and transports more than 130 million cubic meters to the Negev. The high treatment standards allow for unrestricted irrigation of all types of agricultural crops without any risk to public health.

**FIGURE 11.3. Collected, Treated, and Used Sewage, 1963–2015**




*Source:* Israel Water Authority website.

**FIGURE 11.4. Shafdan Soil Aquifer Treatment Method**




*Source:* Mekorot 2016.
*Note:* SAT = soil aquifer treatment.

Favorable pricing policies give farmers a strong incentive to use treated reclaimed wastewater for irrigation. Wastewater is priced at US$0.3 per cubic meter for unrestricted irrigation and US$0.25 per cubic meter for restricted irrigation, whereas the tariff for freshwater for agriculture is US$0.66 per cubic meter. These lower prices of reclaimed wastewater are possible thanks to investment subsidies (60 percent to 70 percent of the investment, at an estimated total cost of US$800 million) for wastewater treatment that include building artificial reservoirs to store the reclaimed wastewater during off-season. More than 400 reservoirs have been built since the late 1980s. As an additional incentive for farmers to use reclaimed wastewater, they were also initially offered to convert their allocation of freshwater to reclaimed water using a ratio of 1:1.2 (20 percent higher allocated water volume).

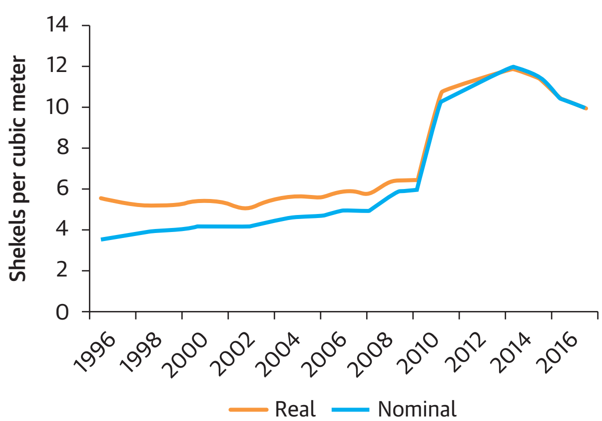
Israeli companies were pioneers in the early 1950s in the development of efficient low-volume irrigation technologies, such as drip irrigation and mini sprinklers. With growing access to treated wastewater, the agricultural sector has continued to irrigate despite a sharp reduction in the amount of available freshwater. Over the past four decades, the output of crops per unit of water has grown sevenfold (due to improved irrigation efficiency and intensification of farming practices). Thanks to ever-increasing productivity of water use, the value of agricultural production has continued to rise in spite of the decreasing allocation of water to farmers (figure 11.5). The efficiency of irrigation systems has been a major factor in the reduction in average water supply to agricultural land, down from 7,000 cubic meters per hectare in 1990 to 5,000 cubic meters per hectare in 2000.

## Large-Scale Desalination Public-Private Partnership for Potable Water Independence

Over the last 15 years, five mega desalination plants were constructed along the Mediterranean Coast with a total capacity of 585 million cubic meters per year and Mekorot as off-taker (table 11.1). Desalinated water now supplies 85 percent of domestic urban water consumption[7] and 40 percent of the country's total water consumption.

Israel's large desalination plants have achieved good performance in terms of energy efficiency and price of desalinated water—from US$0.78 per cubic meter in the Ashkelon plant (2005) down to only US$0.54 per cubic meter in the Sorek plant (2013). These prices for desalinated water are among the lowest in the world and have been key to ensuring the financial viability of the system—meaning desalinated water remains affordable for customers. They were achieved through a combination of two main factors: (a) the size and operational mode of the new desalination plants and (b) build-operate-transfer (BOT) schemes designed to minimize the level of risks for the private sector. Indeed, Israel relies on a few large desalination plants that are mostly operated 24 hours per day, seven days per week. This has made it possible to achieve significant economies of scale and a high absorption rate of fixed costs. This is the opposite of the strategy of many other countries, which use desalinated water mostly to meet peak demand, due to its higher price.

**FIGURE 11.5. Average Municipal Water Tariff in Israel, 1996–2016**




*Source:* Based on Israel Water Authority public data from Katz 2016.

Adopting the BOT approach for large-scale seawater desalination has had a number of benefits. Under a BOT, the private sector has strong incentives to build a plant that minimizes total costs (operating and capital) over the life of the plant, with flexibility (at its own risk) to make technological choices.[8] In addition, the concessionaire bears all cost overruns due to delays and change orders. Finally, the private concessionaire takes all operation and maintenance risks during the operational period of the plant, with swift penalties incurred if the plant does not deliver the contracted amount and quality of water contracted—ensuring the sustainability and efficiency of the new plants.

**TABLE 11.1. Major Seawater Desalination Plants in Israel**

| Project | Year of operation | O&M duration | Concessionaires (%) | Business model | Price per $m^3$ (US$) | Production capacity (million $m^3$) | Estimated CAPEX (billion US$) |
|---|---|---|---|---|---|---|---|
| Ashkelon | 2005 | 25 years | IDE (50), Oaktree (50) | BOT | 0.78 | 119 | 0.27 |
| Palmachim | 2007 | 25 years | Derech HaYam (100) | BOT | 0.86 | 90 | 0.16 |
| Hadera | 2010 | 25 years | IDE (50), Shikun U'Binui (50) | BOT | 0.72 | 127 | 0.43 |
| Sorek | 2013 | 25 years | IDE (50), Veolia (50) | BOT | 0.54 | 150 | 0.41–0.54 |
| Ashdod | 2016 | 25 years | Mekorot (100) | BOO | 0.65 | 100 | 0.41–0.54 |

*Source:* Marin et al. 2017.
*Note:* BOO = build-own-operate; BOT = build-operate-transfer; CAPEX = capital expenditures; O&M = operations and maintenance.

In addition to the inherent benefits of the BOT approach, the design of the Israeli desalination BOTs have allowed the private sector to make more aggressive financial offers with rather low prices for desalinated water. Innovative contractual features with significant financial guarantees provided by the public party include (a) interest change risk borne by the government, by which the concessionaires are fully protected against changes in the market base interest rate and (b) allowing bidders to optimize the fixed payment under the "take-or-pay" guarantee.[9] Another crucial factor for the low price of desalinated water is the control of energy costs, since most Israeli desalination plants have achieved strong performance in energy efficiency. In addition, energy costs in Israel are relatively low compared to most other countries because Israel uses gas-fired power plants supplied by its own gas fields in the Mediterranean.[10] One last, important lesson from the Israeli desalination BOT experience is that careful design and tendering of BOT contracts took time (on average, four years for the whole contracting and financial closing process, before construction can start). This is much longer than actual construction, which takes 2.3 years on average, because private concessionaires have strong contractual incentives to avoid construction delays.

## Developing a National Bulk Water Conveyance Infrastructure

Israel has implemented an innovative system of storing and conveying water from its wetter north to the drier center and south—the main agricultural areas. The integrated use of surface and groundwater initially relied on the first National Water Carrier, a giant pipeline that Mekorot developed and operated since 1964 to transport water from the Sea of Galilea to the main population centers in the center and the Negev Desert in the south. Mekorot has since developed a national bulk water transmission system that conveys 95 percent of Israel's potable water resources (surface water, groundwater, desalinated water) to the regional providers that supply end users (domestic, industrial, agriculture). This massive water infrastructure includes more than 3,000 installations and 12,000 kilometers of transmission pipelines. The overall level of water losses in the bulk transportation system is reported to be 3 percent. The operational flexibility that the National Water System provides has been essential for the strategic combination of water supply based on desalination and reuse with sustainable exploitation of natural water resources.

Developing and ensuring the sustainability of an infrastructure of such magnitude and strategic importance has required a financially solid operator. Mekorot has been able to maintain, so far, a healthy financial situation with total revenues of approximately US$1 billion per year and a AAA national rating (Ma'alot Standard & Poor 2015). As a regulated public utility owned by the state, Mekorot has been able to raise as much as NIS 6,661 million (US$1,800 million) of commercial debt through its balance sheet (Ma'alot Standard & Poor 2015). This has allowed Mekorot to raise approximately US$300 million each year for investment over the last decade, at low interest rates, through issuance of non-negotiable bonds to institutional investors (without any explicit government guarantees).

## Using Aquifers as Strategic Reservoirs

The first integrated supply scheme, based on the National Water System and operated by Mekorot since the 1960s, relies on the storage capacity of the Sea of Galilee (approximately 700 million cubic meters) and three major aquifers—the Coastal Aquifer (yield of 240-300 cubic meters), the Western Mountain Aquifer (yield of approximately 350 million cubic meters), and the Eastern Mountain Aquifer. Mekorot has added major infrastructure since then to connect and rationalize the operation of aquifers, viewed as strategic national assets.

One of the most remarkable innovations of Israel water management is that aquifers have been gradually switched from being overexploited resources to becoming major storage reservoirs. The hydraulic advantages of this integrated scheme are obvious in terms of higher reliability and lower losses to evaporation, although management of aquifers as reservoirs is delicate. It relies on an extensive network of piezometers and solid monitoring of both supplies and the various types of demand (including to avoid illegal abstraction). Each aquifer has specific operational procedures and constraints, and monitoring practices require a high level of human, technical, and financial capacity.

Early on, Israel invested in infrastructure to capture flash floods. Typically, such infrastructure combines retention walls and small dams that could capture and store water that would infiltrate into the underlying aquifers. The amount that can be recharged varies with rainfall pattern and strength, reaching a maximum of 62 million cubic meters in 1980 and a minimum of 4 million cubic meters in 1990. The average recharge achieved in addition to natural replenishment has been estimated to be 8 percent. In addition, the national program of afforestation, in areas where forests have been absent in historical memory, has mitigated flash floods and improved rainwater infiltration into the aquifers. Additional benefits include sequestration of carbon to combat global warming, reduction of soil erosion, and esthetic and recreational benefits. The afforestation program in the arid Negev is particularly interesting because it has revived the techniques for harvesting rainwater that the Nabatean people practiced from the fourth century before the Common Era until the Roman Empire conquered them.[11]

## Achieving Self-Financing of the Water Sector, Despite Acute Water Scarcity

Financial autonomy was accomplished for all users of the water cycle chain, including farmers. This has been achieved by putting in place a new financial framework under the IWA, which sets tariffs for all water users. As of 2017, the Israeli water sector has achieved almost full financial autonomy—with the exception of wastewater reuse (still relying on investment subsidies) and to a lesser extent seawater desalination (with government's financial guarantees for BOT schemes with the private sector).

Mekorot has been transformed into a corporatized public company and operates as a commercial entity. In practice, this means that the price of bulk water has had to reflect its actual costs of production and transportation. Its tariffs are set by IWA annually based on five-year business plans, which incorporate performance incentives for efficient infrastructure operation. Capital expenditures (CAPEX) and private financing costs must be reflected fully in the bulk tariffs.

On the service delivery side, potable water and sanitation utilities have been corporatized and regionalized. The disappointing performance of municipal water and sewerage departments[12] prompted a 2001 law, under the auspices of the Ministry of Interior, that directs local governments to establish public ring-fenced corporations to manage local water supply and sewerage services. In 2009, the responsibility of the Municipal Utilities Administration (MUA) was transferred from the Ministry of Interior to the IWA. As a result, municipal water and sanitation services have been gradually transformed into corporatized utilities, owned by local authorities and regulated under licenses by the IWA. Tariff levels almost doubled in 2009 as a result of the application of the full-cost recovery principle. Almost all investment is now funded through commercial debt financing.[13] In parallel, a process of consolidation has been taking place among 56 regional water and sanitation utilities, serving 187 municipalities and local councils.[14] The MUA has helped the Israeli water and sanitation utilities improve their governance and overall performance. The reform process of Israeli water utilities is still ongoing, and the agglomeration process is continuing.[15]

Several interesting features of the corporatization reform deserve to be highlighted. First, as tariff revenues became the sole source of financing for each utility, strong financial incentives for operational performance were introduced. The MUA uses the tariff-setting process as a regulatory tool by establishing the portion of the national water tariff that each utility can keep.

The regulator allows the dividends resulting from any efficiency gains to be transferred from the utility to the municipal budget. This arrangement provides financial incentives for local governments to support the performance improvement of their water and sanitation services, and reduces political interference in hiring staff, particularly for management positions. Recognizing that many local utilities lacked technical capacity, the MUA has issued regular technical guidance on operational issues, such as salary guidelines (2008), customer service (2015), and engineering standards (2016). These have contributed to improving the efficiency of the water utilities. Benchmarking has also played an important role. The MUA has issued a list of key performance indicators relating to a wide range of operational efficiency and customer relations matters. The MUA publishes[16] the audit results to put public pressure on bad performers to improve. Finally, the MUA has not shied away from imposing and enforcing sanctions. Some of the technical guidelines and key performance indicator targets are mandatory, and not achieving them can lead to sanctions. For example, if nonrevenue water (NRW) is not satisfactory, and the utility does not show any improvement, MUA-imposed sanctions can deny some costs into the allowed tariff, implement forced management changes, or even appoint external management.[17]

Partnering with the private sector for financing CAPEX and improving performance has been a key feature of the Israeli water reforms. The seawater desalination program has been implemented through BOT schemes, whereby private concessionaires have entirely financed the investments and are responsible for operation and maintenance for 25 years. The amount of private investment raised under the four desalination BOT projects with private concessionaires (Ashkelon, Palmachim, Hadera, and Sorek) represents a total of about US$1,300 million. Also, corporatized regional utilities as well as Mekorot are now financed through commercial debt with private banks or bonds issuances, without sovereign guarantees. Water utilities have been encouraged to seek a variety of partnership contracts with the national private sector to improve operational performance and reduce costs. Private contractors perform a large portion of the tasks of the most advanced Israeli water utilities.[18] Finally, following the incorporation of the Municipal Utilities Administration under IWA in 2009, a major tariff increase took place for potable water and sanitation tariff.

IWA now sets tariffs for all water and sanitation services; a uniform tariff level and structure has been instituted for the country[19] with all potable water and sanitation customers paying the same price.[20] This results in cross-subsidies between consumers who live close to water sources and those who live farther away and require additional pumping costs. In 2017, the uniform average tariff for potable water and sanitation—calculated as the weighted average of a modeled representative home consumption—was NIS 8.92 (approximately US$2.4) per cubic meter. Only 44 percent is allocated to the water utilities for water distribution and sewage collection, 22 percent goes to Mekorot for bulk water transport and freshwater production, 18 percent covers sewage treatment costs, 16 percent covers desalination costs, and 4.5 percent goes to subsidies.

The national tariff for potable water and sanitation services is based on a two-tier increasing-block structure. The tariff for the first block, corresponding to consumption up to 3.5 cubic meters per capita per month (115 liters per day), is NIS 6.56 (US$1.8) per cubic meter (2016). The tariff for the second consumption block imposes a 61 percent markup of NIS 10.56 (US$2.85) per cubic meter.[21] Approximately 75 percent of residential consumption is billed at the lower tariff.

Overall, Mekorot provides more than 55 percent of water for agriculture at prices set by the IWA. Water sales from other suppliers, mainly private regional associations, are billed at prices by the IWA, which are supposed to reflect their actual production costs. The prices of irrigation services are among the highest in the world. This has ensured that farmers are using water in the most efficient manner, and has promoted the development of modern farming practices for high-value crops. This is supported by a financial framework for irrigation, which is based on moving toward full cost recovery, albeit different from water supply and sanitation (WSS) services. For irrigation water, tariffs have varied widely depending on the source of water, the region, and the time of the year. Extraction levies vary with the site and season of the water withdrawn.

Freshwater prices are between NIS 0.8 (US$0.22) and NIS 2.6 (US$0.70) per cubic meter depending on the supplier and the region. The price of brackish water depends on the salinity and varies from NIS 0.9 (US$0.24) to NIS 1.6 (US$0.43) per cubic meter. The price of treated wastewater (NIS 0.8 to NIS 1.25 [US$0.22 to US$0.34] per cubic meter) has been set below those of fresh and brackish as an incentive for farmers to use it. The price of treated wastewater is significantly subsidized; it reflects the cost of conveyance but does not cover treatment and storage costs (which other users pay through cross-subsidies and state subsidies for a portion of CAPEX).[22] The government also subsidizes up to 60 percent of the marginal conveyance costs for reclaimed and brackish water to encourage irrigation use.[23] The framework for irrigation tariffs is due to change in 2017, with the approval of new legislation to equalize agriculture water prices across the country, ending the wide variations in water prices between different regions and supply sources. Since all Israeli farmers will pay the same tariff for irrigated water, this will result in wider-ranging cross-subsidies between regions and water supply sources.

### Creating a Supporting Environment for Water Innovation

Israel has made a special effort to promote innovations in the water sector—not known for being particularly innovative—with the establishment of a unique industry-utility-university ecosystem to support the development of innovative water technologies. One aspect of the Israeli water sector is that leading utilities have established technology collaboration frameworks with the private sector, which allow entrepreneurs to test their innovations in "real size," gaining feedback to improve systems and optimize them before they go to market. Realizing the importance of innovation development, the government of Israel has for years supported innovation at the academic, startup, and commercial levels. Several government agencies manage programs to support water innovation, and partnerships with European Union (EU) and U.S. research programs. There have been two main benefits resulting from this proactive policy to support innovations. First, water innovations have played a major role in allowing Israel to achieve water security. Second, they generate a sizable source of national income through exportations of equipment, licenses, and services.

## Lessons and Conclusion

After many years of reforms and massive investment, the Israeli water sector is now in a position to meet all future demand from multiple users. Thanks to the massive development of nonconventional water sources—namely irrigation and treated wastewater—the water production capacity of Israel now exceeds demand. Even irrigation water is not constrained by volume but only by the capacity of farmers to pay its price. Water security has been fully achieved. For a country which is among the most water stressed in the world, this is no small achievement. The "Israel water story" holds many potentially valuable lessons for other countries facing water scarcity.

The following key lessons have been identified. *Public awareness of the value of water* is crucial. *Strong control and enforcement of water allocation* is necessary in a context of extreme water scarcity, with proactive management of aquifers viewed as a valuable water resource management tool. *Comprehensive, probabilistic, and timely data* are crucial for efficient integrated management of water under scarcity conditions. *Wastewater reuse is costly* and cannot be implemented without *significant public subsidies*. *Corporatization and aggregation* of water and sanitation services is a long process that requires *sound regulation and heavy-handed supervision* to be successful. The *success of the BOT schemes* for Israel's four major desalination plants has been contingent on the careful design of the *public-private partnership (PPP) contracts*, with several features introduced to reduce the risks for private investors.

A *national conveyance water system* can help optimize water management under conditions of extreme scarcity. Israel's relatively small size made it possible to create a nationwide water conveyance infrastructure that effectively connects 95 percent of the natural, marginal brackish, recycled effluent, and desalinated water resources. While such large pipeline infrastructure may not be justified for all countries, in the case of Israel it was designed as part of well-thought-out planning for integrated water resource management, and developed so to ensure long-term financial sustainability. The operation of such conveyance infrastructure by an efficient, commercially run entity also proved important.

*Investing in new water infrastructure needs to be done in a financially sustainable manner* through appropriate institutional reforms. This includes putting in place a clear separation of roles between policy setting, regulation and planning, and operation of infrastructure.

Even in a country with strong capacity and where huge efforts have been made toward water reforms, there are *areas for improvements and mistakes can be made*. One weakness is the adoption of a single national water tariff—first for potable water supply and since 2017 for irrigated water—which reduces economic incentives for users at it does not allow the price of water to reflect true local costs of water. The regionalization of municipal utilities has proved a slow process. The last desalination BOT project in Ashdod, in which Mekorot ended up being both off-taker and contractor, and which suffered multiple setbacks, is questionable. Finally, the fact that aquifer sustainability has been achieved at the cost of severe restrictions for Palestinians in the West Bank cannot be ignored.

## Notes

1. Minimum allocation for a "non-water stressed country" is 1,100-1,400 cubic meters per capita per year (Tropp and Jågerskog 2006).
2. Breakdown of water sources transported by Mekorot: desalinated seawater 601 million cubic meters, desalinated brackish water 143 million cubic meters, natural freshwater 581 million cubic meters, and treated wastewater 270 million cubic meters.
3. Including 39 brackish water desalination plants, five seawater desalination plants (BOT—BOO), eight potable water filtration plants (the one on Kinneret Lake is the fourth largest in the world), 13 WWTPs, about 1,200 boreholes, and approximately 1,000 pools and reservoirs.
4. The Water Authority Council—which serves as the IWA board of directors and comprises senior officials from government ministries (finance, agriculture, interior, environment, water, and energy) —and two representatives of the general public facilitate stakeholder dialogue regarding the management and decision-making process in the water sector.
5. Sources: Rainfall trends from the long-time series at Nablus for the 1958-2008 period (Kislev 2010), data from the Palestinian Authority, and water supply data from Israel's Bureau of Statistics (Gilmont 2014).
6. Other noteworthy countries are Singapore (with full reuse but on a much smaller scale) and Cyprus (where about 70 percent of treated wastewater is reused in agriculture).
7. In addition to the five large seawater desalination plants, there are many brackish water desalination plants for a total capacity of 78 million cubic meters per year. Mekorot or municipal utilities operate them, and apart from the one in Eilat on the Red Sea (20 million cubic meters per year), they are small and spread throughout the country.
8. In the case of the Sorek plant, this has allowed energy efficiency of 3.6 kilowatt-hours per cubic meter to be achieved through the use of innovative 16-inch instead of 8-inch reverse osmosis membranes,

among other things. These membranes were installed vertically to reduce surface requirements and the cost of acquiring land.

9. This arrangement has an extra score for a lower fixed payment, up to a threshold. In the case of the Sorek BOT, the proportion between fixed and variable payment is about 50-50.

10. The average domestic electricity price from the grid stood at €0.11 per kilowatt-hour in May 2017.

11. This type of afforestation is called *savanization* and differs from the larger programs in which the Aleppo pine was the tree of choice. The latter program has sometimes been criticized, in part because of the risks that such a monoculture entails and susceptibility to pests of the Aleppo pine.

12. The 2000 report from the State Controller documents in details the waste, neglect, insufficient investments, and high levels of nonrevenue water in Israel's urban water utilities.

13. In special cases, based upon stringent criteria and during the initial organizational period, certain utilities are still awarded state grants to finance construction of sewage treatment facilities.

14. Twenty-seven municipalities serving approximately 4.5 percent of the population remain without a corporatized water utility.

15. The current plan is to have only 11 regional water utilities (water distribution and sewage collection) and seven regional sewerage companies (wastewater treatment).

16. The Israeli Water Authority has published only four audits to date, in 2014 and 2015. See the Israeli Water Authority website, www.water.gov.il.

17. As an example of MUA sanctions: one municipal water utility accumulated a debt of over NIS 100 million for not collecting payment for water supplied to local cultural and religious facilities. After other measures did not avail, the MUA intervened to replace the entire utility's management (board of directors and CEO).

18. For instance, Hagihon, which serves approximately 1 million people in Jerusalem and its western suburbs, has a permanent workforce of 230 employees and has 150 private contractors.

19. In addition to tariffs, setup fees (formerly called building taxes) that developers are required to pay are a major source of funding for infrastructure construction of municipal and regional utilities.

20. There remains a price differentiation between the 56 municipal utilities supply, and some local authorities that do not have established corporatized utilities and pay a lower tariff supply.

21. The reduced tariff for local authorities without corporatized utilities in 2017 is NIS 4.17 per cubic meter for the first consumption block and NIS 9.21 per cubic meter above that.

22. It is estimated that full wastewater treatment costs are approximately US$3.15 per cubic meter, of which US$1.73 is for annuitized CAPEX and US$1.42 for operational expenditures.

23. The incremental cost of interseasonal storage (treated wastewater is produced year-round, but agricultural demand is concentrated in the summer) and conveyance are estimated at US$0.28 per cubic meter (approximately 9 percent of total treatment costs).

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Windhoek, Namibia Zoo Park. *Source:* https://pixabay.com/en/windhoek-namibia-city-zoo-park-269032/.

# Chapter 12 Windhoek, Namibia

The most immediate attraction to the first settlers of the city of Windhoek, the capital of Namibia, was the presence of a secure and plentiful source of water from local springs in an otherwise harsh and arid landscape. With a relatively temperate climate due to its altitude of 1,700 meters, Windhoek thus met the needs of colonial and settler communities. The settlement grew steadily, providing a center for governing a territory whose economy was based on mining and widely dispersed agriculture, more recently supplemented by small-scale manufacturing and a growing tourism and service sector.

With more than 39 percent population growth between 2001 and 2011, Windhoek has a fast-growing population of 325,000 representing more than 15 percent of Namibia's total population (2011 Census). Windhoek contributes 44 percent to the country's gross domestic product (GDP), and poverty rates are well below the national average. Namibia is classified as a middle-income country with a GDP of US$11.5 billion (2015, current). However, this classification is contested because of high rates of inequality (Gini 0.61). Inequality is reflected by Windhoek's contribution to GDP: estimated by the city of Windhoek at 44 percent of the total; and by the relatively low proportion of poverty in the Khomas region (of which it forms the major part): 7.6 percent compared to a national average of 19.5 percent.[1] This combination of population and economic growth and relatively high incomes has placed obvious demands on the water supply.

Because it was apparent that local sources would not be able to meet growing water demands, consideration had long been given to alternative strategies to meet long-term needs. The most significant of these was the water master plan of 1974, which sets out a phased approach to meet the region's needs for the next 30 years. It includes the forecast that, by 2013, the capacity of the first phase of investments would no longer be able to meet the needs of the city. This has been borne out of practice. After a decade of good rains, serious water shortages developed during a dry period between 2013 and 2016; supply was restricted and, by the end of 2016, the city's main source had only enough for another 30 days. As often occurs, a real crisis was averted when, at the last moment, good rains fell in February 2017, providing a temporary respite (map 12.1).

## Climate and Hydrology

Namibia's climate is characterized by aridity as well as by extreme interseasonal and intra-annual variability of its rainfall. Windhoek's average annual rainfall is 370 millimeters with substantial monthly variations. Of this, 80 percent falls between January and May, 1 percent from June to September, and 20 percent from October to December.[2]

As elsewhere in Namibia, it is not unusual for annual rainfall to vary by a factor of four, and monthly rainfalls vary by far greater amounts. This has been observed since 1850, when records were first collected by colonial authorities; extremes of flooding in generally long periods of aridity over the last 2 millennia have been demonstrated by palaeohydrological studies. Figures 12.1 and 12.2 provide further information about the historical characteristics of rainfall for Central Namibia.

Potential surface evaporation rates of between 3,200 millimeters and 3,400 millimeters annually are

**MAP 12.1. Water in Windhoek, Namibia**

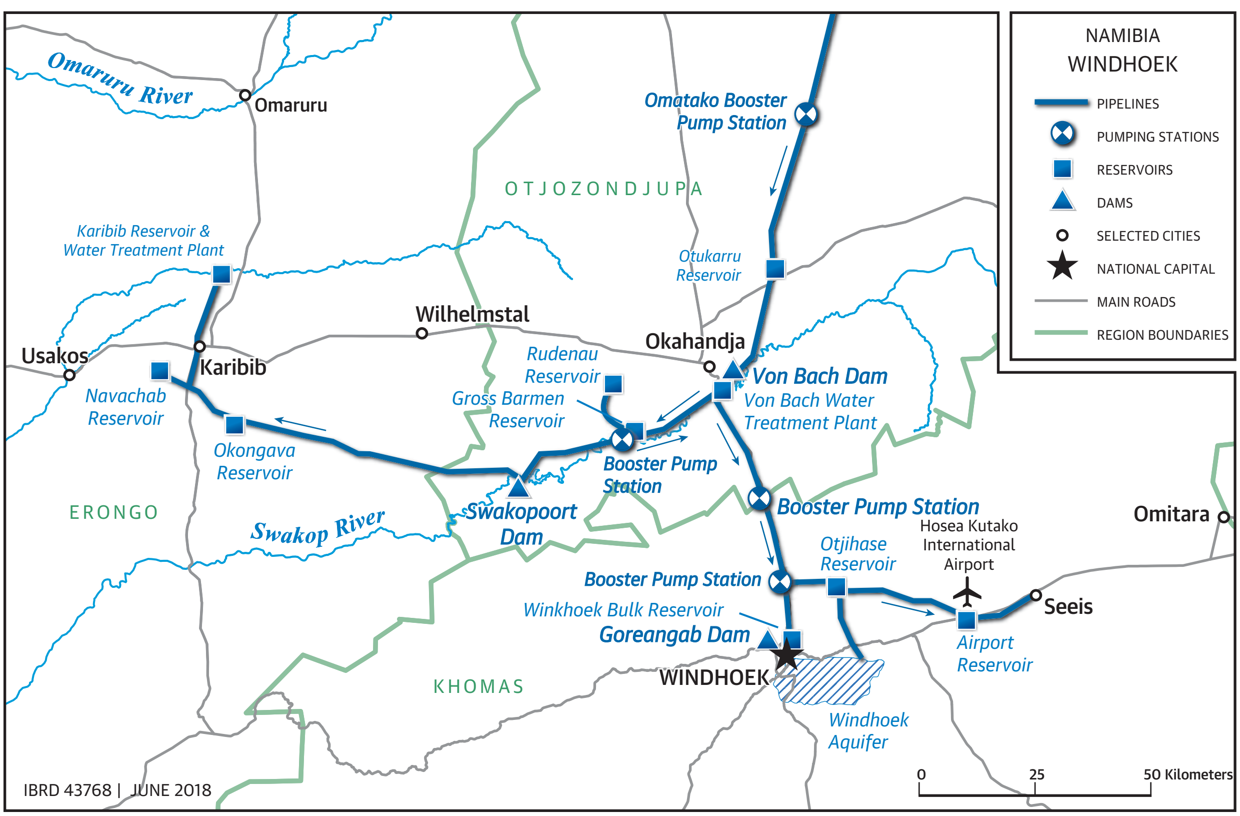
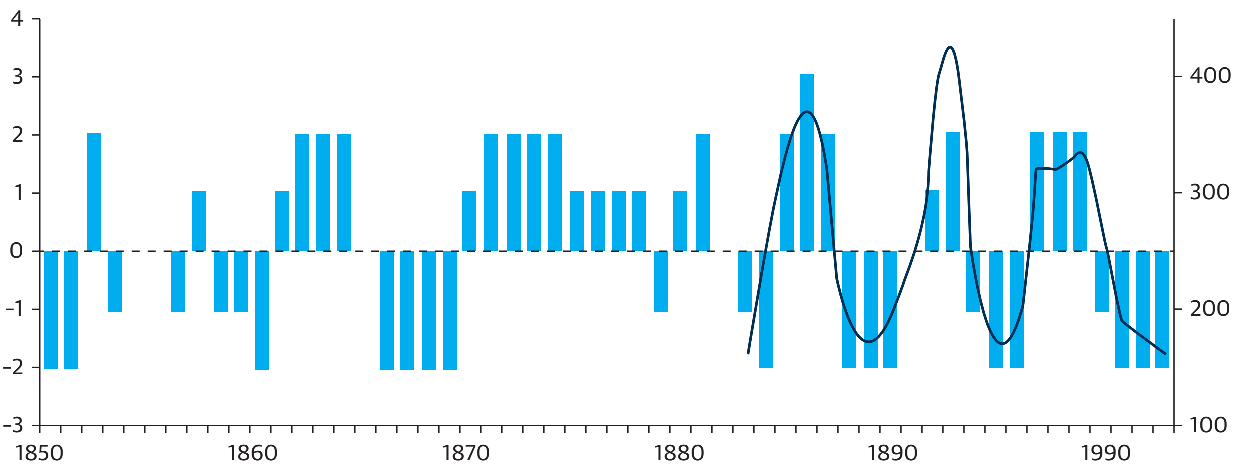
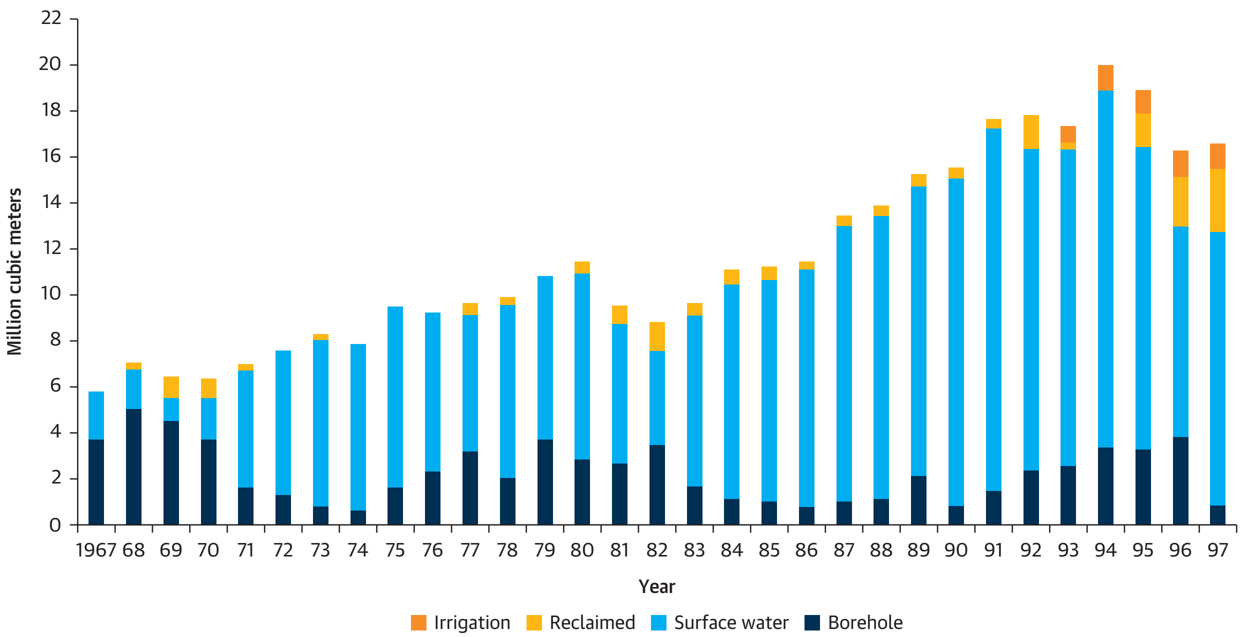


**FIGURE 12.1.** **Time Series of Seasonal Rainfall Character for Central Namibia from 1850 to 1903**




*Source:* Nicholson 2000.
*Note:* Units on the left indicate anomaly classes: +3, +2, +1 correspond to extraordinarily wet, very wet, and wet years, 0 corresponds to normal conditions; and −1, −2, and −3 correspond to relatively dry, very dry, and severe drought, respectively. Superimposed on this is the rainfall record for Rehoboth, a station in region 69; units (on the right) are in millimeters.

**FIGURE 12.2.** **Historic Sources of Water Production in Windhoek, 1961–98**




*Source:* Heyns et al. 1998.

almost 10 times the country's average rainfall. Because of this extreme aridity, very little of the rainfall is translated into surface runoff (2 percent) or groundwater recharge (1 percent). Rainfall and runoff are determined more by the quality of extreme rainfall events than by the average rainfall. This makes it very difficult to characterize the available surface water resources or to estimate likely rates of groundwater recharge for planning purposes.

The city of Windhoek's internal natural resources are primarily groundwater derived from the fractured quartzite aquifer underlying the city. The aquifer is a useful but limited source of water—its potential long-run yield is estimated to be only 1.7 million cubic meters per year, just 5 percent of the city's current requirements (Peters 2013). However, it is also now recognized that the relatively high "storativity" of the aquifer means that it can be used as a reservoir, and that higher flows can be drawn down in periods of shortage and replenished in times of surplus. Its advantage as a storage facility is that it will not lose significant volumes to evaporation; although, if recharged to its pristine state, springs may once again emerge on the surface.

The only significant surface source in the city, the Avis Dam, is not used for water supply and is now a purely recreational facility, although it also contributes to urban flood control. Built on two local streams, it has reportedly been filled only four times since it was built in 1933.

Beyond municipal boundaries, the primary existing sources of water consist of the following three dams, located 60 kilometers to 160 kilometers north of Windhoek, which are connected to the Eastern National Water Carrier (ENWC): (a) the von Bach Dam, (b) the Swakkoppoort Dam, and (c) the Omatako Dam. Although their individual firm yield is 8 million cubic meters per year, their conjunctive management can provide an assured supply of 12 million cubic meters per year. Together with the inflow from other sources connected to the ENWC, a safe yield of 20 million cubic meters per year can be provided.

To the north are a number of groundwater sources, some related to mining operations and others supplying local urban and agricultural use as well as delivering surplus into the ENWC system at Grootfontein. These include a Karst aquifer at Kombat (4.25 million cubic meters per year) and the Goblenz aquifer (0.65 million cubic meters per year) (Peters 2013). The precise contribution of these sources to the Windhoek supply varies substantially since actual abstractions made in times of shortage are likely to be above the sustainable yield, and there is limited technical information about aquifer characteristics (Krugmann and Alberts 2012). Adding to the uncertainty, some reports aggregate all groundwater sources (internal and external).

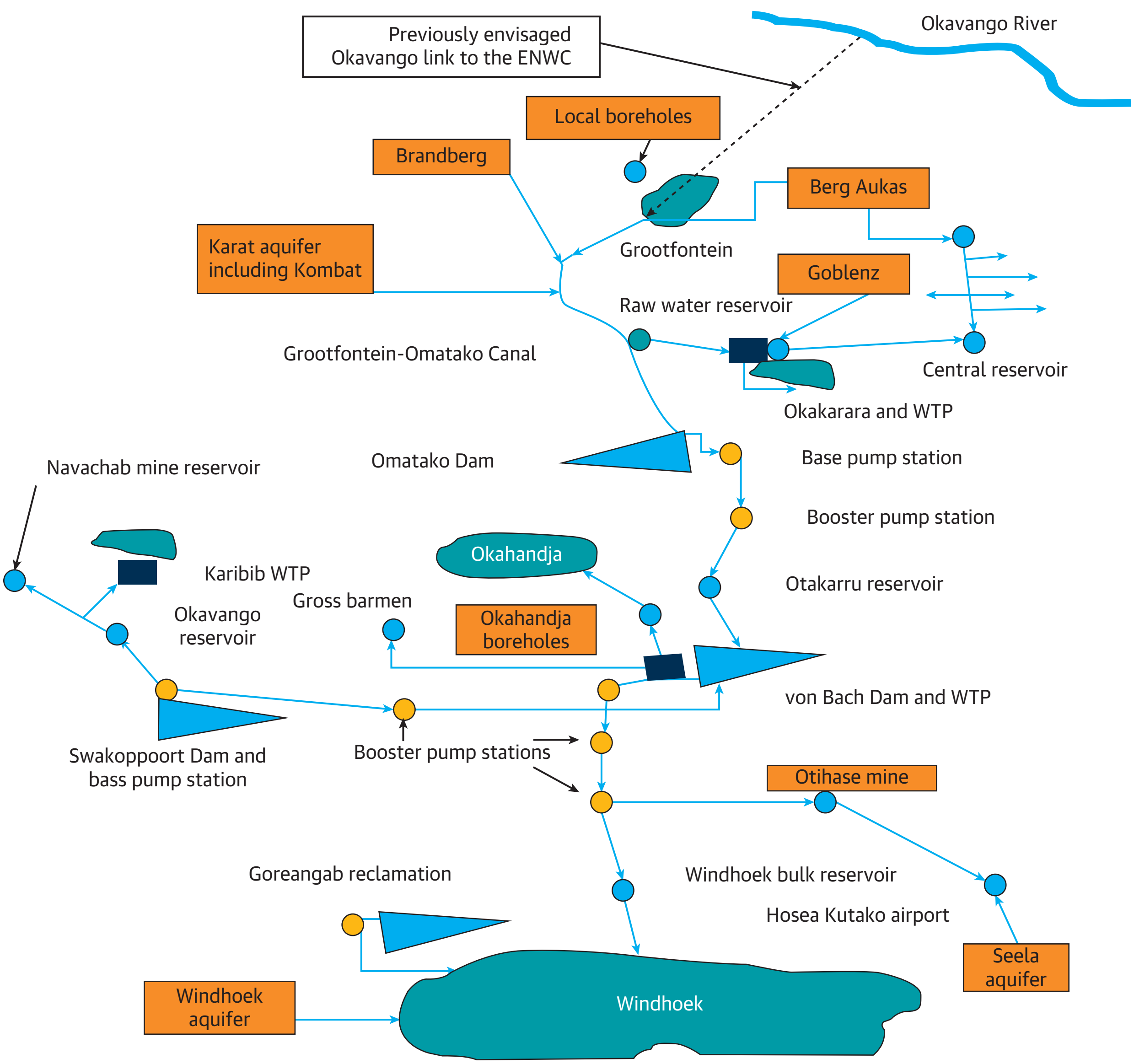
A final specific "source" is the city's wastewater. Windhoek is a global leader in the field of wastewater reuse. It distinguishes between reuse and reclamation, the former referring to nonpotable uses in industry and urban irrigation, the latter to "direct potable reuse" (DPR) of wastewater. Windhoek was one of the first cities in the world to introduce full-scale reclamation with the establishment in 1968 of a treatment plant and associated quality management. This plant was replaced in 2002 by a new and expanded plant that can produce 7.665 million cubic meters per year; it is currently reclaiming about 25 percent of the city's wastewater and plans to build a new plant to expand this to 30 percent, with a maximum envisaged of 35 percent. An additional 5 million cubic meters per year of municipal wastewater and 1.5 million cubic meters per year of industrial wastewater is treated and reused for nonpotable purposes, primarily urban greening (Lahnsteiner and Lempert 2007).

The sources of supply are illustrated in the schematic (figure 12.3). The proportion supplied from each component varies according to the annual hydrological circumstances. However, in "normal" periods, 64 percent has come from the dam system, including supplements from the ENWC; 15 percent from groundwater sources; and 21 percent from reuse and reclamation.

## Water Resources

The majority of external sources of water for the city of Windhoek are supplied by the national bulk water utility NamWater, which originated from the Namibian Ministry of Agriculture Water and Forestry (MAWF) in

**FIGURE 12.3. Schematic Layout of the Bulk Water Supply Infrastructure in the Central Area of Namibia**




*Source:* MAWF 2013b.
*Note:* WTP = water treatment plant.

1997 as a public enterprise and reports to the minister of MAWF. The distribution of water and the management of wastewater is the responsibility of the Windhoek Municipality Infrastructure Department; this includes conventional treatment and reclamation of wastewater, although these are not mentioned in generic local government legislation.

The long-term strategy laid out in the 1974 water master plan envisages the construction of an ENWC that would eventually reach the Okavango River near Rundu. This would provide a permanent, reliable source to meet any likely increase in demand. The system would also provide secure supplies to communities along its route.

The ENWC was built in stages to meet the evolving demands:

- 1970: Von Bach Dam constructed (48.6 million cubic meters), 70 kilometers from Windhoek
- 1977: Swakoppoort Dam completed (63.5 million cubic meters), 100 kilometers from Windhoek
- 1982: Omatako Dam completed (43.5 million cubic meters), 200 kilometers from Windhoek
- 1987: canal from Grootfontein to Omatako Dam completed

The dams are linked to Windhoek by a pumping main, which has recently been refurbished and its capacity increased. The main treatment works is at the von Bach Dam. At the time of the plan, it was forecast that demands would have grown to the point that this extension would be needed by 2013.

Table 12.1 presents a summary of the current water sources for Windhoek, Namibia. The Windhoek supply is already managed as a conjunctive system. In this way, the three dams whose individual firm yield is only 8 million cubic meters per year can provide an assured supply of 12 million cubic meters per year. Taken together with the inflow from the ENWC, a safe yield of 20 million cubic meters per year can be provided. Existing abstraction of water from the Windhoek aquifer is estimated at 1.7 million cubic meters per year. With a further 1.6 million cubic meters per year and 7.7 million cubic meters per year of reuse and reclamation, respectively, this raises the sustainable yield of the system to just over 31 million cubic meters per year.

**TABLE 12.1. Windhoek: Current Water Sources**

| Component | Yield MM3/a |
|---|---|
| External surface water | 20 |
| External groundwater | 4.9 |
| Internal groundwater | 1.7 |
| Reclaimed water (potable) | 7.7 |
| Sub-total potable water | 34.3 |
| Reused water (nonpotable) (municipal) | 5 |
| Reused water (nonpotable) (industry) | 1.5 |
| Sub-total nonpotable water | 6.5 |

In response to emerging supply shortages, the Study into the Augmentation of Water Supply to the Central Area of Namibia and the Cuvelai (CAN) was launched in 2013. This confirmed that the Okavango River, on the border with Angola, is the only freshwater resource that has not yet been tapped and could offer significant yields without impacting local users. To tap this resource would require the construction of a 259-kilometer pipeline and pumping up a 300-meter lift to Grootfontein. From there, the existing ENWC Canal and pipeline infrastructure, whose capacity has recently been augmented, would transport water to Windhoek (requiring a further 140 kilometers of pipeline).

At prefeasibility stage, the CAN augmentation project has identified desalination as the only other potentially viable source with sufficient yield to meet the long-term needs of the city. This would require construction of a desalination plant at the coast and a pipeline of around 290 kilometers to the von Bach Dam, and pumping over a 1,330-meter lift. Although in 2015, the MAWF decided not to extend the augmentation study to consider this option, this decision was later overturned, and desalination is now the subject of a separate study.

Other potential sources that were ultimately rejected include the Kunene River on Namibia's border with Angola. It was decided that this should be reserved for supply to the Cuvelai area northwest of Windhoek (for which it is the only substantial supply source) as well as to maintain flows for existing downstream hydropower generation installations.

Namibia has access to the Orange River, which is more than 700 kilometers south of Windhoek. However, since this is further from Windhoek than the Okavango and, since it is already heavily committed by other riparian countries, it is not considered to be an appropriate long-term source for the city.

### Okavango-Grootfontein Transfer

A feasibility study is now being undertaken of the Okavango-Grootfontein transfer. One challenge to the use of water from the Okavango Basin is that there will be environmental opposition to abstractions on the grounds that this might have a negative impact on the Ramsar wetlands. While the technical evidence is that the impact would be marginal (the main challenges are proposals for extensive irrigation development[3]), it may delay implementation. In this regard, it is relevant that the Okavango River Basin Water Commission (OKACOM), the body that formally advises the riparian countries on the management of the Okavango River, has now supported the project in principle.

There is debate about where the abstraction point should be located. The closest point would be at Rundu, on the Cubango tributary, 250 kilometers from the Grootfontein terminus of the ENWC. To minimize environmental and possible future climate change impacts as well as possible future competition with other users, it has been suggested that an offtake at Bagani below the confluence with the Cuito River would be preferable. However, this will add a further 140 kilometers of pipeline and require additional pumping that will add significantly to the cost. It would be possible to consider the Grootfontein-Rundu link as a first phase with the possibility of an extension to Bagani as a second phase if future circumstances require it.

### Desalination at the Coast

Limited information is available on the costs of the desalination option, which is still being studied. Since the transmission distance is similar to that of the Okavango option, but the pumping lift is almost double and treatment costs substantially greater, the desalination option's costs could be expected to be significantly more. However, costs have been presented that suggest that it could be competitive with the Okavango transfer.

### Aquifer Storage in Windhoek and Capacity Requirements from Augmentation Schemes

Whichever solution is chosen, the capacity required will depend to some extent on the strategy adopted to use the storage capacity being developed by the Windhoek Aquifer Recharge Project. The establishment of a large volume of "strategic storage" at Windhoek will make the system less vulnerable to periods of low rainfall. This in turn will mean that "the size of future augmentation schemes can be downsized significantly" and that "supply sources that were regarded as non-viable due to low annual yields may become viable to keep the 'water bank' full." (MAWF 2015a, 91).

The variability of precipitation is a defining feature of the Namibian climate. Although there is some evidence of a warming trend, there is no evidence yet of any change in precipitation patterns or characteristics. There is also no evidence of a change in the occurrence of extreme events of flood and drought. This does not mean that there are no impacts, but these would be difficult to detect given the extreme variability that characterizes Namibian climate and hydrology at a multiyear level.

In general, it might be expected that more extreme high rainfall events would result in disproportionately higher flood flows and greater surface water availability; similarly, groundwater recharge may increase. However, additional erosion associated with high-intensity events and denuded vegetation might have negative impacts and reduce the capacity of surface water storage infrastructure. Extreme floods may also pose a threat to the transmission infrastructure.

Given these risks and uncertainties, an appropriate response is to design and operate the system to (a) reflect current variability, (b) include substantial strategic reserve capacity close to demand centers, and (c) monitor performance to optimize operating rules when appropriate. Both the Okavango and the desalination options, if implemented with Windhoek aquifer recharge, would appear to meet these criteria and to offer relatively secure and resilient sources of long-term supply.

### Resource Quality Risks and Potential Environmental Impacts

The management of water resources in the extreme conditions of Namibia poses quality challenges. A problem during recent dry periods has been the development of algal blooms in surface reservoirs, which have impeded effective water treatment. This has affected, in particular, the Swakoppoort Dam, which lies downstream of Windhoek.

The quality of groundwater depends on protection from surface pollution and from potentially harmful impacts of overabstraction. Therefore, the interest of the water managers and the wider population will be to protect this resource and respect quality-related constraints on land occupation and other human activities. There is already some evidence of conflict between commercial land use proposals around Windhoek and protection of the aquifer.

Proposals to use aquifer recharge to create a greater volume of strategic storage have quality implications. It is likely that some treatment of the recharge water will be required to avoid clogging or other impacts. Some studies have suggested that—in addition to the risk of suspended solids clogging the aquifer—pyrites in the aquifer may react with the oxygenated recharge water, which could have an effect on the porosity of the aquifer and on the quality of water abstracted. This could impose a further pretreatment requirement. These issues are still being considered, and the outcome will depend on the source of water chosen and the strategy chosen to bring it to site. A potential local impact of introducing larger volumes of water into the urban region—which in other cities might result in the discharge of untreated wastewater—is unlikely in a context in which wastewater is already managed as a valuable resource.

At a larger scale, the environmental impacts of an abstraction from the Okavango River have already been addressed. Should the alternative desalination option be chosen, the environmental impacts of brine disposal will have to be mitigated. In addition, the environmental impact of the energy used would have to be considered; it has reportedly been suggested by project promotors that these could be managed if it were constructed as part of a combined energy-water project that uses renewable energy sources.

## Water Use

The national utility NamWater supplies a substantial proportion of Windhoek's bulk water that comes from sources external to the city.

Virtually all residents of Windhoek have access to safe water from the city's systems. Average domestic consumption in the city is estimated at 163 liters per capita per day. The city reports average total consumption in the city, including commercial and industrial, is 201 liters per capita per day.

The standard of domestic service varies from fully piped 24-hour service in suburban areas to shared communal standpipes and shared prepaid meters in informal settlements. The disparity in level of service between these communities is reflected in per capita consumption estimated in the most recent detailed study (Uhlendahl et al. 2010) at 27 liters per capita per day in informal settlements served by collective standpipes rising to 306 liters per capita per day in high income suburbs. Just under 5 percent of residents report having to walk more than 500 meters to fetch water. The city's target service standard is to have a standpipe within 50 meters of each home serving 25 households, but this has not yet been achieved in the informal settlement areas, where approximately a third of the city's population live. While higher-income areas have waterborne sewerage, this has not been extended to informal settlements, which depend on on-site sanitation.

While domestic consumption is the dominant use of water, there are a number of water-intensive industries, notably in food processing (abattoir, dairy, and brewery). There is significant commercial use, and Windhoek is an important port of entry for the thriving Namibian tourist industry—over 1.3 million tourists visited Namibia in 2013 (MINET AR 2015) and a significant share of the country's estimated 13,000 hotel beds are in Windhoek.

City industries are conscious of the limitations and vulnerability of its water supplies. As the 2015 drought intensified in 2016, the government instructed industry to restrict consumption by 30 percent. While some industries managed to find efficiency savings, Coca-Cola closed its canning lines and resorted to imports, which resulted in local job losses. Elsewhere in the shared Central Area System, the Meat Corporation of Namibia has stated that it intends to close a satellite abattoir 60 kilometers from Windhoek due in part to water constraints.

The population of Windhoek has grown faster than the national average (3.6 percent per year between 2001 and 2011, compared to 1.4 percent nationally) and this trend is expected to continue. If the city succeeds in formalizing the surrounding informal settlements, per capita water consumption is likely to rise. However, a 2013 Strategic Environmental Assessment, undertaken as part of a wider assessment of the needs of the Central Area region, predicts that water demand would grow more slowly than population, at a rate of 2.5 percent per annum, to 84 million cubic meters per year. This would be due, in part, to the disproportionate increases in lower-income families as well as greater water use efficiency in higher consumption households. (MAWF 2013a)

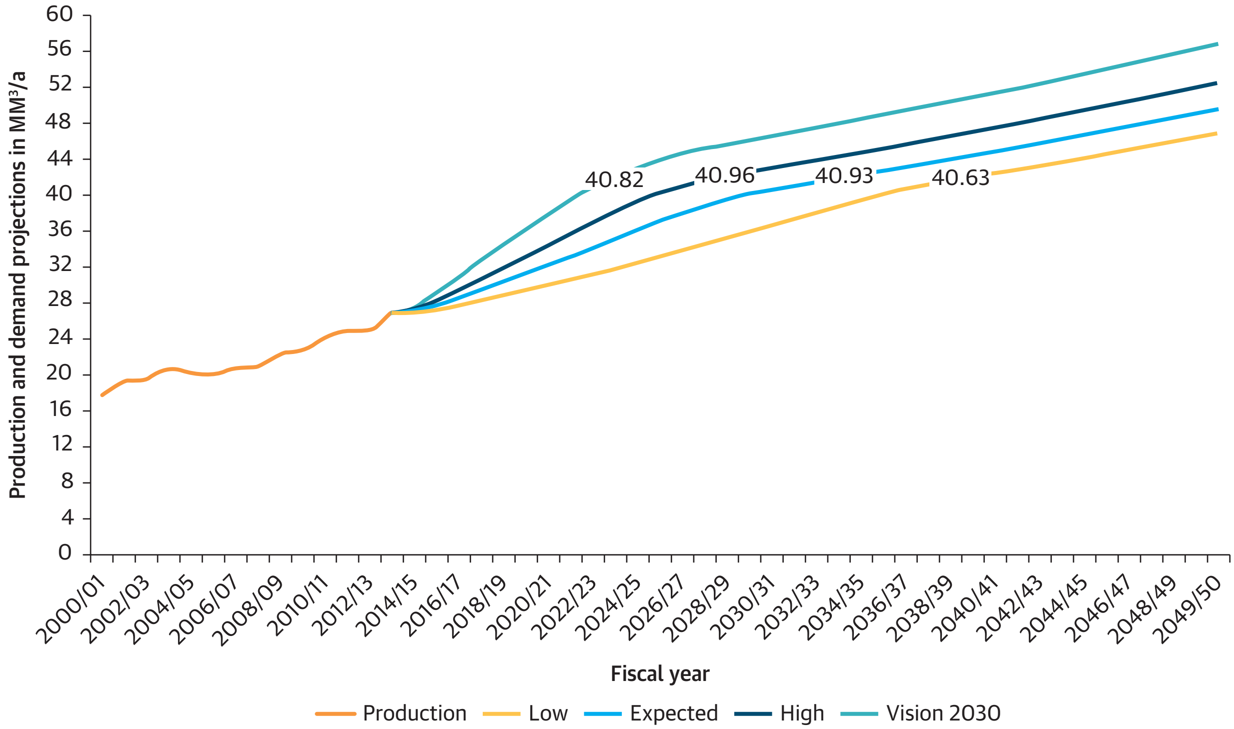
The bulk of Windhoek's water supply already comes from sources external to the city. As its population and economy expands, this dependence on "imports" will grow. This means that the city's water supply will impact on the resource available to surrounding regions, which include a few smaller towns as well as agricultural areas. In some of these smaller towns, water availability is already a constraint on development.

While there is competition for limited regional resources at present, the longer-term perspective envisages Windhoek importing water from even farther away. Therefore, measures to increase the availability of water to Windhoek should benefit communities in the surrounding region and those along the transmission lines from new sources.

## Water Balance for Current Situation without Additional Resources or Actions

A number of projections have been made of the evolution of demand for the city of Windhoek, "Greater Windhoek" (which is the base used for many of the current reports of actual demand), and for those parts of the Khomas Region that are supplied from the common system centered on the Von Bach Dam. Figure 12.4 shows production and water demand projections of the Windhoek Basin for Fiscal Year 2000/2001-2050/2051. The demands for the city of Windhoek continue to be the largest component in forecasts up to 2050. In these projections, growth in demand is influenced by population and economic growth and by the extent of densification in residential areas, which correlates with a reduction in household water consumption. One scenario, the optimistic "Vision 2030," reflects water demand if the aspirational growth and development targets of Namibia's long-term plan for 2030 were achieved. In these projections, growth in demand is influenced by population and economic growth as well as by the extent of densification in residential areas, which correlates with a reduction in household water consumption.

**FIGURE 12.4. Production and Water Demand Projections for the Windhoek Basin, FY 2000/01–2050/51**




*Source:* MAWF 2015a.
*Note:* In 2004, Namibia adopted Vision 2030, a document that clearly spells out the country's development programmes and strategies to achieve its national objectives.

## Solutions—Introduction

Although Windhoek's water challenges are often considered drought emergencies, they are more accurately described in the context of extreme natural variability. Namibia's 1997 drought policy carefully locates the "normal" challenges of dealing with climatic variability as distinct from the occasional truly extreme event (page 3):

> Namibia is an arid country. .... (There is) a high degree of variation from year to year, including a few years of exceptionally high and low rainfall, as well as variable rainfall distribution patterns within a year. Human endeavor must adapt to this reality. Drought, on the other hand, is a relative phenomenon which refers to exceptionally low rainfall conditions. It is something to be expected and managed. The rare occasions when conditions are so severe or protracted that they are beyond what can reasonably be dealt with in terms of normal risk management practices, and when State intervention is considered justified, are to be known as disaster droughts ... .
>
> A workable definition is presented which will see a disaster drought occurring in a particular area in 1 year in 14 on average. It is a far stricter definition of drought, based on the extremity of the event and the history of resource management in a particular area, than has hitherto been applied.

Long-term planning has been undertaken, notably with the preparation of the 1974 water master plan.

While the plan includes a continuing investment in wastewater reclamation and further initiatives to manage demand, policy makers recognized that this investment would not address the underlying emerging deficit and that water imports would be required. As a result, the phased development of the Eastern National Carrier was proposed and key elements were constructed between 1974 and 1984.

However, the master plan predicts that the capacity of the first phase of the system would be reached around 2013. This approach was revisited in 2003 and it is noted that (Andersson et al. 2006):

> Though Windhoek constantly strives to develop other possibilities to provide its inhabitants with water, a 1993 study about supplying the central Namibian region with water (CSE/LCE/WCE Joint Venture Consultants, 1993) confirms an earlier Master Plan from 1972 (Water Resources Investigation and Planning for Part of the Central Area of South West Africa, 1972) which states that a pipeline would eventually be built from the Okavango River to Grootfontein, linking the river system with Windhoek (the "Eastern National Carrier," Pinheiro et al. 2003).

Over the past decade, Windhoek's population has continued to grow more rapidly than the national average and the city accounts for over 40 percent of Namibia's GDP. This population and economic growth has placed further demands on the water supply. Despite these developments, the next phases of the 1974 master water plan were not implemented in a timely manner. This was due in part to bureaucratic inertia and other priorities during the transition from the South African mandate to independence, which distracted from the necessary strategic focus. However, a decade-long dry period led to a 1997 feasibility study of the Okavango-Grootfontein link "as an emergency contingency measure" (MAWF 2015b) proposal to complete the link to the Okavangom, but no action was taken when the drought ended.

In 2004, a further "Feasibility Study on Water Augmentation to the Central Area of Namibia"[14] was completed and presented the following options:

- Emergency abstraction from the Tsumeb and Karst III aquifers
- Managed aquifer recharge of the Windhoek Aquifer with deep well drilling
- Emergency abstraction from the Okavango River as and when required
- Continuous low volume abstraction from the Okavango River to supply water for managed aquifer recharge of the Windhoek Aquifer

However, an unusual sequence of wet years between 2004 and 2012 reduced the urgency and contributed to complacency, and few initiatives were taken to address augmentation. The system planning by NamWater continues to have a short-term focus, taking a two-season view of the adequacy of supplies and not recognizing the deficit that was growing between average available supply and growing demands.

Some progress was made with the drilling and testing of wells in the Windhoek Aquifer to investigate the potential of the proposed aquifer recharge. But a formal study of the augmentation of water supply to the Central Area of Namibia (MAWF 2015b) to establish short-, medium-, and long-term plans for the system was initiated only in 2011. The Strategic Environmental Assessment undertaken in 2013 (MAWF 2013a) reports that the secure water supply (31.45 million cubic meters per year) was already significantly below the then-current demand (33 million cubic meters per year). During a dry period in 2015 and 2016, severe restrictions were introduced to cope with dwindling supplies.

The CAN study seeks to determine the best strategy to meet future requirements and ensure that short-term interventions are consistent with a more strategic longer-term approach. The emerging strategic view continues to focus on the development of the

ENWC to enable abstractions to be made from the Okavango River. Within this strategy, an important new perspective is a recognition of the potential of the Windhoek aquifer to be used as a strategic storage facility within the larger system, which goes well beyond the simple additive contribution of its limited sustainable yield (around 1.7 million cubic meters per year). The concept is to artificially recharge the aquifer when water is available in wet years so that during dry years, a greater volume can be withdrawn than would be sustainable under natural conditions or than could be delivered by the ENWC. The configuration considered would see a recharge rate of 8 million cubic meters per year create a "water bank" of up to 89 million cubic meters: this would allow abstraction in dry years of up to 21 million cubic meters per year.

The advantage of this strategy is that a relatively small transfer from the Okavango could bypass the dam system and be fed directly into the aquifer, avoiding evaporative losses. The dams would be filled only once the aquifer was at its maximum storage level. During dry years, this transfer would be used directly for consumption and would be supplemented by water from the aquifer and any residual storage in the dams. (The detailed operational strategy to maximize water delivery at an acceptable risk still has to be developed.)

An even more significant deviation from the 1974 strategy is the proposal to consider production of potable water at the coast, through desalination, and to pump it to the central region. In the short- to medium-term plan, additional reclamation capacity is being introduced. The CAN Augmentation Study recommends that, following the upgrade of the Gammams Wastewater Treatment Plant (GWWTP), an additional reclamation plant should be built to provide 4.2 million cubic meters per year via advanced membrane technology. Further into the future, this system could be doubled, to provide a total of 8.4 million cubic meters per year of additional water (MAWF 2016).

### Demand Management

Given its location and climate, the city is accustomed to periodic supply shortages and has structured approaches to restriction, using tariff and other measures, to reduce consumption during times of shortage (rising block domestic tariffs are already applied to discourage excessive use). These measures include setting targets for large users and negotiating with them to agree on feasible reductions that do not have catastrophic economic consequences. Current city officials see a challenge—and opportunity—in ensuring that a proportion of the demand reductions achieved are sustained after the current period of shortage is over and formal restrictions are lifted.

During periods of severe restriction, it has been possible to reduce average consumption from 200 liters per capita per day to 130 liters per capita per day, although this has had economic impacts. An aspiration expressed by city of Windhoek officials is to maintain some of the savings made during the period of intensive restrictions and achieve a lower overall average consumption of about 150 liters per capita per day. This goal will depend critically on wide political and social mobilization; in the past, this goal has proved difficult, particularly when a period of restrictions is followed by a period of good rains.

A dimension over which the city has greater control is distribution losses in its own network. This has been a focus for the infrastructure department. However, with NRW reported to be at 13 percent in 2013,[5] there would appear to be limited scope for further reductions; the current target is to reduce distribution losses to 10 percent. More generally, there has been concern about inefficient use in public buildings, notably schools.

## Implemented and Proposed Key Solutions

The CAN augmentation study is considering two long-term strategic options: (a) completion of the Eastern

National Carrier through building a pumping line from the Okavango River or (b) desalination at the coast and pumping to Windhoek. The costs of the different solutions are still being determined on a comparable basis. As part of the CAN augmentation study, some baseline unit costs are presented for existing sources although current prices do not always reflect true costs. Existing supplies:

- Windhoek aquifer groundwater — N$4.80 per cubic meter
- NamWater Supply — N$9.00 per cubic meter
- Reclaimed wastewater — N$9.00 per cubic meter
- Reused wastewater (for irrigation) — N$6.30 per cubic meter

Costs are also presented for some of the proposed options that would comprise elements of a future system, although this does not provide critical information (for instance, the abstraction point from the Okavango or the design flows) and the other dependencies (where would water for aquifer recharge come from). Additional supplies:

- Okavango pipeline — N$45.00 per cubic meter
- Tsumeb aquifer — N$30.00 per cubic meter
- Aquifer recharge — N$16.20 per cubic meter
- New reclaimed wastewater plant — N$17.00 per cubic meter

(The estimate for the proposed 17.28 million cubic meters per year Rundu-Grootfontein pipeline was N$603 million (in 1997 terms—over N$2,100 billion in 2016, inflated by the Consumer Price Index.)

The cost of desalination and pumping from the coast to Windhoek has been estimated at approximately N$40 per cubic meter—even lower estimates have been reported but they are based on the initial value of a tariff that will escalate for 15 years. While these estimates appear surprisingly low, they have been made on a different basis to that used for the other options. They also assume that the energy required would be obtained at zero cost from a large solar installation, which would sell excess power into the grid. The anticipated transfer volumes and assumed utilization rates are not available.

In the interim, the city of Windhoek is implementing a Managed Aquifer Recharge project through building additional boreholes that will both increase the abstraction capacity and enable the proposed volumes to be injected into the aquifer. The cost of this project has been estimated at N$350 million, to be funded by the central Government.

#### Elements of Cost-Benefit Analysis

In the absence of firm costs for the two major long-term augmentation options, it is not possible to provide a detailed cost-benefit analysis. More important, it is not helpful to consider the cost benefit of what are essentially different elements of a larger system without locating them in the context of the overall system. As an example, the capacity of a pipeline (related to either the Okavango or desalination source) will be determined by the strategy chosen to use the strategic storage capacity that will eventually be offered by the Windhoek aquifer recharge development as well as by the potential future demands in the larger Central Area. It would also be necessary to understand the implications of different financing options—would, for instance, the desalination plant be operated on a "take-or-pay" basis and how would that compare to the unit cost for a pipeline system from the Okavango? There is little indication that these strategic considerations have yet informed decision making.

Locally, the immediate demand management interventions are coordinated closely with major water users to minimize the economic impact on current operations. While there is no evidence that water costs influence corporate perspectives on future investments and expansion, supply reliability is an important consideration. No information has been found that seeks to quantify the costs of investment foregone. National proposals to encourage water-intensive industrial activities to locate in less water-stressed areas could also assist cost-basis analysis, although the attraction of Windhoek as an administrative hub, international gateway, and logistics node will make it difficult to incentivize other locations.

#### Identifying and Planning the Windhoek Managed Aquifer Recharge project

The formal client for the current CAN Augmentation study is the MAWF; technical oversight is by a steering committee comprises two representatives each from MAWF, NamWater, and the city of Windhoek.

The city of Windhoek is implementing the Windhoek Managed Aquifer Recharge project and the development of the new water reclamation plant. These developments are currently being coordinated by a ministerial level oversight committee initiated following a presidential intervention.

#### Challenges to the Selection and Implementation of Solutions

What is striking about the Windhoek experience is the apparently lethargic approach to addressing the need for system expansion. There are two roots to this. First, the city has a history of cyclical water crises during dry periods that are eventually resolved by a multiyear period of good rainfall years. This accounts for a "wait-and-see" approach reinforced by the plethora of other, often more immediate priorities. The likely cost and the contested nature of the decisions to be taken on either desalination or abstraction from the Okavango also pose obvious challenges to risk averse decision makers. (The cost of either the ENWC extension or desalination is likely to be an order of magnitude greater than the investment capacity of the city, whose overall annual budget in 2016 was N$3.79 billion, of which only N$179 million was for capital items. Even at national level, only N$6.297 billion of government's N$61.496 billion 2016 budget was earmarked for capital expenditure; the total allocation to the MAWF was just N$2.91 billion. In this respect, Windhoek is typical of many cities that require a crisis to trigger decision-making on major projects; it would appear that the present crisis may achieve that.

The CAN augmentation study notes advantages and disadvantages to the Okavango scheme (MAWF 2013b):

1. The Okavango River appears to have sufficient capacity for supply to the CAN, though this needs to be confirmed.....
2. Flows in the Okavango River appear not to be correlated with the inflows into the 3 CAN dams (i.e., droughts in the CAN do not coincide with droughts in the Okavango River), which means that this is a source independent of the hydrological conditions in the CAN.
3. The transfer of water from the Okavango River to the CAN could make use of existing infrastructure, at least initially, though the sufficiency of the existing transfer schemes and infrastructure will still be confirmed with the further detailed analyses.

The disadvantages are that:

1. Competing water demands in the Kavango Regions ... may create a conflict with respect to a possible abstraction limit / allocation to Namibia.
2. As with the Kunene River, flow in the Okavango River is highly dependent on abstraction upstream in Angola. This is expected to increase significantly in future, with the development of irrigation schemes and even a possible transboundary scheme transferring water from the Cubango River to the Cuvelai area of southern Angola.
3. Climate change effects may result in reduced or more erratic rainfall and hence runoff and flows in the Okavango River.

4. The Okavango Delta is a Ramsar site and now a World Heritage Site and any potential threat to this system will attract international attention.

5. There is no current water use agreement between the riparian states of Angola, Botswana, and Namibia, which means that further water abstraction by Namibia will need to be negotiated at OKACOM, which may take some time to complete, which may delay the design and construction of the scheme.

6. Abstraction is currently only planned to 2050. Beyond this, the future demands are uncertain. If further into the future, demands have increased substantially, it is unlikely that the Okavango River will have sufficient supply capacity, given that other abstractions are likely to have increased as well (particularly upstream in Angola).

A formal analysis of the desalination and pumping option is not yet available. However, while desalination is an obvious option at the coast, the economics appear to militate against desalinating and pumping seawater from sea level to an elevation of 1,700 meters when the alternative source would pump similar amounts of water from an elevation of 1,000 meters, with minimal treatment. Early cost projections for desalination may be based on unrealistic (or certainly noncomparable) assumptions about the likely operational and financing arrangements.

Funding for this has been provided by both City and National Government. However, since the aquifer has already been drawn down over recent years, this will make only a limited contribution to resolving immediate supply challenges. Until additional supplies become available, significant recharge will only be possible in years of above average rainfall. In the longer term, it will be possible to provide additional water into the system directly to recharge without the evaporation losses that are experienced in existing surface water dams.

#### Addressing the Challenges

As is often the case, the main driver of the present accelerated planning activities has been the shortages and restrictions experienced in Windhoek as a result of a few very dry years. Despite this, the cost of the intervention required is beyond the financial capacity of either the City or the national utility NAMWATER. This led to political intervention by the President of Namibia who, when the problem was drawn to his attention in 2015, established a water augmentation committee which has brought together all key players. This has provided the current focus for project management and decision-making.

### Other Solutions

Over the next one to five years, the city will have to manage with its available resources with a small increment in supply capacity coming from the proposed new reclamation plant. Even in years of average rainfall, restrictions will have to be maintained for surface and groundwater reserves to be replenished. In the event of continued below normal rainfall, even more extensive restrictions will be required, which will inevitably constrain economic activity, in addition to its social impacts.

### Limits of Adopted Solutions

The solutions currently proposed would enable the needs of Windhoek (and the surrounding region) to be met at least until 2050. Beyond that, desalination capacity could continue to be increased with no constraint except cost. The Okavango-based supply could also be further expanded, although this would have to be coordinated with upstream developments in Angola and agricultural development plans for the northern regions. Since upstream agricultural developments have proceeded very slowly and have not yet demonstrated their economic viability, it is very likely that a supply of urban water would be given priority from an economic perspective. And since Angola is likely to promote hydropower development, this would not necessarily reduce available flows. At worst, what may be required is the construction of a further extension of the ENWC to below the Cubango-Cuito confluence.

The primary obstacle to the proposed solution is likely to be the initial cost of either completing the ENWC by linking abstraction from the Kavango River to Grootfontein or building a desalination plant at the coast and associated transmission infrastructure. Ongoing operational costs will further contribute to the need for a substantial increase in water tariffs in Windhoek, which may dampen demand but are unlikely to stop it from growing. Financing is unlikely to be raised on the basis of the users' immediate ability to pay; however, the economic argument for promoting the scheme (specifically, the economic consequences of not implementing it) will likely persuade government and financial institutions that it will be a sensible, albeit onerous, investment that will have an immediate positive impact on social well-being and economic activity.

In the longer term, the stated intention of the present administration is to decentralize economic growth so as to moderate water demand in Windhoek (Government of Namibia 2016):

> We will develop incentives to bring industrial sites closer to water resources. The idea is to locate water intensive industries away from the central region and close to the perennial rivers. This would also reduce the influx of settlers from those areas. Specific incentive proposals will be ready by July 2017.

The feasibility of such a proposal remains to be demonstrated. It does however indicate the need to implement an approach that is sufficiently flexible to cope with the different medium- to long-term scenarios that may emerge.

### Lessons

While every city's experience and context is unique, a number of lessons can be derived from the experience of Windhoek over the past five decades, particularly the importance of a long-term urban water supply strategy to ensure urban water security in a climate that is extremely variable over annual and decadal periods. Overall, approaches that establish a multiyear strategic reserve may be more economic than those that provide a constant assured supply during periods of constrained resource availability. This case demonstrates that long-term strategies should include a number of key considerations, including the following: (a) regular reviews and interventions implemented at strategic times while avoiding premature investment; (b) a regional perspective; (c) careful strategy structuring so that implementation can be phased and increments introduced as emergency interventions to contribute to the long-term design; (d) a systems approach to ensure optimization of cost, assurance, and quality; and (e) demand management and water reuse. Additional lessons learned include the consideration of conjunctive uses of surface and groundwater, including groundwater storage, and groundwater storage's advantages under conditions of extreme variability (given the time scale of response of these sources to stress is usually different, and groundwater storage reduces evaporative losses).

There are also cautionary lessons from the challenges of the Windhoek case. First, long-term strategies carry the risk of path dependency that may lock a society into a course of action that fails to identify and exploit new opportunities. It is thus critically important that such strategies be reviewed regularly, first to ensure that they are still valid, and second to confirm the timing of the interventions needed. In addition, it is difficult to motivate the funding of strategic systemic investments as stand-alone projects, particularly if they will be used only during occasional times of severe resource constraint; this limits the potential to fund them through public-private partnership (PPP) instruments. Policy makers will also need to consider the constraint on future investment and development due to uncertain water supplies in both the city and surrounding regions. A risk-based assessment methodology will be more appropriate than a stand-alone cost-benefit analysis (CBA) to evaluate such investments. The risk considered would be the economic impact of restrictions in the supply area.

## Notes

1. See the website "Namibia Statistics Agency." http://cms.my.na/assets/documents/p19dmr57141501927152512mn18631.pdf.
2. See the website "Info Namibia" http://www.info-namibia.com/info/namibia-weather.
3. "The simulated impact on modelled river discharge of increased water use for domestic use, livestock, and informal irrigation (proportional to expected population increase) is very limited. Implementation of all likely potential formal irrigation schemes mentioned in available reports is expected to decrease the annual flow by 2% and the minimum monthly flow by 5%. The maximum possible impact of irrigation on annual average flow is estimated as 8%, with a reduction of minimum monthly flow by 17%. Deforestation of all areas within a 1 km buffer around the rivers is estimated to increase the flow by 6%" (Anderssen et al. 2006).
4. See the "Namibia Water Augmentation" website: http://namibiawateraugmentation.com/project-background.
5. See the AfDB website: http://infrastructureafrica.opendataforafrica.org/NRWM2016/non-revenue-water-model-wss-2016?country=1000350-namibia.

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*Source:* Pixabay.com.

# Chapter 13 Singapore

Singapore is a tropical city-state with a population of 5.6 million people[1] located just north of the equator in Southeast Asia. It is an island of 719 km[2] with one of the highest population densities in the world. Singapore enjoys a high level of development, and its gross domestic product (GDP) of $84,382 per capita (2015 purchasing power parity [PPP]) is the fourth-highest in the world.[3]

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

Singapore is often mentioned as an example of successful urban water management under resource constraints (Garrick and Hall 2014; Sadoff et al. 2015). Water supply, water resources and catchment management, and drainage and sanitation are managed in an integrated manner by the Singapore Public Utilities Board (PUB), which is a statutory board under the Singapore Ministry of the Environment and Water Resources.

## Climate and Water Sources

### Institutional Context for Water Resources Management

In Singapore, the long-term average annual rainfall is 2,328 mm with the driest month of February still receiving about 120 mm on average.[4] Annual and monthly rainfall can vary significantly. For example, 1997 was the driest of the past 35 years with 1,119 mm of rain. During a dry spell in 2014, several weather stations across the island did not receive any rain for more than a month.[5] Although generally rainfall is abundant throughout the year, lack of space to store water and the absence of aquifers means that Singapore is dependent on neighboring Malaysia for part of its water supply. Singapore signed agreements with the Malaysian State of Johor in 1961 and 1962 to ensure access to water resources, which were explicitly mentioned in the Separation Agreement for arranged Singapore's independence in 1965. The 1961 agreement ended in 2011 and the 1962 agreement, which ensures a supply of 250 million gallons of water per day, expires in 2061. The dependency of Singapore on Johor for its water supply provides Malaysia with political leverage, and, there have indeed been tensions over water (Kog 2015; Tortajada, Joshi, and Biswas 2013). As a result and anticipating the expiry of the water agreement in 2061, Singapore aims to become self-sufficient with respect to water security.

## Water Resources

Singapore has four sources of water, which are locally known as the Four National Taps: local catchment water, reclaimed wastewater (called NEWater), desalinated water, and imported water. NEWater was introduced in 2002 and currently can meet up to 30 percent of total demand; the first desalination plant started operating in 2005 and currently desalination can meet up to 25 percent of total demand. The numbers for local catchment water and imported water are not provided publicly, but are likely about 10-15 percent and 40-50 percent, respectively. Projections for 2060 show an increase of the share of NEWater to up to 55 percent and desalinated water to up to 30 percent, with total water demand expected to double.[6]

Map 13.1 provides an overview of Singapore's water resources. Water from the Linggui Reservoir (inset to map 13.1) is released into the Johor River to counter saline intrusion and ensure reliable abstraction. Aside from the Johor River Waterworks (JRWW), which is a water treatment plant operated by Singapore, the catchment of the Johor River is managed by Johor State authorities. The water authorities of Singapore and Johor meet weekly to ensure coordination and address any issues. Upstream of JRWW are two water treatment plants supplying Johor. Challenges in the Johor catchment are rapidly growing water demand due to population and industrial growth, long-term dry weather, and the potential for pollution and spills (Ewing and Domondon 2016).

Rainwater runoff from about two-thirds of Singapore's land area is channeled into one of the seventeen reservoirs (map 13.1). The first reservoirs were constructed in the Central Catchment Area, which is a relatively pristine protected catchment. Subsequently reservoirs were developed in the less densely developed western part of Singapore. Most of these reservoirs were formed by damming estuaries (PUB 2002). Singapore then focused on unprotected water catchments in eastern and southern urban areas to collect water from densely populated towns. The reservoirs are connected with the other water sources to ensure operational flexibility and maximize storage capacity.

Desalination capacity is being expanded with an additional five desalination plants by 2020. Desalination plants are privately built and operated, but their construction is somewhat constrained by the intensive use of the coastal and marine areas surrounding the island and by low flows in the northeastern part of the Straits of Johor between Singapore and Malaysia,[7] which may affect brine dispersal and increase the pressure on the marine environment.

A comprehensive sewer system collects wastewater and transports it using gravity through the Deep Tunnel Sewerage System to treatment and recycling plants, which produce ultraclean NEWater using a three-stage recycling process—microfiltration, reverse osmosis, and ultraviolet disinfection. Currently, five NEWater plants have a combined production capacity of 167 million gallons per day (MGD), or about 47 percent of the treated wastewater volume, and an additional plant is scheduled for completion in 2025. NEWater is used by industry and, although it is safe to drink, indirectly for household consumption through mixing with reservoir water during dry periods. In addition to NEWater, the Jurong Industrial Water Works plant, which has a capacity of 27 MGD, recycles wastewater for nonpotable industrial use on Jurong Island.

The Four National Taps provide a robust system with a diversified portfolio of water sources at different risk and cost profiles. Local catchment water and imported water are the cheapest sources to treat with an energy requirement of 0.2 kWh/m$^3$. Climate change and droughts can affect the reliable yield from these sources. Short-term pollution incidents are known to have halted abstraction from the Johor River, although with strict environmental regulations, spatially distributed reservoirs, and good treatment plants, the risk of local pollution seems small. NEWater production requires 1.0 kWh/m$^3$ with treated wastewater as feedstock, and therefore is dependent on indirect supply from other sources. Desalination requires 3.6 kWh/m$^3$. Seawater is unlimited in supply, but marine pollution (such as oil spills) could potentially affect seawater intake, especially because Singapore is located along one of the busiest shipping routes in the world. Resource use is based on lowest cost resources first, although local reservoirs are mostly kept at maximum capacity for strategic reasons. NEWater and desalination capacity will be expanded for future demand increases, which will increase the energy dependency of the supply system. Use of artificial aquifers and underground caverns for water storage is another area that PUB is investigating (PUB, n.d.).

## Water Use

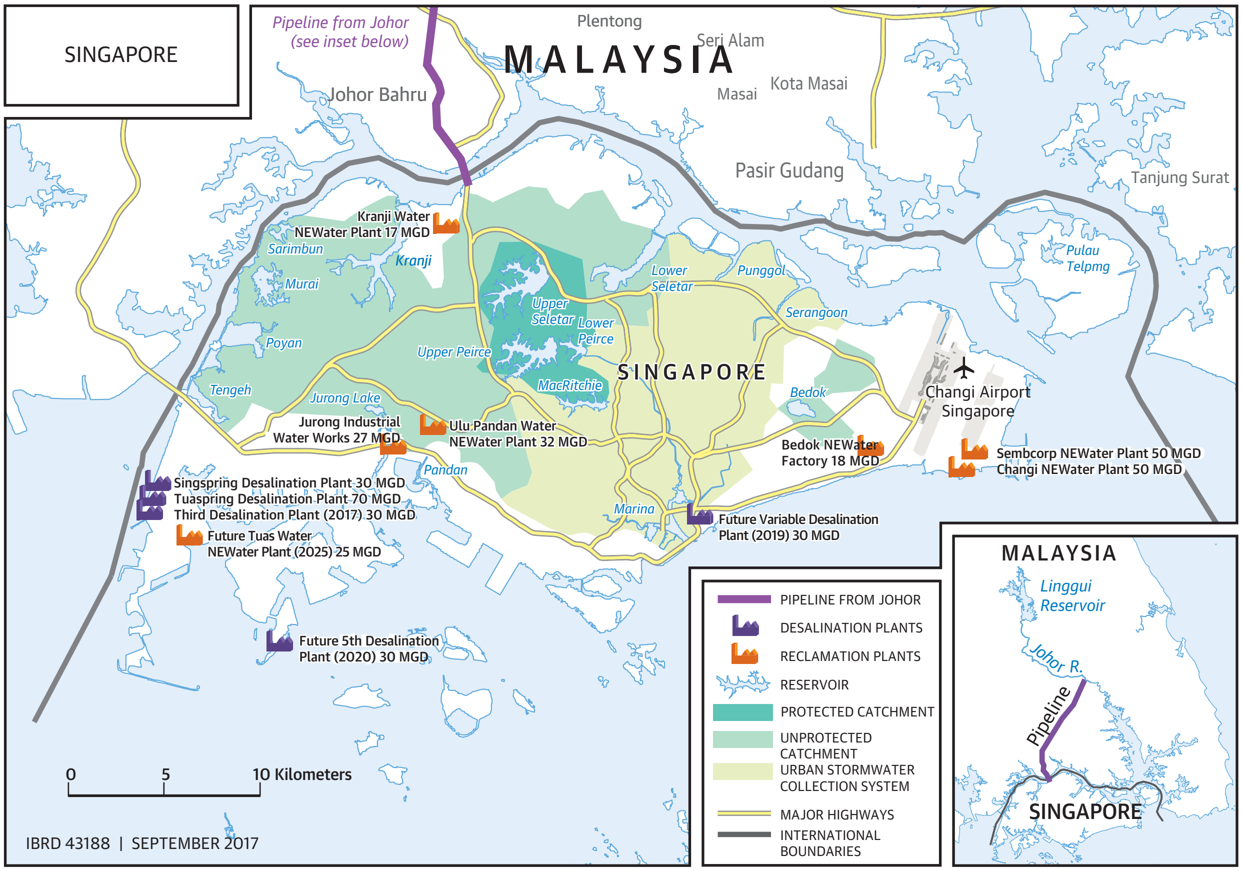
PUB is Singapore's single water provider; network coverage of piped water is 100 percent. Water from the tap is potable and meets World Health Organization (WHO) guidelines for drinking water quality (PUB 2016a). Network disruptions are very rare. Sewerage coverage is also 100 percent; part of the treated wastewater is recycled and part is discharged to the sea.

Water consumption in Singapore is about 430 MGD. Map 13.1 gives the breakdown of water sales for 2015. Households used 44.7 percent of the water, which was equivalent to 148 liters per capita per day (lpcd) in 2016. The agricultural sector is very small, occupying less than 1 percent of Singapore's land (Republic of Singapore 2015), and does not use much water. Manufacturing constitutes about 25 percent of the economy (Republic of Singapore 2015). Singapore houses a large water-intensive petrochemical industry, and several large semiconductor fabrication plants use a significant share of the NEWater. The services sector is about 70 percent of the economy and is dominated by financial and business services and trade through the large port. A total of 14.5 million days were spent in Singapore by foreign tourists in 2014 (Republic of Singapore 2015), which is equivalent to about 40,000 persons in residence for a year.

Water demand is expected to increase by 25 percent by 2030 and to double by 2060 due to population increases and growing nondomestic demand (PUB 2016b). PUB targets a reduction in domestic consumption to 140 lpcd by 2030.[8] The growth in nondomestic demand would represent a worst-case planning scenario.

Singapore's ability to reach self-sufficiency by 2060 (PUB 2016b) will inevitably require the use of the more expensive resources such as NEWater and desalination. Despite positive relations between Singapore and Malaysia and a Malaysian government commitment to the water agreement, risks remain from the pressures of increasing water demand in Johor. Finally, the Singaporean people have become used to a reliable water supply, in which leads to complacency toward potential droughts or supply disruptions.

**MAP 13.1. Singapore's Water Resources**




*Source:* World Bank, based on data from OpenStreetMap, Google Earth, and Singstat.

## Solutions

Water challenges in Singapore overlap with development challenges, such as limited land and natural resources. Rapid economic growth, urbanization and industrialization have encouraged Singapore to optimize land use, factoring in future economic and population growth projections.

Long-term planning strategies have also been used to decide on the broad pace of development. Singapore has employed planning instruments such as concept plans, strategic land use and transportation plans that guide development for the next 40-50 years. In addition, statutory master plans reach over a 10-15 year horizon and translate the long-term strategies of the concept plans into detailed plans for implementation by specifying permissible land uses and densities. They affect all types of development, including those of water resources.

When Singapore became independent in 1965, it imported some 80 percent of its water from Johor. Local water storage capacity was very limited, drainage and sewage infrastructure was missing, and recurrent droughts and floods affected both population and economic activity.[9] Financial constraints restricted planning and construction of water supply, drainage, sewage, and flood alleviation projects. As Singapore became more affluent, it became easier to plan and implement water infrastructure projects.

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

Water resource strategies have included systematic, innovative, and forward-looking planning, regulatory, management, development, and technology measures. Between 1960 and 1970, Singapore continued the water supply development plans developed by the British. Singapore started expanding two of the three existing reservoirs in the central catchment area, and the Scudai and Johor River schemes in Johor were developed and set out under the 1961 and 1962 Water Agreements, respectively, to import water.

In 1968, Singapore was presented as a Garden City during the introduction of the Environmental Public Health Bill before the Parliament, which had an overall strategic national focus on improving the quality of the urban environment.

To address water quantity constraints, PUB proposed increasing the runoff that could flow to the reservoirs by indirectly increasing the water catchment area. This was done through runoff collection from nearby water catchment areas. Interagency coordination played an important role in solving water quality problems. The then-Ministry of Environment extended the sewerage network to ensure that all wastewater was collected and treated. For example, the Bedok Reservoir was already earmarked under the 1971 Concept Plan as a potential water catchment area; the Urban Redevelopment Authority (URA), which oversees land use planning in Singapore, rezoned land to protect it against polluting developments. The Housing and Development Board (HDB), responsible for public housing, excavated sand that it required for its future projects and stockpiled it elsewhere so that Bedok Reservoir could be completed in time to meet increasing water demands (Tan, Lee, and Tan 2009).

In 1971, a long-term Concept Plan was prepared for Singapore's physical development assuming a population of 4 million. A key aspect of the Concept Plan was the "ring" approach, which would create a development ring around the central water catchment area. Major industrial areas would be located on the periphery of surrounding corridors, and major recreational areas would be developed from the central catchment area through to the coast. New towns would be built around the central catchment area, where the MacRitchie, Peirce and Upper Seletar protected catchments were located. This framework protected the water bodies from pollution while also developing centers of population in areas other than the central area. The protected catchments were left in their natural state as much as possible. No development works were authorized in these areas.

The same year, a Water Planning Unit was established under the Prime Minister's Office to assess the scope and feasibility of expanding water supplies. This Unit prepared the first Water Master Plan in 1972. It considered both conventional and unconventional water sources and outlined strategies that would ensure diversified and adequate local water supplies by creating urbanized catchments that would meet projected future demand (Tan, Lee, and Tan 2009).

To satisfy water demand, the cleaning of highly polluted rivers and water bodies became a national priority, because both the Concept and Water Master Plans stressed the need to develop unprotected catchments. As a result, animal husbandry activities near catchment areas were relocated, antipollution legislation was introduced and enforced, and drainage, sewage, and flood alleviation projects were developed.

In 1972, a growing focus on environmental issues resulted in the formation of the Ministry of the Environment (ENV). The establishment of the ministry was a pioneering move in Southeast Asia and one that was further backed with new regulations.

In 1975, the Water Pollution Control and Drainage Act was enacted to control water pollution by discharging effluents into sewers and monitoring and regulating water quality. Part IV of the Act primarily addressed water pollution control for inland waters and made it a punishable offence to discharge any toxic substance into inland water. In addition, the 1976 Trade Effluent Regulations enabled the Director of Water Pollution Control and Drainage to ensure that trade effluents were discharged only into sewers.

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

Concurrently with the rapid development of Singapore, appropriate pollution control strategies were adopted, older legislation and regulations were amended, and new ones were drafted. For example, the Water Pollution Control and Drainage Act 1975 was repealed and its relevant powers streamlined into the Sewerage and Drainage Act (SDA) which is administered and enforced by PUB, and the Environmental Pollution Control Act (now known as the Environmental Protection and Management Act (EPMA) was enacted. Each was accompanied by regulations.

The Singapore River and the Kallang Basin were cleaned from 1977 to 1986, in conjunction with large redevelopment activities (Tortajada, Joshi, and Biswas 2013). After cleaning the Singapore River, a comprehensive plan was developed by the URA and the Singapore Tourism Board (STB) in coordination with other departments and statutory bodies. The Singapore River was chosen among one of the 11 thematic zones identified in the Tourism Master Plan seeking to project Singapore as a tourism capital in the twenty-first century (STB 1996).

In the late 1980s, the government began studying the development of Marina Bay as an alternative source of freshwater, as well as for flood alleviation purposes.

## Further Alternatives to Import Water to Singapore

In 1989, then Prime Minister Lee Kuan Yew announced that Singapore was considering the possibility of importing water from Indonesia.[10] Under an agreement signed on August 28, 1990, relating to economic cooperation in the Riau Province, Singapore and Indonesia agreed to cooperate on the sourcing, supply, and distribution of water to Singapore. In 1991, a water agreement signed with the government of Indonesia would provide for the supply of 1,000 MGD from sources in the Province of Riau for 100 years. The agreement would have provided viable supplementary or alternative sources of water for long-term needs. However, its implementation was delayed after evaluating various options.

### Unconventional Sources of Water

The use of unconventional sources, such as recycled water, had been proposed in the 1972 Water Master Plan. Although it was technically possible to produce recycled water that met drinking water standards in the early 1970s, a pilot plant study had shown that the process was costly and technologically unreliable. Thus, recycled water plans mostly proposed using recycled water for nonpotable use. This entailed a host of technical and cost considerations, such as a separate and expensive reticulation system for the lower-grade water with the possible risk of cross-contamination, as well as aesthetic concerns.

Desalination was also considered during the 1980s and 1990s, but desalination had not been implemented anywhere on a large scale and entailed high energy and other costs.

With the development of more cost-effective technology in 1996, consultants were appointed to carry out site feasibility and engineering studies on desalination. Given the results, it was decided that a plant would be built on reclaimed land at Tuas, west of Singapore, and that the first phase of the desalination plant, with a capacity of 30 MGD, would be constructed using the dual-purpose multistage flash distillation process. An adjacent power plant was proposed to be built by 2005.

PUB also announced that it was studying increasing local sources of water by developing suitable marginal catchments to collect storm runoff from new housing estates. Rainwater would be collected and treated to meet drinking water standards instead of being drained for flood control and sent out to the sea. PUB explained that these projects would be implemented with the development of drainage systems in the new towns. The cost of this initiative was estimated at S$170 million and would increase total catchment area by 5,500 hectares (PUB 2010). At the same time, PUB and ENV embarked on a joint assessment on the feasibility of water reclamation using secondary treated sewage effluents. The S$14 million study involved the construction of a demonstration plant with a 10,000 $m^3$ per day capacity using advanced membrane technology to treat sewage effluent that would meet the internationally accepted WHO Drinking Water Standards (PUB 1998).

In 1999, it was decided that the desalination plant should be built by the private sector, from which PUB would purchase the water. It was also agreed that a smaller 10 MGD desalination plant would be owned and operated by the government (PUB 1999). Bidders could choose from a range of available desalination processes including multieffect distillation, multistage flash distillation, reverse osmosis, or hybrid systems. Before membrane treatment of saltwater was developed, distillation was the most commonly used technology. Different distillation variations relied on large amounts of energy to produce heat or the required pressure conditions to evaporate water that would then condense on a cooler surface, a process that made distillation very expensive. Singapore's first 30 MGD reverse osmosis desalination plant was built and opened in 2005 by SingSpring Pte Ltd.

A demonstration plant for recycled water was built in 2000, and an international panel with national and foreign experts was formed to provide independent advice on the study. Technology enabled high-grade reclaimed water to be produced through a multibarrier treatment process that consisted of conventional used-water treatment, micro- and ultrafiltration, reverse osmosis and, finally, ultraviolet disinfection.

In 2002, the plan for producing recycled water began to be carried out: New plants were built and, equally importantly, a communication plan was also prepared. A fundamental part of this outreach effort was to educate the public that this recycled water was safe for drinking, not simply to focus on the technology employed. To change the overall negative popular impression toward recycled water, recycled wastewater was renamed "NEWater," wastewater treatment plants were renamed "water reclamation plants," and wastewater "used water." The new terms were part of a strategy to achieve a change of mind-set, stressing the new approach to water management by communicating to the public the need to look at water as a renewable resource that could be used over and over again.

Similar to desalinated water, the production of NEWater was available for private sector participation.

The first three plants were owned and operated by PUB. However, the fourth and fifth plants were built under a Design-Build-Own-Operate (DBOO) model with the private sector. The purpose was to develop a water industry that would provide services at a specific level of quality and at a cost-effective price, as well as to encourage greater efficiency and innovation in the water sector (Tan, Lee, and Tan 2009).

The Marina Reservoir was built in 2008. It is the most urbanized and largest catchment in Singapore (10,000 hectares). The reservoir was created through the construction of a barrage, formed by land reclamation, across the Marina Channel at the confluence of five rivers (including the Singapore River). It provides a much needed additional source of water and promotes flood alleviation and water for recreational purposes. Together with other reservoirs, it has increased Singapore's water catchment from half to two-thirds of the country's land area.

### Institutional Arrangements

PUB was established in 1963 to supply water, gas, and electricity. In 2001, it became responsible for water supply, sanitation, and wastewater management. Management of electricity and gas were moved to the Energy Market Authority (EMA). PUB's broad strategies include maximization of production and diversification of water resources; water reclamation and reuse; wastewater treatment and disposal; and storm water management and water demand management (PUB 2001). For demand management, water pricing for cost-recovery (see table 13.1), and nonpricing measures including mandatory and technical measures have been developed.

PUB is one of the few agencies in the world that manages all aspects of water resources. In most cities in both the developed and the developing world the services are under two or more organizations. Institutional fragmentation in those cities leads in many cases to a lack of coordination.

### Singapore's Next-Step Options for Further Drought Proofing

To address Singapore's rising water demand and potential droughts, PUB will continue to focus on supply-side engineering solutions. Several desalination and NEWater plants are planned to address rising demand, as well as expansion of the local catchment area.

On the demand side, focus continues on measures to reduce domestic and nondomestic demand. PUB is considering industrial water solutions, such as seawater cooling and maximizing water recovery in production processes. For domestic demand, behavioral studies are being carried out to assess the effects

**TABLE 13.1. Water Tariffs as of July 1, 2018, after a 30 Percent Price Increase over a Two-Year Period**

*Singapore dollars*

| | | Nondomestic water | | | |
|---|---|---|---|---|---|
| | Domestic water | Potable water | NEWater | Industrial water | Shipping customers |
| Tariff | 0–40 $m^3$: 1.21<br>> 40 $m^3$: 1.52 | 1.21 | 1.28 | 0.66 | 1.92 |
| Water conservation tax (% of tariff) | 0–40 $m^3$: 0.61 (50%)<br>> 40 $m^3$: 0.99 (60%) | 0.61<br>(50%) | 0.13<br>(10%) | n/a | 0.96<br>(50%) |
| Waterborne fee for wastewater | 0–40 $m^3$: 0.92<br>> 40 $m^3$: 1.18 | 0.92 | 0.92 | 0.92 | 0.92 |
| Total | 0–40 $m^3$: 2.74<br>> 40 $m^3$: 3.69 | 2.74 | 2.33 | 1.58 | 3.80 |

*Source:* Water Price (database), PUB (accessed July 10, 2017), https://www.pub.gov.sg/watersupply/waterprice.
*Note:* n/a = not available.

of behavioral tools on water use, such as shower meters, in addition to education and communication efforts.

## Conclusions and Lessons for Other Water Scarce Cities

Singapore's urban water and wastewater management during the past 51 years has been exemplary by any standard. This remarkable transformation has been possible primarily because PUB has been a consistently efficient and progressive institution. Singapore is the only city in the world which now has an urban water management plan that extends to 2061, when the treaty to import water from Malaysia expires. This plan is updated every 5 years considering the latest technologies that can be successfully adopted, changes in social, economic and environmental conditions, and new management techniques.

Over the past five decades, Singapore's national water management has consistently received strong political support from national political leadership such as Prime Minister Lee Kuan Yew from 1965 to 1990. Throughout his 25-years as Prime Minister, Lee considered water to be a strategic resource for Singapore's survival and future economic development. Yew's commitment to water security is undoubtedly one of the main reasons for Singapore's urban water transformation and progressive water agenda.

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

Because of the effects of climate change in recent years, there is a probability that before 2061, when the water import treaty with Malaysia expires,[11] a significant source of the water used in Singapore may disappear. Furthermore, if the Linggiu Reservoir becomes dry, there will be a significant reduction in water supply, wastewater generation, and NEWater production.

Per capita daily domestic water use in Singapore in 2016 was relatively high at 148 liters. Other cities in the developed world have brought their consumption down below 100 liters with measures that include public awareness campaigns and economic incentives, and Singapore plans to follow suit. In the past, Singapore has used technological improvements to reduce domestic water consumption and nondomestic water use. In the future, it is likely that technological developments will bring only incremental benefits. Therefore, significantly more emphasis needs to be placed on behavioral and attitudinal changes to meet a target of reducing per capita daily water use to 140 litres by 2030.

Singapore's water price had remained the same for 17 years, until early 2017, when it was announced that it would increase by 30 percent over a 2-year period. During these 17 years, inflation has been around 30 percent. A survey in 2017 indicated that 75 percent of the Singaporeans did not know how much they paid for water. The small increase in price, compared to inflation, is unlikely to have appreciable impact in reducing per capita water consumption.

Overall and looking forward, trends show that Singapore needs to change its narrative from an argument of cost recovery for domestic and nondomestic water uses to one of managing a scarce resource.

## Notes

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7. For a discussion of the hydrodynamics and residence times of the waters surrounding Singapore see Bayen et al. (2013).
8. PUB (Public Utilities Board), "Save Water," (accessed July 10, 2017), https://www.pub.gov.sg/savewater.
9. With 6,900 hectares of flood-prone areas (about 12 percent of the main island area at that time), the government considered it a priority to provide drainage in flood-prone areas and implement flood prevention measures in low-lying areas.
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*Source:* Perth Skyline. Sam Curry. Pixabay.

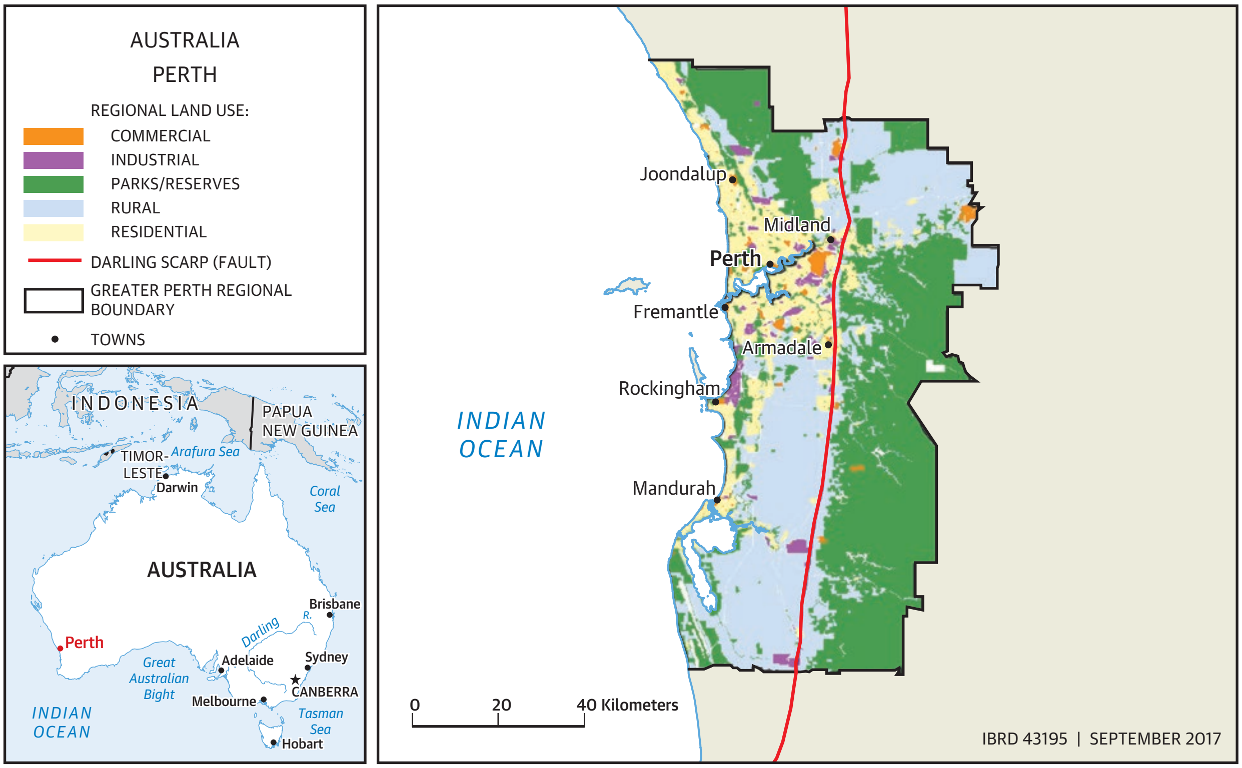
# Chapter 14
# Perth, Australia

Perth is the capital of Western Australia, the fourth-most populous city in Australia with about 2.1 million people—80 percent of Western Australia's total population. The Greater Perth region extends from the Indian Ocean to the Darling Scarp, and approximately 140 kilometers from north to south on the Swan Coastal Plain (map 14.1). Perth dominates the Western Australian economy. During the recent resources boom the rate of population growth doubled to more than 3 percent per year between 2006 and 2013.

The availability of water from fresh groundwater under the coastal plain and dams on rivers has influenced the urban form and the concentration of the state's population in Greater Perth. About half of the water used in Perth is from self-supplied groundwater for nonpotable purposes including horticulture, parks, and gardens. The other half of the water used is from potable supplies—almost half is groundwater, almost half is from desalination plants, and a small amount is from the dams. The drying climate has driven the shift from dams to desalination for potable supplies, and is affecting the availability of groundwater for potable and nonpotable supplies.

The southwest of Western Australia has been in the grip of ongoing climate change since the 1970s and is now drier and hotter than at any time in its recorded history. The Perth region has a Mediterranean-type climate with hot, dry summers and winter rainfall. Annual rainfall is variable. The historical average annual rainfall in the Perth-Peel region prior to 1970 was approximately 860 millimeters on the coastal plain and 1,230 millimeters on the Darling Scarp. However, rainfall declined by about 10 percent during the 1970-99 period. Since 2000 this trend has

**MAP 14.1. Greater Perth Region and Major Land Uses**




intensified with Perth now experiencing a 20 percent reduction in annual rainfall from the pre-1970 average, with a particularly dry year in 2010. These rainfall reductions have coincided with increases in average annual temperatures of about 0.5ºC from 1970-99 and 1.3ºC since 2000 in relation to the pre-1970 average.

## Hydrology and Water Resources

The natural hydrological systems for Perth's water supply include several surface water catchments on the Darling Scarp east of Perth and groundwater aquifers below the coastal plain. Stream flows feed into a number of public scheme supply reservoirs, and prior to 1975 yielded about 338 gigaliters per year. Water quality is fresh at less than 500 milligrams per liter of total soluble salts.

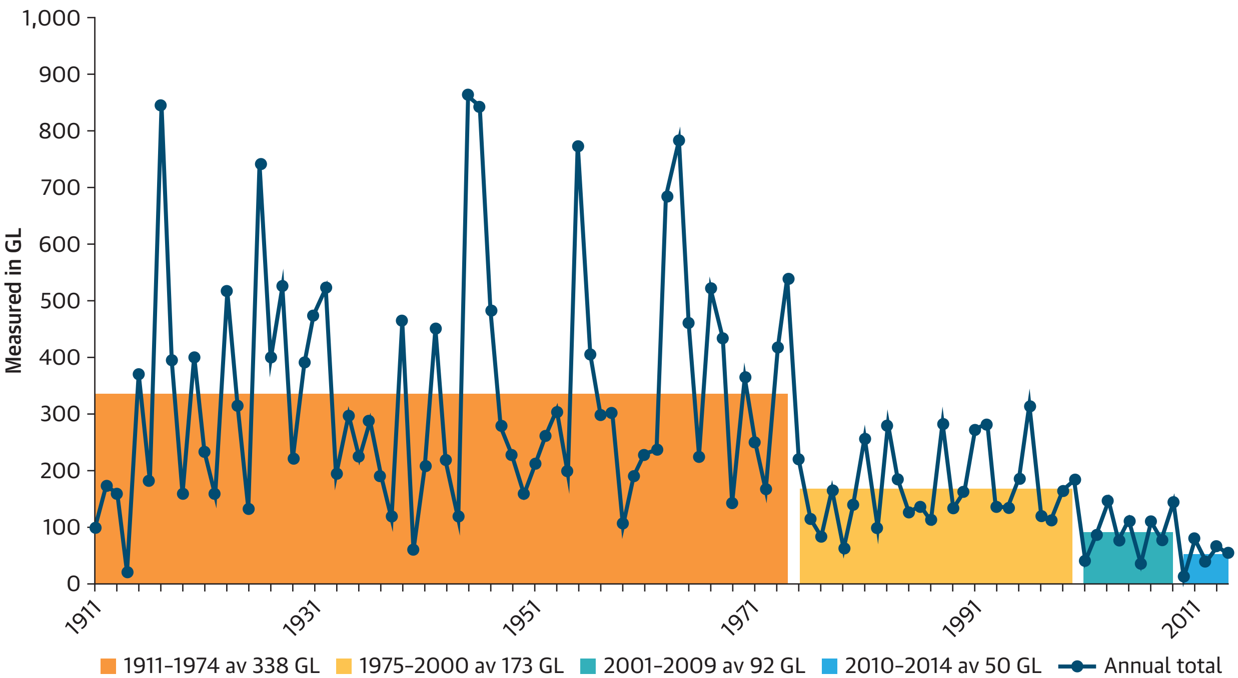
The rainfall reductions have had a significant effect on pre-1975 average annual stream flow with a nearly 50 percent reduction in the 1975-2000 period, a nearly 75 percent reduction in the 2000-09 period, and an 85 percent reduction in the 2010-14 period (figure 14.1).

A system of sedimentary aquifers lies beneath most of the Greater Perth urban area, consisting of shallow, middle, and deep aquifers. Groundwater is a major source for Perth's water supply scheme, and the shallow aquifer supports extensive self-supply use in the region. Water quality varies from fresh to marginal and brackish.

## Water Resources Management and Water Use in the Greater Perth Area

The Department of Water manages the water resources in Western Australia under the Rights in Water and Irrigation Act of 1914, and a water license is needed to take surface water and groundwater (except for

**FIGURE 14.1. Streamflow into Perth's Reservoirs, 1911–2016**



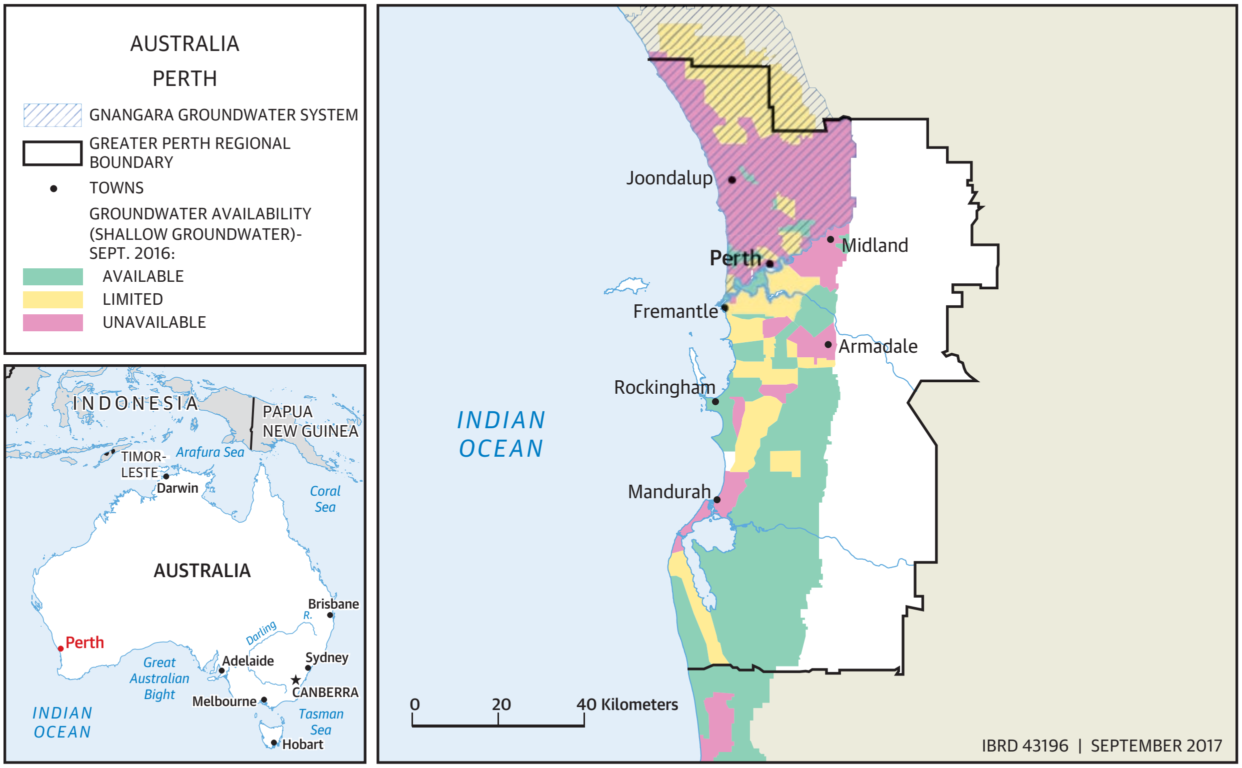

*Source:* Water Corporation website.
*Note:* GL = gigaliter.

small-scale stock, domestic, or garden use). To manage total groundwater and surface water abstraction at resource scale, water is issued up to an allocation limit for each resource management area. Sustainable allocation limits, set through water allocation plans, are based on investigating, monitoring, and assessing the water resources to set how much water can be taken for use and establishing access rules. The extraction of water is then managed through the license, supported by a compliance system.

In the Greater Perth area most groundwater management areas are now overallocated (map 14.2). Allocation limits have been reduced and licensing capped to adjust to the drying climate. Across most of the Swan Coastal Plain, stormwater is managed by recharge to the local shallow aquifer, with relatively small volumes discharged via the drainage system. However, in some areas of recent urban development with high water tables, larger volumes of drainage water are discharged.

More than half of the water used in the Greater Perth region is self-supplied, mostly sourced from groundwater. More than 2,500 self-supply users access the local shallow aquifer. Nearly half of the water used in the region is supplied via the Perth Integrated Water Supply Scheme (IWSS) by Western Australia's largest water utility, the Water Corporation (map 14.3). This is currently sourced from a combination of desalinated seawater (47 percent), groundwater (46 percent), and surface water (7 percent), and represents a significant change from the late 1990s, when about half was sourced from surface water and half from groundwater. Prior to the mid-1970s, about 90 percent of scheme supply was sourced from surface water. The water supply use strategy for the scheme is to minimize demand by improving efficiency of usage, maximize use of climate independent sources such as seawater desalination, make opportunistic use of surface water sources, and minimize use of additional groundwater.

**MAP 14.2. Gnangara Groundwater System and Water Availability in Shallow Groundwater Management Subareas of Greater Perth**



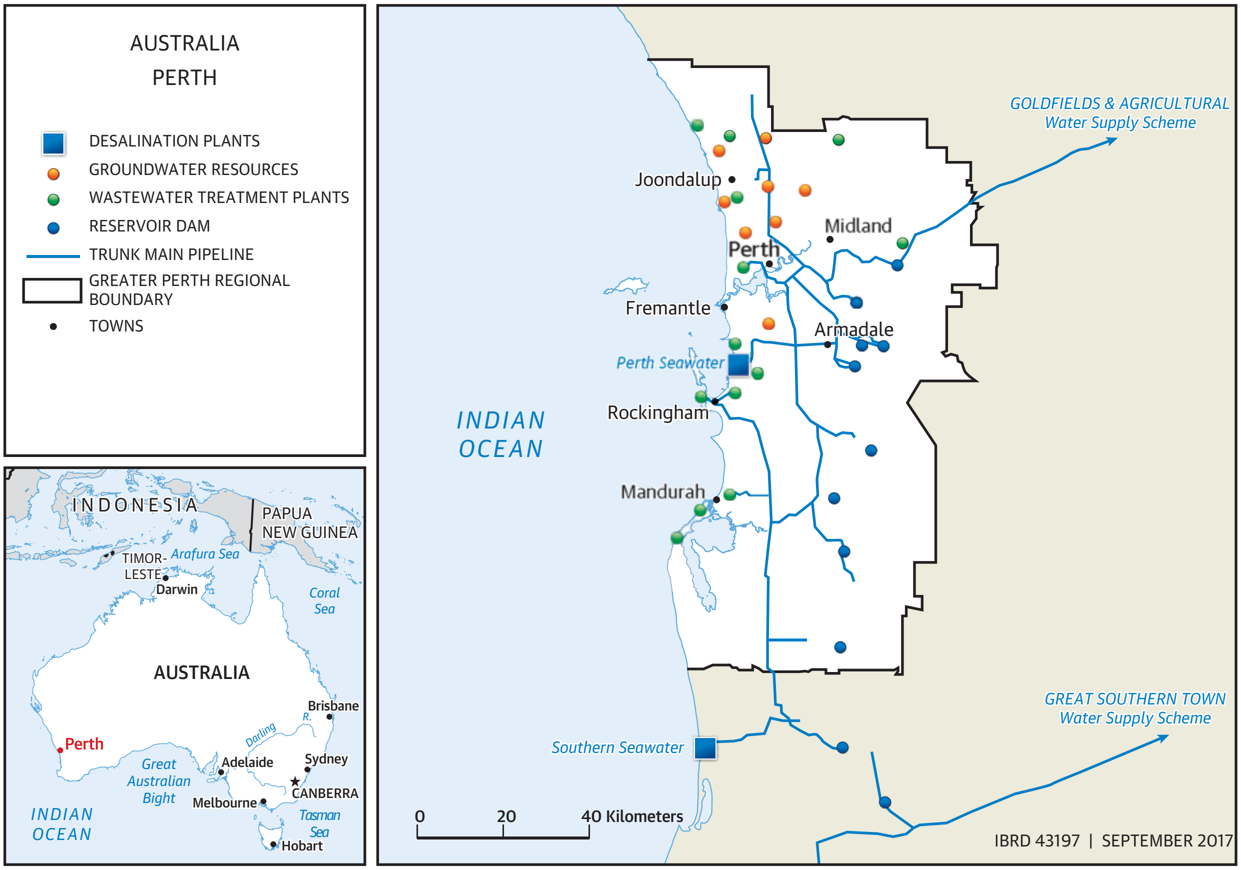

## Other Potential Water Resources for the Greater Perth Region

Wastewater is a climate-independent and growing resource, with treatment costs for recycling lower than for desalinating seawater. The Water Corporation is about to commence production from the first Groundwater Replenishment Scheme (GWRS). Water from the Beenyup wastewater treatment plant will be recycled through advanced treatment and recharged into the middle and deep aquifers. Through outstanding public engagement, the concept enjoys good community acceptance and is estimated to cost approximately $A2.25 per cubic meter.

Potential future water sources for the Perth IWSS include groundwater sources north of the current urbanized areas, with an estimated supply cost of around $A1.60 per cubic meter, and expanded or additional seawater desalination plants with estimated costs of around $A2.04 per cubic meter (for expanded) and $A3.54 per cubic meter (for additional). Large-scale seawater desalination plants (50–100 gigaliters per year capacity) need suitable coastal locations and integration with existing water infrastructure. Smaller, more widely distributed desalination plants with a capacity of around 20 gigaliters per year could be an option depending on how unit cost compares to ongoing operating costs.

Potential sources to meet future nonpotable self-supply water demand are more limited. The capacity to pay for water to irrigate public open space, horticulture, and industrial processing means most of the higher-cost water supply options are less viable.

MAP 14.3. **Perth Integrated Water Supply Scheme**




If self-supply demand cannot be met through a combination of water efficiency measures and lower-cost source options, future self-supply water demand is likely to either shift to the public water supply scheme or the activity would be curtailed.

## Urban Water Supply and Sanitation Institutional Framework

The Water Corporation supplies drinking water to most of the population in the Greater Perth region via IWSS, the largest public water supply scheme in Western Australia. The IWSS connects multiple water sources to residential and nonresidential customers by an integrated trunk main and distribution system that includes major storage and service reservoirs. About 30 gigaliters per year of water are exported to supply inland agricultural and Goldfields regions to the east of Perth, which have very limited local freshwater resources.

The Water Corporation operates sewerage and major drainage services for most of the region. The sewerage system collects wastewater and pumps it to centralized wastewater treatment plants for disposal of secondary treated wastewater to the ocean or for recycled water use. The Water Corporation also owns and operates the Kwinana Water Recycling Plant (KWRP), which treats wastewater and supplies it to industry for nonpotable uses.

A few private companies have recently obtained licenses to provide water services (potable, sewerage, nonpotable recycled water) for small communities in the region's south. Local government authorities (municipalities) provide local drainage services across the region.

### Types of Water Use

In 2015-16, the IWSS supplied 267 gigaliters of water to the Greater Perth region. About 70 percent of this was used by households and about 18 percent by other users including commercial, institutional, and light industry. The remaining 12 percent is nonrevenue water (NRW) consisting of authorized, unbilled consumption such as firefighting, apparent losses (metering inaccuracies and unauthorized use), and real losses (through leakages). Total per capita scheme water use was 127 cubic meters per person for 2015-16.

Self-supplied water use in Greater Perth is estimated to be about 300 gigaliters per year for households (30 percent); agriculture (26 percent); parks, gardens, and recreation areas (24 percent); heavy industry (12 percent); mining (6 percent); and commercial (2 percent). There are estimated to be over 175,000 domestic garden bores in the Greater Perth region, used to water about 30 percent of all household gardens.

### Economic Dependence on Water

No severe watering restrictions have been placed on scheme water users for several decades due to reductions in per capita water use and the development of climate-independent supply sources such as seawater desalination by the Water Corporation. The introduction of water use efficiency measures had no major impacts on the regional economy.

Users of self-supplied, nonpotable water in the region are heavily dependent on ready access to relatively low-cost, untreated groundwater. This partly diverts demand from the IWSS and hence reduces overall supply costs by using untreated groundwater for nonpotable purposes. Now, with less natural groundwater available, farmers, local governments, and industry water users that plan to increase area or output will need to become more efficient or find alternative, higher-cost water sources.

Economic impacts of water supply disruptions and growing demand for water are being minimized by pro-active water supply planning by the Water Corporation and the Department of Water. The shift to the climate-independent water sources of seawater desalination and recycled wastewater significantly reduces the risk of future scheme supply disruption.

### Water Demand Pressures and Competition for Water

Despite a 30 percent population increase in Greater Perth since 2000, overall water demand on the IWSS has not increased due to water use efficiency programs and decreasing dwelling lot sizes. Since 2000, scheme water use per person has decreased from 180 kiloliters per year to 127 kiloliters per year in 2015-16. The Water Corporation aims to further reduce per capita consumption to a maximum of 115 kiloliters per year by 2030. Competition for groundwater from the shallow aquifers has been reduced through sourcing more than 70 percent of the water for scheme supplies from deeper aquifers.

Little or no shallow groundwater is now available for self-supply in areas planned for urban expansion. New urban developments need to have 10 percent of the area designated for public open space. Expansion of the metropolitan area has already displaced peri-urban horticulture in several parts of the region, and food producing areas now on the urban fringe are facing changes in land use and competition for water resources.

Heavy industry in Greater Perth is mostly located in the Kwinana Industrial Area. Current water demands are met from a combination of groundwater abstraction, recycled wastewater, and a small amount of public scheme supply. Limited groundwater is available to support future growth. Investigations are underway to recycle water from the nearby Woodman Point wastewater treatment plant for aquifer recharge for later extraction by industry.

### Institutional Arrangements for Managing Allocations and Supply Risk

The Department of Water's water allocation plans incorporate the effects of a continuing drying climate on water resources. Licenses issued under water legislation provide annual water entitlements for water use, and are subject to local water availability and impact assessment. The actual use of surface water is largely self-limiting since decreasing reservoir storage levels are visible. The Water Corporation manages surface water extraction rates to retain some water in storage for emergency use.

Unlike surface water storages, declining groundwater levels are not visible and the sustainable abstraction rate is a much smaller proportion of the overall resource storage volume. Groundwater allocation limits are reviewed over 5- to 10-year periods based on reassessments of rainfall, recharge, and aquifer response. However, the climate is changing rapidly and rebalancing of abstraction rates lags behind. The challenge is to rebalance abstraction with recharge so groundwater levels can stabilize or recover and groundwater-dependent environmental and social values are maintained.

## Water Balance for the Current Situation without Additional Resources or Actions

Currently for the IWSS, the water available from groundwater resources and the two seawater desalination plants is enough to meet most of the region's scheme water demand. Surface water is still needed to meet between 5 percent and 10 percent of demand so successive dry years would trigger contingency strategies. An additional source will soon be available through the Beenyup GWRS.

## Solutions

The relatively sudden 80 gigaliters per year reduction in average annual surface water flows presented a major challenge to IWSS supply security in the early 2000s. The response was a combination of demand management and new supply sources. A comprehensive water use efficiency program was introduced by the Water Corporation. It included community awareness initiatives and incentives to reduce use. The new IWSS water sources developed progressively since 2001 include the following:

- Increase in groundwater scheme, with new borefields to significantly increase abstraction from the deep aquifers.
- Temporary use of additional groundwater.
- Opening of Perth Seawater Desalination Plant at Kwinana with a production capacity of 45 gigaliters per year (November 2006).
- Construction of Southern Seawater Desalination Plant at Binningup south of Perth (stage one: 50 gigaliters per year, September 2011; stage two: doubled capacity to 100 gigaliters per year, January 2013).
- Water trading with Harvey Water (an irrigation water supplier) for 17.1 gigaliters per year (2006).
- Kwinana Water Reclamation Plant supplying up to 8.7 gigaliters per year of recycled wastewater to industry (2008 onward) to reduce demand for IWSS supply and self-supplied groundwater.
- Beenyup GWRS's advanced treatment of wastewater, reinjection to deep aquifers, and subsequent groundwater extraction (trials between 2010 and 2012; online in 2017).

Solutions for self-supply groundwater and surface water use included the following:

- Department of Water's groundwater allocation plan for the Gnangara Groundwater Areas (Government of Western Australia [GoWA] 2009a)—developed in response to downward trend in groundwater levels—capping use, reducing allocation limits, and triggering a first stage of reduced abstraction for the IWSS.
- Demand management programs and measures for licensed self-supply water users.

- Department of Water restriction of use of domestic bores for garden irrigation to three days a week and introduction of total winter sprinkler ban in 2010.

### IWSS Demand Management Solutions

Water demand management options were the first solutions initiated in the early 2000s in response to drought. They could be brought into play relatively quickly and at a modest cost. Some were immediate short-term options, while others were structural solutions to provide long-term benefits.

The Water Corporation initiated a very active water use publicity campaign to raise community awareness of the supply security and the need to work together to reduce water use. Water use efficiency incentives were introduced for residential customers, including retrofitting of low-flow shower heads and low-flush toilets. The Water Corporation also began to engage and work with major nonresidential customers to determine ways to reduce their water use.

Residential garden irrigation was a major focus since it constituted about half of residential IWSS water use (a third of all IWSS water use) and was subject to overuse during summer. Restrictions on the use of fixed sprinkler systems were part of the emergency contingency planning for the IWSS. A two-day-per-week roster for garden watering by sprinkler systems was implemented without damaging gardens and lawns. The sprinkler roster system, accepted by government and the community, was implemented as "good watering practice" rather than "restrictions," and has been in place ever since.

The initial effect of these demand management solutions was to reduce IWSS water demand by about 30 gigaliters per year. Subsequent reductions in per capita water use from about 150 cubic meters per year to 127 cubic meters per year by 2016 are due to a combination of these demand management solutions and smaller residential lot sizes.

### IWSS Water Source Solutions

The first water source solution was introduced in the late 1980s and early 1990s. The groundwater scheme was significantly increased with new and expanded borefields to increase overall groundwater production, and independent artesian bores to significantly increase production from the deep aquifers.

Temporary additional groundwater extraction of up to 30 gigaliters per year was initially a contingency solution introduced in the early 2000s. The costs were relatively low and additional extraction could be implemented relatively quickly. Surface water flows never returned to their previous levels, instead they reduced further, resulting in continued reliance on the "temporary" additional groundwater. To offset the effect of taking that additional groundwater for the IWSS, a greater proportion of abstraction was shifted to deeper aquifers and less environmentally sensitive locations, and conditions for temporary access were tightened.

The Perth Seawater Desalination Plant treats seawater and supplies 45 gigaliters of drinking water per year. The seawater reverse-osmosis (SWRO) plant was completed in 2006 and was the first of its kind in Australia. Electricity for the plant is offset by the 80 megawatt Emu Downs Wind Farm. The desalination plant has one of the world's lowest specific energy consumptions, due in part to the use of pressure exchanger energy recovery devices. Seasonal excess water from the plant is stored in selected surface water reservoirs.

The Southern Seawater Desalination Plant is located near Binningup, about 150 kilometers south of Perth. It was built in two stages, each with a capacity of 50 gigaliters per year. The first stage was completed in 2011 at a cost of $A640 million plus an additional $A315 million to integrate it into the IWSS. The second stage of the project was completed in 2013 at an additional cost of $A450 million and expanded the plant's capacity to 100 gigaliters per year.

The $A72 million Harvey Water Pipe Project was completed in 2006. This water-trading initiative between

Harvey Water and the Water Corporation converted open irrigation channels to pipes, harvesting seepage and evaporation losses. This made 17.1 gigaliters per year of water available to the IWSS in a permanent trade. It benefited the irrigators by providing a pressured pipe irrigation system that controlled irrigation that suits higher-value horticulture crops.

The $A28 million Kwinana Water Reclamation Plant (KWRP) was initially commissioned in November 2004 to provide recycled wastewater to two major industrial customers; it expanded to its full capacity in early 2008 to provide additional recycled wastewater. This has reduced demand for IWSS and self-supplied groundwater by 6 gigaliters per year. It uses advanced filtration and reverse osmosis processes to further treat secondary-treated wastewater to produce high-quality, industrial-grade water.

The Water Corporation undertook a trial of groundwater replenishment at its Beenyup wastewater treatment plant between 2010 and 2012. This involved managed aquifer recharge of highly-treated wastewater with subsequent extraction and treatment of an equivalent amount of groundwater from groundwater bores for public supply. The trial was successfully completed in December 2012. This project has received good public support. Construction of Australia's first full-scale GWRS for 14 gigaliters per year began in October 2014 and is currently in the final stages of commissioning. The state government announced expansion of the scheme in July 2016, doubling its capacity to 28 gigaliters per year at a cost of $A232 million.

To meet the supply gap of water demand for the IWSS since 2000, demand management has accounted for about 80 gigaliters per year, additional groundwater up to about 30 gigaliters per year, seawater desalination about 145 gigaliters per year, water trading 17 gigaliters per year, and wastewater recycling about 6 gigaliters per year. For Perth, groundwater and seawater desalination would now be regarded as "conventional" supply sources, while trading and recycled water would probably fall in the "unconventional" category.

### Regulatory and Self-Supply Solutions

The Department of Water restricted use of domestic bores for garden irrigation to three days a week in 2010 and is working closely with local government authorities (municipalities) to improve the irrigation efficiency for public open spaces.

The department released the Gnangara Groundwater Areas Allocation Plan in 2009 (GoWA 2009a). Its aim was to slow the pace of groundwater level decline by introducing staged reductions in groundwater extraction and by capping the amount of groundwater pumped for self-supplied water use. These regulatory measures have driven improvements in water use efficiency and interest in alternative nonpotable water sources across all water sectors.

### Planners of Water Source Solutions

The Water Corporation led the scheme supply planning response to the ongoing reductions in source capacity from 2000 to the present day. The corporation worked closely with the Department of Water and successive state governments. The Department of Water led the planning for the regulatory and self-supply responses to the reduced levels of available water.

In 2002 the state government and the Water Corporation went to the people of Western Australia for input into planning for water source development and management of demand, which culminated in the State Water Strategy (GoWA 2003). The strategy's objective was to "ensure a sustainable water future for all West Australians by: improving water use efficiency in all sectors; achieving significant advances in water reuse; fostering innovation and research; planning and developing new sources of water; and protecting the value of our water resources."

Other programs included the Water Corporation's "Water for Life" report (GoWA 2006) which outlined its "security through diversity" strategy to "secure Western Australia's water future through a diverse portfolio of supply and demand programs."

The state government gave water and the management of water resources strategic priority through the development of the *State Water Plan* (2007).

The Water Corporation released "Water Forever, Towards Climate Resilience" in October (GoWA 2009b), a comprehensive, long-term water supply strategy for Perth's scheme supply. It addresses the major water issues for the Perth region—a drying climate, increasing population, and minimizing environmental impact—by using less water. The strategy set out a portfolio of options to reduce water use, increase water recycling, and develop new sources.

In November 2009 the Department of Water released the "Gnangara Groundwater Areas Allocation Plan" (GoWA 2009a). It set limits on groundwater abstraction for scheme supply and targets to reduce this to 120 gigaliters per year, with desalination coming onboard, to relieve pressure on the groundwater system. The plan capped allocation limits for licensed self-supply. In December 2009, the Department of Water released the *Perth-Peel Regional Water Plan*, a comprehensive document that addresses public and self-supply and explains the department's position and actions on (a) water use efficiency; (b) security of supply; (c) alternative sources; (d) waterways and wetlands; and (e) water sensitive cities.

In response to the very dry winter of 2010, when there was virtually no inflow to the IWSS dams, the Water Corporation released "Water Forever Whatever the Weather: Drought Proofing Perth" (GoWA 2011). This is a 10-year plan to drought-proof Perth by 2022, whatever the weather, by (a) transferring groundwater abstraction to deeper aquifers; (b) replenishing the deep aquifers with recycled water through a new GWRS; (c) expanding seawater desalination capacity (by 50 gigaliters per year) to continue to make gains in water use efficiency; and (d) using wastewater recycling for nondrinking uses.

Multiple options have been progressed simultaneously to provide Perth with water security through diversity. The primary criteria for selection of IWSS source options have been unit cost, yield volume, and climate independence. This led to efficiency in demand management and water use, seawater desalination projects, and investigation of managed aquifer recharge of treated wastewater. With successful trialing and community acceptance of the latter option, groundwater replenishment has replaced seawater desalination as the preferred new water source, due to its lower unit cost. However, both recycling and seawater desalination are likely to be needed into the future.

### Main Challenges to Selection and Implementation of Solutions

The Water Corporation has had good support from the government and the Department of Water (the water resource manager) in selecting and implementing the source solutions for the IWSS. A water policy unit was established in the Department of Premier and Cabinet in the early 2000s to support and coordinate the government policy response. Initial resistance to proposed restrictions on domestic garden watering by the nursery, turf, and irrigation industries was overcome by genuine engagement.

A major challenge since the early 2000s has been managing the decline in groundwater levels. Addressing this challenge requires reductions in scheme and self-supply water extraction. The Department of Water has worked with the Water Corporation over the past decade to reduce the dependence of the IWSS on groundwater sources. The department is currently developing an updated water allocation plan for the Gnangara groundwater system to manage sustainable groundwater extraction by 2030.

As the first major seawater desalination plant in Australia (and the southern hemisphere), the Perth Seawater Desalination Plant broke new ground in terms of the technology, regulatory approvals, contractual, and operational aspects. The very dry winter in 2010 triggered a decision to double the capacity of the state's second plant, the Southern Seawater Desalination Plant, while it was still under construction.

The Water Corporation's groundwater replenishment source is a climate-independent, affordable scheme supply option utilizing wastewater. Large-scale managed aquifer recharge of recycled wastewater for indirect potable reuse had not been attempted in Australia before and required new thinking in terms of the water treatment technology required and the approvals processes with the three regulators (Department of Water, Department of Health, and Department of Environment Regulation).

The restrictions on the use of IWSS-supplied domestic garden irrigation (two days a week) and domestic self-supply bores (three days a week) had the potential for conflict with householders. However, the community engagement on these actions was handled well, and these restrictions have now largely been accepted as ongoing good watering practice.

The proposal to use recycled wastewater for potable water supply had potential for community opposition. A direct reuse proposal in Queensland a few years before had to be abandoned due to community opposition. Thus, the Water Corporation actively engaged a broad cross-section of the community as well as technical experts, political leaders, and individuals identified as potential opposers in the development of the project. It conducted a very effective community engagement program, and this alternative supply source has received a high level of community acceptance (consistently greater than 70 percent in the general community and 90 percent from those who have visited the trial information facility).

The state needed to make significant capital investments in new water sources infrastructure over the past 15 years. Large capital investment to support metropolitan scheme supply included the Perth and Southern seawater desalination plants, Harvey pipe project, Kwinana water reclamation plant, stage 1 Groundwater replenishment scheme, and improvements to the distribution system.

There is no competition for seawater desalination as a drinking water source since Perth is a coastal city, and there are few other users able to afford the cost. However, there is potential competition for recycled wastewater between the Water Corporation's GWRS and other potential users of recycled wastewater. Groundwater replenishment is considered an important in the short-, medium-, and long-term source for future scheme supply. Recycled wastewater, most likely through aquifer recharge, is emerging as a potentially valuable source for future self-supply.

## Other Solutions

### Solutions Considered but Not Implemented

Water source options for Perth that were considered but not implemented include the South West Yarragadee groundwater supply—an option to harvest 45 gigaliters per year from the South West Yarragadee aquifer. There was some local community opposition, and the investigations indicated that insufficient groundwater was available. Another was harvesting 30 gigaliters per year of groundwater from the Gingin-Jurien area. The option did not proceed because this source had higher risks due to the continuing drying climate and potential community opposition. Several other options were rejected because they were either more expensive than seawater desalination or climate-dependent or both (GoWA 2009a). Seawater desalination is now the benchmark for considering all future source options since it is climate-independent.

The Water Corporation is currently updating its long-term demand and supply forecasts for the IWSS. The Department of Water's preliminary work indicates that the current IWSS demand of 300 gigaliters per year will increase to about 460 gigaliters per year by 2050. This estimate accounts for projected population growth as well as continuing water use efficiency gains that should reduce per capita water use from 127 cubic meters per year currently to 115 cubic meters per year by 2030.

The Department of Water's assessment of the outlook for self-supply water users in the Greater Perth region indicates that current self-supply demand of 305 gigaliters per year will increase to about 490 gigaliters per year by 2050. Including the projected effect of climate change on the groundwater and surface water resources in the region, the gap between unconstrained self-supply water demand and water availability is likely to be about 140 gigaliters per year by 2050.

## Projected Future Limits on Current Solutions

By 2060 the total volume of treated wastewater in the region is projected to be about 270 gigaliters per year (GoWA 2009b). When estimating the effect of water use efficiencies on available wastewater volumes, this figure could reduce to about 210 gigaliters per year, about 60 gigaliters per year more than the projected IWSS demand-supply gap by 2050.

In planning for self-supply water users, the objective is to meet the projected gap of about 75 gigaliters per year for licensed uses through water use efficiency gains and recycled water use. The objective for the estimated 2050 supply-demand gap of 65 gigaliters per year for water uses exempt from licensing is to meet this demand through making significant improvements in domestic bore water use efficiencies and preventing future growth in the installation of domestic bores. Limiting the growth of domestic bores could transfer demand to the public supply scheme; however, it would be at a reduced volume since average scheme garden watering rates are lower than those for domestic bores.

Locally recycled wastewater supplemented by drainage water could be a source for licensed self-supply water use. Recycled wastewater is preferable as it is climate-independent, but this resource is limited and will be subject to competition from the IWSS. Local supplementation with drainage water is therefore an important tool for future self-supply water users. On the eastern parts of the Swan coastal plain, groundwater tables are high in winter and most of the new urban development areas require subsoil drainage to control the water table. This subsoil drainage represents a potentially large and viable supplementary water source for self-supply use.

## Lessons

Perth's long dry summers, natural groundwater, and location present a particular challenge. Groundwater has been the go-to water resource for Perth for many years, enabling scheme security and irrigation of parks and gardens to offset the effects of an extremely long and dry summer. Perth's location—on the western side of a land mass at latitude 32—means it is subject to an ongoing drying effect of declining rainfall with reduced recharge to groundwater.

The drying climate has impacted water availability for Perth's IWSS as well as those who draw their water supplies directly from their own groundwater bores. State governments have invested significantly in new scheme water sources to stay ahead of the drying climate and water demand due to population growth. But with recent years among the worst recorded in terms of inflows into Perth's drinking water dams, the development of climate-independent initiatives is being accelerated.

The Water Corporation is planning for the next climate-independent sources, and is looking at a range of longer-term options. Dams will still be important: storing water in wetter years and seasonally from desalination plants, supplying local communities, and providing carefully managed flows for small-scale downstream water users and the environment.

The Water Corporation's groundwater replenishment trial has ensured the necessary time and expertise to test the technology in local conditions and gain endorsement from state regulatory agencies. The corporation also carried out an extensive community engagement program during the trial and gained a critical level of community support for the project.

Guided by contemporary scientific studies and modeling, as well as practical input from stakeholders, the Department of Water is planning for reductions to total groundwater abstraction, encouraging further gains in water efficiency and exploring alternative sources for nonpotable water needs. Reducing groundwater use while maintaining economic growth will be challenging and will rely on clear direction and strong community engagement.

Self-supply groundwater users have noted the Department of Water has periodically granted the Water Corporation's application for a temporary additional groundwater allocation to mitigate a potential public water supply shortfall. However, while maintaining public supply is an important priority, this contingency approach is expected to be phased out due to surmounting challenges.

The people of Perth have adjusted to sprinkler rosters, responded to demand management campaigns, and reduced average per person water use. Perth's water future will continue to rely on support from a water-aware community, and increasingly on climate-independent sources, further innovation for nonpotable sources, and water-smart but highly livable urban design.

Perth's water future depends on a sustainable groundwater resource that contributes water for scheme supplies, local horticulture, industry, parks, sporting grounds, schools, and gardens. Over time, introducing alternative water sources will take pressure off natural groundwater and build climate resilience for businesses and the community.

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View from Nahargarh Fort in Jaipur, Rajasthan, India. *Source:* https://pixabay.com/en/jaipur-city-india-top-view-indian-166512/.

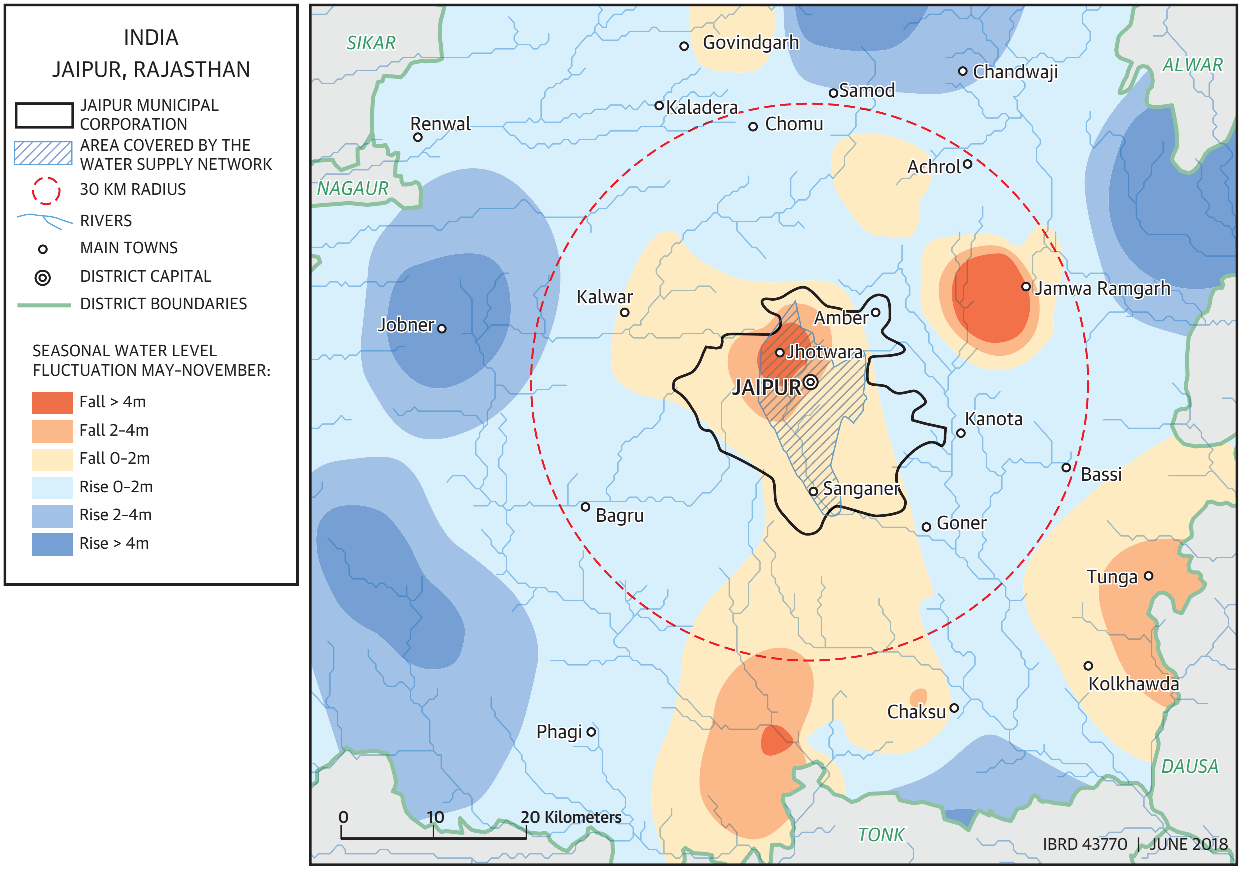
# Chapter 15
# Jaipur, India

Jaipur is the capital city of the Indian state of Rajasthan. India's water policy gives priority to water use for human survival with water use prioritized in the following order: drinking, community, domestic use, agriculture use, and industrial use. Agriculture uses about 80-90 percent of the available water; drinking water uses about 5-6 percent; and industry, energy, and other uses make up the remaining water demand (NITI 2016). With greater urbanization and industrialization, urban and industrial use's demand of water is expected to only increase and thereby continue to put pressures on the existing sources of water.

At 290 years old, Jaipur was originally developed because water was abundantly available compared to other locations in the region. The site for city of Jaipur was chosen because of these key factors: (a) adequate drinking water due to the presence of perennial water from River Dravyavati emerging from the Aravali Hills (i.e., north of the proposed city location); and (b) the area had a good capacity for rainwater being captured below the sand dunes at a easily recoverable depth of 5-10 meters. The area also had a good natural drainage system toward the northeast leading into a swamp. The overflow from the lake drains toward River Dhund behind the Eastern Hills and hence provides safe areas from a flooding perspective.

Jaipur has attempted to manage water scarcity by constantly managing water resources and supply strategies to safeguard itself against risks associated with depleting water resources and pollution. Map 15.1 shows the water scarcity situation in Jaipur. The city has attempted to achieve reliable urban water supply for its growing population as well as mitigate the water stress risk associated with climate change and other natural factors.

**MAP 15.1. Water Scarcity in Jaipur, Rajasthan**




This chapter discusses how Jaipur has managed its water resources and summarizes the strategies the city has adopted and its successes and failures.

## Climate and Geology of Jaipur

The region of Jaipur has patchy rock outcrops that are limited, occasional, and narrow in northeast ridges, projecting from a vast alluvial and sandy plain. The hills around Jaipur are part of the Aravalli chain that stretches from Delhi toward the state of Gujarat (Navin, Mathur, and Gupta 2015). Jaipur District is characterized by a wide spectrum of landscapes including hillocks, pediments, undulating fluvial plains, aeolian dune fields, ravines, and palaeochannels (CGWB 2013).

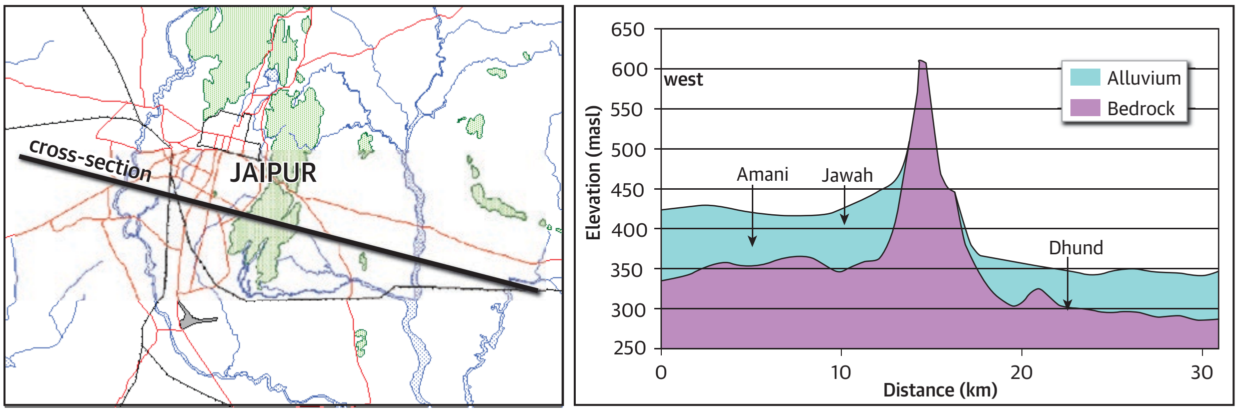
The quaternary sediments consist mainly of layered deposits of sand, silt, and, to a lesser extent, clayey sand of aeolian origin, which have been deposited on the base rock layer, now eroded and flattened (GSI 2011). The sediment soil cover varies between 45 meters and 120 meters over the base rock. This upper sandy layer forms the aquifer of Jaipur from which water has been mined. The base rock is very thick and believed to be over 1,000 meters deep. Map 15.2 is a of the area with a typical cross section West-Northwest-South-Southeast axis.

All the rivers, channels, drains, and nalas in Jaipur are ephemeral, that is, they flow only during and just after rainfall events. However, many drains are now carrying treated or untreated wastewater from the city.

**MAP 15.2. Jaipur Area West-Northwest-South-Southeast Vertical Cross-Section Showing Alluvium and Bedrock**

a. Cross-section line across Jaipur area

b. Corresponding vertical cross-section

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The Jaipur area has the following major catchments, covering an area of approximately 170 square kilometers:

- North and North East Catchment (Brahmpuri Nalla and Nagtalai Nalla), which flows into Jal Mahal Lake, which overflows into River Dhund downstream of Kanota Dam
- Southern and South Western Catchment, which includes tributaries such as Jawahar Nala and Jhalana Nala, these then flow into the Aminasha Nala before the confluence with River Dhund.

The climate of Jaipur, which is situated on the eastern boundary of Thar Desert, is semiarid. Nearly 90 percent of the annual precipitation occurs during the monsoon months (DWR 2015). The rainfall in the Jaipur area varies from a typical 500 millimeters per year in the western region, to 780 millimeters per year in the hills north of Jaipur. The average rainfall in Jaipur region is 620 millimeters per year.

## Institutional Agencies Involved in the Water Sector

The water supply and sanitation (WSS) sector in Jaipur is governed by a fairly complex institutional structure categorized by fragmented responsibilities for different sets of institutions including municipal bodies, state entities, and other institutions. Since the WSS is a state subject, the Rajasthan government is responsible for developing overall policy and standards, and directing investments in the sector. The responsibilities of the state include development, financing, and cost recovery for WSS within its territory.

The city of Jaipur has a number of agencies involved in the water sector. Rajasthan Public Health Engineering Department (PHED) supplies drinking water to all cities in the state of Rajasthan, including Jaipur. This agency is responsible for bulk water supply, including mining of groundwater, treating it as required, and supplying it to consumers. The Rajasthan Ground Water Department (RGWD) develops and maintains the infrastructure for mining groundwater for the purposes of drinking and irrigation. The RGWD sets the limits for groundwater extraction. The Rajasthan Water Resources Department (RWRD) supplies water to the city of Jaipur from the Bisalpur Dam. The Jaipur Development Authority (JDA) plans and develops urban infrastructure for the city of Jaipur. The JDA provides water and sewage infrastructure for new development areas, and makes investments in new sewage and storm drainage infrastructure projects.

Jaipur Nagar Nigam (JNN) is the urban local body that operates and maintains all Jaipur's urban infrastructure projects—including sewer collection and stormwater drainage—but not water supply, which is done by PHED. The Rajasthan Urban Infrastructure Development Project (RUIDP) develops the urban infrastructure in Rajasthan, including water, sanitation, sewerage, and sewage treatment projects. Many infrastructure improvement projects in Jaipur have been executed by RUDIP, such as improvement of sanitation, new sewer lines, and sewage treatment plants.

## Development of Jaipur's Water Supply

The water supply scenario in Jaipur can be classified into following distinct periods:

- 1700s-1955. Water supply provided by rainwater storage tanks and shallow groundwater wells
- 1955-82. Water supply provided by rainwater storage tanks, the Ramgarh Dam, and shallow and medium groundwater wells
- 1982-2006. Water supply provided by the Ramgarh Dam and groundwater mined using deep tube wells with submersible pumps that gradually replaced the diminishing Ramgarh surface water supply
- 2006-10. Virtually all the water supplied using deep tube wells with submersible pumps (effect: water table diminishing at 3-4 meters per year)
- 2011-present. Majority of water supply provided by the Bisalpur Dam (83 percent) and some groundwater being mined using deep tube wells (17 percent).

Because of the high extraction of groundwater, the water table has been gradually decreasing (CGWB 2015). Groundwater level, which was at about 5-10 meters deep in 1951, has presently decreased to 75-80 meters. The water supply problem has worsened because the water quality has deteriorated with time. It has high total dissolved solids, high nitrates ($NO_3$)—typically in areas where there is old habitation and near areas where wastewater flows, such as Amanisha Nala—and is contaminated with fluorides in the southern region.

### External Events that Influenced Jaipur's Development and Water Supply

After the partition, there was a sudden increase in the city's population, which led to a sharp expansion of the urban area. During this period, water was provided through groundwater changing the surface to groundwater ratio from 2.3 to 0.7. From 1951 to 1971, to meet the water demand due to population increases, additional surface water was supplied from the Ramgarh Dam, which resulted in a change in the surface to groundwater ratio from 0.3 to 3.2, later reduced to 1.90 by increased groundwater extraction. From 1971 to 1985, the increase in water demand was met by higher groundwater extraction, with surface water to groundwater ratio around 2.2. However, the heavy rainfall on July 23, 1981, resulted in a major loss of about 40-50 percent of the water supply sources: shallow dug wells were completely clogged, and rainwater storage structures were significantly damaged. This incidence resulted in increased groundwater mining, which changed the surface to groundwater ratio from 2.20 to 1.20.

The increased groundwater extraction resulted in a very rapid decline of groundwater table, by as much as 1.5 meters to 2 meters per year. The Ramgarh Dam—the only surface water source—became a nonviable source in the late 1980s to the early 1990s, when it experienced a reduction of inflow into its catchment due to the gradual reduction in the catchment area because of encroachment and unplanned expansion (Roberts, Reiner, and Gray 2014). The problems were further aggravated due to poor rainfall. The anthropogenic activities and a couple of years of poor rainfall resulted in an extreme water crisis in the year 2005-06, during which surface water flow from Ramgarh Dam completely dried and virtually no surface water was available for supplying water to Jaipur (Dass, Jethoo, and Poonia 2013).

Jaipur's water supply from surface water sources was about 70 percent from 1941 to 1981 until high rainfall destroyed a major portion of rainwater storage tanks that supplied surface water to the city of Jaipur. Subsequent unplanned and poor reservoir management primarily attributable to anthropogenic activities—such as construction of check dams and anicuts, changes in land use, additional farmhouses, and reduction forest land in the catchment—led to poor inflow into the dam. This situation resulted in a gradual decline of inflow of water into the Ramgarh Dam; its supply of nearly 60 percent of Jaipur's surface water dropped to almost *zero,* making Jaipur almost completely dependent upon groundwater until 2011. In that year, water from the Bisalpur Dam arrived to the city.

## Water Tariff

The water tariff for city of Jaipur, Delhi, and Bangalore for different types of water users is summarized below. The tariffs have been increased with the addition of a sewerage charge, which in each city are as follows:

- Jaipur water tariff, plus 25 percent sewerage charge
- Delhi water tariff, plus 60 percent sewer charge
- Bangalore water tariff, plus 25 percent sewerage charge.

An independent water tariff review (Agam 2010) from 2010 shows the direct cost of water is about US$0.22 per cubic meter for direct operating costs and US$0.35 per kiloliter including cost of recovery of investment. The current operating cost of water for Jaipur: (a) tube well water is about US$0.25 per cubic meter; and (b) Bisalpur water is about US$0.40 per cubic meter. The cost of water is estimated to be in the following ratio: (a) water consumer, 40 percent; (b) government, 60 percent.

## Bisalpur Dam Water Supply Project

The Bisalpur Water Supply Project (BWSP) was designed to supply drinking water to Jaipur and Ajmer and provide irrigation to areas in the Tonk District. To ensure completion of the proposed BWSP, the State of Rajasthan requested the Asian Development Bank (ADB) provide assistance.

The BWSP was designed to supply water to the city of Jaipur to reduce the dependence on the severely constrained groundwater resources. The execution of the BWSP was based on recommendations in Safege Consulting Engineers' Jaipur Water Supply and Sanitation Feasibility report, prepared in 2000. The project's components included a pumping station at the headworks; construction of an 8.4-kilometer raw water pipeline; construction of a new water treatment plant (with a capacity of 400 million liters per day); and construction of approximately 97 kilometers of clear water pipelines; it also had the provision to supply potable water to villages along the pipeline route.

The dam is about 120 kilometers south of Jaipur on the Banas River and has a storage capacity of 38.70 thousand million cubic meters, and of this the Central Water Commission has made 33.15 thousand million cubic meters available, with 75 percent reliability factor considering evaporation and other losses. The net water available for drinking and irrigation is approximately 24.5 thousand million cubic meters with allocation as follows:

- 11.1 thousand million cubic meters to Jaipur, Tonk, and en route villages for drinking water supply schemes
- 5.1 thousand million cubic meters to Ajmer, Beawar, Kishangarh, and Kekri for drinking water supply schemes
- 8.0 thousand million cubic meters for irrigation of 81,800 hectares of agricultural land in Tonk, Todarsingh, and Deoli.

### Monsoon Influence on Groundwater Levels

The Rajasthan Ground Water Board (RGWS) records the levels in wells two times a year: premonsoon (usually May to June), and postmonsoon (usually October to November). Of the available data of 368 wells, only 100-125 have numerical values and other data points either have "no data" or are reported as "dry" or "filled."

### Sewerage System in Jaipur

Jaipur is partially sewered, and there are several ongoing projects to increase the percentage of sewerage coverage. The work of laying sewer lines is carried out by the JDA, the Jaipur Municipal Corporation (JMC), the Housing Board, the RUIDP, and the PHED. Many areas of urban Jaipur have sewer lines (i.e., laterals) and many new areas have planned sewerage collection schemes.

The laying of sewers has not kept pace with the increasing population (Rathore 2004). There are many *kachha bastis* (nonpermanent dwelling places) that have no water supply (except for government-installed hand pumps) and no or very little sanitation or sewage collection infrastructure. The growth of kachha bastis and the migration of people exceed the planned phased of development of Jaipur. Therefore, while the actual area under sewerage (as percentage of city area) has increased, the population served has decreased.

Jaipur has three large operational sewage treatment plants capable of treating 202 million liters per day; however, at present they treat only about 125-130 million liters per day. Additionally, there are three small sewage treatment plants treating 3 million liters per day of sewage for reuse in the green areas. Five new sewage treatment plants are under construction with a total treatment capacity of 65 million liters per day.

While there are many existing and planned sewage treatment plants, the efficiency and level of treatment is broadly subpar. There is a need to ensure that the assets created function efficiently so that the untreated or partially treated wastewater does not adversely impact the water quality of surface water bodies.

## Current Challenges

### Sustainable Groundwater Recharge

Jaipur has a sloping ground with the higher levels in the northwest quadrant and lower levels in the southeast. Generally, on such sloping grounds the infiltration is dependent upon the intensity of rainfall, impervious area, substrata, and local depressions, which could permit a delayed infiltration. In general, the runoff is quite high.

The runoff coefficient varies with rainfall intensity of rainfall. Rainfall below about 10-15 millimeters per day with intensity less than 1-2 millimeters per hour does not produce any significant runoff. During such rains, water is absorbed into the ground and aids infiltration or is lost as evaporation, generating a low runoff. However, during heavy intensity showers, the runoff is more because the rate of infiltration into pervious areas is less than the intensity of rainfall.

Since Jaipur generally experiences more short duration, high-intensity showers, there is more runoff and lower infiltration of water that is available for recharging groundwater. This essentially means that it may take a very long time to rebuild the groundwater resources primarily due to geographical and geological features.

The groundwater rejuvenation challenge is further worsened due to the increase of impervious area and reduction of forest area by change in land use. Also, the filling of local depressions for urban development has led to a reduction of Jaipur's wetlands, which served as surface water bodies and groundwater recharge facilities.

### Security of Bisalpur Water Supply

A "declining trend" of inflow into the Bisalpur Dam despite normal rainfall has been observed during recent decades (Gupta, Bhartik, and Jethoo 2014).

The inflow into the dam from the dam's catchment area over the years has decreased due to these reasons:

- Changes in land use pattern in the Bisalpur Dam's catchment area and construction of small water harvesting structures, that is, anicuts in the catchment area
- Increased surface and groundwater abstractions from the Banas River, which flows into the Bisalpur Dam (Gupta, Bhartik, and Jethoo 2014)

The design capacity of the Bisalpur Dam is 1,100 million cubic meters at 50 percent dependability. The inflow into the Bisalpur Dam and its dependability has reduced. Considering these observations, the Rajasthan government has proposed interlinking various river basins so that the quantity of water available for filling water in the Bisalpur Dam increases.

### Untreated Wastewater Polluting Groundwater and Surface Water

While sewerage coverage has increased, the sewage treatment effectiveness has lagged. Adequate sewage is not reaching the treatment facilities due to no clear-cut ownership of operating and maintaining the sewage collection system infrastructure. There are inadequate funds available for JNN, the sewage treatment plant operator, which is unable to pay the outsourced operators. As a result, they do not have replacement funds for maintaining the facilities. While present cost allocation for sewerage treatment is 25 percent of the water tariff, sewage treatment needs funds more than or at least equal to the water tariff.

### Nonrevenue Water

Jaipur has high nonrevenue water (NRW), which is about 45 percent of the water supplied (Chandrasekharan, Sharma, and Sundaram 2004). The high NRW is attributable to factors such as defective water supply meters or no meters and an aging water supply system that needs to be replaced.

During a pilot study on NRW and 24/7 water supply, the following activities were undertaken (Indian Energy Exchange 2014):

- Information, education, and communication activities include the benefits of 24-hour water supply and benefits to consumers such as saving electrical power, adequate and reliable water supply, and lower possibility of contamination.
- District metering activities involve preparation and verification of water pipeline plans and laying of new pipelines to pilot areas from the service reservoir; installation of isolation valves and bulk water meters; replacement of consumer water meters; and commission of district plan to access the performance.

The pilot study demonstrates that there are significant inefficiencies in the water supply system that can be improved to improve the overall water availability.

## Planned and Ongoing Solutions

### Rejuvenation of Amanishah Nala and Dravanti River

One project is to develop Amanishah Nala as a center of attraction and an important natural water body for the city of Jaipur (Jaipur Development Authority 2018). Steps include the following:

- Prevent raw sewage or effluent entering into the nala by construction of intercepting sewers;
- Use the treated sewage to rejuvenate the water flowing in the nala;
- Ensure management of floods and reduce risk of flooding in the low-lying adjoining areas;
- Develop landscaped area for public use and for social and commercial infrastructure.

The work will include course correction and strengthening of the Amanishah River embankments, including protective lining against high levels experienced during heavy rain, enhancement of carrying capacity, and development of peripheral structures with landscaping.

Sewerage interception, treatment, and disposal involves intercepting the sewage from existing drains and sewer lines; then treating and discharging into the nala. There would be four sewage treatment plants with a total capacity of 125 million liters per day, and treated water quality would be biochemical oxygen demand (BOD) of less than 10 milligrams per liter and total suspended solids (TSS) of less than 10 milligrams per liter.

### Enhancement of Water Supply Bisalpur

The Rajasthan government has approved the Bisalpur Phase-II project, which will cover the remaining areas under the JNN as a long-term solution to the drinking water problem in Jaipur. The Japan International Cooperation Agency (JICA) will finance the project. It will enhance the capacity of Bisalpur water from 600 million liters per day to 930 million liters per day. The project will involve construction of a new intake pumping station, additional raw water pipeline and water treatment plant at Surajpur (from where water shall be pumped to the Bambala pumping station and onward to Jaipur).

### Rainwater Harvesting

JDA and JNN have built about 82,000 square meters of roof water harvesting in institutional buildings at a cost of about Rs. 18,000 per square meter. However, the impact of these structures on groundwater level needs to be reviewed. JDA has a plan to clean the water harvesting structures after the first rain shower in excess of 5 millimeters so the solids and rubbish that come with the first rain can removed and cleaned.

JDA has instituted a regulation that all buildings built on land size greater than 300 square meters (with a maximum built-up area of 60 percent) should have rainwater harvesting structures. This requirement is mandatory only for new construction or an old construction being modified. Presently, the installation of rainwater harvesting structures does not apply to existing buildings. The effect of rainwater harvesting structures on groundwater needs to be verified with a regular monitoring of groundwater table. The impact results of such regulations are likely to take a few years to manifest.

### Interlinking of River Basins Chambal—Brahamani—Banas

A project development company jointly promoted by Government of Rajasthan and Infrastructure Leasing and Financial Services Limited (IL&FS) (PDCOR), prepared a detailed project report for PHED in 2016 to address the mitigation of the reliability of lower inflow in Bisalpur Dam. The report states that the Bisalpur Dam—developed as a source of drinking water for Jaipur, Ajmer, and Tonk—has a water demand of 459 million cubic meters for drinking. Yet only 121.7 million cubic meters of water would be available at Bisalpur at 90 percent reliability, leaving a deficit of 337.3 million cubic meters. Bisalpur is an important source of water for a large area of 19 towns and 2,881 villages. It is expected that by 2050 it would be the major source of drinking water for 10 million persons.

PDCOR has prepared a mitigation strategy that proposes a river interlinking project to ensure that the excess rainwater in the Chambal and Brahamni rivers would flow to the Bisalpur Dam to meet drinking water and irrigation requirements. The project would involve the following:

- A dam on Brahamni River of capacity of 177 million cubic meters is proposed to be constructed
- Construct a pumping station capable of lifting 4.5 million cubic meters per day from Jawahar Sagar; it would be constructed on the Chambal River through 3,200 millimeter pipes to the Brahamni Dam
- Construct a transmission system from the Brahamni Dam to the Bisalpur Dam by tunnel, aqueduct, and gravity channel
- Lift an estimated 234 million cubic meters from Jawahar Sagar and 177 million cubic meters from

the Brahamni Dam at 50 percent dependability (i.e., 411 million cubic meters during deficit years), which would make Bisalpur a sustainable water source for drinking water.

The cost of this project is estimated to be around Rs. 6,000 (US$900 million), with a start date of 2018-19 and a six-year completion period. This project has received government approvals to proceed and is currently being undertaken for transaction and execution.

## Lessons

Jaipur is a great example of the water resource infrastructure development story for any growing city that wishes to achieve long-term water sustainability. A study of the nearly 300 years of Jaipur's development shows how a city considered as an ideal location for habitation has faced and continues to tackle the challenges of population growth, water source mismanagement, and natural events.

The city's location was chosen primarily based on the availability of natural resources, particularly water. The growth of Jaipur suggests that population growth cannot be based only on groundwater, especially in semiarid regions. The experience of Jaipur clearly highlights the importance of developing water resource infrastructure with an optimum and well-balanced reliance on both surface and groundwater resources. For many decades Jaipur has maintained a sustainable balance by relying on both surface water (dams and ponds) and shallow groundwater wells. However, after the heavy rain event that damaged a large portion of the existing surface water sources, the city's dependence on groundwater resources increased significantly, which apparently disturbed the natural balance. The groundwater problems have further accelerated due to easy access and adoption of technological advanced solutions (submersible pumps in this case), unplanned development, and overexploitation by the growing population.

When Jaipur relied on groundwater as a water reservoir to capture and store (albeit naturally) surface and rainwater and mined it incrementally or during periods of drought, the natural water balance between demand and supply was maintained. The delicate balance was easily lost, however, as shown by the high rate at which groundwater levels dropped in the region. Urban planners can use the experience of Jaipur to see the need for integrated urban water management planning and development.

As part of an integrated urban water management process, the Jaipur case illustrates the need to adopt well-planned urban development programs and execute them efficiently. To protect surface water sources, it is not enough to just focus on rainwater harvesting or building ponds and dams. It is also critically important to look at two other main factors: (a) protection of catchment areas from encroachment or infringement due to myopic urban planning strategies; and (b) control of wastewater treatment and discharge into the catchment areas of water resources. As witnessed in Jaipur, not only have the groundwater levels been depleted but also the quality of water from many groundwater wells have been significantly impacted due to prolonged and uncontrolled anthropogenic activities.

Another very important lesson from Jaipur's case study is that good quality and adequate water resource infrastructure development is costly, and without proper cost recovery mechanisms and sustainable revenue streams, it is very difficult for governments alone to continue serving the growing water requirements. There is a clear case for rationalized water tariffs for water supply and sewage along with multistakeholder participation in water governance and institutional reforms to ensure that city residents appreciate that good water comes at a cost.

While access to water is a human right and providing access to a certain minimum quantity of water for meeting basic human needs is one of the fundamental responsibilities of the state, it is important to understand that the challenges in water space cannot alone be managed by the government. The study of Jaipur and a quick look at the proposed and ongoing initiatives clearly highlights this aspect. The city is now working on multiple solutions, including large infrastructure projects such as augmenting surface water sources (Bisalpur water project and interlinking of rivers); rainwater harvesting initiatives (policy for public participation); wastewater management (Amanisha nala and other wastewater treatment and reuse projects); and initiatives that have been designed with a clear focus on multistakeholder participation and involvement.

Jaipur appears to have learned its lessons—perhaps the hard way—since it is working on taking varied steps to enhance its water resources. However, it is yet to be seen whether the efficiency of the stakeholders in making the ongoing and planned water management initiatives will be successful in reviving the city's water resources and making them more resilient and sustainable.

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Seashore of Fortaleza. *Source:* ME/Portal da Copa http://www.copa2014.gov.br/pt-br/dinamic/galeria_imagem/14406.

# Chapter 16
# Fortaleza, Ceará, Brazil

Fortaleza is the state capital of Ceará, located on the Atlantic Coast of northeastern Brazil. The metropolitan region of Fortaleza has 4 million inhabitants and is composed of 15 municipalities that hold 55 percent of the state's population. With 2.6 million inhabitants in the municipality of Fortaleza alone, it is the fifth most populated city in Brazil. The municipality of Fortaleza has the largest gross domestic product (GDP) of the northeast region (US$9,920 per capita in 2014) and the 10th largest in the country. Though its economy has historically relied on agriculture, the city started to attract industrial investments in the early 20th century and later became a commercial hub. Today, tourism is the largest sector in the service economy and is steadily on the rise (map 16.1).

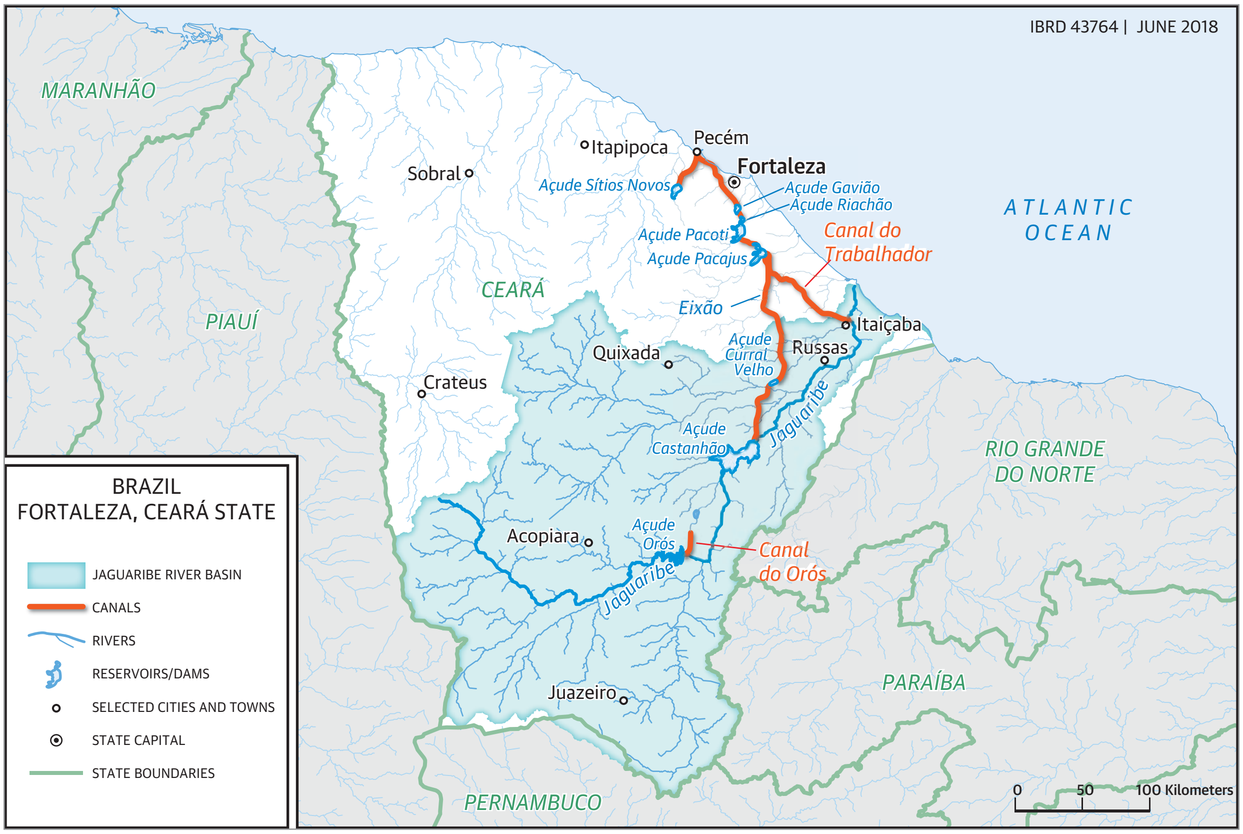
Recurring droughts have been documented in Ceará since the beginning of the 17th century. Like most of semiarid northeast Brazil, Ceará faces an ongoing drought that started in 2010 and is considered one of the worst in recent decades (Gutiérrez et al. 2014a). Between 2010 and 2016, four years had the least precipitation on record during the rainy season since the 1950s.

## Climate and Hydrology

The northeast region of Brazil accounts for 18 percent of the country's territory and about 28 percent of its population. However, the region contains only 5 percent of Brazil's freshwater resources and overlaps almost entirely with the semiarid territory of Brazil, also called the Drought Polygon (Formiga-Johnsson and Kemper 2005).

The coastal city of Fortaleza has a tropical savanna climate, with high temperatures and high relative humidity throughout the year; the interior of Ceará has a predominantly tropical semiarid climate. The temporal and spatial variability of precipitation in Ceará is

**MAP 16.1.** **Fortaleza, Ceará, Brazil**




very strong, with a concentrated rainy season from February to May accounting for over 70 percent of the annual rainfall. In some parts of the state, the majority of annual precipitation occurs in only one month (Gutiérrez et al. 2014b).

The average annual precipitation in Ceará is 875 millimeters, but it ranges from approximately 1,300 millimeters in Fortaleza to 400 millimeters in the semiarid inland. Although these rates of rainfall are higher than those in many dry areas in the world, the region's rocky, impermeable soil and high insolation yield low water storage and retention capacity and elevated rates of evapotranspiration (up to 1,500 millimeters annually on average). Since groundwater aquifers are present only in 20 percent of the state, 90 percent of the water used comes from surface water.

Although Fortaleza is located in the coastal basin, the metropolitan area depends principally on the Jaguaribe River Basin for water. About 70 percent to 78 percent of Fortaleza's water supply comes from the interbasin transfer. The Jaguaribe River Basin is an independent basin situated entirely in Ceará—its drainage area covers approximately 48 percent of the state's territory. Because cyclical droughts occur at least every five years, all of the basin's rivers would be intermittent were it not for regulation and the water resource management system put in place by the state (COGERH 1999a). In the northeastern states, climate change has exacerbated droughts and the need for water resource management over the past decade.

Three large dams provide regulation to the Jaguaribe River, forming the Orós, Banabuiú, and Castanhão reservoirs and representing 75 percent of the basin's total storage capacity of 13.6 billion cubic meters). Many smaller reservoirs dot the river basin, but only a few are deemed strategic and monitored by the Companhia de Gestão dos Recursos Hídricos (COGERH). About 70 percent of Jaguaribe water goes to Fortaleza, which has caused some conflicts with other users.

## Water Use

Water supply coverage is close to 100 percent, but sanitation services lag in Fortaleza. Both services are provided by Companhia de Água e Esgoto do Ceará, the state-owned utility (CAGECE 2013). About 57 percent of the city is connected to sewerage,[1] and access to the network is characterized by significant spatial variability. Although coverage exceeds 90 percent in the city center and along the coast, it ranges from zero percent to 50 percent in the south of Fortaleza. Over 16 percent of the population lives in informal settlements with inadequate sanitation, drainage, and housing.[2] Though the Plan Fortaleza 2040 (2017) indicates that 69 percent of households in the metropolitan area have access to "adequate" sanitation, onsite sanitation solutions often consist of unlined pits that can cause groundwater contamination. Further, according to CAGECE (2013), 12.5 percent of the city's population is not connected to the sewer network despite living next to an existing sewer line, due to the connection cost.

As the city expanded, investments in sanitation infrastructure have not kept up, negatively affecting the urban environment. Only 2.5 cubic meters per second (25 percent of total wastewater generated) is collected and treated in the city. Though Fortaleza has many environmental assets, untreated sewage discharges have caused substantial pollution to the city's water bodies, including its beaches and rivers. Socioeconomic inequality is reflected spatially, with some of the poorest areas located along the coast or near bodies of water, where they are vulnerable to floods and exacerbate pollution. CAGECE is coordinating with the municipal government of Fortaleza (Prefeitura Municipal de Fortaleza) (PMF) to implement a municipal sanitation plan, with the objective of achieving universal service coverage and treatment of domestic sewage by 2033.[3] CAGECE (2013) estimated that coverage of sewerage and wastewater treatment of 83 percent is realistic by 2026. Furthermore, the city is currently studying the feasibility of wastewater reuse.

Water quality is a major concern in the Jaguaribe River Basin.[4] Many urban areas upstream of the basin have expanded without the development of adequate sanitary infrastructure, and discharging untreated sewage into rivers and water bodies is common. In addition, regional agricultural practices have generally given little consideration to the effects of excessive agrochemical use. In the reservoirs, the lack of turnover of resources causes high retention times, which in turn also negatively affect water quality.

The city's economy relies heavily on the service industry, especially on tourism, making potable demand a priority. In 2016, the total production need (including all uses and losses) in Fortaleza was 10 cubic meters per second, predominantly allocated to potable water use. According to CAGECE, water consumption in 2015 was 127 liters per capita per da y,[5] a relatively low number for a water scarce area, and as of March 2016, the average consumer price in Fortaleza was US$0.97 per cubic meter. Rapid urbanization is further exacerbating the pressure on the system's water resources, especially as the state enters its sixth consecutive year of drought. For 2025, the national water agency, Agência Nacional de Águas (ANA), predicts a water demand of 16.8 cubic meters per second for the metropolitan area of Fortaleza (ANA 2010). To keep up with demand, ANA forecasts a required investment of US$233 million, which includes US$94 million currently allocated to the treatment plant east and the reservoir Taquerão.

The transfer of water from the Jaguaribe River Basin to the city of Fortaleza has intensified the conflicts between local stakeholders in the basin and COGERH. About 70 percent of the Jaguaribe water goes to Fortaleza, and other users fear the future loss of water.

In turn, government agencies have seen the large water transfers as a way to reduce Fortaleza's vulnerability to drought (Lemos and de Oliveira 2005). With reservoir levels now below 10 percent,[6] these concerns have been exacerbated. In the past, users have gone as far as tampering with infrastructure to prevent water from leaving the basin.

## Water Balance

Overall demand for the city of Fortaleza is 10 cubic meters per second and is projected to keep increasing. The per capita consumption in the city is quite low at 127 liters per capita per day, which indicates significant system inefficiencies. Today, the city of Fortaleza gets over 80 percent of its water from the transfer with the Jaguaribe Basin, and CAGECE purchases this water from COGERH.

There are also private wells throughout the city, especially in commercial areas and in some condominiums for irrigation and swimming pools. However, the use of groundwater is not under CAGECE's purview and therefore goes largely unmonitored, yielding increases in saline intrusion and wastewater contamination in the aquifer. Estimates put groundwater use at 5 percent of the total consumption. Groundwater use consumption is believed to be marginal compared to overall urban water use.

Another transfer is underway, through the construction of a water transmission canal from the San Francisco River. This water would serve the Fortaleza metropolitan area as well as other areas in Ceará. Because this water passes through various basins and is of uncertain quality, a production price cannot be estimated at this time.[7] Nevertheless, continuing to rely on external transfers remains a stopgap solution for Fortaleza, especially as conflicts around its use of Jaguaribe's water continue to rise as the drought continues.

Indeed, the municipality's plan Fortaleza 2040 highlights its goal to become less dependent on the Jaguaribe River Basin. The plan suggests several measures under consideration—such as wastewater reuse for industrial purposes and irrigation and rainwater harvesting—to reduce dependence on the river basin by 20 percent by 2040. The city has begun investing in desalination and wastewater reuse and is exploring the reclamation of polluted groundwater and addressing saline intrusion into the aquifer as potential new approaches to water management.

Finally, Fortaleza has begun to turn toward demand management, but still has a margin for improved system efficiency. Nonrevenue water (NRW) in CAGECE is currently at 36 percent. In 2016, real losses accounted for 52 percent and apparent losses for 48 percent of that number. The utility has launched some programs to reduce these losses. Today, the suburban areas have the largest portion of apparent losses.[8] In the face of the drought, some conservation measures have been launched, in particular the use of water budgets in 2015. However, other Jaguaribe Basin stakeholders remain unhappy with the city's efforts. A contingency group was formed to respond to the drought and prioritize water needs, with participation from CAGECE, Secretariat for Water Resources (Secretaria dos Recursos Hídricos [SRH]), COGERH, and Cearense Foundation of Meteorology and Water Resources (Fundção Cearense de Meterologia e Recursos Hídricos [FUNCEME]), but still the river basin committee is considering withholding transfers to the city to send a stronger message. Despite the progressive and inclusive approach developed in the river basin around water allocations and negotiations, it is critical for the city to continue improving its own system efficiency and developing local water sources to balance dependence on water transfers.

## Solutions

Despite the six-year drought that has affected the region, Fortaleza has managed to secure its water needs and limit the effects on its economy. The strong institutional structures for integrated water resource management in place at the state level in Ceará have enabled the reallocation of water through interbasin transfers to meet urban water demand and have contributed to Fortaleza's resilience. Furthermore, the processes for stakeholder engagement that ensued and the institutionalization of user-based management organizations have allowed for clear mechanisms to prioritize uses and establish significant conservation measures in the face of drought.

Until the early 1990s, water resource policy and management in the Jaguaribe Basin was under federal control and closely associated with drought relief and energy production, with a focus on increasing supply. Ceará was the second state to pass a state Water Law in Brazil, in 1992, which focused on the river basin as the territorial unit for planning and management, with decision-making placed in the hands of stakeholder committees and basin agencies acting as their executive arms.

The reform process in the Jaguaribe Basin was marked by two distinct phases: first, the decentralization from the federal to the state level, a result of the increased technical, institutional, and financial capacity of Ceará's water resource management agencies; and second, decentralization from the state to the local level through the formation of deliberative and consultative bodies at the river basin and lower territorial levels. The following sections detail the process and challenges of both phases and their contribution to resilience in Fortaleza.

## Building Resilience through Integrated Water Resources Management at the Basin Level

### Creation of a State Water Resource Management Company

Historically, the federal government focused on increasing available water resources, especially by using a network of reservoirs to store water for the dry season and potential drought years. As a result, water resource infrastructure in the Jaguaribe River Basin was already well-developed before the Water Reform decentralized water resource management to the state level in the early 1990s. Because the system originally grew without close control, many small reservoirs are scattered throughout the basin, making monitoring complex.

In the late 1980s, the state government began to play an increasingly important role in water resource management, including supporting the promulgation of a State Water Resources Plan; promoting the implementation of a new water resources paradigm through the implementation of legal water rights; charging for water; educational campaigns; and decentralized decisions (Campos, Studart, and Costa 2000). However, institutional change in Ceará was marked by the creation of the SRH and the passage of the state Water Resources Law. The law embraces the main principles of modern water resource management: integrated water management with the river basin as the planning unit; water as a finite and fragile resource, and as an economic good, managed through a decentralized and participatory approach. Ceará established the following management instruments, later instituted by the federal law: state and basin water resource plans, bulk water use permits, bulk water charges, and a water resource information system.

Although most states relied on existing environmental or water agencies funded by the general state budget, in Ceará, a strong, independent, and self-financed water resource management company—COGERH—was created in 1993 to carry out management, monitoring, and enforcement functions, and to assume control over federal infrastructure in the state. COGERH is an authorized capital corporation, in which the state of Ceará owns at least 51 percent of the voting stock.[9] Unlike SRH, a state government organization, COGERH has more flexibility to implement innovative concepts for water resource management, such as seeking incentives for efficiency and hiring and firing personnel (Porto and Kelman 2000).

### Centralizing Functions

The principal technical functions of COGERH are to manage water resources at the state level by overseeing the infrastructure system and its operations and management, setting prices for bulk water sales, and providing technical and administrative support to the river basin committees within its jurisdiction (Formiga-Johnsson 2014). COGERH also carries out monitoring and enforcement functions and, most important, provides planning, technical information, and simulations to the user commissions and basin committees to aid them in negotiating water allocations. Ceará oversees "negotiated water allocations," in which users' commissions or basin committees collectively decide on allocations based an assessment of the availability and demand for water. The state and the river basins now have water resource management plans that reflect comprehensive and high-quality knowledge about local water problems.

Over time, water management and allocation decision-making for strategic reservoirs has become more democratic and participatory, evolving into an informal water rights system. COGERH played an important role in organizing the users and dam associations to ensure stakeholders were equipped to participate in those larger decisions. In turn, the SRH is in charge of issuing water rights in the basin, except for hydroelectric use, which remains under the purview of ANA. By Brazilian law, human consumption and animal needs have priority over other uses, although in Fortaleza the focus given to the city and its municipal uses has led to some criticism.

Water rights are not tradable, and although formal rights never existed in the state of Ceará before the implementation of the Water Resources Law, many users believed that they held their rights through historical use before their formalization (Campos, Studart, and Costa 2000). The SRH therefore faced the challenging task of convincing many users that formalizing their water rights was necessary and beneficial to ensure future use. The state decree that instituted a price on bulk water deterred many from going through the request process. However, the negotiation of water use at the reservoir level through users' commissions and river basin committees has been successful apart from water rights allocation.

### Water as an Economic Good: Establishing Payments for Bulk Water

In 1996, Ceará was the first state—and the only one until 2003—to implement a system of bulk water charges, which apply to domestic, industrial, and some irrigation uses (Formiga-Johnsson 2007), thus providing COGERH with financial self-sustainability. The decision to centralize water payments helps redistribute resources among the basins in the state, since the Greater Fortaleza Basin is the only one able to cover its own operations and management expenses. In fact, most of Ceará's basins are underdeveloped and therefore benefit from the transfers of revenues from charges from the metropolitan basin (Formiga-Johnsson and Lopes 2003). Water prices are proposed by COGERH and approved by the State Council, composed of representatives from the state, municipalities, and farmers.

Although charges were introduced gradually with tariff adjustments in 2003 and 2017, they have faced much opposition. After some disputes, COGERH took over water supply to industry (and the associated revenue) from CAGECE in 1998. A first attempt to introduce charges for irrigation started in 2001, combined with an effort to shift cultivation to less water-intensive and more profitable crops under the Department of Agricultural Development (Secretaria de Desenvolvimento Agrario) (SDA). Since 2005, COGERH has been expanding the state water charge system, gradually including irrigation, shrimp farming, fishing, and other uses. The tariff for agricultural irrigation varies between US$0.48 per 1,000 cubic square meters and US$7 per 1,000 cubic square meters; for shrimp farming, between US$2 and US$45; and for fish farming, between US$1.50 and US$6, depending on infrastructure needs.

The Fortaleza metropolitan area still contributes over 90 percent of the total collected revenues, subsidizing prices for agricultural activity throughout the basin. COGERH's charges to industry (US$726 per 1,000 cubic meters) are 15 times what it charges

CAGECE for public water supply (US$48 per 1,000 cubic meters) and 30 times more than other water companies, including in the Jaguaribe Basin.[10] In turn, agriculture represents only 1 percent of bulk water revenues, although this is not proportional to the sector's water use because irrigation charges are much lower than those for other sectors. COGERH is also one of the only state water resource management agencies to have financial independence. In 2017, revenues totaled about US$30.4 million, covering both their personnel and operations and management costs (COGERH 2017).

## User Organizations: A Model for Improved Water Allocation

The formation of basin institutions has occurred gradually over more than 15 years, under the initiative and coordination of COGERH and with the support of SRH. COGERH was created first to demonstrate positive results in managing water resources with other stakeholders. Only when water users were better organized at the reservoir scale were the river basin committees created (Porto and Kelman 2000). The user commissions and dam associations served to locally mobilize stakeholders around key reservoirs until the creation of the river basin committees, and they continued to play an important role in local water negotiations thereafter (Formiga-Johnsson 2014). The local organizations that participate in the decentralized decision-making process are (a) the Jaguaribe-Banabuiu user commission—equivalent to a river basin council—defines the annual operating rules of the three major reservoirs of the basin, according to the negotiated water allocation between the users of the regulated valley; (b) 72 users' commissions of "strategic" reservoirs that provide for multiple water uses during drought periods; and (c) 12 subbasin committees that cover the entire territory of the Jaguaribe River.

Ceará has a history of intense interventions by local stakeholders around reservoirs and along the regulated river valleys. Indeed, before the reform, private interests and wealthy landowners took water security into their own hands and created thousands of small reservoirs to meet local needs, many of them on private land (Lemos and de Oliveira 2005). This strong localized involvement motivated the creation of dedicated users' commissions organized around shared reservoirs to avoid focusing solely on the hydrographic regions and their subbasins.

The users' commissions consist of representatives of water users and civil society as well as state, federal, and municipal governments, and their main role is to discuss and decide on the use and allocation of bulk water among the users of their respective reservoirs (Lemos and de Oliveira 2005). They allow for a transparent process involving all relevant stakeholders to define the volumes to be released from the reservoirs, as well as water use and conservation rules. These rules are defined by those who must abide by them and have resulted in a substantial reduction in water use in the Jaguaribe River Basin. Conflicts among stakeholders have also decreased, and participation has increased. Though larger water users still dominate decision-making, the existence of the commissions has encouraged previously unrepresented and disenfranchised stakeholders, such as small farmers, to participate in the process.

The subbasin committees were created a few years after stakeholder participation was established through the commissions. The committees have broader water management responsibilities than the commissions, such as setting guidelines, approving basin plans, and resolving conflicts. The user commissions and basin committees meet annually before the dry season begins to assess water availability and demand. When water is insufficient to meet the demands of the upcoming dry season they implement rationing. COGERH's role in this coordination process is crucial—it provides much of the technical assistance required for the decision-making process (Formiga-Johnsson 2013).

Through decentralization, awareness of water scarcity and the stakeholders' role in the sustainability of the river basin has increased. Concern around Fortaleza's water use shows that other stakeholders are invested in ensuring sustainable water use in the basin. The allocation process has increased transparency and water security in the basin, but it has not yet translated into regularization of the uses. (Formiga-Johnsson 2014) Its main achievements have been the sustained involvement of stakeholders across the basin, improved flexibility and efficiency in the water allocation system, and growing awareness of environmental issues' link to water resource management decisions. However, not all users hold water rights, which sometimes poses problems in the formality of uses. The negotiated amounts, depending on the drought conditions, do not always avoid economic losses. The allocation process could benefit from simulations relying more on weather data and exploring how each use could incorporate water efficiency in rationing. (Formiga-Johnsson 2013)

## Challenges

Water conservation in Fortaleza has not been as effective as anticipated by other stakeholders. Tensions have increased around the allocation for Fortaleza, especially since it currently uses approximately 50 percent of the basin water. To date, the necessity for water conservation efforts across the city has not been properly communicated to users: radio spots and media campaigns have tended to focus more on infrastructure-heavy, supply-side solutions than on aggressive demand management. However, CAGECE has launched campaigns for more responsible water use, and it has put in place water budgets based on each household's consumption as of 2015 to encourage users to stay within a given allocation. Since 2014, this program has shown reductions of 21 percent, which seems very promising. The drought has also begun to shift policy makers' attention toward more alternative or local solutions, such as desalination and groundwater management, but efficiency is still falling by the wayside.

In response to what it perceives as lack of demand management, the river basin committee has discussed withholding a portion of the transfers to Fortaleza. Showing results in this area and launching more aggressive conservation measures will thus be a crucial part of Fortaleza's future water security. More political involvement will be required to induce users to reduce demand. Today, an extra charge of 120 percent of the tariff is applied to those accounts that go beyond their allotted water amount, based on previous average consumption. This tariff structure was introduced in 2015, but these measures are not timely enough. There remain questions as to whether the pricing signal is strong enough.

## Developing More Local Solutions

Due to the large portion of water use represented by the municipality of Fortaleza in the river basin, the city's practices have been subject to strong scrutiny from other stakeholders, especially as the drought lingers on. One topic of debate is water conservation in Fortaleza, and whether the city is truly doing its best to manage demand in the face of the drought. Overall, the municipality has made it a goal to become less dependent on the Jaguaribe River Basin, as outlined in the plan Fortaleza 2040.

In particular, given the city's advantageous location on the coast and access to the ocean, desalination could prove a good alternative to supplement for imported water during droughts as demand increases in the metropolitan area. A bidding process for the first desalination plant in Ceará is currently underway, which would provide 1 cubic meter per second at an estimated cost of US$1 per cubic meter. This investment would provide a local source of water, but high production costs would force the plant to operate only on a demand basis.

Since 2016, the city of Fortaleza has also been studying wastewater reuse for industrial purposes. At the national level, there is little experience with wastewater reuse other than for irrigation of parks and lawns. The city partnered with a private company in a consortium to plan and build a modular treatment plant with an initial capacity of 1 cubic meter per second, to be later increased to 2.5 cubic meter per second. This plant would supply the industrial area of Port do Pecém, 50 kilometers from the city, and would thus require new costly transmission and pumping infrastructure. The investment is projected to cost US$209 million. In March 2017, Fortaleza hosted the "First National Symposium on Desalination and Reuse: Enabling Alternatives to Water Scarcity." The city could play a pioneering role in the adoption of new technologies in Brazil, where the potential for reuse and alternative sources such as rainwater harvesting is high but underdeveloped.

## Conclusion

Ceará provides a good example of how the principles of integrated water resource management can be adapted to a semiarid context for more efficient water allocation and reduction of conflicts among stakeholders. In fact, water resource management improvements affected not only the legislation but also the behavior of the actors involved. Stakeholder engagement and participatory water resource management creates accountability, which can in turn yield great water conservation results. Existing conflicts around water resources can also help galvanize interest and participation around decision-making on water resource management and ensure that solutions relying on partnerships can thrive. In the future, Fortaleza will, however, have to be mindful of its water use efficiency and manage water demand to avoid additional conflicts that could lead to a reduction in its share of Jaguaribe water. The development of more local sources could further help the city in the face of drought and population growth, while building resilience through reduced dependence on water transfers and basinwide decision-making.

## Notes

1. See https://cagece.com.br/numeros/indice-de-cobertura.
2. Project Appraisal Document 153012, available at http://documents.worldbank.org/curated/en/710321493604135885/pdf/Brazil-Main-PAD-04112017.pdf.
3. Project Appraisal Document 153012, available at http://documents.worldbank.org/curated/en/710321493604135885/pdf/Brazil-Main-PAD-04112017.pdf.
4. Interview with COGERH/SRH. July 2017.
5. See the IBNET database, available at https://www.ib-net.org/.
6. Interview with Eduardo Sávio Passos Rodrigues Martins, adjunct professor at the Federal University of Ceará, Fundação Cearense de Meteorologia e Recursos Hídricos (FUNCEME), July 10, 2017.
7. Information from email exchange with CAGECE representative. July 2017.
8. Interview with Eduardo Sávio Passos Rodrigues Martins, adjunct professor at FUNCEME, July 10, 2017.
9. See the Brazilian government website on water resources, "Management in Brazil; Agencia Nacional de Águas" (accessed on July 10, 2017). http://hidroweb.ana.gov.br/cd2/water/docs/part2.html.
10. State of Ceara, Decreto No. 32.159, February 24, 2017.

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# Part II B

## Southwest United States Case Studies

*Source:* Pixabay.com.

# Chapter 17 Introduction to the Southwest United States Section

## What Do We Mean by the Southwest United States?

The Southwest region of the United States (U.S. Southwest) is defined in various ways for different purposes, but for the purpose of water resource management, the U.S. Southwest will be defined as the portion of California south of the San Joaquin Valley, and the entire states of Nevada and Arizona. The common connection between Southern California, Nevada, and Arizona is that each area is part of the Lower Colorado River Basin and has historically drawn a large proportion of its water from the Colorado River. The lower Colorado River system is extremely stressed by the legal over-allocation of its water resources,[1] water use exceeding the legal allocation, increased pressure from climate change, and by environmental regulations that increasingly limit human consumption.

Although there are substantial variations within the region, the U.S. Southwest is broadly and historically characterized by low, erratic precipitation and high temperatures that predate more recent climate change (U.S. Bureau of Reclamation 2012). As map 17.1 shows, simply looking at a satellite map of the United States shows a relative lack of water resources in this region compared to the rest of the country. A trend of rapid population increase in the 20th century differentiates the region's urban development patterns, and relative demand for water, from the those of the rest of the country.

The region has relied, since the early 20th century, on imported water—water generated in another state or transported to urban centers over large distances from other parts of a given state. Reliance on rapidly diminishing imports threatens the local resilience of

**MAP 17.1. Satellite Image of the United States Showing Water Resources**

*Source:* 2002 NASA public record image.

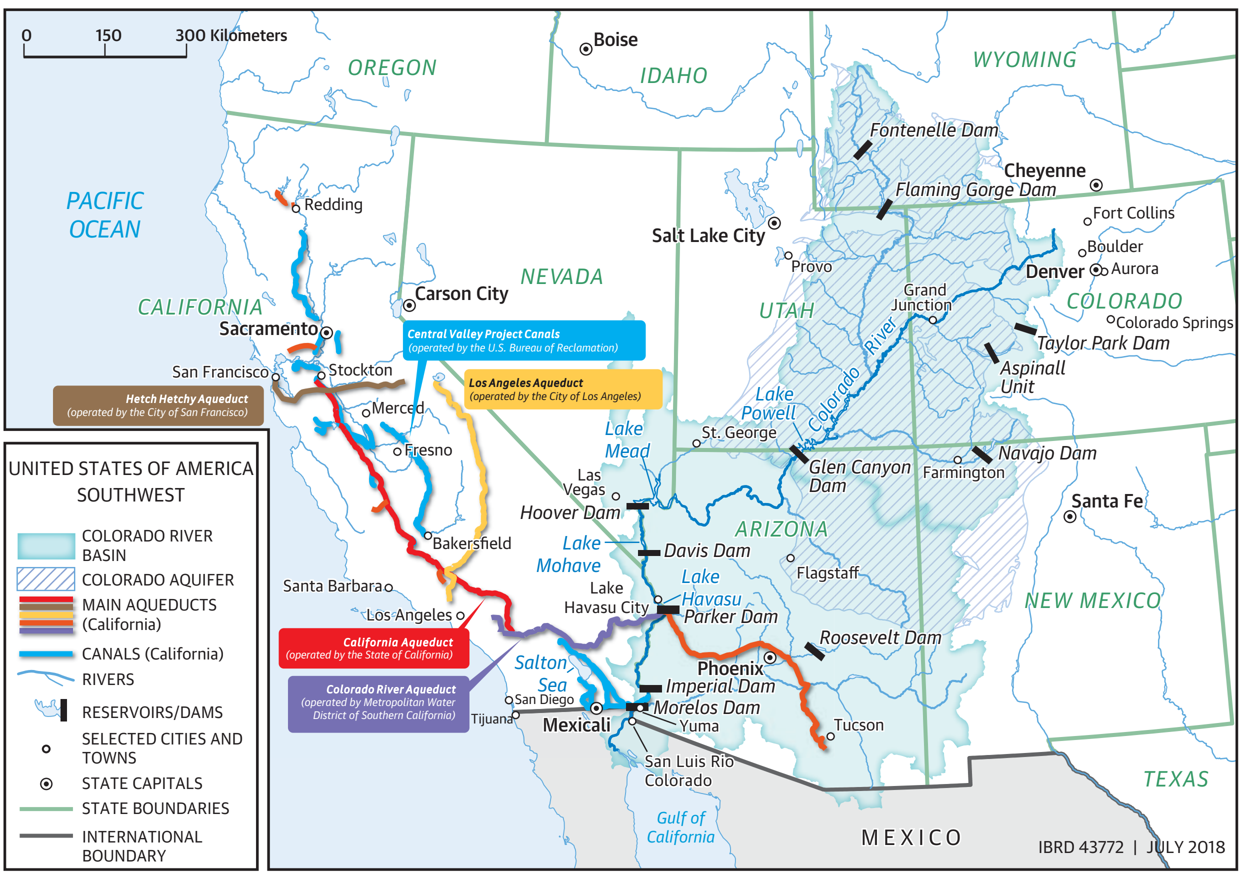
many cities in the U.S. Southwest. In fact, there is no unappropriated surface water and virtually no unappropriated groundwater in these states (Tidwell et al. 2014). The clear diminishment of imports during the 21st century, which has already begun, has encouraged both water utilities and water wholesalers to consider options to diversify their water portfolio.

For instance, the recent 6-year drought experienced in California has led to the testing and application of innovative solutions by urban water systems to drought-proof their water resource supplies. Both Nevada and Arizona also feature successful examples of nonconventional solutions to water scarcity in urban spaces. Documenting the challenges faced by different urban areas in the U.S. Southwest and the processes they have undertaken to diversify their water portfolios can provide important lessons and principles of success for comparable challenges faced by global cities, which share commonalities in climate, raw water resource endowments, and population concentration.

## Overview of Water Resources—Volumes Mobilized from Each Resource

The Colorado River is the common water resource that links the U.S. Southwest across other administrative and political boundaries. A series of reservoirs, which is drawn on by each state, has been built along the entire river system to ensure water supply, although flow within the river is highly variable even on a year-to-year basis (Richter 2014). However, the magnitude of other raw water resources available within each of the three areas varies substantially (map 17.2). Southern California, while often viewed as emblematic of water scarcity, has a much more diversified supply base than Arizona or Nevada. Moreover, despite recent drought conditions

**MAP 17.2. The United States Southwest**



and strict limits on urban residential consumption, each state continues to devote about 80 percent of its total consumptive use to agriculture, much of it for exports, which suggests that state-level political solutions would reduce the pressure on water scarce cities most broadly.

### Southern California

The statewide California average annual precipitation is about 23 inches; Southern California, however, averages slightly more than one-half that total. In California, 40 percent of wet-year water demand and 60 percent of dry-year water demand is drawn from groundwater. Groundwater has historically been ample particularly in the central part of the state, although severe overdrafting has reduced both water and storage space (Hanak et al. 2011). Approximately 30 percent of the state's water on average comes from runoff from snowpack from the Sierra Nevada Mountains. The remainder of the supply is derived from imports from elsewhere in the state or from other states.

Dry Southern California is home to half the state's population, and the region depends on three imported water sources—the State Water Project from Northern California, which draws on Sierra Nevada runoff, the Colorado River Aqueduct, and the Los Angeles Aqueduct (a designated source for the city of Los Angeles secured from the eastern Sierra Nevadas)—for about half its supply. Within Southern California, there are also vastly different groundwater resource endowments. San Diego, for instance, has very little underlying groundwater compared to Los Angeles or Orange County.

For water use in the state as a whole, the split between human uses is roughly 80 percent for agriculture and 20 percent for urban areas, including residential, commercial, and industrial uses (Hanak et al. 2011). Within Southern California, however, the split is nearly reversed.

### Nevada

Nevada receives the least precipitation of any state in the country, with an average annual precipitation rate of 9.5 inches. Approximately 30 percent of the state's total water supply is derived from groundwater; the rest is sourced from the Colorado River. Nevada is allocated the smallest share of Colorado River water, less than 2 percent of total river apportionments. A small amount of surface water is available from in-state rivers, which are small and fed perennially by snowmelt from the western slope of the Rocky Mountains.

Within Nevada, the southern portion of the state receives only four inches of rain annually, but accounts for 75 percent of the state's total water demand due to its much denser population, mainly in the Las Vegas area. As opposed to the northern portion of Nevada, this region relies almost entirely on Colorado River water; 90 percent of its water flows from the artificial Lake Mead created by the Hoover Dam. As in California, the state of Nevada as a whole is split between roughly 80 percent of water use for agriculture and 20 percent for urban areas, including residential, commercial, and industrial uses. Within Southern Nevada, however, the split is more than reversed, with urban use dominating (Southern Nevada Water Authority 2017).

### Arizona

Like Nevada, Arizona is a very dry state, with average annual precipitation of about 13 inches. The Colorado River (37 percent) and other surface water sources (17 percent) provide 54 percent of Arizona's total water supply. In contrast to Nevada, however, Arizona is allocated one of the largest shares, 19 percent, of total Colorado River apportionments. Colorado River water is largely drawn from the reservoirs of Lake Mead (jointly managed with Nevada) and Lake Powell (jointly managed with Utah). The vast majority of the remainder of the state's water supply, approximately 43 percent, is derived from groundwater, with about 3 percent from reclaimed wastewater (ADWR, n.d.).

Also like Nevada, the state's population is concentrated in one area: Central Arizona, which contains 80 percent of the state's population. The Central Arizona Project (CAP) delivers Colorado River entitlements to the Phoenix area. This region has also managed its groundwater more actively than other areas of the state or the broader U.S. Southwest (US EPA 2016c). Partly as a consequence, Arizona devotes less than 70 percent of its total water supply to agriculture and the rest to urban areas.

## Historical Water Imbalances and Challenges

In addition to having scarce total water resources, each of the three areas in the U.S. Southwest faces a profound disconnect between the geographic concentration of water resources through the hydrological system and its human population centers. This disconnect is a consequence of the two-way relationship between development patterns and water resources management decision-making. Until at least the mid-20th century, water supply was primarily viewed as a means to the end of population and economic growth, and was sought from any source possible (Reisner 1993). Opportunities to secure new sources have become increasingly difficult since the 1970s when new federal environmental regulations were put in place, and strains on existing sources have become undeniable since the 1990s (Erie and Brackman 2006; Bureau of Reclamation 2011).

The U.S. Bureau of Reclamation was charged with securing water for growth across the U.S Southwest in the early to mid-20th century. The Bureau is housed within the U.S. Department of the Interior and was supported in this effort by the U.S. Army Corps of Engineers within the Department of Defense (Reisner 1993). The Bureau and the Army Corps had a role in financing and building most of the infrastructure for Lower Colorado River basin delivery. Since completion of the Colorado River projects, the Bureau remains the largest wholesaler of water and second largest supplier of hydropower in the United States.[2] The close relationship between the Bureau and the U.S. Southwest is evidenced by the fact that the Bureau defines one of its five operational divisions as the Lower Colorado River basin.[3] The Bureau's role in western water development was to "water the West." Agricultural uses were encouraged to ensure a food supply for the nation, as well as to build economies and commerce. A large portion of the Colorado River entitlement in California goes to the Imperial Valley, a vast food-growing region in the southeastern part of the state, bordering the Colorado River at the Mexican border.

### Increasing Demand due to Population Growth

The U.S. Southwest grew and continues to grow to support and encourage population growth and economic opportunity. The main motivator for federal and state efforts to enhance water supply was a desire to support commerce and local economic opportunity, as well as to encourage agricultural uses to ensure a food supply for the nation. In some cases, water was actively secured to encourage a vision of growth, as in Southern California (Hundley 1992). In other cases, such as the CAP, water was secured to ensure sufficient supply for existing and future growth. In all cases, population growth in the 20th century in the U.S. Southwest was truly remarkable, contrasting with slowing or declining growth in many other regions of the country. By the 1990s, this growth also began to overwhelm the water supply projects constructed in each of these areas. Between 1920 and 2000, the population increased 890 percent in California, 2,500 percent in Nevada and 1,435 percent in Arizona (Gleick 2010).

Although the rate of growth has slowed in the past few decades, estimates for each of the three areas project substantial growth over the next several decades. According to the Southern California Association of Governments (SCAG), the 2015 population of 18.8 million people in Southern California will increase by 27 percent to 23.8 million by 2050.[4] Similarly, Southern Nevada's water demands are projected to increase by 85 percent by 2065.

Since around the turn of the century, each of the three areas has begun to reduce per capita water use, but due to population growth, it is unclear whether this will lessen overall demand. For instance, Nevada ranked in the top three of the fifty U.S. states in per capita decline in water use since 2005 (Donnelly and Cooley 2015). Phoenix, by far the largest city in Arizona, has achieved an over 25 percent per capita reduction over 20 years, whereas other large urban areas have achieved over 5 percent gains (McGlade 2015). Perhaps most remarkably, urban residential users in California achieved over a 25 percent per capita reduction in use over a 6-month period following the state governor's mandate in 2015.

### Climate Change

Although climate change was much less anticipated than population growth, water management policy makers and planners have had no choice but to recognize this phenomenon since the turn of the 21st century. There are several known effects of climate change in the U.S. Southwest: higher temperatures and more erratic precipitation coupled with lower total precipitation (Christian-Smith, Heberger, and Allen 2012).

Climate change trends show increases in average temperatures in the U.S. Southwest. In Nevada and Arizona, the average temperature has increased two degrees Fahrenheit in the last century, whereas the average increase in California has been three degrees (US EPA 2016a). One direct consequence of higher temperatures in this region on water supply reliability is that, over the past 50 years, the snowpack throughout the Colorado River Basin (and relevant to Southern California, the Sierra Nevada snowpack) has been melting earlier in the year. Early melting leaves upstream dam users less able to cope with periodic droughts (US EPA 2016c), and this trend is expected to increase (Berg and Hall 2017). The flow of the Colorado River has also decreased from around 15 million acre-feet (MAF) annually in the early 20th century to approximately 12 MAF today.

Another direct consequence of increasing temperatures is increased demand for water among agricultural users to adapt to quicker evapotranspiration rates and increased demand for water among urban users to combat heat effects. More erratic, concentrated precipitation also makes existing storage capacity, which was built to accommodate previous precipitation patterns, less useful in securing supply for the future. Compounding states' or local agencies' ability to address this issue is the virtual denial of climate change by the existing federal administration and the uneven embrace of this reality by southwestern states other than California.

### Fluctuations in States' Use of Their Colorado River Allocations

Relatively recent changes in population growth, climate change, and substantial drought have put severe pressure on water management decisions throughout the region. In addition, increased competition and legal claims to Colorado River water have changed relative supply endowments across the U.S. Southwest. Books have been written about the evolution of Colorado River water use and legal agreements over the last century. The history is summarized briefly here (Fleck 2016).

Mandated by the U.S. Department of the Interior in 1922, and affecting the seven states through which the river flowed, the Colorado River Compact was the first major transboundary agreement regarding the Colorado River. The Compact defined the distinction between the upper basin and lower basin states and split the annual flow evenly between the upper and lower basins. In 1928, the flow amounts were quantified among the lower basin parties and final signoff to flows occurred in 1944. Entitlements were determined by prior appropriation principles and other considerations, which resulted in allotments of 2.8 MAF to Arizona, 4.4 MAF to California, and 0.3 MAF to Nevada. By no means, however, did this settle disputes, particularly between Arizona and California and within California, which to some extent continue to this day (Hiltzik 2014).

The interstate tension stems from the effort in the 1930s by the Metropolitan Water District of Southern California (MWD) to build diversion and storage infrastructure, particularly Parker Dam, to use more than its legal allocation of Colorado River water. The overuse of river water by Southern California prompted Arizona's desire to build the CAP to divert and use its Colorado River apportionment (Reisner 1993). In 1963, the U.S. Supreme Court issued a decision largely settling the decades-old dispute between Arizona and California, which subsequently enabled Arizona to build the CAP starting in

1968, but made its rights subordinate to California's in times of drought.

Within Southern California, an initial agreement was reached in 1931 among seven parties, mainly irrigators and urban users, for Colorado River water use. One party, the Imperial Irrigation District (IID), received an outsized proportion of the initial allocation relative to its size and economic importance. Disputes directly and indirectly related to river use between the MWD, the City of Los Angeles, the City and County of San Diego (SDCWA), and the IID, have continued to this day (Erie and Brackman 2006).[5]

In 2003, a Quantification Settlement Agreement (QSA) brokered by the U.S. Department of the Interior between MWD, San Diego, IID, and other parties partly resolved the dispute, although at a much higher price per acre-foot than other comparable imported sources. The agreement facilitated the transfer of water from IID to San Diego County Water Authority (SDCWA) of up to 200,000 acre-feet per year (AFY) and from IID to Coachella Valley Water District (CVWD) and MWD combined of up to 103,000 AFY. The agreement also specified terms for the transfer of conserved water from the lining of the IID-managed All-American Canal to SDCWA and certain Native American tribes in exchange for the payment of project costs and a portion of the conserved water (IID 2017).

In 2007, the U.S. Secretary of the Interior brokered Interim Guidelines to deal with acute drought. The 20-year agreement specifies how Lake Powell and Lake Mead will be managed. The agreement created the water accounting mechanism of Intentionally Created Surplus (ICS), under which parties developing additional consumable water from the same supply would be able to store that water in Lake Mead and use it outside the ordinary Colorado River allocation system (Colorado River Research Group 2015). This agreement has eased some of the tensions among Lower Basin parties, but does not present a permanent solution.

## Current Regional Governance

There are both commonalities and differences in governance of water resources in the three regions of the U.S. Southwest. At the state level, different agencies manage different aspects of water governance, although in each state responsibilities are split between a water resource agency and a subunit of the state's environmental protection primacy agency in each state. At the substate level,[6] one influential agency in each of the three population centers (Southern California, Nevada, and Central Arizona) dictates much of current water resource management strategy.

### California

In California, the most influential state agency managing water resources is the State Water Resources Control Board (the Water Board), a division of the California Environmental Protection Agency (CalEPA). The Water Board, and its nine regional divisions across the state, governs ambient water pollution, water rights, drinking water quality and equity provided by individual drinking water systems,[7] and groundwater management. The Water Board has recently become more aggressive in governing the functioning of individual water systems with respect to conservation and access equity. By contrast, the state Department of Water Resources' core function is to operate the State Water Project, its storage dams and conveyance facilities, and integrated water resource management areas across the state, but it has taken on few new functions in the past several decades.

The most influential water governance body in Southern California is the MWD, which manages both imported water from the State Water Project in Northern California and Colorado River water. It delivers water to 26 public wholesale and retail agencies, which provide water to 19 million people in Los Angeles, Orange County, and Riverside, San Bernardino, San Diego, and Ventura counties.

Other subregional influential water agencies are primarily clients of MWD. These include, in the Los Angeles area, the City of Los Angeles Department of Water and Power, which provides retail water service to the entire city of Los Angeles, and the Water Replenishment District, which manages groundwater for 40 percent of Los Angeles County's population. Other important regional governance authorities include the Western Municipal Water District (Riverside County), the Orange County Water District (OCWD) and the Irvine Ranch Water District (both in Orange County), the SDCWA (San Diego County), and the IID (Imperial County).

### Nevada

In Nevada, the responsibilities for governing ambient water pollution and the drinking water quality and equity provided by individual drinking water systems are housed within the Nevada Division of Environmental Protection that is located within the state's EPA agency. However, the Nevada Division of Water Resources is responsible for groundwater management, watershed management, and water rights.

The most influential water governance body for urban scarcity decision making in Nevada is the Southern Nevada Water Authority (SNWA), which was formed in 1991 to address Southern Nevada's unique water needs. The SNWA is a cooperative, not-for-profit water utility comprised of seven members, much like the MWD in Southern California. Despite its recent origin, it has even greater sway over Nevada water management than MWD has in California, reflecting the strong influence of Las Vegas on state resource decisions.

SNWA members represent various levels of government: the Las Vegas Valley Water District, the Big Bend Water District, the City of Boulder City, the City of Henderson, the City of Las Vegas, the City of North Las Vegas, and the Clark County Water Reclamation District. The SNWA's trademark is its extremely aggressive conservation program initiated under the leadership of general manager Patricia Mulroy. Despite population growth of over 520,000 people between 2002 and 2014, the SNWA aimed for a per capita water use reduction of 40 percent through turf replacement and indoor fixture upgrade programs.

### Arizona

The responsibilities for governing ambient water pollution and drinking water quality and equity in Arizona are provided by individual drinking water systems housed within bureaus of the Arizona Department of Environmental Quality. However, the Arizona Department of Water Resources (ADWR) manages groundwater, watershed, and water rights. Since 1980, the ADWR has been particularly notable compared to the rest of the U.S. Southwest for taking an assertive role in partitioning groundwater monitoring across the state into five active management areas, three of which have a safe-yield goal by the year 2025.[8]

The Central Arizona Water Conservation District (CAWCD) may be the most important urban water governance institution in the state. The CAWCD was formed in 1971 to manage the CAP that draws Colorado River water through a 336-mile water conveyance system and ultimately delivers water to 80 percent of the state's population. A board of directors of 15 elected members governs the CAWCD (CAWCD 2016).

## Current Trends in Portfolio Diversification and How Different Cities Are Dealing with Growing Risk

The U.S. Southwest has witnessed upward trends in pressure on Colorado River water use, environmental regulations, climate change, and population growth. In addition, the region faced medium-term extreme drought for many years following 2000. Until the rains in winter 2017, the ongoing California drought was being compared to the Millennium Drought experienced in the Murray Darling Basin of Australia. As of January 2017, Lake Mead, which supplies the critical Southern Nevada region, was at 40 percent of capacity (Ritter 2017).

The combination of these pressures has heightened the need for portfolio diversification among urban water governance agencies, leading to considerable innovation. Urban water conservation for demand management is now ubiquitous throughout the U.S. Southwest. The SNWA, however, was the first and has been the most aggressive in offering and ensuring financial incentives to households to reduce their outdoor usage, particularly in Las Vegas.

Large-scale recycling of greywater for nonpotable use has also become a common supply-side strategy employed by urban water agencies. Decentralized nonpotable use strategies have been slower to catch on due to state regulations and lack of popular interest, but the San Francisco Public Utilities Commission has recently initiated a citywide reuse ordinance for new buildings. Tucson, Arizona, also passed the first rainwater harvesting ordinance and incentive program for households in the United States.

Although Arizona has been a leader in regional groundwater basin management, the OCWD pioneered the Groundwater Replenishment System, arguably the world's most advanced urban aquifer recharge program. Urban stormwater management and voluntary stormwater capture have been ambitiously pursued in the U.S. Southwest.

Despite severe administrative hurdles, mutually beneficial storage and trading arrangements between urban agencies and agricultural interests have become a key strategy in portions of California. Large-scale water banking in Kern County has provided security and flexibility to federal and state water delivery systems and to large urban retailers such as MWD, while also economically benefitting the local and statewide economy—including manufacturers of farming equipment, creating opportunities for employment, and facilitating international trade of farming commodities. The voluntary trading arrangement stemming from the QSA between San Diego, the IID, and other parties provides a secure water supply for San Diego and suggests that mutually beneficial water trades between urban and rural areas will one day constitute a more viable water management strategy option throughout the region.

## Notes

1. As discussed further below, in addition to these states, the states of Colorado, New Mexico, Utah, Wyoming, and the country of Mexico to the south also have a claim on the Colorado River.
2. About Us. U.S. Bureau of Reclamation, Washington, DC (accessed September 4, 2017), https://www.usbr.gov/main/about/.
3. Lower Colorado Region. U.S. Bureau of Reclamation, Washington, DC, (accessed September 4, 2017) https://www.usbr.gov/lc/.
4. Adopted 2012 RTP Growth Forecast (Southern California Association of Governments), Los Angeles, CA, (accessed September 4, 2017), http://gisdata.scag.ca.gov/Pages/SocioEconomicLibrary.aspx ? keyword=Forecasting#.
5. See also MWD Rate Challenges (SDCWA), San Diego, CA (accessed September 4, 2017), http://www.sdcwa.org/mwdrate-challenge.
6. Even more so than at the federal and state scales, there is a wide array of local entities involved in managing and delivering irrigation and drinking water. For instance, just for drinking water in California, there are 3,000 community water systems—those which serve drinking water to more than 15 households year-round—regulated by the state (CA SWRCB, 2017). Individual water systems may be managed by investor owned utilities, city governments, county governments, mutual corporations, irrigation districts, or small private owners. Moreover, this figure for California does not include the more than 4,000 publicly-regulated water systems in the state which serve transient or temporary populations, or the roughly 5% of the state which is served by private wells.
7. This responsibility was transferred from the California Department of Public Health to the Water Board in 2013 and is more commonly managed by state departments of public health outside the U.S. Southwest.
8. Active Management Areas (AMAs) & Irrigation Nonexpansion Areas (INAs) (Arizona Department of Water Resources), Phoenix, AZ (accessed September 7, 2017), http://www.azwater.gov/azdwr/WaterManagement/AMAs/default.htm.

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*Source:* Pixabay.com.

# Chapter 18
# Las Vegas, Nevada

## Southern Nevada Water Authority Water Conservation and Water Banking

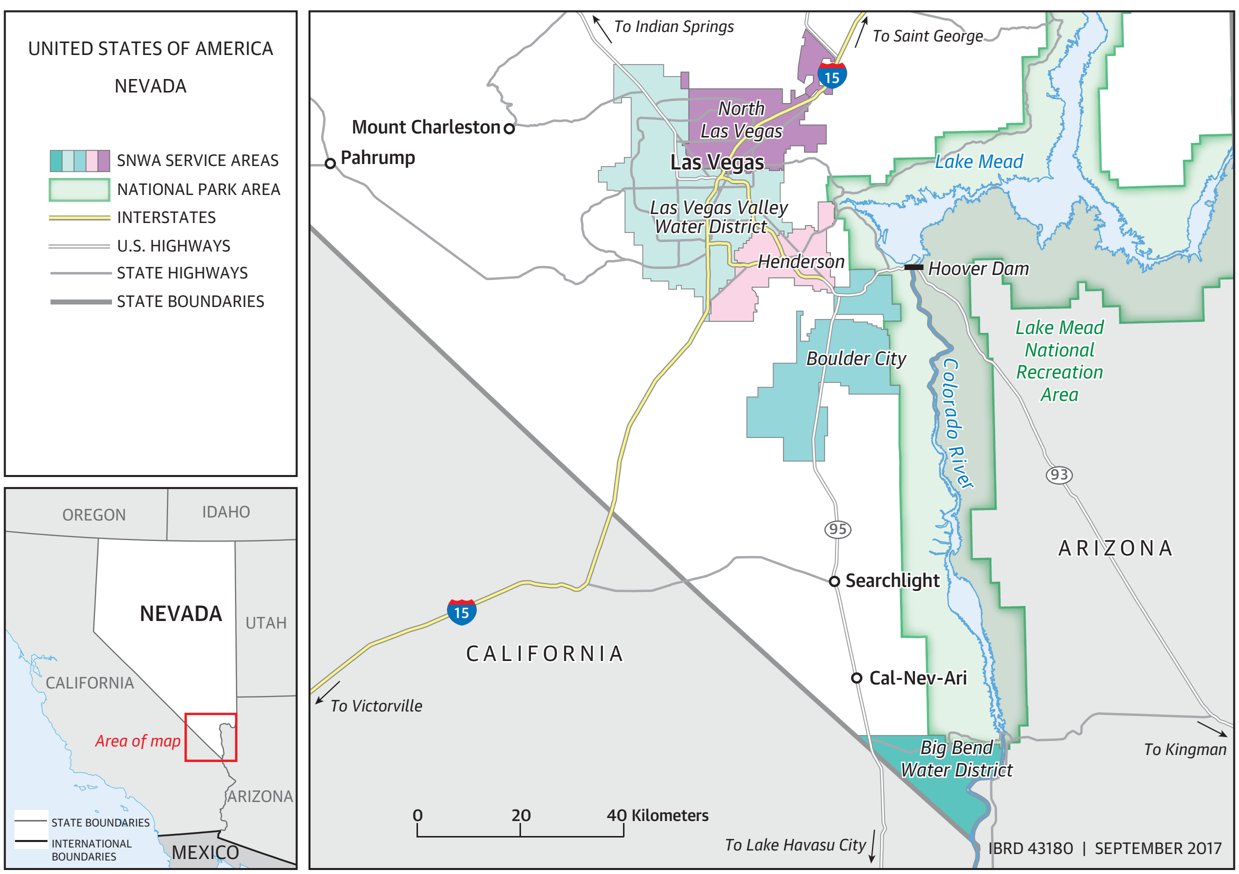
Created in 1905 as a way station for the San Pedro, Los Angeles, and Salt Lake Railroad, Las Vegas has since outgrown its humble beginnings and made the surrounding Southern Nevada area the nation's fastest-changing region in the past 70 years. Spurred by tourism and military activity, economic growth has allowed the population to grow by a factor of 50, from about 40,000 in 1950 to over 2 million in 2014. With over two-thirds of Nevada's population, Las Vegas is home to over 632,000 people,[1] while Southern Nevada has the highest population density in the interior western United States (SNWA 2015).

Nevada, the driest state in the United States, is severely affected by rising temperatures caused by climate change (US EPA 2016). Low average annual precipitation (106 millimeters), summer temperatures that exceed 35°C, and population growth are additional water stressors in the region. When Nevada was allocated 370 million cubic meters per year from the Colorado River through the Boulder Canyon Project Act in 1922, groundwater seemed plentiful enough that negotiators were satisfied. However, the limited availability of groundwater and wasteful practices have forced the region to build additional infrastructure to wheel water from the Colorado River. This infrastructure yields what is now known as the Southern Nevada Water System, which provides the region with a 3.41 million cubic meters per day capacity. Southern Nevada represents 70 percent of the state's population and economic output, yet the region uses less than 5 percent of the state's available water resources.

The Nevada water system is managed and operated by the Southern Nevada Water Authority (SNWA), created in 1991 through a cooperative agreement between seven water and wastewater agencies in the region.[2] These agencies had previously contracted with the Secretary of the Interior for most of Nevada's Colorado River allocation, and through the formation of the SNWA they agreed to collaboratively manage Southern Nevada's water resources. The creation of the SNWA marks a shift in the region's approach to water resources management (SNWA 2015), providing it with a unified institutional mechanism for managing Colorado River water in Nevada (Harrison 2014). Collectively, the agencies that constitute the SNWA provide water and wastewater services to 2 million Southern Nevada residents and 40 million annual visitors (SNWA 2014), although the Las Vegas Valley Water District (LVVWD) serves 70 percent of that customer base. Map 18.1 shows SNWA's service areas in color.

The Las Vegas area largely depends on Lake Mead for water: The Colorado River water stored there accounts for approximately 90 percent of Southern Nevada's water supply. The lake level is the trigger for declaring shortage conditions according to the 2007 Interim Guidelines, which set priorities and conditions for water use in times of shortage and surplus. If the level were to drop below 328 meters above sea level, Southern Nevada would have to reduce its Colorado River allocation by 16 million cubic meters per year (4.3 percent).

**MAP 18.1. Southern Nevada Water Authority Service Area**



Despite its reliance on the Colorado River, SNWA has built a diversified water portfolio to buffer drought conditions and ensure future resilience (table 18.1). The diverse portfolio has provided water security for periods when snowfall and runoff into the Colorado River basin have been low, such as between 2000 and 2014, which yielded the lowest 15-year average elevation on record (photographs 1 and 2). The elevation of Lake Mead dropped by over 30 meters between 2000 and 2010. As of April 13, 2017, the elevation of Lake Mead was 331 meters and has been dropping steadily since March 2017.[3] One important feature of SNWA's strategy has been water conservation: Since 2002, the region has reduced its water use by 38 percent despite a 41 percent increase in population. The nonrevenue water for LVVWD is under 6 percent, and its rate of water main breaks rate is eight times lower than the national average, due to the combination of the system's relatively young age and active infrastructure maintenance activity.

### Other Solutions

The long-term water management strategy of the SNWA relies on the availability of diverse sources through the development of in-state resources, particularly by securing groundwater rights. Existing groundwater rights on the Las Vegas Valley total 57.7 million cubic meters per year, but SNWA is developing access to groundwater by (1) pursuing applications for permits currently under review by the Nevada State Engineer; (2) securing water rights in basins outside the Las Vegas Valley and arranging to deliver them to the Valley; and (3) securing water rights outside the Las Vegas Valley for development. Once developed, these groundwater rights could provide up to 90 percent of the Colorado River allocation. Existing water rights are either being pumped or traded for in-lieu recharge credits.

SNWA is also seeking to preserve its access to Lake Mead water through improved infrastructure. For example, to allow for pumping despite the decreased water level, SNWA has built a third intake to draw water below 305 meters and is currently building a pump station to pump water from an elevation as low as 267 meters above sea level.[4] SNWA is also exploring desalination of both brackish groundwater and seawater in California and Mexico to augment the Colorado River supply.

## Water Conservation

SNWA does not have the authority to regulate water use by end users or to establish customer rates. SNWA works with its member agencies to define the components of the conservation plan to ensure a harmonious program. The member agencies implement the policies, codes, and regulations. Community participation is at the center of this success, both through the community's use of the programs outlined in the SNWA's Water Conservation Plan and because every major decision is reviewed by a citizens advisory committee. To date, these efforts have shown impressive results: SNWA has reduced per capita water use by 38 percent since 2002, with 2016 net consumption at 465 liters per capita per day (lpcd).[5] SNWA's conservation efforts have focused on consumptive use for several reasons: (1) limited resources; (2) the large percentage of reuse in the area; and (3) gross or total-system consumption remains close to 800 lpcd, which is high compared to other water scarce areas. Residential net consumption is estimated at 284 lpcd.[6]

### A Bit of History

Launched in 1991, the conservation program was the first attempt at harmonizing conservation practices across SNWA's service area. The first decade focused on best-management conservation practices published by the U.S. Bureau of Reclamation. The SNWA's initial comprehensive 5-year Conservation Plan was approved by the SNWA Board of Directors in 1999. The 2003 SNWA Drought Plan gave new impetus to conservation efforts just as drought conditions in the Colorado River basin were worsening. By 2004, Southern Nevada achieved the 25 percent conservation goal that was set in the mid-1990s. New targets

**TABLE 18.1. SNWA Water Sources**

| Type | Definition | Sources |
|---|---|---|
| Permanent resources | Available independently of Colorado River operating conditions, with some conditions | • Nevada basic apportionment of the Colorado River (370 million cubic meters per year)<br>• Unused apportionment from other Nevada Colorado River contract holders<br>• Return-flow credits (RFCs)[a] or indirect reuse (expands Colorado River allocation by approximately 75 percent)<br>• Direct reuse (approximately 27 million cubic meters per year)<br>• Flood control and domestic surplus in times of higher water availability<br>• Intentionally Created Surplus (ICS) (tributary conservation ICS and imported ICS)[b]<br>• Las Vegas Valley groundwater rights (57.7 million cubic meters per year) |
| Temporary resources | Resources that can be used to meet potential short-term gaps between supply and demand | • Banked resources, either locally or through agreement with other states<br>• ICS (system efficiency ICS, extraordinary conservation ICS, and binational ICS) |
| Future resources | Resources that will become available to SNWA within its 50-year planning horizon, that are under consideration, or that are potential options | • Desalination (in California and Mexico)<br>• In-state groundwater<br>• Virgin River/Colorado River augmentation[c]<br>• Transfers and exchanges |
| Water conservation | Unlike other resources, conservation reduces existing and future demand and extends available supply | • SNWA uses various conservation tools such as education, incentives, regulation, and pricing<br>• U.S. Bureau of Reclamation Pilot System Conservation Program |

*Source:* SNWA 2015.
*Note:* SNWA = Southern Nevada Water Authority.
a. For every cubic meter of Colorado River water treated and returned to the Colorado River after nonconsumptive use, the U.S. Bureau of Reclamation's RFC policy allows SNWA to withdraw one cubic meter of water from the Colorado River. Highly treated wastewater is thus returned to Lake Mead through the Las Vegas Wash (upstream of the lake) and the quantified amount and earns the city equivalent RFCs.
b. The ICS system allows a Colorado River user to fallow a surface water right in a tributary or convey a groundwater right to the river and earn credits for Colorado River water.
c. In accordance with the 2007 Seven States Agreement, the SNWA has suspended the development of its rights to 113,000 acre-feet per year (AFY) from the Virgin River in exchange for the cooperative pursuit to develop 75,000 AFY of permanent water supplies to augment the Colorado River.

were then set to intensify conservation efforts as recommended by a citizens' advisory committee: 946 lpcd by 2010 and 928 lpcd by 2035. The first target was achieved in 2008, 2 years ahead of schedule. Similarly, although 2009 projections aimed for a 2012 consumption level of 920 lpcd, the achieved level was 830 lpcd.

In the Las Vegas Valley, community conservation efforts reduced consumption by 114 million cubic meters between 2002 and 2016, despite an increase of over 600,000 residents during that time. Building on these efforts, the 2014 Water Conservation Plan adopted the new goal of 753 lpcd by 2035.

Climate conditions, a slowing economy, stabilizing population, and conservation program participation may have contributed to the region's conservation success. It is estimated that SNWA will achieve its goal of 753 lpcd by 2035, representing a total of 340 million cubic meters in savings over the 2004 water demand projections.

## Conservation Measures

About 60 percent of Southern Nevada's water is used consumptively, which means it can be used only once. The single largest consumptive use is landscape irrigation. Ninety-nine percent of nonconsumptive water use is reclaimed and either returned to the Colorado River, earning SNWA RFCs, or delivered for other municipal uses such as golf course irrigation. The high percentage of water reuse means that outdoor water use is the true culprit of water waste—water wasted or evaporated outdoors cannot be reclaimed.

### Water Pricing

SNWA's member agencies use three key demand-management practices to maintain conservation gains: metering, nonrevenue water management, and tiered water rates. Customer connections are metered regardless of type, with meters read monthly and data closely monitored to identify inefficiencies. Nonrevenue water is generally low in the SNWA service area, but programs are in place to ensure continued efficiency. All potable water service providers in SNWA use increasing block tariffs to promote efficient water use while ensuring affordability for essential uses. In 2005, a citizens' advisory committee recommended that water rates should keep pace with inflation to maintain conservation gains. Restructuring rates and increasing prices were part of the effort by member agencies to accelerate water conservation, though each agency carried out these changes individually. The increasing block tariff provides for a water budget of about 19 cubic meters per household per month in the first (lowest) tier. The volumetric portion of the water bill represents about 70 percent of the charges across SNWA, based on an average water bill.

### Regulation

Regulation is the responsibility of city and county governments and includes land-use codes and water-use ordinances that promote efficient water use. As early as the 1990s, member agencies adopted landscape and plumbing codes to limit water use. Drought restrictions were put in place under the 2003 Drought Plan, in particular for landscape watering, vehicle washing, lawn installation, mist systems, and golf course irrigation, and were permanently adopted in 2009. For example, turf is prohibited in front yards and can cover only 50 percent of backyards.

### Incentives

Incentives invite the community to participate in conservation efforts through modifications in their homes and habits. Water smart programs are an important part of SNWA's conservation strategy and have contributed the majority of the savings to date. The Water Smart Landscapes rebate program provides financial incentives to replace lawns with water-efficient landscaping. Each square meter of lawn replaced saves approximately 20 liters of water per year, and the program has saved more than 257 million cubic meters since inception. The Rebate Coupons program offers instant rebate coupons for single-family residential property owners to finance investments that would help save water, such as the purchase of swimming pool covers.[7] The 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 annually. Customers can also request indoor water audit and retrofit kits for their homes, such as leak detection tablets and sink aerators.

### Education and Outreach

Education and public outreach tie SNWA's conservation strategies together to generate support from the community and to ensure that customers understand the implications of living in a desert. Before putting in place the 2003 conservation measures, SNWA carried out quantitative public opinion research to better understand customers. It found that people were overwhelmingly supportive of the program and that their main concern was that changes be rolled out equitably. Following the study results, communications have focused on clear explanations about program requirements through a series of subcampaigns. Specific outreach measures include an aggressive advertising campaign through radio, television, and print, including the Water Smart Living publication, mailed to over 700,000 homes in Southern Nevada three times a year, and the Water Ways television program. An interactive website allows customers to look up their watering schedule, apply for rebates, and access a water smart database. Youth education programs allow students to join a youth advisory council and teachers to engage in a continuing education program through the Water Education Institute. Demonstration gardens throughout the Las Vegas Valley showcase water-efficient landscaping and a Conservation Helpline phone center allows customers to easily access rebate and conservation program information, publications and watering schedules, and to report water waste.

Every year SNWA hosts the world's largest conference focused on water conservation, the WaterSmart Innovations Conference and Exposition in Las Vegas, to connect entrepreneurs to water agencies and potential partners. SNWA has also developed local partnerships with businesses and other stakeholders to promote water conservation in their sectors.[8] The WaterSmart Homes program, which certifies new homes as water smart, is considered the most successful such program in the country: It has led to the construction of over 10,000 new water smart homes, with associated water savings of 2.8 million cubic meters annually, and has inspired the U.S. Environmental Protections Agency's WaterSense New Homes Program.

### Participatory Process

One of the most notable features of SNWA's water management is its reliance on stakeholder engagement to make important decisions. Before infrastructure projects or significant changes in SNWA's practices are approved, the board of directors appoints a citizen advisory committee to participate in the decision-making process. These committees of 15-20 people meet once a month sometimes for up to a year.

## Challenges

As more lawns and fixtures are replaced and because new developments are allowed to build only water-efficient landscaping and fixtures, the ability of conservation programs to grow and continue to yield savings is decreasing. SNWA's 2014-18 Water Conservation Plan discusses demand hardening, which occurs when "the more aggressive and responsive a community is to the call for conservation, the more difficult it becomes to realize additional conservation gains." As a result, it is unlikely that the conservation trends seen in the past 15 years will continue until 2030, not because the region is reducing its efforts, but simply because the low-hanging fruit have been picked.

SNWA is regularly compared to the rest of the southwestern United States, although it receives much less rain on average. However, Las Vegas may have chosen not to invest ratepayer money in indoor conservation, for example, because the largest gains for the region are in reducing outdoor water use. Therefore, it is more sensible to benchmark SNWA's progress against its own performance.

SNWA has also diversified its temporary and future water sources; portfolio diversification is important regardless of conservation levels. For example, RFCs play an important role in stretching the Colorado River allocation to an additional 75 percent. Through additional conservation and resource diversification, SNWA may be able to hold off use of its future resources until 2045, even with increased shortages and high water-demand projections.[9]

## Water Banking and Trading

Water banking and trading are at the center of Las Vegas's strategy for resource resilience, particularly if Colorado River water is unavailable. Since the early 2000s, SNWA has been storing unused Colorado River water in various water banks in Nevada and out of state. This water can be withdrawn should the Colorado River drought intensify, though the conditions for withdrawal depend on the water bank (table 18.2). Today, the banked water resources of SNWA total 2,220 cubic meters.

ICS also provides a way for SNWA to transfer in-state water resources to the Colorado River and receive credits. Any ICS created and not used within the year is converted to extraordinary conservation ICS credits, which are stored into Lake Mead like a bank account.

**TABLE 18.2. SNWA Banked Water Resources**

| Water Bank | Amount (million cubic meters) | Details | Conditions for withdrawal |
|---|---|---|---|
| Southern Nevada Water Bank | 415 | • Stored in the Las Vegas Valley aquifer through an agreement with LVVWD | • Can be recovered under any conditions, including shortage<br>• Maximum recovery rate of 25 million cubic meters per year |
| California Water Bank | 407 | • Stored by MWD in various off-aqueduct storage facilities and groundwater banks.<br>• Intentionally Created Unused Apportionment (ICUA) from SNWA is agreed with MWD and stored under the SNWA Interstate Account.<br>• Amount stored per year can be renegotiated throughout the year based on ICUA and drought conditions. | • Recovery rate of 37 million cubic meters per year under normal and shortage conditions, subject to agreement terms<br>• If California were undergoing a drought, it is unlikely that SNWA would withdraw water. |
| Arizona Water Banking Authority (AWBA) | 741 | • Stored in Arizona aquifers<br>• First agreement in 2001, amended in 2013<br>• Additional water can be banked on a pay-as-you-go[a] basis up to 1,540 million cubic meters | • Arizona would use banked water and forgo equivalent portion from the Colorado River, which SNWA could withdraw from Lake Mead<br>• Recovery rate 50 million cubic meters per year during any water supply condition and 74 million cubic meters per year during a declared shortage. |

*Sources:* Elaboration based on SNWA 2015. Water Resources Plan 2015 and Storage Interstate Release Agreement among the United States of America, acting through the Secretary of the Interior; The Metropolitan Water District of Southern California; the Southern Nevada Water Authority; and the Colorado River Commission of Nevada (Contract No. 04-XX-30-W0430), dated October 27, 2004. https://www.usbr.gov/lc/region/g4000/4200Rpts/DecreeRpt/2015/13-MWD-SNWAInterstateBankingTableOfContents.pdf on March 7, 2018. MWD of Southern California 2004.
*Note:* LVVWD = Las Vegas Valley Water District.
a. The pay-as-you-go tariff depends on the AWBA's actual costs (such as for pumping and delivery) and is set year-by-year if SNWA asks to store water. The last time SNWA stored additional water with AWBA was in 2013, when the AWBA had already stored approximately 740 million cubic meters at a total cost of $123 million. There were no additional fees.

A 5 percent reduction is applied to ICS in the year water is stored for the benefit of the system. To account for evaporation from the reservoir and other losses that might occur, a 3 percent annual reduction is also assessed. SNWA has accumulated close to 700 million cubic meters in Lake Mead through ICS. The one caveat is that, unlike other forms of ICS, extraordinary conservation ICS credits cannot be accessed during declared shortages.

### The Role of SNWA

SNWA was a key participant in the drafting of interstate water banking regulations. Since the early 1990s, SNWA had pursued changes to the Law of the River, which governs the use of Colorado River water, that would allow the marketing of surplus water from the upper basin states (Wyoming, Colorado, Utah, and New Mexico) to increase its allocation of water from the Colorado River. Not only did Nevada have the lowest allocation of any basin state, but Nevada also lacked an agricultural sector. In other states, the agricultural buffer would enable urban municipal water managers to purchase water from agricultural interests in times of need. Through the AWBA, Arizona finally saw a way to safeguard its unused allocation of the Colorado River (Gelt 1997). Arizona was also building on draft federal regulations that allowed the storage of intra- and interstate water transfers for future use.

In 1994, the Nevada Water Summit was organized by SNWA and the Colorado River Commission of Nevada in order to hear proposals to develop new water sources for Southern Nevada. The Nevada Initiative was launched as a result, calling for the establishment of a water bank in the lower Colorado River basin. SNWA saw the opportunity to begin negotiations for an interim supplemental water source through banking with Arizona. Regulations were adopted in 1999 by the U. S. Secretary of the Interior to authorize Colorado River water storage and interstate release agreements.[10] The regulations provided that in the event of ICS, the U.S. Secretary of the Interior and the Bureau of Reclamation could enter into such agreements with authorized entities in storing states and consuming states. In 2001, the guidelines were published by the federal government and an agreement with the AWBA was approved for the storage of up to 1,480 million cubic meters in Arizona for future use. Another such agreement was entered into in 2004 with the Metropolitan Water District of Southern California (MWD).

No sooner had the agreement with AWBA been signed than the worst drought on record hit the Colorado River. The drought posed a challenge to an agreement made for the most part to secure surplus water and forced Nevada to rethink its approach to creating water to be stored, but it also further strengthened public support for water banking. As explained by Davis of SNWA, “these types of activities reflect a collective, concerted effort to manage the river and forestall shortages.”[11] The use of RFCs had already enabled Nevada to stretch its apportionment—had it not been for RFCs, SNWA would have exceeded its allocation by 1992—but it also enabled Nevada to remain below its apportionment for consumptive use. Reducing Nevada’s consumptive use and conservation became crucial in ensuring that population growth did not threaten these savings. The Interim Surplus Guidelines provided another tool in 2007 through the definition and authorization of ICS, allowing SNWA to store surplus it had created into Lake Mead. ICS credits can be generated by fallowing a surface water right in a tributary, conveying a groundwater right to the river, or improving system efficiency.

Litigation and its prevalence in the Colorado River history have motivated collaboration between SNWA and basin stakeholders. In the last 50 years alone, the Supreme Court has heard California and Arizona water disputes nine times.[12] One of SNWA’s main achievements in the process of developing regulations for water banking is the avoidance of costly litigation. In 2001, then-U.S. Interior Secretary Bruce Babbitt took negotiations between Arizona and Nevada as an opportunity to push California to resolve internal disputes and agree to limit its water use to its official Colorado River allocation.

## Conclusions

The experience of Las Vegas shows that water conservation plays a central role in sustainable water management for urban centers in arid areas. Despite having the smallest allocation on the Colorado River and a booming population and tourism industry, Las Vegas and its surrounding areas have used multiple tools to ensure their water future. Accounting for reuse through RFCs enables Las Vegas to multiply its allocation by a factor of approximately 1.7, while conservation programs have managed to reduce water use by about 40 percent since 2002. This demand management has enabled the creation of surplus water for banking through a series of in-state and interstate agreements, generating temporary resources for backup. According to SNWA projections, this "pursue anything and everything" approach (Harrison 2014) has created a strong portfolio that promises to meet demand until 2065 (SNWA 2015).

## Notes

1. Population and Housing Unit Estimates (U.S. Census Bureau database), U.S. Census Bureau, Suitland, MD (accessed Population and Housing Unit Estimates July 1, 2017), https://www.census.gov/programs-surveys/popest.html.
2. The agencies are Big Bend Water District, City of Boulder City, City of Henderson, City of Las Vegas, City of North Las Vegas, Clark County Water Reclamation District, and Las Vegas Valley Water District.
3. Lake Mean Water Level, *Lakes Online.com* (accessed August 17, 2017), http://mead.uslakes.info/level.asp.
4. Note that when the elevation of Lake Mead reaches 273 meters above sea level, Hoover Dam can no longer release water downstream to California, Arizona, and Mexico.
5. This number reflects water from all sources used by residents and businesses served by municipal water providers, as well as recovered indoor water treated and returned to the Colorado River system and water used by 40 million annual visitors (SNWA 2014).
6. J.C. Davis, Cultural Arts & Tourism, City of Henderson; Las Vegas Valley Water District, LVVWD), interview with author, April 18, 2017.
7. The rebate equals $50 or 50 percent of the price of a manual pool cover, whichever is less, or $200 or 50 percent of the price of a permanent mechanical pool cover, whichever is less. The pool cover rebates have produced estimated savings of over 7.6 cubic meters.
8. For example, the Water Conservation Coalition is a group of local businesses and community leaders who promote water-efficient practices, such as the Water Upon Request program, through which restaurants serve water only to those clients who request it.
9. Shortages will increase if, as a result of the prolonged drought, SNWA's allocation of Colorado River water is reduced by 50 cubic meters. Currently, the Interim Guidelines only allow for a 25 cubic meters shortage. "Upper demand" or high water-demand projections reflect the increased uncertainty of changes in demand that are associated with climate variability, economic recovery, increased population, and water-use patterns.
10. Offstream Storage of Colorado River Water and Development and Release of Intentionally Created Unused Apportionment in the Lower Division States, 43 C.F.R. § 414.3 (1999). https://www.usbr.gov/lc/region/g4000/4200Rpts/DecreeRpt/2016/19.pdf.
11. JC Davis, Cultural Arts & Tourism, City of Henderson; Las Vegas Valley Water District, LVVWD), interview with author, April 12, 2017.
12. Colby Pellegrino, Colorado River Program Manager at Southern Nevada Water Authority and JC Davis, SNWA, interview with author, April 18, 2017.

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*Source:* pixabay.com.

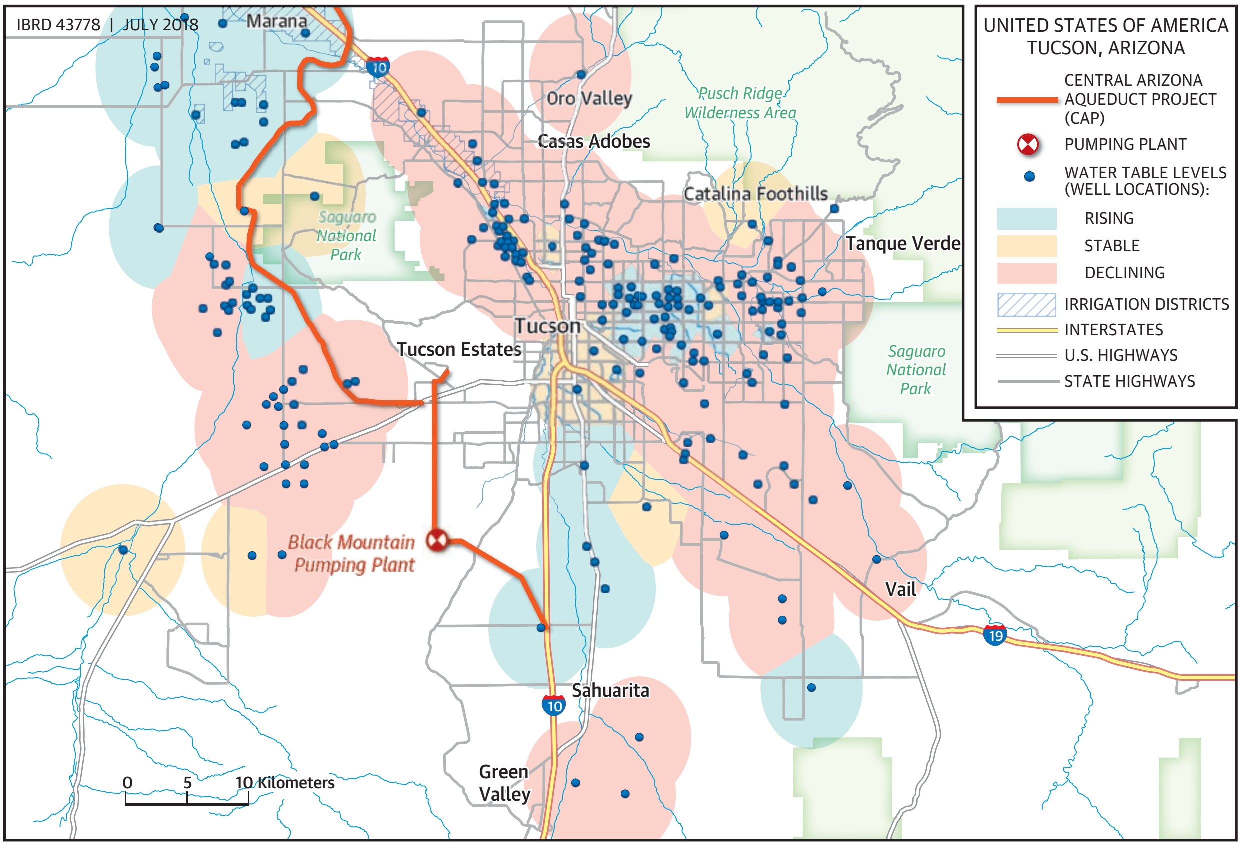
# Chapter 19
# Tucson, Arizona

Arizona's agricultural sector has historically driven the state's demand for water. In the past three decades, however, the need for irrigation has been rapidly outpaced by human demands as urban centers grow; this expansion, coupled with recurring drought, has significantly contributed to concerns about a shortage of water (Larson, Gustafson, and Hirt 2009). Therefore, municipalities in Arizona have increasingly sought alternative water sources, driving major statewide shifts in demand and provision. Tucson, a city that receives only an average 28 centimeters of annual rainfall, has been embedded in these changes (NOAA 2016, 2017) (map 19.1).

Arizona traditionally met agricultural needs with groundwater, but this resource became scarcer over time, leading consumers to drill deeper for lower-quality water at a higher cost (Larson, Gustafson, and Hirt 2009). Furthermore, overextraction caused fissures and subsidence, which could damage city infrastructure (Carruth, Pool, and Anderson 2007; Leake 2016). In response, Congress approved the Central Arizona Project (CAP) in 1968 to facilitate distribution and storage of water from the Colorado River for central and southern Arizona (Water Education Foundation and UA WRRC 2007). Because the development failed to attenuate groundwater use as anticipated, the Arizona legislature passed the Groundwater Management Act (GMA) in 1980 to control groundwater overdraft (ADWR 2002).

Most GMA policies were designed with the intent of regulating active management areas (AMAs), where overdraft was most severe (ADWR 2002). Tucson, located in an AMA, responded to the GMA in 1992 by offsetting its groundwater and directly delivering sources allocated through the CAP. However, CAP water was too acidic,

**MAP 19.1.** **Tucson, Arizona, United States of America**




corroded pipes, and had an appearance and taste unacceptable to consumers (ADWR 2014). Tucson addressed this challenge by passing the Water Consumer Protection Act in 1995, which was designed to prohibit direct CAP water delivery to consumers.

The utility constructed the Clearwater Renewable Resource Facility to recharge the aquifer and filter CAP water, blending this with local, alkaline groundwater; beginning in 2001, the recovered mixture was used to supply potable water to Tucson's customers (PAG 2002; Tucson Water Department 2013). Because of Arizona's junior priority for CAP water, storage facilities associated with the recharge project were also constructed to help Tucson prepare for water shortages were it to lose access to CAP water (Water Education Foundation and UA WRRC 2007).

**Recognizing the limitations of reliance on groundwater, CAP supply, and wastewater, Tucson has further expanded its water portfolio by implementing and promoting rainwater harvesting (RWH).**

As its population grows, Tucson uses reclaimed water (effluent) for landscape irrigation and to develop riparian habitats (City of Tucson 2000; Davis 2014). Potable reuse is another option being considered by the Tucson Water Department (Tucson Water); however it is not required to fulfill short term needs because demand for water has actually *declined* over the past several years, and consumers have shown little support for recycled drinking water (Hummer and Eden 2016; McGlade 2017).

Although a small contribution to the water supply, its popularity is increasing in city development and among consumers.

## Rainwater Harvesting in Tucson

In arid and semiarid climates, diversification of water supply is a key feature of development that integrates land use and water resources (e.g., CDWR 2016; Reidy 2015; SNWA 2011). For more than a decade, Tucson has embraced an integrated approach by promoting different forms of low-impact development (LID) and green infrastructure (GI). LID is a technique that modifies land to mimic predevelopment hydrology and helps maintain infiltration and drainage to reduce pollutant runoff. Alternately, GI comprises structural developments and techniques used to achieve LID objectives (City of Tucson 2013a). GI comes in many forms, such rain gardens or landscape designs that collect, distribute, retain and filter water; rain barrels that hold harvested water for later use; and green streets that incorporate features of rain gardens and swales (vegetated or earthen channels that convey runoff) along roadways and in public rights-of-way in order to treat stormwater, beautify the community, and calm traffic (US EPA 2009). Tucson's first implementation of integrated Rainwater Harvesting (RWH) has been through an ordinance to require commercial RWH, followed by the introduction of tax incentives and rebates for residential RWH installations.

### Commercial Rainwater Harvesting Ordinance

Tucson passed the first commercial RWH ordinance in the United States in 2008. The ordinance requires new commercial developments to include RWH plans and use harvested water for at least 50 percent of their estimated yearly irrigation water budgets (PAG 2015). Tucson Water ensures compliance by requiring consumers to submit annual water-use budget reports, which detail rainfall totals and site water usage by month (City of Tucson 2008). To increase participation in RWH, the Pima Association of Governments (PAG) has considered extending the RWH ordinance to include residential properties (PAG 2015).

### Rainwater Harvesting Incentives and Education

Tucson's population and potable demand is projected to grow steadily over the next 30 years (Tucson Water Department 2013), and landscape irrigation makes up almost half of residential demand of installed rainwater collection systems. Given that an average 0.10 hectare lot in Tucson receives a sufficient annual amount of rainfall to meet the demand of a family of three, RWH can reduce the negative impact of excessive water consumption (Lancaster 2008; Phillips and Sousa 2007).

Tucson Water has two residential programs dedicated to RWH. The 2009 Regional Residential Green Building Program offers an opportunity for builders and owners of new homes to receive certification for installed rainwater collection systems. Builders can receive $200 for each residential unit constructed with a collection system, and homeowners are eligible for a one-time tax credit up to $1,000 (City of Tucson 2013c). The city's Green Remodeling Program also extends these opportunities to builders and residents for systems on older homes (City of Tucson 2013b). In 2012, the second program offered two different RWH rebates. Single-family homes can use the first rebate to cover 50 percent of the cost of materials (such as some landscape supplies and equipment rental) and labor of licensed contractors for passive RWH up to $500 (City of Tucson 2015). The second rebate assists residential users with the costs of cisterns (also referred to as active RWH).

To qualify for the rebate programs, Tucson Water consumers with current service must participate in a utility-approved RWH workshop that covers RWH methods and strategies (City of Tucson 2017c). The utility has also partnered with the University of Arizona and a nonprofit organization to provide community education programs for various audiences (City of Tucson 2015).

### Demonstration Sites and Green Streets

The Tucson Graywater and Rainwater Harvesting Stakeholder Group has spearheaded development of 16 water harvesting demonstration sites to help foster successful implementation of RWH projects. Tucson Water has given funding priority to those that offer public access, provide educational opportunities, and emphasize compliance with RWH ordinances (City of Tucson 2015). Tucson's Green Streets Active Practice Guidelines also captures and retains the first 1.27 centimeters of rainwater during a storm, as well as detains, infiltrates, or filters runoff from the street and sidewalk; it can also remove debris and sediment from water. The benefit-cost ratio of the Green Streets program is $2.10/$1—for every $1 the community invests in Green Streets, $2.10 of value is created (PAG 2015).

## Main Challenges to Selection and Implementation of Rainwater Harvesting

The RWH rebate programs have been problematic because of their relatively high costs to the utility and its customers and the exclusion from participation of low-income residents. Tucson Water finances not only RWH programs, but efficiency programs for greywater and high-efficiency appliances, by imposing a fee of $0.08 per .028 cubic meter (7.48 gallons) of monthly water consumption; this accounts for approximately 20 percent of the average water bill of a single-family household (City of Tucson 2017b). In the past nine years, the utility's conservation fee has grown 167 percent, with the greatest increase (40 percent) in 2012, coinciding with the introduction of the Rainwater Harvesting Rebate Program (City of Tucson 2015). As a result, Tucson Water customers have expressed discontent at town hall meetings (City of Tucson 2017a).

The utility has also found that the net benefit of the RWH rebate program is not demonstrably high. In recent studies of residents who installed active and passive RWH systems, preliminary measures have shown no reduction in use at the water meter following installation (City of Tucson 2015). It may be that some participants in the RWH rebate program already use relatively less water or that customers do not reduce water usage because they care more about landscape irrigation than the cost of their water (Ransom 2015). In 2015, participants of the RWH program collectively reduced water usage by 2,108,010 gallons, but this accounted for just under 4 percent of what the city consumed in gallons per capita per day and does not include 421,602 gallons of storage, which accounted for 0.07 percent of the gallons per capita per day (City of Tucson 2015). If water costs and rates of consumption were higher, more participants might be motivated to use the RWH program to reduce their intake. Most of Tucson Water's residential customers are a part of a single-family household and what the utility considers "low-volume" users; about 80 percent of Tucson's consumers use approximately 7,480 gallons per month, paying at most an average of $39.82 (City of Tucson 2017b). Annually, this accounts for only 1.3% of Tucson's median household income of $37,149 (U.S. Census Bureau 2015).

Additionally, only 40 percent of the RWH best practices workshop participants attend after their systems have been installed, suggesting that the rebate was the incentive for their initial attendance (City of Tucson 2015). Until 2016, Tucson Water distributed checks to rebate program participants with delinquent accounts (City of Tucson 2016). The city then established a policy of abstaining from processing checks until customers' accounts are balanced.

Although Tucson Water has increasingly offered more RWH rebates, the high costs associated with RWH have made the program socially exclusive (City of Tucson 2015). Since the program's creation in 2012, even with financial support, many of Tucson's low-income residents have been unable to participate because they are unable to afford the installation and upkeep of RWH systems (Davis 2016). This is of particular concern because more than 25 percent of city's residents live in poverty (City of Tucson 2012; U.S. Census Bureau 2015).

## Addressing Challenges Related to Selection and Implementation

Although the capital costs of RWH programs present a great challenge to Tucson, identifying and addressing the emerging problems of these initiatives take time. Tucson is responding to the current challenges of its RWH initiatives by examining the net value of active and passive approaches, and Tucson Water is beginning to improve the access of low-income participants to the RWH rebate program.

Potential mechanisms to reduce costs have been identified, which suggests that passive approaches are more cost-effective than the installation of RWH barrels. In a technical guidance manual for the City of Tucson, a review of the costs of GI and LID has found that infiltration trenches, xeriscape swales, and water harvesting basins (all passive approaches, often referred to as groundworks) provide social and environmental benefits that outweigh their associated costs. Furthermore, modifying the land for passive rainwater harvesting (RWH) presents opportunities to improve the area's tree canopy, which can provide direct and indirect economic benefits, such as reducing electric bills for cooling and cost of irrigation (NOAA 2017; PAG 2015).

Tucson recognizes the importance of making RWH broadly available to residents. It has thus taken initial steps to improve the accessibility of the RWH rebate program to low-income participants. In 2014, Tucson Water having noted that these members of the community were not participating in the program, the city hired an environmental justice specialist and hosted a roundtable discussion with local nonprofits and groups serving low-income persons to explore ways to improve access to the rebate program (Davis 2016). In 2016, the Mayor and Tucson City Council allocated $300,000 for a 1-year pilot program to assist 100 low-income families with participation in the RWH rebate program (City of Tucson 2017a). Currently, Tucson Water partners with the Sonoran Environmental Research Institute (SERI) to provide the required rebate classes and offers loans and grants to low-income participants. Loans of up to $2,000 are offered to finance the capital costs of the water systems and grants range up to $400, often helping cover costs of materials for passive RWH (SERI 2017). Funds not administered to participating families are used for other program costs (Elias 2016).

## Conclusion: Lessons for Water Scarce Cities

Moving forward, stakeholders from local, regional, and state levels are working together to drive the development and expansion of RWH in Tucson. In early 2017, Tucson Water hosted the Tucson Stormwater Summit, where participants from governmental, nonprofit, and private sectors shared unique knowledge and collaborated in theoretical planning exercises in which they identified competing and complementary goals that drive their perceptions of where and why GI should be introduced. Key takeaways from the meeting were that Tucson needs champions in the regulatory community to push for further development of RWH and must reframe problems and solutions in ways that garner support for RWH across stakeholders with competing goals (Tucson Stormwater Summit 2017).

Tucson is not facing an immediate water crisis, but its population is projected to increase by approximately 50 percent by 2050 (ADOA 2015). The city, therefore, will need to consider alternative sources to ensure sufficient long-term water supplies. Although Tucson has begun to use recycled wastewater, its availability is dependent on demand, which has recently declined in proportion to the population. Furthermore, although consumers are in favor of recycled wastewater for irrigation, there appears to be a lack of support for potable reuse. This suggests that wastewater, at best, is most appropriate as a supplementary source, dedicated to a limited range of uses.

Tucson's push to adopt various RWH approaches, however, presents opportunities beyond water conservation. LID and GI can help develop Tucson's tree canopy, for example, to improve public safety through the reduction of excess stormwater and provision of shade to pedestrians. This also provides benefits to households, such as lower bills for electricity and piped water. Because passive forms of RWH have been found to offer net benefits greater than those of active methods, it may be valuable for Tucson Water and the customers of the rebate program to focus exclusively on financial assistance and education dedicated to development of groundworks. On the other hand, active RWH could have an increasingly high net value if access to potable water becomes critically limited.

Lastly, Tucson Water will likely need to secure more funding as its RWH rebate, loan, and grant programs continue to develop and expand. Consumers having already expressed some discontent about increased water bills, the utility may be able to justify its costs by further refining how it quantifies RWH benefits. One approach may be the systematic measurement of water that is actively and passively harvested at the residential level. Participants in the rebate program, for example, could review the specifics of their RWH systems to estimate the volume of water they harvest over a given period of time.[1] These data could then inform allocation decisions for Tucson Water's budget.

## Groundwater

Beginning in the 1940s, Arizona experienced both rapid population growth and improved technologies in water pumping, which drove increased water use and aquifer overdraft that would continue over the next four decades (Megdal 2012). Access to secure water meant costly drilling for deeper sources that often contained higher levels of salts and minerals; overextraction also led to subsidence and fissures that damaged city infrastructure (ADWR 2002). In 1980, the Arizona State Legislature introduced the GMA to mitigate overdraft, allocate the state's groundwater sources efficiently to meet changing needs, and implement developments to boost the state's groundwater supply (ADWR 2002). At that time, the Arizona Department of Water Resources (ADWR) was created to implement the GMA by developing, overseeing, and enforcing management plans for AMAs, or regions in which significant overdraft had occurred (Larson, Gustafson, and Hirt 2009). In the Tucson AMA, the primary management goal is to achieve a safe-yield by 2025, meaning that annual groundwater withdrawal does not exceed what is replaced in the same year.[2] Today, Tucson still uses groundwater, but the ADWR has introduced policies over the past three decades that limit the city's extraction.

The Tucson AMA currently uses requirements, permits, programs, and alternative sources in an effort to achieve the safe-yield goal. First, large municipal water providers such as the Tucson Water Department (Tucson Water) have a total-gallons-per-capita-per-day requirement, under which the system must not exceed losses of 10 percent annually. Second, since 2005, residents within the Tucson Water service area have no longer been allowed to drill exempt wells. Residents must first obtain a permit to pump groundwater, which is then subject to certain conditions relating to quantity and reason for use. Third, Tucson's key programs to regulate groundwater use are the Assured Water Supply (AWS) Program, and the Underground Water Storage, Savings, and Replenishment Program. In 1995, the ADWR adopted the AWS Program to ensure the use of renewable supplies, which include surface water, Colorado River water delivered by the CAP, and effluent. AWS rules prohibit new growth (such as land sales and subdivisions) in the AMA without prior demonstration that (1) there are sufficient and adequate supplies of water for 100 years; (2) proposed water use aligns with the management plan and goals of the AMA; and (3) there are sufficient financial resources to develop a water delivery system (Governor's Water Management Commission 2001). The Underground Water Storage, Savings, and Replenishment Program, established in 1986, allows the Arizona Water Banking Authority to store and later recover surplus supplies of water from underground (ADWR 2010, 2016; Tucson Water Department 2013). Tucson has three underground facilities for storing and allocating CAP water: the Central and Southern Avra Valley Storage and Recovery Projects and the

Pima Mine Road Recharge Project (Tucson Water 2013). Finally, in addition to recharged CAP water, Tucson has increasingly come to rely on surface water (for example, through RWH) and recycled wastewater.

Tucson's current level of water use is the same as it was in 1985, even though its population has grown by approximately 70 percent (City of Tucson 2016). Yet, even if Tucson continues to use groundwater at a hydrologically sustainable rate, it could still deplete its allowable groundwater credit account, as designated by the AWS (Tucson Water Department 2004). Furthermore, Tucson is but one of many groundwater users within its AMA, and collective municipal demand is projected to increase, which could deplete available resources across multiple jurisdictions. Thus, a coordinated effort will be necessary to reduce extraction (ADWR 2012).

## Recycled Wastewater

Like other water users throughout Arizona, Tucson has historically relied heavily on groundwater to meet local consumer demand. Yet widespread challenges related to overextraction led the state to introduce legislation in 1980 to limit groundwater use. Since then, Tucson has expanded its water portfolio. Today, the city's primary source of water comes from the Colorado River and is delivered by the CAP. Although Tucson has the largest municipal and industrial entitlement to CAP water in the state, its annual demand may eventually supersede the river's long-term average yield. This, combined with continued drought and climate variability, has driven the city's water utility to find the acquisition and development of recycled wastewater increasingly important as a means of securing water supply (Tucson Water Department 2015).

The majority of Tucson's wastewater comes from three water reclamation facilities (WRFs) owned by the Pima County Regional Wastewater Reclamation Department. The Tres Rios and Agua Nueva WRFs provide wastewater that has undergone secondary treatment (removal of biosolids and suspended organic compounds), which Tucson then pumps into adjacent recharge basins for future use or to its reclaimed water treatment plant for tertiary treatment (further filtration and disinfection). The third (and comparatively smallest) source is the Randolph Park WRF, which provides tertiary-treated water (CH2M HILL 2013; City of Tucson and Pima County 2009; Dubois and Martin 2014).

Tucson currently uses recycled wastewater for irrigation, groundwater recharge, and riparian restoration and maintenance. The city uses recycled water to irrigate more than 700 single family homes, as well as 65 schools, 50 parks, and 18 golf courses (Tucson Water Department 2017). Because water needs fluctuate throughout the year, excess wastewater that has undergone secondary treatment is sent to Tucson's Sweetwater Wetlands Facility. Sweetwater consists of artificial wetlands and a tertiary filtration plant, where water infiltrates the aquifer and is stored until extracted to meet peak irrigation demand (usually during hotter months). The wetlands bring additional benefits to the community, serving as a habitat for local and migratory wildlife, as well as a learning center for ecology and water resource management (Tucson Water Department 2015).

Through the use of recycled wastewater, Tucson has been able to offset its reliance on CAP supplies, retain its nonrenewable groundwater sources, and supplement other renewable sources such as RWH, which still has uncertain availability (Tucson Water Department 2015). Furthermore, the majority of Tucson's turf irrigators use recycled wastewater; excess beyond what is sent to the Sweetwater site may be a source of additional groundwater recharge or even potable water supply (Tucson Water Department 2013, 2015). However, this use may not occur any time soon.

In 2011, Tucson entered into an intergovernmental agreement with Pima County to jointly construct the Southeast Houghton Area Recharge Project, which could store additional effluent for peak demand or lease storage space for other water managers. This project may not come to fruition, however, as Pima County has now identified alternate priorities for water use (Pima County Wastewater Reclamation 2016). Finally, only if the city faces severe water shortages will potable reuse be considered a real possibility. To date, consumer demand has declined, and the city has stored a sufficient amount of its CAP entitlement. The earliest the utility would consider potable reuse is likely sometime after 2027. Additionally, Tucson's consumers have indicated that, despite their support for recycled wastewater, they would not be as amenable to potable reuse (Hummer and Eden 2016).

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Aerial photo of recharge in Orange County. *Source:* Orange County Water District.

# Chapter 20
# Orange County, California

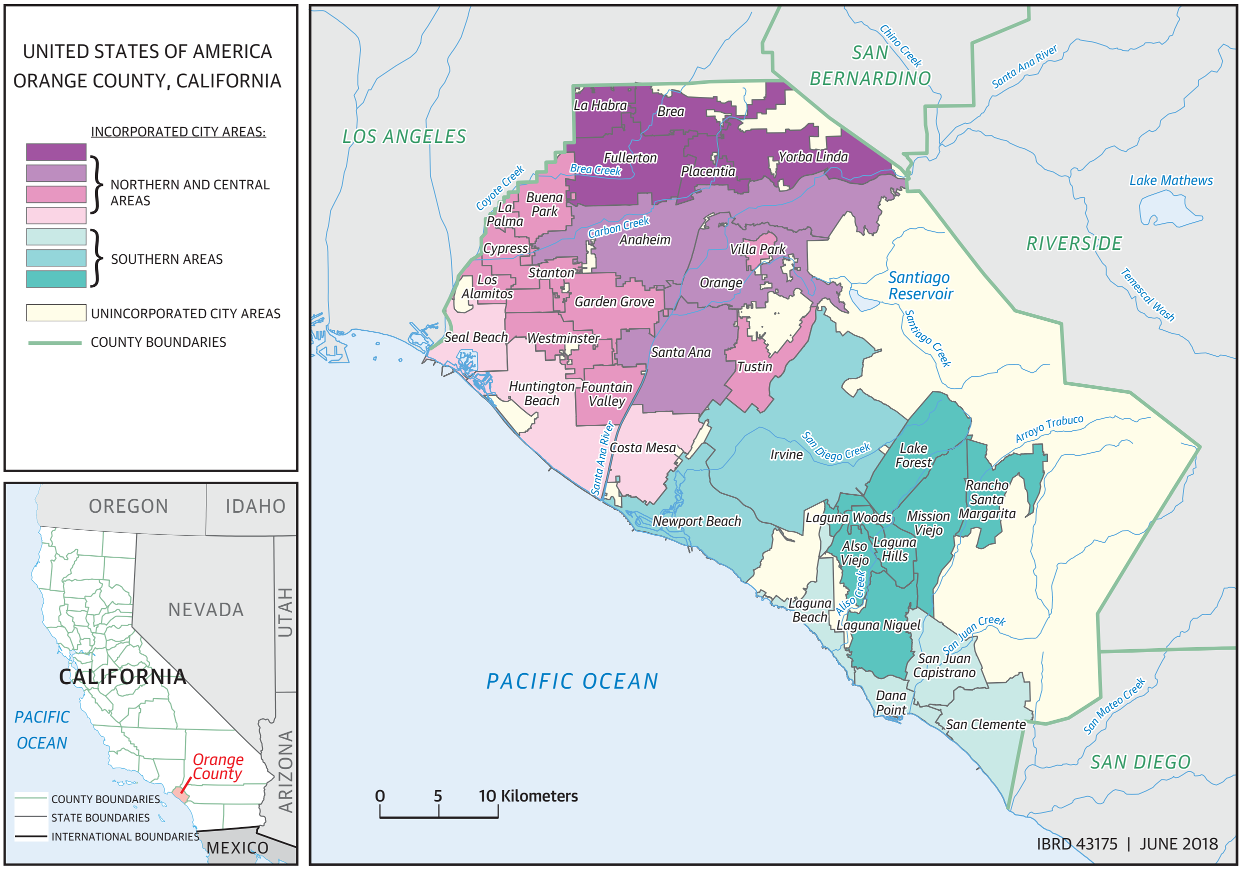
Orange County is located in Southern California and comprises two shallow coastal valleys. With more than 3 million inhabitant, it is the 3rd most populous county in California and the 6th in the United States. Its economy, originally based on agriculture, is today dominated by manufacturing, tourism, and the service industry. Of the 34 cities that make up Orange County, 5 ranked among the nation's 20 wealthiest cities.

## Background Information

Orange County was subject to a state mandatory conservation goal of 25 percent in 2015. In 2014, imports from Northern California supplied as little as 5 percent of requested water to Orange County. Water security has therefore been an important preoccupation for Orange County authorities. As Orange County has undergone continuous urbanization since 1950, agricultural use decreased from 87 percent of pumped groundwater in the 1930s to less than 2 percent today. Currently, water use is mostly residential (64 percent) and commercial (35 percent). Population growth is one of the main sources of pressure on water demand, with municipal use tripling between 1933 and 2015.[1] This trend will likely continue as population within the Orange County Water District's (OCWD) service area is expected to increase from the current 2.3 million people to approximately 2.7 million people by 2035 (OCWD Board of Directors 2017) (map 20.1).

The climate of Orange County is characterized by Southern California's Mediterranean climate: A semi-arid environment with mild winters, warm summers, and moderate rainfall. Although the region is subject to significant variations in annual precipitation, the average annual precipitation in Orange County is

**MAP 20.1. Orange County, California, USA**



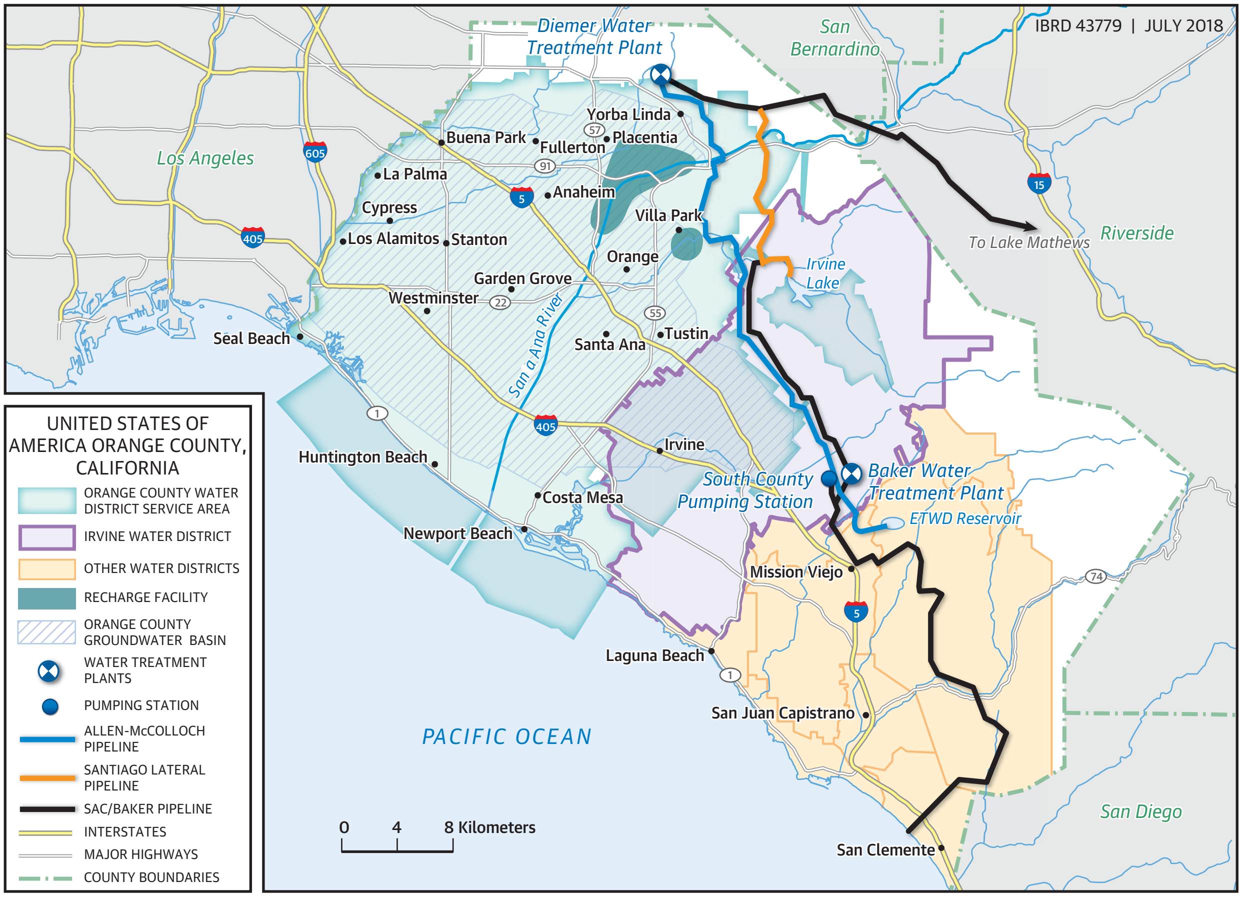

*Source:* Enacademic 2017.

355 millimeters, compared with a 564 millimeter average overall in Southern California. The hydrological system in Orange County is not geographically uniform. Northern and Central Orange County are underlain by a large groundwater basin that is naturally recharged by the Santa Ana River. The basin stores an estimated 81 square kilometers of water, although only approximately one square kilometer can be sustainably pumped without causing physical damage such as seawater intrusion or potential land subsidence (Woodside and Westropp 2015). When the local source of water is not available, Southern Orange County relies principally on imported water. This case study focuses on Northern and Central Orange County to understand how water authorities have sought to capitalize on this basin in order to meet growing water scarcity.

OCWD was created in 1933 to monitor and conserve groundwater supplies in the Santa Ana Valley basin and to protect local water rights from upstream users. OCWD manages the aquifer and sells groundwater to local retailers (cities) within its service area (map 20.2). Each year, OCWD permits local retailers to pump a certain percentage of their water demand and purchase imported water from the Municipal Water District of Orange County (MWDOC) or directly from the Metropolitan Water District of Southern California (MWD).

The water portfolio of the cities in Northern and Central Orange County consists of local groundwater (approximately 70 percent in 2015), imported water (27 percent) and local sources (4 percent), such as recycled water. The Northern and Central Orange

**MAP 20.2. Orange County Water District Service Area**




County core water resource management strategy centers on the groundwater basin to protect the water quality in the aquifer and to control the volume of water pumped to ensure long-term supplies.

The availability of this local resource increased OCWD's clients' independence from imported water, while creating a need for sound aquifer management and protection to ensure its sustainability. OCWD has set itself apart from other water authorities in California by devising a diversified aquifer recharge strategy to increase capacity and fight seawater intrusion, and instating groundwater level monitoring and pumping quotas at a time when the state did not have any restrictions on groundwater usage.[2] Orange County is renowned for its Groundwater Replenishment System (GWRS), which treats wastewater to potable water standards and injects it into the aquifer for replenishment and to fight saline intrusion. As part of its groundwater management strategy, Orange County water authorities also capitalize on stormwater flows to recharge the aquifer.

## Other Solutions

Other options for future water portfolio diversification include desalination and water conservation. Currently, a desalination plant with a capacity of 69 million cubic meters is in the late-stages of the regulatory permit approval process and could be operational as soon as 2019 (OCWD 2017c). OCWD would use this water as an additional source of aquifer recharge to buffer the increasing unreliability of imported water and rain flows.

Water conservation may become an integral part of Orange County's water resources resilience strategy. Water conservation has improved in the last decades with per-person water consumption falling by 21 percent between 1991 and 2014. Water conservation measures include financial incentives (such as a turf removal program and high-efficiency toilet rebates) and educational programs, but also prohibitions or restrictions on specific water usage such as outdoor irrigation. Figure 20.1 represents Orange County water authorities and their water portfolio.

## The Core Water Strategy: Groundwater Basin Governance

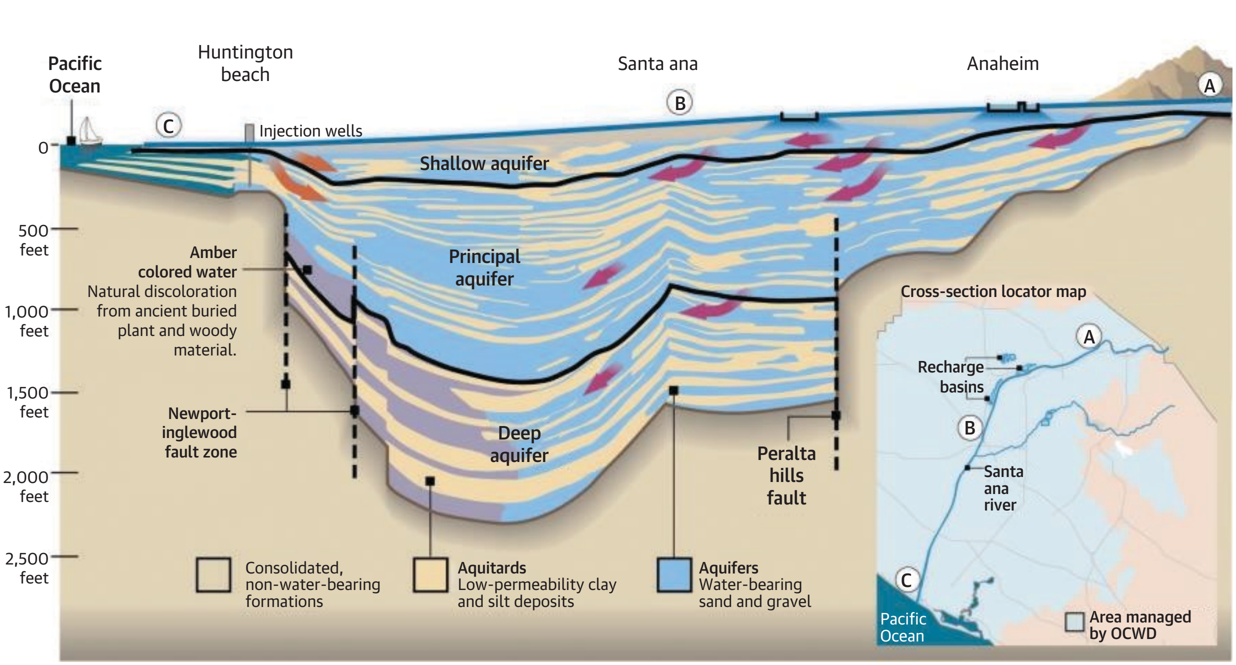
OCWD's groundwater basin governance ensures the sustainability of the aquifer as a resource for the area by increasing capacity and diversifying recharge sources, while maintaining the integrity of the aquifer through combatting seawater intrusion and improving regulation. The cost of producing water from the groundwater basin within OCWD's service area is $0.525 per cubic meter, about one half the cost of imported water.[3] Thus, the residents and businesses that overlie Orange County's groundwater basin enjoy tremendous economic savings compared to areas that rely mostly on imported water and lack other options. Since the 1950s, groundwater production from the basin has increased by more than 50 percent while water quality has been maintained and storage capacity increased (Wehner 2016).

## A Diversified Recharge Strategy

The resilience of OCWD's recharge strategy lies in the diversification of its sources; it distributes risk and provides different options when some sources become scarce.

The primary source of recharge water to the Orange County groundwater basin is the Santa Ana River, with

**FIGURE 20.1. Schematic Section of Orange County Groundwater Basin**




*Source:* Markus 2016.

flows generally consisting of treated wastewater and seasonal storm flows. The OCWD also recharges approximately 89 cubic meters per year of advanced treated recycled water from the GWRS. In addition, the groundwater basin receives an average of 74 cubic meter per year of natural recharge from precipitation and infiltration of irrigation water (Herndon and Markus 2014). OCWD purchases imported water to recharge the groundwater basin. OCWD has also invested in regional stormwater capture projects and developed strong upstream and downstream capture systems. However, on-site urban stormwater capture has not been widely implemented because its impact on the main aquifer is minor and controversial.[4]

### Groundwater Monitoring and Regulation

OCWD operates the basin as a reservoir to withdraw or store water and buffer alternating periods of drought and water availability. For this purpose, OCWD monitors groundwater levels in the aquifer and sets optimal pumping allowances accordingly. Based on historical experience and observations, OCWD established a basin operating range. If groundwater levels approach the low end of the range (with more than 432 cubic meters of storage space available), OCWD has the authority to provide financial incentives for well operators to reduce groundwater pumping and shift more of their supply to imported water. Alternatively, as the stored volume approaches the high end of the range (with less than 123 cubic meters of storage space available), OCWD can allow groundwater pumping to increase.

Though OCWD cannot legally force its member agencies to stop pumping, financial incentives encourage groundwater producers to pump within a target range. The framework establishes the Basin Production Percentage (BPP), which is the percentage of each producer's total water supply that should come from OCWD groundwater for a given year. The BPP is set uniformly for all producers based on estimated hydrologic conditions for the coming year, basin storage levels, availability of imported water supplies, and other basin management objectives. Water retailers pay OCWD a Replenishment Assessment (RA) in proportion to the amount of extracted groundwater. However, if they pump above the BPP, they are charged a Basin Equity Assessment (BEA), in addition to the RA, which is calculated so that the cost of groundwater production is equal to the cost of purchasing imported potable supplies. OCWD also sometimes encourages the pumping of groundwater that does not meet drinking water standards in order to protect water quality in the aquifer through BEA exemptions, which compensate qualified participating agencies for the costs of treating poor-quality groundwater.

## From Water Supply Augmentation to Closing the Cycle: Wastewater Reuse

### The Groundwater Replenishment System, a Cutting-Edge Project

Operational since 2008, the GWRS is the largest planned indirect potable reuse project in the world. Water from this plant prevents approximately 113,000 cubic meters of seawater intrusion daily and replenishes the Orange County groundwater basin by approximately 265,000 cubic meters daily, accounting for 30 percent of the average annual groundwater recharge for the years 2009-10 to 2013-14 (OCWD 2016, 2017d). This ambitious project drew from OCWD's experience operating the Water Factory 21 plant from 1975 to 2004, a water purification program designed to fight growing seawater intrusion as imported water supplies became less available.

The GWRS was born out of a joint collaboration between OCWD and Orange County Sanitation District (OCSD). OCWD needed additional water to inject into the Talbert Seawater Barrier in the mid-1990s. As usage increased, saline water was drawn in further, threatening the potability of the aquifer. At the same time, OCSD faced the challenge of having to build a second costly ocean outfall to discharge treated wastewater into the Pacific Ocean. The GWRS enabled the treatment and management of OCSD's excess wastewater flows while providing a new and secure source of water for OCWD. Both districts shared the cost of constructing the first phase of the GWRS. OCWD funded the initial expansion at a cost of $142 million. OCSD supplied OCWD with stringently controlled, secondary treated wastewater at no charge.

The GWRS treatment process consists of three steps: microfiltration, in which all bacteria, particles, and protozoa are filtered out; reverse osmosis, which removes dissolved chemicals, pharmaceuticals, and viruses; and treatment with ultraviolet light with peroxide of hydrogen, which acts as a safety barrier by destroying potential harmful trace of organics.

GWRS water exceeds state and federal drinking water standards, making it the highest quality recharge water available. The final treated water has a total dissolved solids (TDS) concentration of approximately 54 milligrams per liter, compared to the TDS concentrations of imported water and Santa Ana River water of approximately 500 and 600 milligrams per liter, respectively, and compared to the permit limit of 500 milligrams per liter (OCWD 2016). Water from the GWRS has therefore improved the water quality of the Orange County basin. The cost is equivalent to that of imported water. Additionally, producing GWRS water uses one half the energy of imported water and one-third the energy needed to desalinate seawater (OCWD 2017e).

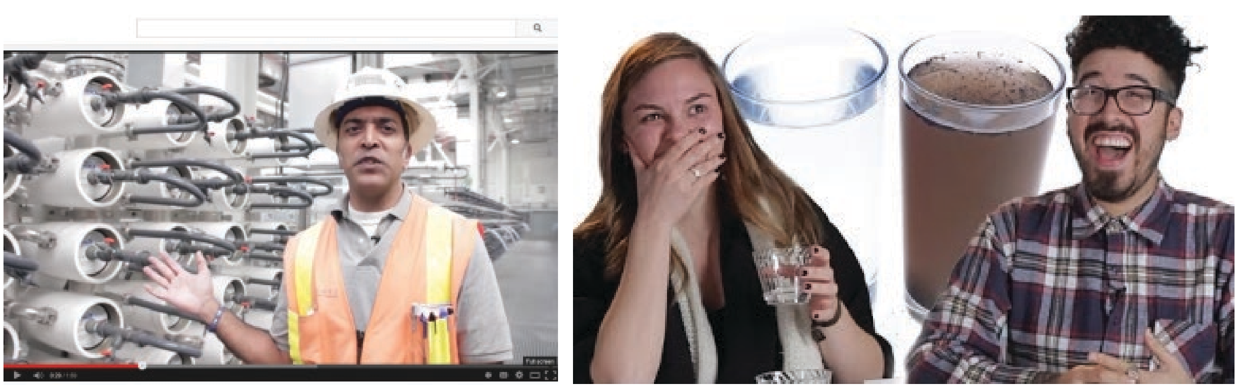
## Challenges

### Public Outreach and Technical Problems

The OCWD and OCSD boards feared the community perception of wastewater reuse for drinking, often referred to as "toilet-to-tap." Similar water treatment projects in Los Angeles and San Diego were defeated, and the WaterReuse and International Water Associations identified public acceptance as the main hurdle to implementing water recycling projects. Therefore, from the project's onset, OCWD and OCSD considered public relations to be imperative to the success of the GWRS (Markus 2016).

OCWD managed an aggressive outreach campaign with a diverse target audience such as elected officials, the media, and the general public (photo 20.1 and photo 20.2). One key factor in the success of the outreach campaign was its launch nearly 10 years prior to the project start-up and its continuation throughout the project's life to maintain support. The success of the campaign was demonstrated by the absence of organized opposition to date. Media support was secured from *The New York Times* and *National Geographic*, and more than 600 letters of

**PHOTO 20.1. Images from the Video *People Drink Sewage Water for the First Time***



*Source:* OCWD Newsletter February 2015.

**PHOTO 20.2. 19th Annual Children's Water Education Festival Hosted by OCWD's Groundwater Guardian Team in March 2015**

*Source:* OCWD Newsletter April 2015.

support were obtained, including from every city council and chamber of commerce in OCWD's service area. OCWD secured $92 million in state, federal, and local grants to fund the project (AAEES 2013). In 2015, a video entitled *People Drink Sewage Water for the First Time*, showing a blind taste test of tap water, Fiji-brand water, and GWRS water, received more than 1 million views on BuzzFeed.

A key technical issue that OCWD faced after project start-up was the diurnal fluctuations in the supply of secondary effluent from OCSD. The GWRS had to be run at higher flows during the day and lower flows at night to coincide with effluent availability. Therefore, the initial expansion of GWRS, completed in 2015, included the construction of two large reservoirs to store and balance the diurnal effluent flows from OCSD. The flow equalization allows the GWRS to operate at a steady-state flow, simplify operation, increase water production, and reduce the unit cost of water produced.

## Conclusion

Orange County authorities have made the most of their groundwater basin through innovative governance structures, close monitoring, and continuous research toward diversification of water sources. By closing the water cycle, water reuse fosters Orange County's water resilience. Particular lessons that can be drawn from the Orange County water scarcity experience include.

The existence of OCWD, a unique and unifying authority devoted to sustainable groundwater basin management. The driving idea behind OCWD is that the basin should not be managed as an ordinary water source but as a reservoir where storage volume and stored water quality are carefully monitored. To replicate this governance, a real-time monitoring system must be established by an entity with jurisdiction over the majority of the groundwater aquifer, with the legal ability to encourage water retailers or private users to pump, or refrain from pumping, water.

The long-term partnership between two agencies that usually operate separately—OCWD and OCSD—enabled them to draw on each other's strengths and launch projects that gave great importance to community outreach. This collaboration shows that integrated water resource management can foster water supply reliability and sustainability, particularly in water scarce regions, by encouraging service providers to develop local resources, foster creative joint solutions, and "close the water loop."

The diversification of water sources is an essential contributor to Orange County's portfolio resilience because it distributes risk and provides different options if some sources become scarce. The development of local water sources such as wastewater reuse, stormwater capture, demand-management, and desalination provide added resilience. These options should be assessed and ranked based on their relative uncertainty and the associated costs to develop a range of responses based on climatic conditions and future availability scenarios.

## Notes

1. OCWD (Orange County Water District). "History." OCWD, Fountain Valley, CA. http://www.ocwd.com/about/history/.
2. OCWD was sought out by the governor of California and key policymakers for its expertise in sound planning and sustaining groundwater supplies during drafting of the Sustainable Groundwater Management Act of 2014.
3. This figure represents the average cost for water retailers (operational costs and the price charged by OCWD). It therefore includes a melded cost of groundwater recharge.
4. Wehner (Assistant General Manager, OCWD), interview with author.

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Irvine, California. *Source:* Kevin Zollman/Wikimedia Commons.

# Chapter 21
# Irvine Water District, California

Irvine Ranch Water District (IRWD) is a service agency responsible for providing domestic water service, sewage collection and treatment, water recycling, and urban-runoff natural treatment in Central Orange County. IRWD's service area has faced several severe droughts during the last decades (IRWD 2016). In 2008, before the implementation of state mandatory conservation, the average water use in Orange County was 719 *liters per person per day*—52 percent less than the rest of Orange County.

Population growth, drought conditions in the late 1980s and early 1990s, and increasing wholesale water charges led IRWD to choose a comprehensive water conservation strategy that uses a budget-based rate structure and a recycled water program to reduce water consumption and ensure IRWD's revenue stability. To this end, IRWD has allocated fixed and commodity service charges at 60 percent and 40 percent, respectively. Fixed charges are the base charges that cover fixed costs such as infrastructure maintenance and fixed operating costs; commodity service charges are the price per volume of water used and cover all variable costs. Therefore, even when water demand declines, IRWD still recovers its costs.

Water is sold to customers under a four-tiered structure adapted to their monthly water budget. Customers using an amount of water within their budget purchase water in the lower two tiers and are rewarded with very low water bills. Customers using water in excess of their budget purchase water in one to two steeply ascending upper tiers, resulting in a pricing signal for excessive use. Revenue generated from these higher billing tiers is used to fund expenses associated with the purchase of additional expensive imported water,

**TABLE 21.1. Irvine Ranch Water District's Residential Tiered Rates, 2015**

| Tier | Rates per $m^3$ | Use (as a percentage of allocated budget) |
|---|---|---|
| Low volume | $39 | 0–40% |
| Base rate | $57 | 41–100% |
| Inefficient | $138 | 101–130% |
| Wasteful | $513 | 131%+ |

*Source:* Irvine Ranch Water District.

urban runoff treatment, targeted water conservation programs, and other costs of water supply and consumption associated with higher levels of demand. Separating commodity and fixed service charges enabled IRWD to overcome the revenue hurdle that traditionally prevents retailers from implementing conservation programs. A budget-based rate structure also raises an issue of water pricing and the principle of cost-of-service. IRWD has to be cautious with its budget-based rate structure to ensure that it respects the principle of cost-of-service.

Since implementation of the billing structure, IRWD residents have decreased their water use by approximately 15 percent while benefiting from the lowest rates in Orange County. Water conservation also results in significant money savings for the IRWD: Between 1991 and 1997, the district avoided an estimated $33.2 million in water purchases while investments in conservation programs amounted to $5 million. This pricing structure has increased drought resilience without the need for mandatory restrictions.

Consumer education and efficient supply management must go hand in hand with rate structure implementation so that consumers can stay within their water allocated budgets while satisfying their base level of demand and maintaining quality landscapes. When first implementing allocations, IRWD undertook a public outreach campaign that incorporated intensive communication with various customer groups and meetings with local community groups. IRWD has also invested in local wastewater recycling for a drought-tolerant source of nonpotable water. IRWD has an extensive dual distribution system, which delivers recycled water from its two recycling treatment plants. The district has established lower commodity service charges for recycled wastewater than for potable water to encourage the use of recycled water.

The case study of IRWD highlights some key success factors of water conservation programs, including the role of local agencies as highly effective agents of water conservation. They are able to manage the local water portfolio and therefore provide an incentive for the optimal use of water by, for example, reducing potable water demand through wastewater recycling programs. Pricing signals, such as the tiered-rate structure, seem more efficient than traditional conservation measures (such as the state conservation mandate). A cost-benefit approach should be adopted by water agencies to justify conservation and implement a virtuous circle by reinvesting savings into conservation programs. Drought and dry periods should be used as policy windows by water authorities in order to implement new water strategies.

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*Source:* Pixabay.

# Chapter 22
# West Basin, Los Angeles, California

The Water Replenishment District of Southern California (WRD) is the largest groundwater agency in the State of California. Its mandate is to manage and protect local groundwater resources for an areas area covering a 420-square-mile region of southern Los Angeles County, the most populated county in the United States. The WRD's service area covers 43 cities, including a portion of the City of Los Angeles. (map 22.1)

## Historical Challenges and Institutional Formation

Groundwater management has played a vital role in the expansion of Southern California's economy and built environment because local surface supply has long been insufficient to support continued growth (Porse et al. 2016). From the 1930s to 1960, groundwater pumping proceeded at an alarming rate throughout much of the state, but particularly in the Central Basin of west Los Angeles. Overpumping resulted in aquifer depletion at an average rate of 2.44 meters per year, with levels dropping far below sea level (Johnson 2013). This reckless pumping resulted in aquifer compaction and subsequent land subsidence, but more importantly it resulted in a reversal in groundwater flow, allowing sea water intrusion to contaminate previously potable sources (Johnson 2007; LADPW 2013). To combat these problems, in 1959 the California state legislature enacted Assembly Bill 2908, which established the WRD to manage the Central and West Coast Groundwater Basins (CWCB).

The two basins serve more than 400 wells, which routinely extract volumes of groundwater in excess of the natural recharge for the consumptive use of

**MAP 22.1. West Basin, Los Angeles, California**


the overlying population. The WRD provides artificial replenishment commensurate with extraction to maintain healthy groundwater levels (Johnson 2013; WRD 2017). WRD operates to ensure the availability of groundwater resources through both natural and enhanced recharge, but also through water conservation efforts. Natural recharge efforts encompass 121 wetted hectares of spreading ground basins, which are inundated with storm, recycled, and imported water up to a capacity of 1.13 million cubic meters with estimated passive percolation of 2.12 cubic meters per second (Los Angeles Department of Public Works 2017a; WRD 2015, 2016). Concurrently, WRD undertakes enhanced recharge by directly injecting water into aquifers through wells.

Through these efforts, WRD successfully supplies 250,000 acre-feet annually (approximately 50 percent of total indoor consumptive needs) to 4 million people in Los Angeles County. Since the WRD was created, it has replenished nearly 7 million acre-feet (MAF) of imported and recycled water into the jointly managed basins.

The WRD remains the only jointly managed groundwater district of its kind in California and the joint management strategy stands in contrast to the tradition of standalone basin management through adjudication in the rest of Southern California (Heikkila 2004). The WRD is governed by a board of five members who are directly elected by the 4 million residents living in 43 cities in the 1,088 square kilometers of the WRD (WRD 2017a). Moreover, the WRD has a unique governance position in the delivery of drinking water as a wholesale agency that relies on another wholesale agency, the Metropolitan Water District of Southern California (MWD), for much of its supply. The WRD does not directly interact with water end-users; WRD water is sold to drinking water systems that serve retail customers.

Recent leadership of the WRD has taken a multifaceted approach to achieving complete local water reliance. Given the WRD's track record of moving away from imported water dependence since 1962, this goal seems potentially attainable. In the early 1960s, at the time the WRD was formed, 36 percent of the WRD's recharge came from stormwater and 64 percent came from water imported from the MWD. In 2015, 20 percent of recharge was derived from imported water, 40 percent from recycled water, and 40 percent from stormwater (WRD 2015). The goal of 100 percent local reliance has begun to be operationalized through the Water Independence Now (WIN) program, which aims to develop enough sustainable local water to supplant the WRD's imported water needs.

## Water Scarcity Solutions

WRD's unique structure and outsized influence in the western portion of Los Angeles County has led to periodic internal governance challenges. The Central Basin has pursued legal and financial redress based on claims that the WRD's joint arrangement is not equitable. Specifically, in managing the vast area encompassed by the CWCB, WRD held rights that conflicted and overlapped with those of the Central Basin. The Basin claimed to have the legal right to "store . . . any water, including sewage and storm waters . . . in the district" and sought to use subsurface basin storage that it considered underused (Chester 2013). With respect to the legal proceedings between Central Basin and WRD surrounding preferential basin rights, a 2013 legislative ruling deemed it in the best interests of overall basin management that WRD remain the sole steward of the CWCB aquifers; the Central Basin consequently assumed diminished operational responsibilities (Chester 2013).

The WRD is not without controversy and criticism from external sources. It has been levied with charges of corruption from various sources, and the state of California has expressed concerns about a lack of transparency in its management. Finally, constituent water purchasers have complained about rising prices for water sold by WRD (California State Auditor 2004; Waldie 2016). It is certainly true that, even though residents indirectly served by WRD are allowed to vote for its board on a regular basis, general public awareness of and meaningful public participation in the governance of the WRD is low. This is generally true, however, of wholesale, as opposed to retail, water agencies.

In October 2011, MWD terminated the discounted replenishment water program that the WRD had used since 1959, and has not yet offered a new replenishment program. WRD members must rely on more expensive Tier 1 water if it is available from MWD-member agencies or purchase higher-priced Tier 2 water if Tier 1 water is unavailable (WRD 2017). Tier 1 Supply Rate—recovers the cost of developing and maintaining a reliable water supply. Tier 2 Supply Rate—set at Metropolitan's cost of purchasing water transfers north of the Delta. The Tier 2 Supply Rate encourages the maintenance of existing local supplies and the development of cost-effective local supply resources and conservation. The tiered rates provide the capitalization. WRD has budgeted for untreated (raw) Tier 1 water for its spreading grounds and treated Tier 1 water for the in-lieu program. In-lieu refers to the process of delivering the treated surface water instead of pumping groundwater. WRD has paid the treated Tier 1 rate for decades to ensure the availability of imported water for injection at the seawater barrier wells. The current retail price of imported water from MWD is $1,254 per acre-foot, and imported costs are likely to rise in the future (Business Wire 2015). The termination of the discounted replenishment rate has motivated the WRD's push to achieve 100 percent local water reliance by 2018. One of the positive effects of WRD's coordination across a wide swath of cities is relative equity in drinking water costs for these users (UCLA Luskin Center 2015).

Water produced from other recycling methods and "new source" production such as desalination have even higher unit costs. By contrast, the WRD 2015–16 levies a uniform assessment of $283 per acre-foot for purchasers (pumpers) of its water across the two underlying groundwater basins. Some of the pumpers have protested that the per acre-foot price that individual pumpers pay should reflect their individual cost of service depending on their position within the basins. The Central and West Coast basins' prevailing nontreated and treated rates, range from approximately $660–$1,030 per acre-foot (WRD 2015). The WRD derives 95 percent of its annual revenue, approximately $70 million, from levying the uniform replenishment assessment on its users. The WRD also maintains total restricted and unrestricted reserves of approximately $60 million (WRD 2016/2017a).

The WRD is prohibited from accruing revenues from the replenishment assessment paid by pumpers that exceed the costs of its operation and maintenance services. In other words, WRD recovers costs that almost exactly equal its expenses on an annual basis. About two-thirds of the WRD's current operation and maintenance costs, in turn, are currently allocated to imported water purchases from MWD (WRD 2016/2017). Although WRD pumpers pay the same rate per acre-foot, the end-use tariffs paid by retail customers of WRD pumpers can vary dramatically (UCLA Luskin Center 2015).

In addition to having a stable revenue stream, as a public agency the WRD is able to rely both on low-interest public bond financing and on state funding streams such as California propositions, which specifically fund needed water infrastructure. Most recently, in 2016, the WRD was awarded funding from California Proposition 1 for its Groundwater Reliability Improvement Project (GRIP), in the form of an $80 million low-interest loan and $20 million grant. It is not yet clear exactly how the WRD will recover costs incurred for capital improvements and debt service in its new projects, but presumably these costs will be incorporated into the cost of service charged to pumpers and may be offset by lower operation and maintenance outlays on imported water purchases.

## Water Replenishment District Present Practices

Currently, as CWCB groundwater volumes have been fully adjudicated to ensure the WRD's rights to water and to curb irresponsible extraction, the WRD maintains highly accurate groundwater pumping monitoring (Los Angeles Department of Public Works 2017b). The volumetric payment structure for purchasing entities was designed to be cost-causative, burdening users in accordance with their consumption and providing an incentive for conservation (WRD 2015). Revenues collected from these charges are then used to purchase water for groundwater recharge. Currently, recharged water is a mixture of recycled and storm waters, as well as imported water from Northern California and the Colorado River. In 1965–66, WRD began an in-lieu replenishment program, which encourages groundwater conservation in years when surface water supplies are plentiful by paying groundwater pumpers to preferentially use surface water (California Department of Water Resources 2013).

Beyond the basic function of WRD to replenish water directly, the agency also maintains numerous projects to bolster the physical integrity and cost stability of its supply over the long term. Most notably, WRD has directed two prominent programs: the Coastal Seawater Intrusion Barriers Project (CSIBP), and the GRIP.

## The Coastal Seawater Intrusion Barriers Project

Following excessive inland groundwater pumping during the first half of the 20th century, aquifer levels fell to record lows of 49 meters below sea level, resulting in rapid seawater intrusion into groundwater aquifers (Johnson 2013). Although some intrusion is natural, the rate of salt contamination progressed rapidly and caused some wells along the coast to be abandoned (LADPW 2013). In response, in 1943 the U.S. Geological Survey Water Resources Division and the Los Angeles County Flood Control District (LACFCD) concluded that groundwater injection wells were the best solution to the problem. Various water agencies across Los Angeles County developed the CSIBP, which consists of three distinct barriers: the West Coast, the Dominguez Gap, and the Alamitos Gap Barriers.

Through the CSIBP, approximately 290 injection wells convey more than 30,000 acre-feet of treated water to aquifers at depths up to 700 meters (Johnson 2007). The injections create an artificial potentiometric head that slows the rate of intrusion and thus protects existing groundwater wells from contamination. As the CWCB is composed of surface aquifers as well as stratified deep aquifers, replenishment by injection is necessary because passive percolation would be inhibited by aquitards in the subsurface. The existing relationship between the operating agencies is complex because the well managers, water treatment facilities, and water purchasing parties are not unified. For example, although the LACFCD manages and operates the wells at all three sites, each site receives water from a different treatment agency and all water is purchased and owned by the WRD (WRD 2007).

The CSIBP, having operated for over 50 years, has faced little public resistance, but faces the challenge of aging infrastructure (Johnson 2007). The six participating agencies are working to optimize barrier performance and examine alternatives to the current infrastructure and methods. Notably, WRD's primary function of groundwater replenishment decreases the energy costs and need for the CSIBP by increasing the potentiometric head flowing to the coast.

## The Groundwater Reliability Improvement Project

Although the GRIP is tangentially motivated by its environmental impact, it is the cornerstone of WRD's WIN program. It aims to offset WRD's current 20 percent reliance on imported water by increasing recycled water availability and use by 21,000 acre-feet. Generating this volume will be accomplished through two processes: first through the construction of an advanced water treatment facility (AWTF), and second by expanding capacity at an existing water treatment plant. The GRIP AWTF is planned to have an annual capacity of 10,000 acre-feet and will further treat wastewater treatment plant effluent using microfiltration, reverse osmosis, and ultraviolet disinfection (MWD 2016). These processes will raise the AWTF effluent quality above the required U.S. Environmental Protection Agency (US EPA) standards before reintroducing it to groundwater aquifers through spreading basins and injection wells in the Central Basin.

The second component of the GRIP project is the expansion of storage at the existing San Jose Creek Water Reclamation Plant. This additional storage capacity will allow for a sustained production of 11,000 acre-feet of recycled water for groundwater replenishment despite diurnal and seasonal variability in wastewater availability. This additional volume will be transported to the Montebello Forebay Spreading Grounds to be used independently or blended with AWTF waters. To minimize cost while ensuring project flexibility, a hybrid approach was selected in which GRIP would use water from both an existing plant and through the production of a new AWTF. Procuring water from both sources ensures ease of use in spreading basins, which require water treated to lower than the GRIP AWTF standard, but also ensures that there is higher quality water available required for direct injection to aquifers (CH2M Hill 2013).

## Lessons Learned for Water Scarce Cities

At its outset in 1959, the WRD's formation as an entity stewarding adjoining neighboring groundwater basins was without precedent. Similarly, its investments in recycling as early as 1962 were without parallel. The formation of the WRD itself at a time of interregional and regional conflict demonstrates that regional entities can form and coordinate stability of water supply in times of crisis. The WRD's protection of saline intrusion for the region, as well as its support of water supply for more than forty cities and water systems, suggests that there are substantial economies of scale in groundwater management and stormwater capture within urban areas that may not be realizable by otherwise fragmented governance structures. The WRD's gradually increasing focus on recharge through wastewater recycling shows that investments in long-term solutions are more prudent in water scarce regions such as Los Angeles.

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*Source:* Pixabay.com.

# Chapter 23
# San Diego, California

Located on the shore and southernmost tip of California, San Diego County is the state's second most populous county (San Diego Regional Economic Development Association 2017). Today an Diego is home to a large military installation and is a thriving hub for tourism and various industries including manufacturing and technology.

San Diego enjoys a dry Mediterranean climate with an average annual precipitation of 264 millimeters, the lowest on the U.S. West Coast and less than half that of Southern California. Over the past 15 years, San Diego has experienced annual rainfall variability, compounded by a statewide four-year drought from 2011 to 2014. Growing water scarcity has spurred increased water conservation and source diversification efforts, particularly from the San Diego County Water Authority (SDCWA). As the water wholesaler for the city and county, SDCWA has developed alternatives to reliance on imported water: The share of SDCWA's imported water portfolio has decreased from 95 percent in 1991 to 41 percent in 2016 (SDCWA 2017a).

San Diego's hydrological system consists mainly of surface water reservoirs[1] and relies primarily on imported water purchased from the Metropolitan Water District of Southern California (MWD) through SDCWA, which stores water in its network of reservoirs for later distribution. With respect to statewide water allocations, San Diego has long been considered to be "at the bottom of the tap." Despite its high reliance on imported water the city is located at the end of both the State Water Project (SWP) and Colorado River pipelines. San Diego purchases imported water from SDCWA as one of its 24 member agencies.

Today, SDCWA relies on three sources: the SWP (20 percent), the Colorado River (64 percent) and local supplies (16 percent).[2] Colorado River supplies are acquired in three ways: (1) through purchase from the MWD; (2) through a long-term water conservation and transfer agreement with the Imperial Irrigation District (IID); and (3) through two canal-lining agreements that transfer conserved water to San Diego County. This water is wheeled for a fee to San Diego County through MWD's water distribution infrastructure. In part, imported water has lower quality than local resources due to the long transfer time in pipelines and associated evaporation, which concentrates salts and other dissolved solids. The second and third sources are obtained through the Quantification Settlement Agreement (QSA), under which SDCWA negotiated with other California parties using Colorado River water to secure a more reliable supply from the river for its municipal uses.

## Other Solutions

The need for reliability is central to SDCWA's water resources planning. As the cost of imported water has tripled in the last 15 years and continues to rise, attempts to reduce dependency and increase the reliability of water resources has precipitated the exploration of ways to diversify the water portfolio. The plan is to feature desalination: In 2012, the Claude "Bud" Lewis Carlsbad Desalination Plant was launched, which produces about 50 million gallons per day of desalinated water to enhance water resilience. Other local sources include surface water, groundwater, recycled water, and conservation. SDCWA is exploring the potential for further seawater desalination and encouraging its member agencies to develop local water reclamation projects and conservation measures and to explore the potential of local groundwater sources. The agency has also developed a Water Shortage and Drought Response Plan delineating steps to minimize the impact of periodic drought (SDCWA 2017a).

San Diego's water portfolio features the planned Pure Water project, which will reclaim wastewater through an advanced treatment train and inject the purified product into the city's reservoirs.[3] Once fully implemented, the Pure Water project will generate one-third of the city's supply locally. The city also relies on rainfall to recharge its reservoirs and has implemented water recycling for nonpotable uses through three wastewater reclamation plants, which will be expanded as part of Pure Water.

## The Transfer Agreement between Imperial Irrigation District and San Diego County Water Authority

The long-term water conservation and transfer agreement with the IID entitles the SDCWA to 200,000 acre-feet of water per year starting in 2021, for up to 75 years. The transfer enables water to move from primarily agricultural uses to meet increasing the demand for urban use. The agreement takes advantage of three things: (1) the nature of IID's "present-perfected" rights to Colorado River water, which, due to their seniority,[4] must be satisfied first in times of shortage and are therefore more secure and reliable; (2) the definition of appropriative water rights that legally establishes that IID must improve the efficiency of its water use; and (3) the fact that IID has the largest annual consumptive use entitlement of Colorado River water among the Lower Basin states (IID 2015).

The transfer ensures that the security of IID's present-perfected right is passed on to SDCWA, giving it access to Colorado River water with a higher priority and reliability than the supply it historically purchased from MWD. It also puts water to beneficial and non-wasteful use: Conservation measures and improved irrigation efficiency in IID's service area enables it to sell the unused part of its allocation to SDCWA to sell to urban users. In turn, the IID can use the money generated by the transfer to modernize its distribution systems. The IID is responsible for identifying the specific conservation measures that will yield the agreed amount, although fallowing is allowed only for the first 15 years of the agreement.

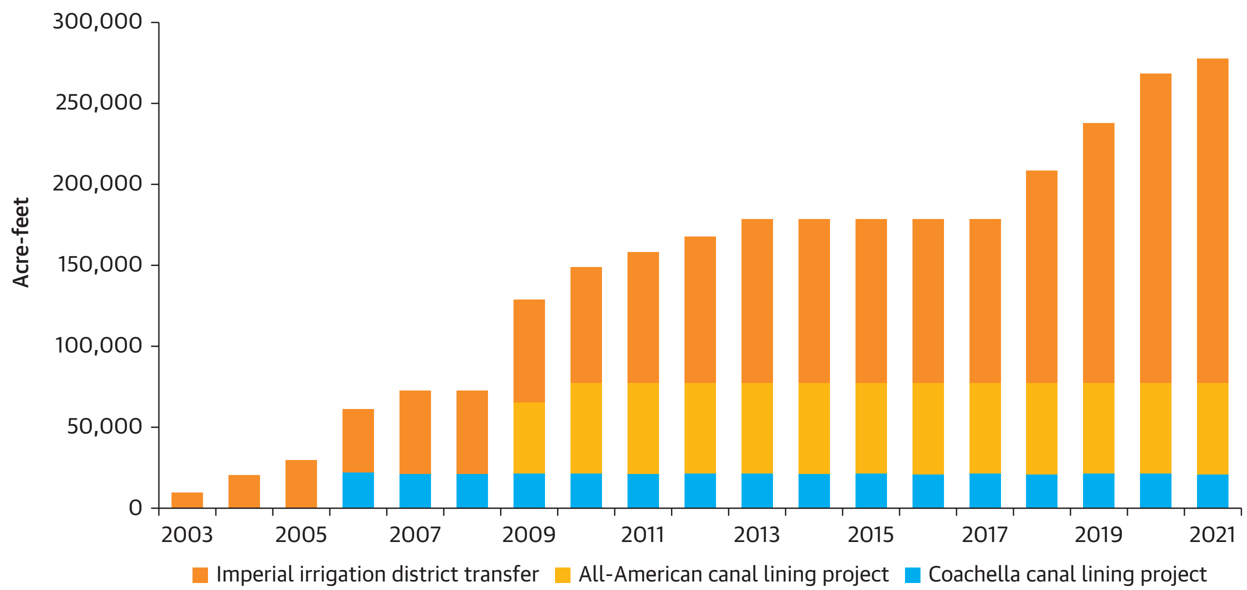
The delivery quantity increases according to a yearly schedule between signing in 2003 and 2021, when it will reach 200,000 acre-feet. The agreement is valid for an initial 45 years, at which time both parties can agree to renew for an additional 30 years. Figure 23.1 shows the increasing amount of the IID transfer as a portion of all water received by SDCWA under the QSA.

### A New Look at Colorado River Water: The Quantification Settlement Agreement

The IID-SDCWA water transfer is a key component of the QSA. The QSA was signed in 2003 to implement measures to reduce California's Colorado River water use to its 4.4 MAF-per-year entitlement to decrease unsustainable pressure on the river. Indeed, since the initial creation of formal allocations of Colorado River water for the basin states (California, Nevada, Arizona, Utah, New Mexico, Colorado, and Wyoming) sharing riparian rights, the Law of the River—the compendium of laws that govern the Colorado River—has been shaped by a succession of legal disputes. California's dependence on surplus water from other states' shares for its municipal use, in particular, has been a source of conflict since the signing of the Colorado River Compact in 1922. Because senior Colorado River water rights in California were first allocated to the agricultural sector, the state initially relied on surplus from Arizona and Nevada to fill the gap. Once water use by the lower basin population met water availability, California began to rely on surplus from upper basin states (Wyoming, Utah, and Colorado). The focus on securing additional water supplies brought California's Colorado River water consumption up to 5.3 MAF annually (Lochhead 2004) (approximately 900,000 acre-feet over its allocation). In 1991, based on these growing tensions, the governor of Colorado told his California counterpart that Colorado would not oppose California's reliance on upper basin surplus, as long as California began planning the transfer of water rights from senior agricultural to junior municipal uses.

These challenges were addressed through the California Water Use Plan for the Colorado River and the signing of

**FIGURE 23.1. Quantification Settlement Agreement Water Supply to San Diego County Water Authority, 2003–21**




*Source:* San Diego County Water Authority.

the QSA. The 4.4 Plan detailed the measures California would implement to reduce water use, particularly the transfer from agriculture to urban water uses. After signing, the QSA allowed California 15 years to gradually reduce its excess use of Colorado River water. The main features of the QSA include the following: (1) establishing the IID's and Coachella Valley Water District's (CVWD) Colorado River entitlements at 3.1 MAF and 330,000 acre-feet, respectively; (2) authorizing and quantifying water transfers from IID to SDCWA, MWD, and CVWD; (3) authorizing water transfers from the Palo Verde Irrigation District to the MWD; (4) funding repairs for the lining of the All-American and Coachella Canals to conserve water to be transferred to SDCWA (80,000 acre-feet) and San Diego County native tribes (16,000 acre-feet); (5) providing water for mitigation of environmental degradation of the Salton Sea; and (6) settling disputes among the seven states and four agencies that share Colorado River water.

The QSA marked an important change in California water allocation because it prioritized municipal use and condemned water waste by agricultural users previously protected by the seniority of their water rights.

## Agreement and Disagreements

From 1991 to 2003, tense negotiations took place (Bulkley 2004) and inscribed themselves in a history of dispute over California water distribution and among Colorado River basin states. By 1998, the QSA components had were identified, understood, and moving toward a resolution.[5] However, disputes lasted until the QSA was signed in October 2003. Eventually, Interior Secretary Gale Norton suspended the Interim Surplus Guidelines in 2002 and effectively created a municipal water shortage in Southern California to force all parties to finally agree.

### The Salton Sea

Between 1905 and 1907, the Salton Sea was created by an unplanned deviation of the Colorado River; it lies at the heart of the aforementioned conflicts.[6] The largest lake in California, it is now fed mostly by agricultural run-off, which has decreased with the improved efficiency of agricultural water use. Although the Salton Sea provides an important habitat for fish and migratory birds, the quality of its overall environment has declined due to elevated concentrations of salinity and selenium. The Salton Sea Authority[7] was formed in 1993 to improve its environmental quality. Concerns were raised during the QSA negotiations about the impact of water transfers that would divert water from the Salton Sea.

California law requires that parties involved in water transfer mitigate related environmental and socioeconomic impact. Debate occurred about the QSA-approved mitigation measures, including protection of native species and financing. For example, in 2002, when the State Water Resources Control Board (SWRCB) legally approved modifications to IID's water permit to facilitate the water transfers, it was promptly petitioned for reconsideration by six entities claiming that adverse effects to the Salton Sea were not adequately addressed. The SWRCB denied the reconsideration which increased pressure on the state to find solutions for the Salton Sea. The SWRCB highlighted that inflow was decreasing and the SWRCB's decision was based on an Environmental Impact Report and consistent with the California Endangered Species Act. It was also noted that without the QSA, Southern California might lose Colorado River water and increase pressure on the Bay Delta, which in turn would have statewide environmental effects (California State Water Resources Control Board 2002).

In July 2003, the IID board threatened to withdraw from the QSA, because it believed that the IID was potentially liable for large expenses for mitigation at the Salton Sea (their transferring water and improving irrigation efficiency would mean reduced runoff) and that the QSA did not properly account for the socioeconomic impact of a water transfer out of IID. Interior Secretary Gale Norton launched a federal investigation of whether IID was wasting water and found that it was wasting some 300,000 acre-feet of water annually, which should have been available to other Colorado River users. Faced with the potential loss—without compensation—of the water it would otherwise transfer to SDCWA, IID rejoined the negotiations and an agreement was reached in October of that year.

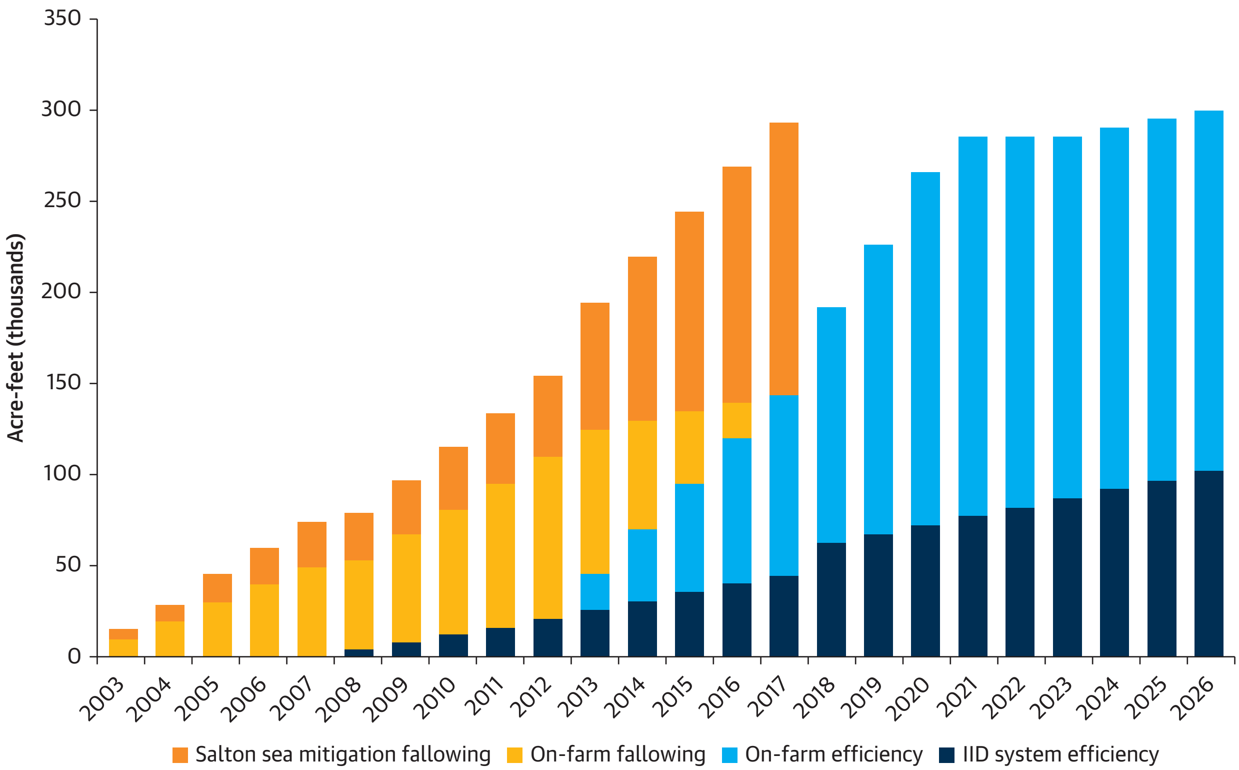
By 2018, QSA transfers may reduce agricultural drain water inflows into the Salton Sea by about 30 percent (CDWR 2007). A Joint Powers Authority was formed to support the implementation of environmental mitigation activities. California also was charged with coordinating the restoration of the ecosystem through the identification and financing of preferred restoration alternatives. However, restoration activities were delayed after the publication of several studies (Cohen 2014; U.S. Bureau of Reclamation 2007) and government deliberations. On March 16, 2017, the Natural Resources Agency released its 10-year plans for restoration, budget, and financing (California Natural Resources Agency 2017).

#### Implementation

Litigation followed the QSA into implementation as Imperial County, its air pollution control district, and local landowners questioned the legality of the QSA under the California Environmental Quality Act. A Sacramento Superior Court rejected all challenges in 2013 and remaining appeals were dismissed in 2015.

Concerns remained about the ability to meet water conservation targets, which could undermine the principle underlying the agriculture-to-urban water transfer. However, conservation targets have been met, as well as their water deliveries through fallowing and the additional measures shown in figure 23.2.

**FIGURE 23.2. Imperial Irrigation District-Quantification Settlement Agreement Water Transfer Schedule, 2003–26**




*Source:* IID 2018.
*Note:* For a breakdown by year, see IID 2015.

## Conclusions

The QSA was an important demonstration that water rights and associated uses can be reliably quantified and reallocated among users according to demand. Despite significant legal disputes surrounding the QSA, even in seemingly overallocated Southern California, the system is flexible enough to accommodate changing requirements. Finally, as the largest agriculture-to-urban water transfer in the United States, the IID-SDCWA water transfer established a precedent for the prioritization of uses under conditions of growing scarcity.

## Notes

1. SDCWA manages a total of 24 reservoirs with combined capacity of about 746,000 acre-feet.
2. The percentages represent 2011–15 five-year averages (Kerl 2016).
3. Has been running a pilot plant of 1 million gallons per day to test the water quality produced through advanced treatment of wastewater from its North City Water Reclamation Plant. The pilot was combined with a study on the reservoir limnology to assess the potential impact of the purified water on the reservoir. The study and pilot showed that overall this new source would actually improve water quality at the San Vicente reservoir.
4. IID's water rights, initially defined as 2.6 million acre-feet (MAF) per year, preempt the 1902 Reclamation Law and as such are not subject to reclamation law limitations.
5. The Interim Surplus Guidelines stated that Southern California was allowed 800,000 acre-feet of surplus water from other states until active steps were taken to reduce its water use to the allowed 4.4 MAF by 2002.
6. The river burst through poorly design irrigation controls in Yuma, Arizona, and flooded the Salton basin for over a year, causing damage to the local inhabitants and the main line of the Southern Pacific Railroad.
7. The Salton Sea Authority comprises the IID, the CVWD, and Imperial and Riverside Counties and coordinates closely with the state and federal governments.

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*Source:* Pixabay.com.

# Chapter 24
# Los Angeles, California

Water has been the engine behind the growth of Los Angeles County to a population of 10,241,335 as of January 1, 2016. Both drought and flooding characterize the climate in Los Angeles—ensuring both an adequate water supply and addressing periodic floods is a challenge.

Rapid urban growth, which was mainly dependent on well water, led to the overexploitation of groundwater, as well as to pollution of surface waters. The undergrounding of drainage into storm drains and increasing amounts of impervious pavement reduced infiltration of water to groundwater and increased urban runoff. In addition, flooding became exacerbated during storms, which led to the construction of a hardened drainage system. The construction of urban wastewater treatment plants in the 20th century increased wastewater treatment quality but discharged the treated water to channelized[1] rivers and the ocean rather than replenishing the groundwater basins. Low density, sprawling growth, high water use, and a declining groundwater table resulted in a situation that could not be sustained.

The geography of Los Angeles County's watersheds made water supply and flood control even more challenging. The metropolitan area is ringed on the east by the San Gabriel Mountains, one of the world's steepest mountain ranges, measuring 60 miles from crest to sea level. The vast quantities of water speeding off these slopes during storms and heading toward the sea result in floods that can change the course of rivers or send speeding mudflows down the mountains. Taking into consideration the region's geography, Mediterranean climate, and highly variable storm seasons, two solutions were developed to address imported water supply and channelized flood control channels.

## Imported Water

The City of Los Angeles led an initiative to supplement local water sources by completing the development of the 233-mile long Los Angeles Aqueduct, which diverted water from the Owens River on the east side of the Sierra Nevada Mountains. In 1941, the Aqueduct was extended another 105 miles north, along with the construction of additional reservoirs, to encompass a greater area of the Eastern Sierra Nevada Watershed.

With escalating growth in Southern California, the California State Legislature created the Metropolitan Water District of Southern California (MWD) to develop a series of dams on the Colorado River and the 242-mile Colorado Aqueduct, completed in 1939.

The final piece of Southern California's imported water infrastructure is the California State Water Aqueduct, bringing water from the western side of the Northern Sierras south to the Sacramento River Delta. From there, water would be diverted south by pumps into the California Aqueduct to bring water to Central Valley farmers and over the Tehachapi Mountains to Southern California.

Los Angeles County has depended on these three aqueducts for imported water for decades. The groundwater basins of the San Gabriel Mountains continue to be a major source of water for the San Gabriel Valley and for some Los Angeles basin communities.

Because imported water has been relatively cheap and dependable in this region during the last 104 years, the need for developing local water supply sources was largely ignored. The successful completion of multiple projects to bring imported water into the region to meet water demand enables the population to continue to grow.

## Flood Control

As urban growth expanded and impervious surfaces increased runoff, stormwater events created more flooding. As ample imported water flowed from the aqueducts to meet water demand, stormwater was less than an impediment to urbanization next to the rivers. Therefore, the rivers came under the management of the state-created Los Angeles County Flood Control District in 1915, which had the mission of controlling floods and capturing some water through constructed spreading grounds, but no role in water supply. The District worked with the Army Corps of Engineers to build a system of dams and debris basins to "hold back the mountains" (McPhee 1989, 183) and to transform rivers and their tributaries into an elaborate system of channelized rivers and tributaries (Salazar 2013).

Within the 3,000 square miles of Los Angeles County, there are nearly 500 miles of open, concrete channels, 2,800 miles of underground storm drains, and an estimated 120,000 catch basins (Los Angeles County Flood Control District 2015). Thus, the rivers were contained, but flows increased and flow rates accelerated in narrow, straight smooth channels to the ocean. Many pollutants were scoured from developed areas and farms into the rivers, reducing water quality in the channels and the ocean. Even greater flood control measures were required in the 1980s as urbanization increased, land subsided to below sea level near the Lower Los Angeles River, and urban runoff from new urbanization increased. In 1980, the Army Corps of Engineers and the Los Angeles County Flood Control District started planning to raise the channel walls on the Lower Los Angeles River and finished the project at the turn of this century.

## Water Scarcity Solutions: A Change in Paradigm for the 21st Century

Importing water supply from afar and treating local stormwater as a flood hazard were the water supply and flood control solutions for 20th century Los Angeles. For many reasons, however, these cannot be the solutions for the 21st century. Water availability throughout California has been affected by record-breaking drought over 11 of the last 15 years. Climate change is affecting both temperature and the snowpack that stores water for the dry season in California and making a highly variable rainfall pattern more extreme. Imported water is less reliable and predictable, and costlier, because of scarcity, electrical power costs, and water treatment costs.

Although Los Angeles Aqueduct water quality remains high, the same cannot be said for water from the Colorado River or the State Water Project. Water from the Colorado River and State Water Project is conveyed by aqueducts. Massive treatment plants are required to bring this water to safe drinking water standards (Metropolitan Water District of Southern California, n.d.).

In the face of these challenges to continued reliance on imported water supplies, a new paradigm was created that strikes a balance between local and imported water, focusing on (1) water efficiency by water providers; (2) consumer conservation; (3) managing groundwater basins for safe yield, water quality, and replenishment; (4) recycling treated water; and (5) capturing local stormwater.

Two stormwater capture efforts for water supply were initiated in Los Angeles County. The first was a stormwater capture plan that projected the effects of climate change on water supply in Los Angeles County as the basis for a new management plan (U.S. Bureau of Reclamation and County of Los Angeles Department of Public Works 2016). The purpose of this study was to plan ways to alter and augment stormwater infrastructure and its management to capture more flood water and infiltrate it to groundwater.

In the 180s, it became clear that local stormwater was wasted and that both the ways urban areas convey stormwater to rivers and the ways channelized rivers convey stormwater contributed to the pollution of lakes, rivers, and the ocean. In 1987, the U.S. Congress amended the Clean Water Act, adding section (402)(p) to limit polluted stormwater discharge under the National Pollutant Discharge Elimination System. In response, the U.S. Environmental Protection Agency (US EPA) unrolled a permitting program in 1990 that limits the discharge of pollutants into stormwater. Federal regulations were adopted to implement this legislation, which, together with the permitting program, set forth requirements for municipal separate storm sewer systems and industrial activities including construction (National Research Council of the National Academies 2009).

As a result, with delegated authority from the US EPA, the California State Water Resources Control Board, established stormwater permits for the transportation and industrial sectors, while its seven Regional Water Quality Control Boards established municipal and agricultural stormwater permits. The Los Angeles Regional Board issued its first Municipal Stormwater Permit to the County of Los Angeles and its 88 cities in 1990. Each subsequent permit, in 1996, 1998, and 2001, increased the requirements, with growing resistance from local governments.

Initially, the recommended solution to stormwater pollution was treatment, which involves intercepting contaminated stormwater before it gets to or in the municipal stormwater system and treating it before it reaches rivers or the ocean. But as the drought years dragged on and water scarcity intensified, capturing stormwater for water supply before it was polluted and then using or storing it made sense. As a result, the cities responsible for paying to reduce stormwater pollution could not only address water quality issues but also benefit from either additional water supply or ancillary benefits, such as parks that could capture and infiltrate stormwater. The 2012 Municipal Stormwater Permit for Los Angeles County was designed to facilitate these options, giving priority to stormwater pollution prevention through capture and encouraging projects that have multiple benefits.

The big challenge to implementing these permits to capture stormwater and meet water quality standards in surface waters is that there are 88 cities in Los Angeles County, and city boundaries bifurcate watersheds and rivers. There was no way to develop coherent plans for shared regional projects without joint planning between cities, something that is rarely done in Los Angeles County.

The 2012 permit gave the permittees (cities and the County) the following three options, broadly based on the perspective either of water supply or water quality. First, each permittee could implement the permit within its own boundaries, meeting the water quality standards by the deadlines set for the water bodies in or next to their boundaries. Second, the permittees in the same watershed or same subwatershed could agree to work together on a Watershed Management Plan for their combined jurisdictions. They would develop joint and separate projects that capture and infiltrate or store stormwater, before it becomes polluted and drains to the nearest water bodies. In the third option, the cities could come together with the County of Los Angeles to develop Enhanced Watershed Management Plans (EWMPs). These groups were given three years to complete the more complex EWMPs, which were approved by the Los Angeles Regional Board in 2016. There are 17 watershed management groups in Los Angeles County working with their partners to implement those plans (LARWQCB 2017).

## Challenges

Challenges remain to identifying the best pathways to maximize local water supply potential and improve water quality. Best Management Practices (BMPs) are increasingly being considered as potential solutions to increase available local water supplies. BMPs can include regional projects, distributed projects, such as green streets or low-impact development (LID), or management measures. The US EPA provides a national menu of potential BMPs (US EPA 2017) but BMPs are not limited to this list; other BMPs can be used as long as required removal efficiencies can be achieved. In the Los Angeles region, BMP performance and suitability will be assessed through a Reasonable Assurance Analysis, which is required as part of the EWMP process to assess whether expected water quality benefits are being achieved (Los Angeles Regional Water Quality Control Board 2013).

The size and location of potential BMPs are constrained due to Los Angeles's urban fabric. Most stormwater pollution BMPs in the Los Angeles region are installed to comply with water quality requirements for metals, nutrients, bacteria, and trash, all of which behave very differently from each other in the environment and in BMP facilities. It is critical that the new stormwater capture and infiltration systems neither become "gateways" for pollution of groundwater basins nor affect the plumes of pollution that already exist in the basins. Infiltration-type BMPs are fairly somewhat effective at removing pollutants, especially pathogens, from the watershed (US EPA 1999) and also provide the greatest potential to recharge.

Larger projects can be more cost effective because they manage larger volumes of stormwater and, in the case of infiltration-type BMPs where connectivity to groundwater can be established, easier to quantify from a water supply benefit perspective. However, at least some stormwater treatment BMPs need to be placed in the lower portions of the affected watersheds and water bodies. In heavily urbanized landscapes such as Los Angeles, smaller-scale distributed BMPs are often the only ones that will fit in the lower portions of the watershed. Both larger-scale regional BMPs and smaller-scale distributed BMPs will serve as part of the solution, as will adding BMPs on both public and private lands.

Research is underway to develop innovative technologies to improve the efficiency of BMP treatments and enhance the performance of distributed LID and regional systems. Increasing the use of these technologies will generate an increased capacity to gather, store, and share relevant data broadly. Important streams of research include increased monitoring of stormwater BMPs; identifying potential sources of pollutants to the watersheds; studying surface water and groundwater interaction to better characterize the water supply benefits of stormwater capture projects; and developing a framework in which this data can be shared.

Recent studies address the costs and benefits of stormwater infrastructure and analyze the suite of BMPs that could be used to capture stormwater and meet water quality standards in the 130 square miles of the highly urbanized Ballona Lagoon. Such studies indicate that it is challenging to obtain the robust cost data for a diverse and large set of projects that will allow project comparison. The range of costs for projects is also wide and reflects project variability.

Cost measure in all cases is cost per volume of water captured—water supply (not water quality), flooding, recreation, and other benefits. The Los Angeles Basin Plan (U.S. Bureau of Reclamation and County of Los Angeles Department of Public Works 2016) tries to recognize multiple benefits in a numeric system but does not quantify the financial benefits of improved water quality, open space, or recreation land—only water supply. As a result, projects that collect the most water where it can be easily measured and stored are going to be the most cost effective. Smaller projects more widely distributed throughout the permeable urban area generally require extensive retrofits of the storm drain system (which is more expensive), with multiple stormwater infiltration points (making it harder to measure water captured).

Distributed water capture projects have many benefits but may entail higher costs. If many smaller, distributed projects are to be built and managed to maximize both stormwater capture and stormwater quality, then separate agencies need to collaborate on these projects.

Multibenefit financing has pushed stormwater capture implementation projects forward in Los Angeles County by encouraging projects that provide multiple benefits such as increased water supply and improved stormwater quality. For example, in 2002, City of Los Angeles voters passed a ballot measure, Proposition O, that funded up to $500 million in projects with multiple benefits.

Much of the previous resistance to treating stormwater was that it was seen as costly, with little or no value to upstream communities not near the polluted rivers and coast. Following Proposition O, California voters passed Proposition 84 in 2006, which provided $90 million in grant funds for stormwater capture or treatment projects with multiple benefits throughout the state. In 2014, state Proposition 1 provided additional funding to make stormwater capture a priority and to provide capital funds for multibenefit stormwater projects.

It is critical to identify multiple sustainable funding streams to increase stormwater capture investment. Without a funding stream dedicated to these programs, investment in stormwater capture may need to compete with investments in other public services.

## Conclusion

Retrofitting a drainage system to capture stormwater is expensive and limited by existing development patterns. Funding options in the Los Angeles region are generally restricted to planning and capital costs of construction. It is important to establish funding streams that can fund the maintenance of green infrastructure, such as including the costs of stormwater capture projects in water rates.

A key option is to design sustainable and multipurpose stormwater drainage and recapture plans as development or redevelopment progresses. Where possible, the width of rivers should be considered to contain flooding, and development should be set back from the riverbanks. Opportunities to store and divert water from water sources during periods of excess flow also provide water security opportunities.

The water infrastructure system in Los Angeles County requires costly retrofitting in part due to the separation of the governance systems for stormwater, water supply, groundwater management, and treated wastewater. Rather than segregating stormwater and groundwater authorities, water scarce cities can develop programs that integrate governing authorities to ensure that stormwater is a valued and well-managed resource. Managing flood control alongside water supply also provides the opportunity for stable water supplies and flood-risk reduction.

Although small distributed projects (such as rooftop water cisterns) may be relatively expensive compared to larger structural projects, small projects may be lucrative for older parts of cities if it is too expensive to rehabilitate or replace drainage structures. Finally, coordinated water management may provide opportunities to simultaneously implement both regional and street-scale stormwater capture projects to maximize benefits and minimize costs in city growth areas where removing old infrastructure is cost efficient.

## Note

1. The U.S. Environmental Protection Agency (US EPA) defines "channelization" as "river and stream channel engineering undertaken for the purpose of flood control, navigation, drainage improvement, and reduction of channel migration potential. Activities such as straightening, widening, deepening, or relocating existing stream channels and clearing or snagging operations fall into this category" (US EPA 2010). This can also involve the concretization of the river channel to prevent its future movement.

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*Source:* Whitney Wood.

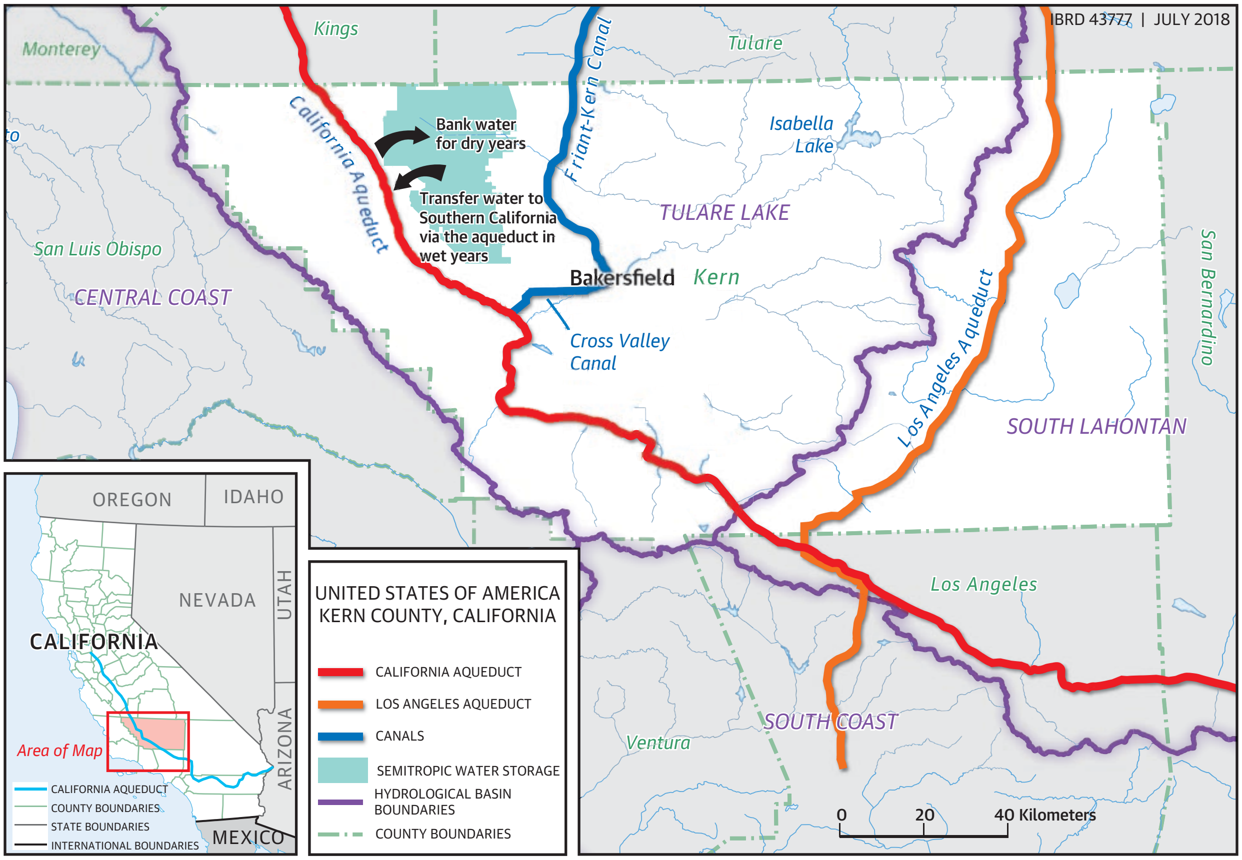
# Chapter 25
# Kern County, California

Kern County is located in central California and is the agricultural heartland of the State, comprising rural communities, and cities such as Wasco, Delano, Arvin, Taft, Bakersfield, and Shafter. Agriculture and energy have long been economic mainstays of the region, as an important hub for food security and international agricultural trade. The semi-arid climate presents extreme variability with water. Thus, Kern County has adapted with measures such as cooperation between farming communities, as well as locally governed and financed groundwater banking operations (map 25.1).

This discussion highlights the geologic, hydrologic, economic, legal, and social factors that are necessary for highly sophisticated and successful groundwater banking operations. These factors came together in Kern County to create a viable, large-scale private water market. Other locations might not possess all these factors, and Kern County may be unique in terms of scale.

The Kern County experience illustrates the long time required for groundwater banking projects to mature, especially if out-of-county infrastructure investments are required. A turning point in the development of groundwater banking operations were agreements reached in 1994 among the California Department of Water Resources (CDWR) and the State Water Project (SWP) contractors, illustrating that successful projects require a collective understanding of the compelling need and a willingness to compromise among parties—both urban and agricultural. Outside of Kern County, mid-20th century investments in massive, statewide water infrastructure allow exchanges, transfers, and flexibility in water banking operations. Financial arrangements with banking partners provided financial

**MAP 25.1. Kern County Water Resources**




security and allowed water storage districts (WSDs) to develop the groundwater banking facilities. Operating rules protect neighboring districts from the adverse impact of excessive water extraction, and the quality of pump-back water is closely monitored. The experience in Kern County shows that, when multiple factors align, long-term benefits may accrue to all parties. This experience may motivate those in other parts of the world to integrate groundwater banking operations that serve both urban and agricultural regions.

**Water banking operations in Kern County, California, are hailed as the most effective groundwater storage programs in the United States and probably the world.**

Groundwater banking in California is one means of coping with the ever-increasing dry spells and declining winter snowpack caused by climate change. Groundwater banking increases drought resiliency by storing water underground in wet years, making it available in dry years. The process may entail direct recharge, using percolation ponds or injection wells, or in lieu recharge, through which surface supplies are provided to groundwater users in lieu of pumping groundwater and the amount of groundwater that otherwise would have been pumped becomes banked water (Hanak and Stryjewski 2012).

California's Water Code allows water marketing and banking provided sellers have the right to use the water and the water they sell is "wet" (not an unused "paper" right); buyers must have the means to get the water from source to destination (Hanak and Stryjewski 2012).

## Kern County Water Banks

Water banking evolved from recharge programs to managing fluctuations in water supply and offsetting groundwater overdraft. A number of factors make Kern County ideal for groundwater banking, including geology and proximity to imported water supplies and delivery systems. The groundwater basin is not hydraulically connected to other basins or surface waters.

With conjunctive use, aquifers serve as the underground reservoirs and reserves that can be drawn upon as needed to augment surface supplies. Percolation ponds, or spreading basins, are used in Kern County in areas with good permeability along the Kern River alluvial fan, a huge wedge of sand and gravel, formed over thousands of years since the Ice Age, where the Kern River exits the Sierra Nevada foothills and spreads along the southern end of the San Joaquin Valley. The alluvial fan created an unconfined aquifer hundreds of feet thick, leading to extensive groundwater pumping for irrigation and severe overdraft in the 20th century. However, this also provided the potential for a vast amount of groundwater storage (Christian-Smith 2013).

Groundwater banking partners in Kern County provide for reliability of in-district supplies (such as the Kern Water Bank), and others are partnerships between Kern County water districts and out-of-county entities. The out-of-county entities provide capital to help construct and maintain the banking infrastructure, and then bank their own surplus water in the groundwater basin. A portion of the banked water is non-recoverable to compensate for evaporation losses and other intrinsic losses. In return, the participating water districts use the infrastructure and fees collected from their partners to help meet their consumptive use needs (Parker 2010). The Arvin-Edison (Arvin-Edison) WSD and Semitropic (Semitropic) WSD programs are of this type. Some banking programs are developed solely for long-term water sales, primarily to southern California entities. The joint Buena Vista WSD-Rosedale-Rio Bravo WSD project is of this type (Parker 2010). In a related project, the Irvine Ranch Water District (IRWD) in Orange County bought land adjacent to Rosedale-Rio Bravo, made improvements, and signed a 30-year contract with Rosedale-Rio Bravo to recover approximately 17,500 acre-feet of water in any given year (IRWD 2012).

### Physical Characteristics and Shared Experiences

Groundwater depletion in the last century resulted in widespread declines in the elevations of California's Central Valley groundwater, particularly the Tulare Lake Hydrologic Region in Kern County, with depth to groundwater of 50-200 meters (Scanlon et al. 2016). This extensive unconfined aquifer provides the capacity to support groundwater banking.

Located at the southern end of the San Joaquin Valley, the Kern area is conveniently located for geology and proximity to water supply and delivery systems (Christian-Smith 2013) (map 25.1). The California Aqueduct (also known as the SWP) is on the west, the Friant-Kern Canal (Central Valley Project) and the Kern River are on the east, and a Cross Valley Canal links these units. The groundwater basin in Kern County is closed, meaning no surface water is lost once water is placed in the ground. The unconfined aquifer at the Kern Water Bank is 50-70 percent sand with high transmissivity and percolation rates of several inches per day (Parker 2010).

The discussion below highlights three groundwater banking operations in Kern County: Semitropic, Arvin-Edison, and the Kern Water Bank. Common problems experienced in the 1980s and early 1990s were severe drought, groundwater overdraft, rising energy and water costs, and increasingly unreliable SWP contracted deliveries. A common element in the success of these operations is that the banked water is imported from a hydraulically disconnected source—that is, from a source outside Kern County (Thomas 2001). The Semitropic Water Storage District Bank and the Kern Water Bank are two of the largest in the world (Kennedy/Jenks Consultants 2011; Semitropic WSD [Water Storage District] 2004).

## Planning and Development: Three Examples

California law allows the formation of various districts for the development, control, and distribution of water (CDWR 1965). A district may be formed by a general act of the legislature or by special act prescribing its powers as a form of local government with an independent board of directors elected by the district's voters for a fixed term. For example, the Semitropic WSD's board comprises farmers elected by landowners. The Kern Water Bank Authority is a Joint Powers Authority whose directors represent a group of public and private water districts and operate the Kern Water Bank. Some WSD boards are elected by a weighted vote of property owners; others use a one-person-one-vote rule (Hanak and Stryjewski 2012).

Semitropic, which extends over 221,000 acres in the northern part of Kern County, sought a water-banking partner to finance a groundwater banking program. The Semitropic banking operations began with a demonstration project by the CDWR for deliveries of SWP surface water to farmers in the district in lieu of the farmer's pumping and irrigating with groundwater. The amount of SWP delivered becomes banked in the district. To pay back CDWR, Semitropic would forego a future delivery of its SWP entitlement water and Semitropic (or the farmers) would extract groundwater in amounts equal to the banked water for irrigation. But in 1991, there was no SWP water available due to a very dry year and the San Joaquin River delta pumping restrictions in the north. This showed the importance of having pump-back facilities and agreements to deliver stored water directly to the California Aqueduct. The Metropolitan Water District of Southern California (MWD), which had been tracking these operations, wanted a water banking agreement with Semitropic but only if it had a pump-back component. This agreement was concluded in 1994. Today the system's capacity is 1.65 million acre-feet. During wet years the banking partners (MWD and Santa Clara Valley Water District, each with an allocation of 350,000 acre-feet) deliver surplus water to Semitropic, and the water is returned by exchanging Semitropic's entitlement or pump-back (Semitropic WSD [Water Storage District] 2004). The Semitropic water banking agreement and memorandum of understanding with surrounding districts served as a model for other agreements.

Arvin-Edison comprises 132,000 acres located in the extreme southeastern portion of the San Joaquin Valley. Imported water was made available from the U.S. Bureau of Reclamation's Central Valley Project, which brought water south from the San Joaquin River through the Friant-Kern Canal, and Arvin-Edison was organized to contract with the Central Valley Project. However, the firm supply was only an 11 percent supplement with the remaining 89 percent only "as available" during wet years. This put growers at perpetual risk of lack of water in drier years (Vaux 2002). The answer lay in connecting to the California Aqueduct and constructing a Cross Valley Canal to serve users at the southern end of the San Joaquin Valley. In a memorandum of understanding, Arvin-Edison gave up its firm commitment and about one-third of its nonfirm supply to upstream users on the Friant-Kern Canal in exchange for a greater firm supply from the California Aqueduct. Those upstream users on the Friant-Kern Canal were entitled to SWP water but couldn't access it because water would have to have been pumped uphill against the flow in the canal (Vaux 2002). This exchange benefited all parties. After the success of the Semitropic-MWD project, Arvin-Edison and MWD entered into an agreement to bank SWP water with pump-back components, build new spreading ponds, and construct a bidirectional intertie pipeline.

The Kern Water Bank comprises about 20,000 acres of percolation ponds, canals, and habitat areas. The land was bought by the CDWR in 1988. The CDWR began to phase out tenant farming leases with the plan to develop a water bank. The area is ideal for percolation with sandy soil from alluvial deposits that percolate up to 6 inches of water per day. The state ran into difficulties with endangered species, high costs, complicated negotiations, arsenic standards for pump-back to the California Aqueduct, and uncertainty over the volume of water that could be delivered from the California Aqueduct. In 1994, the state deeded ownership of the land to local water districts in exchange for 45,000 acre-feet of annual SWP entitlement and allowed the transfer of water entitlements from agricultural users to urban entities under the so-called Monterey Amendment of the state water contract. Six water districts, the Project Participants, formed the Kern Water Bank Authority and executed a memorandum of understanding in 1995 for the operation of the Kern Water Bank (Parker 2010; Thomas 2001). The Kern Water Bank can take advantage of water deliveries from three sources: the Kern River, the Friant-Kern Canal, and the California Aqueduct. A canal was built to connect the Kern River to the California Aqueduct. There are about 7,500 acres of recharge basins, and the remaining 12,500 acres are habitat in land between the recharge basins. The Kern Water Bank is the only bank in the county with no surface cultivation; it is subject to a 75-year habitat conservation plan.[1]

## Economic and Financial Aspects

For Semitropic, the percolation rates are not high and water is banked primarily by in lieu deliveries. The arrangements include full compensation to Semitropic when water is stored, when it is returned from storage, for energy costs to deliver water to the California Aqueduct, and for operation and maintenance costs (Semitropic WSD [Water Storage District] 1995). Contracts with individual landowners specify payments and operations and include provisions that Semitropic may use a landowner's well to extract water for pump-back with compensation. Water banking partners have first right to use new facilities for the banking operations, although the facilities remain the property of Semitropic.

For Arvin-Edison, the costs of the new facilities come from fees charged to MWD for operations, energy costs, and conveyance. Arvin-Edison is protected further through the requirement of a minimum amount of yearly storage. Arvin-Edison would have been unable to build the facilities without the financing of a banking partner such as MWD (Thomas 2001). The location of Arvin-Edison at the end of two major surface water importation facilities was of critical importance, as was the fact that these facilities could be tied together physically, thereby allowing the exchange of waters between facilities. The agreement with the exchange districts located upstream on the Friant-Kern Canal allowed Arvin-Edison to increase more than three-fold the quantity of its firm surface water allocation at little cost (Vaux 2002).

The Kern Water Bank was purchased from the state in 1994 through an entitlement transfer negotiated under the Monterey Amendment, which set conditions for transfer to agricultural contractors in exchange for the retirement of 45,000 acre-feet of long-term supply of contractor's water from the SWP. The property ownership was transferred to the Kern County Water Agency and then to the Kern Water Bank Authority for local development as a water bank (Parker 2010). The water bank does not deliver water south of Kern County. It engages in exchange deliveries, through which an entity upstream takes water from the California Aqueduct and the Kern Water Bank Authority returns the same amount downstream (Parker 2010). In 2010, the cost to recharge water was $13 per acre-foot, and the cost to recover water was about $70 per acre-foot. The Kern Water Bank stores water on behalf of its participants, who may then use or sell the water to others; the resale price can be quite high depending on the hydrologic cycle and market conditions.

The IRWD's arrangement with the Rosedale-Rio Bravo WSD is an example of equity ownership of water banking capacity. IRWD, located in Orange County, south of Los Angeles, wanted to expand its operations through storage on behalf of other cities in return for the use of 50 percent of the water stored (IRWD 2012). This agreement is unlike other Kern County water banking agreements because IRWD's partnership provides for long-term equity ownership of water banking capacity rather than a contract or lease.

Today, the various program elements allow for exchange deliveries with upstream storage transfer through the California Aqueduct as well as for out-of-county, long-term arrangements with southern California entities. The three largest water banks—Arvin-Edison, Kern Water Bank, and Semitropic—have a combined storage capacity of about 3 million acre-feet. Water banking capital costs are much lower than those for surface reservoirs. In addition, once water is recharged there are no evaporative losses, which can exceed five feet per year in Kern County.[2]

## Cooperating Agreements

The so-called Monterey Amendment, part of a large-scale restructuring of water supply contracts, was signed in 1994. The Monterey Amendment is without a doubt a "success story"; it brought SWP contractors - both urban and agricultural - together with the CDWR. This occurred through mediated negotiations to settle disputes and agree on principles for certain operations:

- Article 18 of the original SWP contract provided that shortages in water supply would be allocated proportionally among all entitlements, rather than cutting agricultural users before urban users.
- Article 21 of the original SWP contract was amended to provide that extra water from the SWP in wet years ("interruptible water") would be delivered proportionally among all entitlements—rather than agriculture first. Urban contractors understood that the agricultural-first cutbacks were of limited value, primarily because the SWP had never developed dry year supplies. This was glaringly apparent during the 1991 drought.[1]
- The "leveling" of water supplies according to long-term contracts benefited all contractors. Agricultural contractors were relieved of agricultural-first cutbacks during dry times, and urban contractors received better access to wet period water.[2]
- Urban and agricultural contractors alike realized that local storage programs such as groundwater banks and surface storage reservoirs. would be important for future water reliability. The Monterey amendments gave contractors the express right to store water outside their service areas, as long as the stored water was intended for ultimate use within the contractor's service area. The original arrangement, in essence, required case-by-case approval. This proved unattainable, as shown by an unsuccessful 10-year effort by the MWD.[3]

## Policy Issues

### Private Water Markets

The Kern Water Bank has been described as a financial success that also creates habitat (Hanak and Stryjewski 2012). But the project faced an initial challenge to the transfer of a public asset to private ownership (Public Citizen 2003). Such controversies may create skepticism about state versus local control and ownership (Pitzer and Sudman 2010). In fact, the transfer of ownership was negotiated between the CDWR and the SWP Project Participants, after the state was unable to develop the Kern Water Bank and finally halted feasibility studies and design work on the project in 1993 (CDWR 1993, 2015; Parker 2010). The lesson is that private water markets can be effective in timely implementing programs for water supply security.

The heart of the Monterey Amendment was the transfer of responsibility for water supply reliability from the state to the contractors. Local storage projects were, therefore, a central consideration for many contractors, who wanted to know that their storage concerns were addressed. The removal of the agriculture-first preference for wet-period water was an important consideration for what became the MWD's Diamond Valley Lake, as well for the groundwater programs.[3]

### Effects on Adjacent Properties

Some claimed that the Kern Water Bank affected adjacent landowners (Nelson et al. 2015). Neighboring water districts that overlie the same groundwater basin alleged that a lack of control over the rate at which banked water was recovered affected groundwater levels, quality, and historic hydraulic gradients.[4] The adjacent Rosedale-Rio Bravo WSD alleged that pumping huge amounts of water in dry years reverses the area's underground hydraulic gradient (New York Times 2011). The complexity of the private legal arrangements among the Kern Water Bank parties and the issues about the Bank's operations underscore the need for cooperation (Nelson et al. 2015), especially with respect to keeping track of water withdrawals and the impact on adjacent operations during prolonged drought. In the Kern Water Bank-Rosedale-Rio Bravo case, two different groundwater models were evaluated and revised based on third-party review. Today, a Joint Operating Committee (governed by a Joint Operating Plan) resolves issues (Kern Water Bank Authority 2016). The Kern Water Bank and Rosedale-Rio Bravo WSD coordinate operating plans applicable to the cumulative effects of both projects.[5]

### Quality of Pump-Back Water

The quality of pump-back water and its regulation are concerns for the WSDs (CDWR 2016). The state has a nondegradation policy for pump-back water, although blending within the aqueduct may be considered for groups coordinating discharges to maintain or improve water quality (CDWR 2012). In the case of Semitropic, water pumped back to the California Aqueduct is lower in total dissolved solids, nitrate, and bromide and higher in arsenic and chromium than that contained in the aqueduct (Boschman 2009). Semitropic monitors its 440 wells for arsenic levels, uses a flow-network model to help moderate arsenic levels, and employs an arsenic treatment system with a natural pond feature to lower arsenic levels in pump-back water to less than 10 parts per billion.

In general for such projects, WSDs must assess whether the pump-back water should be treated for all constituents that exceed ambient levels in the aqueduct, or whether there should there be some credit for improvements in some constituents that offset degradation in other constituents. WSDs could consider paying downstream users to treat constituents that result in incremental degradation. There are also policy issues as to whether pump-back water quality should be regulated for background, blended water, or drinking water criteria.

A challenge with water storage projects is how to capture large flows such as floods. Large flows can be missed due to lack of facilities to capture the high flows (Parker 2010). Large flows are likely to become more pronounced in California as climate change intensifies hydrologic events such as less snow and more rain. Expansion of recharge facilities should be initiated.

The return flows or "take" from groundwater banking operations are limited by pumping infrastructure and the transmissivity of underlying formation. Return flows are not well suited for demands that fluctuate during the year. At Semitropic, for example, water can be returned through direct pump-back only during the off-peak irrigation season.

## Characteristics of Successful Projects

As noted previously, much of the Kern County area is excellent for recharge ponds, and the groundwater basin is relatively isolated and not hydraulically connected to other basins or surface waters.

Water-marketing experience in California shows movement to greater local control. The Monterey Agreement was a transfer of responsibility from the state to local districts with compromises that worked for both urban and agricultural interests. The Kern Water Bank experience showed the state's difficulty in putting together a banking project, including getting permits from other agencies.[6] The absence of competing groundwater extractors, who were not members of the district and whose individual actions might impinge on incentives to invest in groundwater banking, enabled Semitropic and Arvin-Edison to take collective local action.

### Banking Water Otherwise Not Available

In the examples cited here, the banked water is imported from hydraulically disconnected sources. This water would not have been available to the groundwater basin. The state's attempt to establish an Emergency Drought Groundwater Bank in the Sacramento Valley in 1994 met with limited success in part because it substituted groundwater for SWP deliveries. Those actions created a backlash from Sacramento Valley counties that most have since enacted restrictive groundwater export ordinances.

### Measures to Protect Adjacent Land Owners

Semitropic employed several measures to ensure that neighboring groundwater users would not be affected. For example, a fifteen-foot-three-year rule specifies that groundwater withdrawals may not cause groundwater levels to decline by more than fifteen feet over a 3-year period compared to what would have occurred without the project (Semitropic WSD [Water Storage District] 2003). None of the extraction wells at Arvin-Edison are located near a property boundary with an adjacent water district. To protect the groundwater basin a certain loss factor is imposed on all banked water. At Semitropic and Arvin-Edison, for example, evaporation, migration or other losses are accounted for by an assumed 10 percent loss of furnished water. The Kern Water Bank and the Rosedale-Rio Bravo Water Bank have a Joint Operating Plan to work out any disagreements.

### Financial Security

Successful projects insulate the WSD from financial risk. Contractual arrangements ensure that the costs for conveyance, recharge, extraction, and pump-back are covered by the beneficiaries (Thomas 2001). Semitropic, for example, was cash strapped and would have been unable to develop the water banking facilities alone.[7] Thus, the water banking partner's investment in the infrastructure and operations make the venture essentially cost and risk free to the WSD, as is the case with the MWD's arrangement with Semitropic and Arvin-Edison and with commercial financing for the Kern Water Bank.

### Prior Experience

Landowners in the area have a long history of experience with conjunctive groundwater use. The landowners have a common interest, because the districts in the region are primarily agricultural. Experience shows the need for local control; no district wants to give an outsider control of rights to its basin.

## Notes

1. W. Phillimore, Executive Vice President, Wonderful Orchards, Shafter, CA, personal communication, July 24, 2017.
2. J. Gianquinto, General Manager, Semitropic WSD, personal communication with author, July 17, 2017.
3. T. Quinn, Executive Director, Association of California Water Agencies, personal communication with author, July 23, 2017.
4. Petition for Writ of Mandate and Complaint for Injunctive and Declaratory Relief, Rosedale-Rio Bravo Water Storage District and Buena Vista Water Storage District v. California DWR, No. 270635-KCT (Kern County Superior Court).
5. J. Parker, General Manager, Kern Water Bank Authority, personal communication with author, July 24, 2017.
6. W. Phillimore, Executive Vice President, Wonderful Orchards, Shafter, CA, personal communication, July 24, 2017.
7. J. Gianquinto, General Manager, Semitropic WSD, personal communication with author, July 17, 2017.

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*New York Times*. 2011. "Storing Water for a Dry Day Leads to Suits." July 26. https://www.nytimes.com/2011/07/27/science/earth/27water-bank.html?_r=1&hpw.

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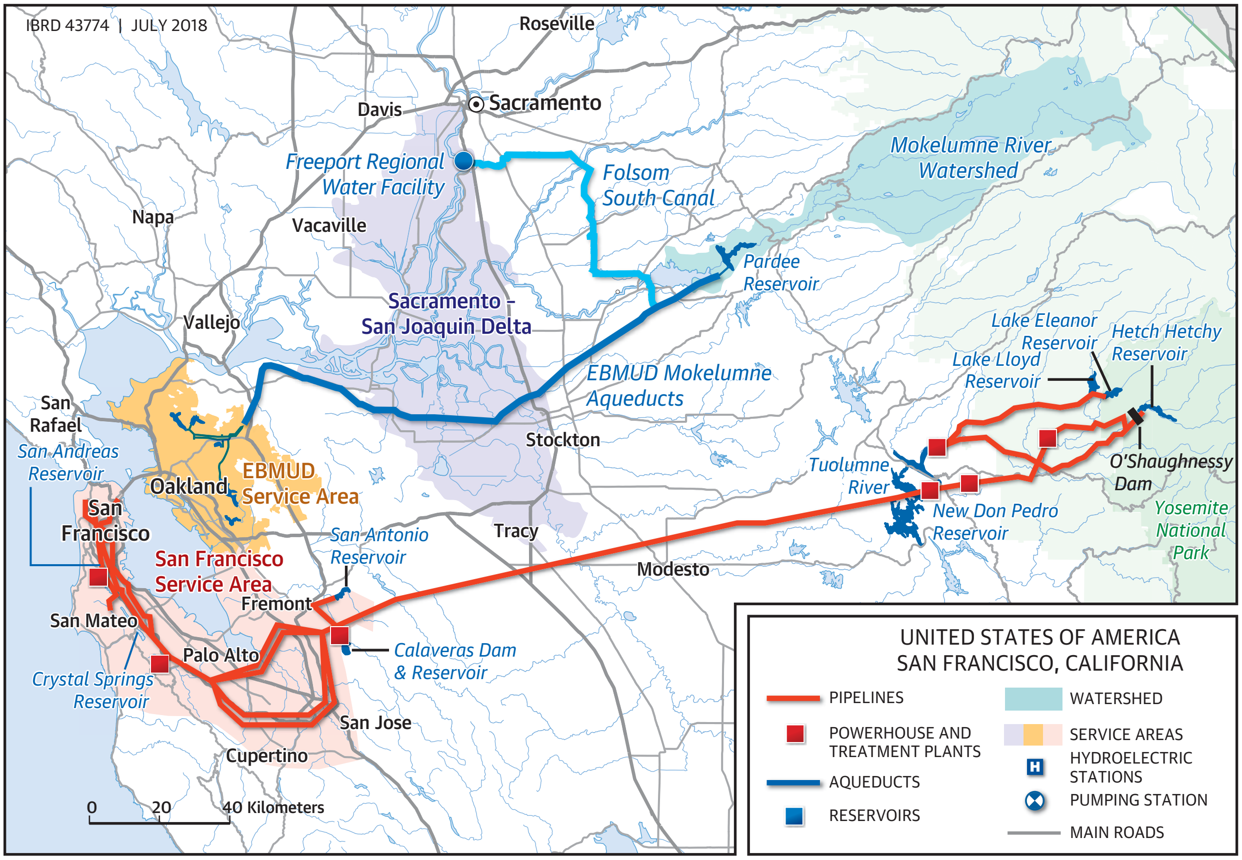
*Source:* Pixabay.com.

# Chapter 26
# San Francisco, California

San Francisco, CA, situated on a peninsula, has a population of 850,000 and high population density (6,700 people per square kilometer). Given its Mediterranean climate (long dry season, short wet season, and an average 600 millimeters of rainfall per year), rainwater and stormwater are insufficient to meet a significant portion of the city's demand for water.

Water, wastewater, and power services are provided by the San Francisco Public Utilities Commission (SFPUC) (see map 26.1). The SFPUC also operates five reservoirs located near the city. The SFPUC distributes water to the City and County of San Francisco and 26 wholesale customers through a system of local storage reservoirs and a piped distribution network. The main source of water supply for 2.6 million people is the Tuolumne River watershed, located in the pristine Sierra Nevada mountains in eastern California. Run-off and snow-melt are stored in the Hetch Hetchy reservoir and transported to San Francisco through a 269-kilometer piped aqueduct. The raw water is minimally treated using ultraviolet disinfection and chloramination. In San Francisco, average total water consumption is 300 liters per capita per day (lpcd), and average residential water consumption is approximately 150 liters per capita per day (SFPUC 2016), which is one of the lowest water use rates in the United States. SFPUC has achieved these low water consumption levels by promoting conservation for more than 25 years. The conservation program includes financial incentives such as rebates and mandatory requirements through local ordinances to install efficient fixtures. Water rates are based on an incremental block tariff.

**MAP 26.1.** **San Francisco, California, United States of America**




Although the SFPUC Regional Water System has provided a reliable source of excellent quality water for over 83 years, recent droughts have motivated SFPUC to explore options for diversifying its water supply portfolio. For example, after extensive studies to characterize water quality and sustainable extraction rates, the SFPUC started a pilot program that blends deep groundwater extracted from local aquifers with its surface water supplies (SFPUC 2015).

Another strategy being pursued by the SFPUC to diversify its water supply is water reuse. A centralized, nonpotable water reuse project is currently under construction at the Oceanside wastewater treatment plant, which involves adding tertiary filtration, reverse osmosis,[1] and ultraviolet disinfection, as well as construction of 13 kilometers of recycled water pipeline (SFPUC 2017). This project will provide advanced treatment to 7,570 cubic meters of water per day to be used for irrigating landscapes and refilling Lake Merced (a small lake used for recreation). However, centralized nonpotable reuse projects face barriers to large-scale implementation, due to their cost and the disruption caused by installing a piped distribution system for the recycled water.

Recognizing these barriers, in 2012 the City and County of San Francisco adopted article 12C of the San Francisco Health Code, which established a streamlined permitting process for projects installing and operating onsite nonpotable water systems in San Francisco. The Nonpotable Water Program (NWP) enables the collection, treatment, and use of alternate water sources for nonpotable purposes. In 2015, article 12C was amended to mandate onsite reuse for new buildings larger than 23,225 square meters. New construction over 23,225 square meters and permitted after November 2016 is required to capture available rainwater, foundation drainage, and graywater to meet nonpotable demands for toilet flushing and irrigation. New construction over 3700 square meters is required to plan and budget for possible nonpotable recycling, but it is not mandated. In March 2017, the SFPUC issued guidelines to provide district-scale systems (systems that serve more than one parcel) with means of alternative compliance with article 12C. The guidelines include an option for "sewer mining," in which the recycled wastewater is sourced from a municipal sewer line rather than from the buildings to which the recycled water is provided.

The SFPUC headquarters building is the first to recycle wastewater in San Francisco. Wastewater is treated using an onsite system with a capacity of 19 cubic meters per day, which consists of a primary settling tank, tidal and vertical flow wetlands, cartridge membrane, ultraviolet disinfection, and chlorine disinfection (Hendrickson et al. 2015). The tidal and vertical flow wetlands are incorporated into the building's outdoor and indoor (atrium) landscaping; other components are located in the basement. The treated water is stored in the basement and supplied to toilets through a dedicated pipe network isolated from the potable water supply. The entire system is connected to the municipal potable water and sewer system, and, in the event of a stoppage or failure, wastewater can be automatically diverted to the sewer and potable water can be allocated to end uses.

The estimate for the capital cost of the onsite wastewater system is $1 million, out of construction project costs of $147 million, and total project costs of $202 million. The building is estimated to reduce potable water use by 65 percent, from an average of 45 liters per building inhabitant per day to 19 liters. Annual operations and maintenance costs for the Living Machine is estimated at $15,000 to $20,000, with an estimated life span of 20-25 years.

As of June, 2017, there were over 60 projects in various stages of the permitting process under the NWP, with the majority of these projects designed to collect and treat rainwater to meet San Francisco's Stormwater Management Ordinance. Several projects have proposed the use of recycled graywater, including: a mixed-use building's proposal to use graywater and rainwater for toilet flushing; the San Francisco Public Safety Building's proposal to use graywater, condensate drainage, and rainwater for toilet flushing, irrigation, and cooling systems; and the Transbay Transit Center's proposal to use graywater and stormwater for toilet flushing.

## Challenges

The implementation of San Francisco's innovative NWP is still an emerging practice, and a more complete evaluation will not be possible until the installation and monitoring of more projects has been completed. Nonetheless, many of the policy barriers have already been effectively addressed (Kehoe 2017). A guidance manual has been prepared to assist municipalities through the process of establishing and implementing an onsite reuse program (SFPUC 2014). A high level of coordination and significant leadership have been required to develop the ordinance and permitting process to allow onsite reuse, including participation by government agencies such as SFPUC, the San Francisco Department of Public Health (SFDPH), San Francisco Department of Building Inspection (SFDBI), and San Francisco Department of Public Works (SFDPW). Although there may be a negative stigma related to recycling of wastewater and blackwater, it is possible to build legitimacy around the technical approaches to assure the public that the practice is safe.

Treatment technologies that are most likely to be successful have designs that are modular, can be easily scaled to different sized buildings, and can be operated and monitored remotely. Factors to be considered include water quality, operational energy requirements, capital and operating costs, ease of operation and maintenance, reliability, sludge management, footprint, odor, and other aesthetic issues.

More projects need to be implemented before a good accounting of the capital and operational costs can be determined. SFPUC offers grant funding for eligible projects, which can offset some of the capital costs, but the funding levels are insufficient to cover all capital costs. New business models are needed to provide the services to operate and monitor the onsite treatment systems effectively and efficiently. The developer's return on investment for onsite reuse projects is likely to be spread over decades, accounting only for the water savings, due to relatively low water rates. Changes to property values are difficult to quantify. In the long term, if the NPW reduces the city's need to develop more expensive alternative water supplies in the face of extreme water scarcity, the financial benefits to the customers of SFPUC could be substantial.

In California, the onsite treatment and disposal of wastewater is regulated at the local level, whereas water recycling is regulated at the state level. SFPUC is participating in state and national efforts to standardize practices for onsite nonpotable water systems. To address the public health concerns with onsite recycling, the SFPUC, the Water Research Foundation, and the Water Environment and Reuse Foundation sponsored an independent advisory panel to develop guidance for water quality and monitoring issues. These efforts seek to provide common regulations across jurisdictions and decrease information barriers and regulatory costs thereby increasing the number and capacity of onsite nonpotable projects.

## Conclusions

Around the world, wastewater from individual or small groups of buildings is being treated onsite and recycled for nonpotable uses. However, implementation of this practice is not yet widespread. Recycling water near where it is generated and reused can avoid the costs and infrastructure of transporting it to and from a large, centralized location, which include sewerage and a distribution system for the recycled water separate from the potable water distribution system. Recycling could be particularly attractive in cities that are not yet completely served by centralized sewerage and wastewater treatment. Even in cities with centralized infrastructure, decentralized reuse may be an attractive option for increasing local water supplies. Many factors must be considered to ensure that the practice is effective and safe, and failure to address these factors will prevent this approach from reaching its full potential.

## Note

1. Reverse osmosis is not needed to meet regulations for public health protection, but is used to reduce the salinity of the recycled water, which is increased by saline intrusion into the sewer collection system.

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