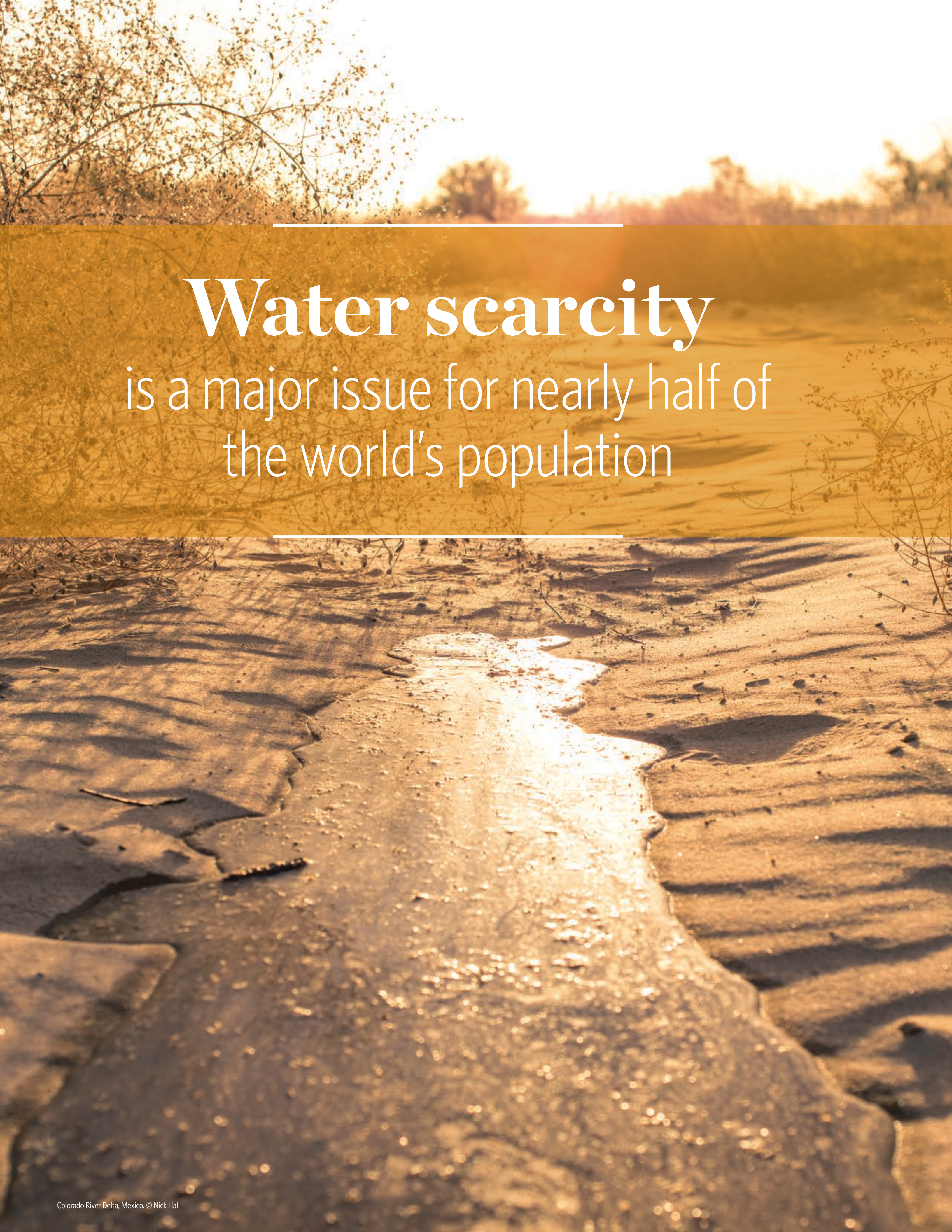
Water Share

Using water markets and impact investment to drive sustainability

The Nature Conservancy

Water scarcity
is a major issue for nearly half of the world's population



Colorado River Delta, Mexico. © Nick Hall

Acknowledgements

Lead author

Brian Richter

Primary contributors

Giulio Boccaletti, Lauren Ferstandig, Emily Powell and Charles Wight

Institutions or individuals contributing data and/or analyses

Austin Water: Jill Mayfield

California Environmental Associates: Amy Dickie

CDP: Cate Lamb

Conservation International: Ian Harrison

Culp & Kelly LLP: Peter Culp

International Union for Conservation of Nature: Will Darwall

Lower Colorado River Authority: Lyn Clancy

San Antonio Water System: Adam Conner

San Diego County Water Authority: Tim Bombardier and Stuart Williams

Texas Commission on Environmental Quality: Joe Nicosia

The Nature Conservancy: Jonathan Higgins, Dale Turner and Emily Chapin

The Rockefeller Foundation: Fred Boltz and Alex Martinez

University of Colorado and Colorado River Research Group: Douglas Kenney

University of Kassel: Martina Floerke and Christof Schneider

University of Massachusetts Amherst: Casey Brown

University of Minnesota: Kate Brauman

University of Virginia: Peter Debaere, John Harbin, Amelia Syvrud, Hannah Backman, Briana Bergstrom, James D. Brown, Rachel DiBenedetto, Adrianna Gorsky, Emily Keenan, Jason Knickmeyer, Chantal Madray, Martha Morris, Benjamin Pickus, Devin Rowell, Susan Ryu, Laura Szczyrba and Xiaoxia Xiang

Reviewers

The following people served as report reviewers. Their contributions helped strengthen the report. The content and positions expressed in this paper, however, are those of The Nature Conservancy and do not necessarily reflect the perspectives of those who provided input: Adam Conner, Lyn Clancy, Peter Debaere, Amy Dickie, Taryn Goodman, Laura Huffman, Charlotte Kaiser, Eloise Kendy, Alex Martinez, Stuart Orr, Chris Perry, George Wente and Michael Young

Designer

Paul Gormont, Apertures Inc.

Editors

Andrew Myers and Meghan Snow

Funding support

This report would not have been possible without the generous support of The Rockefeller Foundation and Lyda Hill Foundation.

Please cite this document as: Richter, B. 2016. Water Share: Using water markets and impact investment to drive sustainability. The Nature Conservancy: Washington, D.C.

Printed on recycled paper.

Sabie River, South Africa. © Brian Richter

Table of Contents

More than 50%

of the world's cities and 75% of all irrigated farms are experiencing water shortages on a recurring basis

Medina Lake, Texas, United States. © Blake Gordon

Foreword

This report addresses the fundamental question of how to share water when there is not enough to satisfy all needs for people and nature. Water scarcity touches the lives of nearly half the people on this planet. Half of all large cities and three-quarters of all irrigated farms are already experiencing recurring water shortages. Today, more than 90 percent of water consumption in water-scarce regions goes to irrigated agriculture, and – from Pakistan to Kenya, from the United States to China – a changing climate and increasing demands from a growing global population are testing the limits of what scarce water supplies remain. For many communities suffering from water scarcity, the option of building additional, often expensive, supply infrastructure is not available. And while we face the consequences of increasingly limited resources, water diverted for cities, industry and crops often comes at the imperilment of freshwater ecosystems.

The fundamental challenge is to do more with less – to efficiently allocate water to the most productive uses. Water markets are institutions designed to do just that. If constructed and regulated well, they can help increase the efficiency of water allocation, and by revealing the value of water to different users, drive greater efficiency. Of course, water markets are not a solution to all scarcity situations, but they are a powerful regulatory construct to manage limited resources.

While they offer a way of mediating scarcity for commercial and public uses of water, their inability to account for environmental needs is often perceived as a critical flaw of these constructs. This report shows that through new approaches to water markets, we have an opportunity to shift water back to the environment while increasing the productivity of irrigated agriculture and meeting the needs of cities. In many regions, a well-functioning water market can provide the institutional framework for users willing to consume less to be rewarded by those needing more or wanting to return water to the environment.

Recognizing the potential for water markets to alleviate water scarcity around the world, including the needs of nature, The Nature Conservancy launched a new model called Water Sharing Investment Partnerships. WSIPs rely on investment capital to acquire a pool of water-use rights within existing markets. Those rights can be used to reallocate water to the environment, provide ongoing water security through lease agreements to users in the community and generate financial returns to investors.

Today, at least 37 countries in water-scarce regions have established water allocation systems based on the issuance of water rights. These countries are potential candidates for WSIPs. The research described in this report shows that if fully scaled, WSIPs – or other creative financing solutions to water scarcity – could mobilize USD$13.4 billion per year in transaction value to reallocate water, corresponding to an underlying assets value of USD$331 billion. Therefore, models such as WSIPs, when enabled by high-functioning water markets, can help provide a more water-secure future for cities, agriculture, industries and essential ecosystems.

Doing this will not be easy. Unleashing the full potential of the water market solutions discussed in this report will require policy and regulatory reforms, mobilization of unprecedented levels of public and private investment and inspired leadership from both non-governmental organizations and political decision-makers. It will require transforming the way we think about water management in the 21st century. By working together, farmers, lawmakers, investors, conservation groups and water managers can set a path to more responsible water management that meets the needs of both people and nature.

Giulio Boccaletti, PhD
Global Managing Director, Water
The Nature Conservancy

More than 30%

of the rivers, lakes and aquifers on our planet are being heavily tapped for their water resources

Murray River, Australia. © Mark Schapper

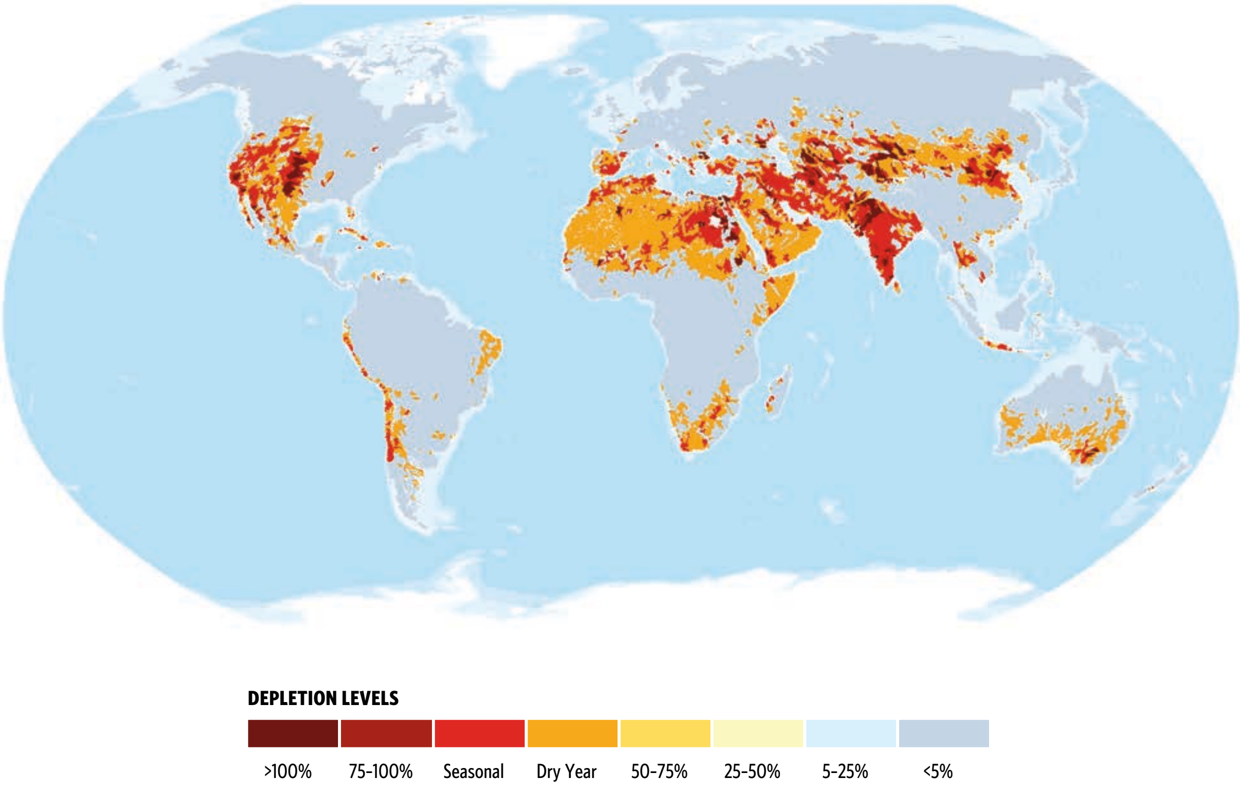
Executive Summary

Water scarcity is a top risk to global prosperity and ecological integrity

Water scarcity is a consequence of allowing too much water to be consumed relative to the renewable, affordable supply of water. When human consumption of water begins to approach the limits of the available supply, communities, businesses and ecosystems face great risk of water shortages with damaging consequences.

The problem of water scarcity is planetary in scale: today, at least one-third of the rivers, lakes and aquifers on our planet are being heavily tapped for their water resources. More than 90 percent of water consumption in water-scarce regions goes to irrigated agriculture. Globally, irrigation consumes 10 times more water than all other uses combined. There are few places in the world where water scarcity can be alleviated without substantially reducing the volume of water being consumptively used in agriculture. Given concerns over food security in many regions, and the importance of protecting the social fabric of rural communities, this must be accomplished in ways that sustain agricultural production and livelihoods.

Figure ES-1. Global water depletion



Across more than one-third of all water basins, communities are now bumping up against the limits of their renewable, affordable water supplies. This map highlights basins where the renewable replenishment of water is being depleted by more than 75 percent on a regular, annually averaged basis (75-100 percent or >100 percent), seasonally, or during dry years (adapted from Brauman and others, 2016[5]).

Water scarcity presents enormous challenges for the growth of cities and industries. Cities are reaching far and wide into distant water basins to bolster their supplies and investing in other costly and energy-intensive strategies, such as desalination, to secure additional water. Water scarcity also threatens our food supply. More than three-quarters of all irrigated farmlands are vulnerable to water shortages, and one-fifth of all irrigated crops are being produced with nonrenewable groundwater abstraction.[1]

Nature is the silent and unseen victim of water scarcity. The excessive removal of water from freshwater ecosystems is a leading cause of imperilment for freshwater species. According to the *Living Planet Report*, freshwater species populations declined by an estimated 76 percent globally between 1970 and 2010.[2]

It is time for new approaches in water management

Historically, communities and governments have focused heavily on infrastructure solutions – such as building water storage reservoirs or importing water from other places – to ensure that their water supply kept pace with growing water demands.

However, it is now highly unlikely that these supply-side approaches will be able to arrest or reduce water scarcity at its current levels, nor prevent further expansion and intensification of water scarcity, for three major reasons: 1) There is no more surplus water to be found in most water-scarce regions; 2) The renewable water supply is declining in many regions as the climate changes; and 3) The costs to secure more water are too high for communities to bear.

The promise of water markets

Many cities, farms and industries have in recent decades begun to give much greater attention to water conservation and other forms of demand management, enabling levels of water use to stabilize in many regions. Sustainable water management in the 21st century will require more than just stopping scarcity from worsening, however. The volume of consumptive use must be lowered below current levels to alleviate water scarcity. This will require that governments, or communal water systems such as irrigation districts, set firm limits or 'caps' on consumptive water use to avoid exhausting the available water supply, and to ensure that sufficient water remains available in freshwater and estuarine ecosystems to sustain their health and productivity.

A common misconception is that any reduction in consumptive water use in irrigated agriculture would necessarily result in a loss of agricultural productivity or revenue generation. To the contrary, there are many practical and cost-effective ways to reduce non-beneficial water consumption in irrigated agriculture without compromising economic returns or crop production, including investments in improving irrigation efficiency (i.e., regulated deficit irrigation), improving soil management, reducing water losses in delivery systems, shifting to less water-intensive crops, temporarily fallowing certain crops, reducing farm-to-market crop losses and other proven measures.

Water use remains highly inefficient in many places, and far too much water is being used for low-value or wasteful purposes, dampening the water productivity and economic prosperity of many regions. Given pressing needs to feed and clothe a growing global population, the productivity of water – meaning the production of crops or others goods, or the economic returns gained per unit of water use – will need to rise sharply in coming decades.

Lowering existing levels of consumptive water use, while at the same time increasing water's productivity, will require both strong governmental leadership as well as game-changing innovation in the private sector. The establishment of high-functioning and well-governed water markets[3] – in which a cap on total use is set; rights to use water are legally defined, monitored, and enforced; and in which rights can be exchanged among water users – can provide a powerful integration of public and private efforts to alleviate water scarcity. A well-functioning water market can provide financial incentives for improving water's productivity by enabling those willing to use less water to be compensated by those needing more water, or wanting to return water to the environment. By so doing, water markets open up pathways for entities wanting to access more water to do so in a highly cost-effective manner that is far less environmentally damaging than building new infrastructure.

The necessary governance (enabling) conditions to support high-functioning water markets exist in only a few countries presently, and problematic impediments to water trading can be found in all existing water markets. The intent of this report is therefore aspirational: to make the case that water markets offer a powerful mechanism for alleviating water scarcity, restoring ecosystems and driving sustainable water management.

There are six noteworthy benefits of water markets:

1. ***Stimulating water savings*** – By establishing a monetary value for water, water markets can provide strong stimulus for reducing consumptive water use because a water-saving entity can be rewarded financially by selling or leasing the portion of their water rights that is no longer needed. When water is appropriately priced it also discourages waste.

2. ***Increasing water availability*** – By accessing additional water through a market, a community or government can avoid expensive, time-consuming and environmentally-damaging alternatives for increasing their water supplies.

3. ***Improving community flexibility*** – By enabling the transfer of water between users, individuals and communities can adapt more quickly to changing conditions, personal preferences and needs. This includes providing farmers with new, revenue-generating opportunities and options for averting irrigation shortages during droughts.

4. ***Improving water's productivity and allocation efficiency*** – By discouraging wasteful or low-value uses of water, the trading of water facilitates reallocation of water rights to more productive uses, commonly resulting in more revenue generation in local economies.

5. ***Returning water to nature*** – Markets offer opportunities for conservation interests and government agencies to restore water flows in depleted freshwater and estuarine ecosystems by purchasing water in the market and then dedicating its use to environmental purposes.

6. ***Improving accounting for water use and availability*** – When water is appropriately priced and water assets are being traded, water users are more willing to participate in transparent water measurement and reporting practices.

There are four case studies in Appendix I of this report demonstrating many of the economic, social and environmental benefits to be gained through water market trading. These case studies illustrate not only the potential for reducing consumptive water use on irrigated farms, but also for transferring the rights to the saved water to other farmers or uses, including the environment.

- The **San Diego County Water Authority in California** (United States) negotiated an agreement with a large irrigation district that pays farmers to reduce their consumptive water use. The water saved is transferred to the metropolitan area, providing more than one-third of its water supply each year.

- **Austin Water** in Texas (United States) purchases up to 40 percent of its water each year from a river authority that has been bolstering the volume and reliability of its own water supplies through acquisition of water rights from irrigation districts.

- More than half of water deliveries by the **San Antonio Water System** in Texas (United States) have come from water rights purchased from farmers or through water-lease agreements with other water providers.

- Farmers in the **Murray-Darling Basin** of Australia have prospered from an active water market in which more than 40 percent of water use comes from trades in annual water allocations. This water trading has provided a new revenue stream for farmers and helped them manage the impacts of irrigation shortages during severe droughts.

The Nature Conservancy is now advancing an innovative new concept based upon the strategic trading of water-use rights within select river and lake basins, called a "Water Sharing Investment Partnership." These institutions operate with investor capital within existing water markets for the purpose of redistributing water use in a manner that enables water productivity to increase and economic benefits to grow, while returning water to nature.

The Nature Conservancy launched its first Water Sharing Investment Partnership in Australia in 2015. As of May 2016, approximately AUD$27 million has been invested in the Murray-Darling Basin Balanced Water Fund, with a goal of scaling to AUD$100 million within the next four years. The Nature Conservancy is now building off of this success in Australia, as well as its existing track record of using philanthropic dollars to purchase water on behalf of the environment in North America, to craft WSIPs and a variety of other water transactions and investment mechanisms to help rebalance water use in stressed basins.

Conclusions and recommendations for action

The potential benefits that could be realized from the establishment of high-functioning, well-governed water markets are significant. At least 37 countries in water-scarce regions have already established water-allocation systems based on the issuance of water rights – an essential precursor for water markets – and more than half of these countries already allow re-allocation of water through trade. If additional countries adopt water rights systems and other important enabling conditions, and allow trading of water-use rights, they too would be able to realize the benefits of water markets elaborated in this report. Those benefits include overall GDP growth with greatly-lessened water constraints, helping all water users better adjust to and manage economic shocks associated with water shortfalls, and reducing social and ecological disruption during droughts and water shortages.

This report concludes with four major market-based strategies for alleviating water scarcity that would be applicable in at least two-thirds of all water-scarce basins, presuming that appropriate governance frameworks were in place. These strategies are tailored to four of the six scarcity conditions found in water-stressed basins, as illustrated in Figures ES-2 and ES-3.

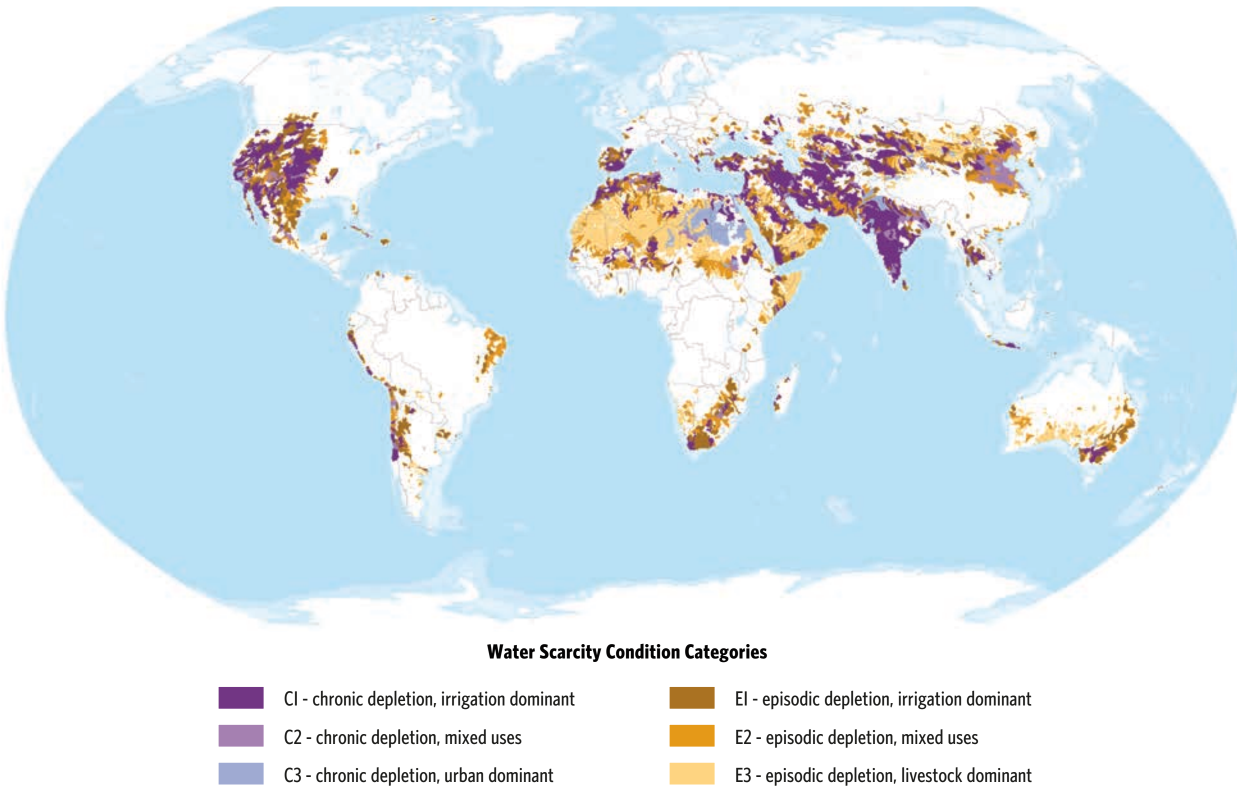
- *Strategy C1 – Facilitate long-term (permanent) water trades within farming communities by establishing 'farmers' water markets.'* This strategy is tailored to basins experiencing chronic scarcity, with irrigation water use dominating. Whereas both permanent and temporary water trades will be very useful in these basins, the exchange of permanent rights will be particularly important in reducing long-term, chronic scarcity. A good model is the Murray-Darling Basin, where in recent years nearly 10 percent of all water entitlements, worth nearly AUD$2 billion, have been exchanged each year on average.

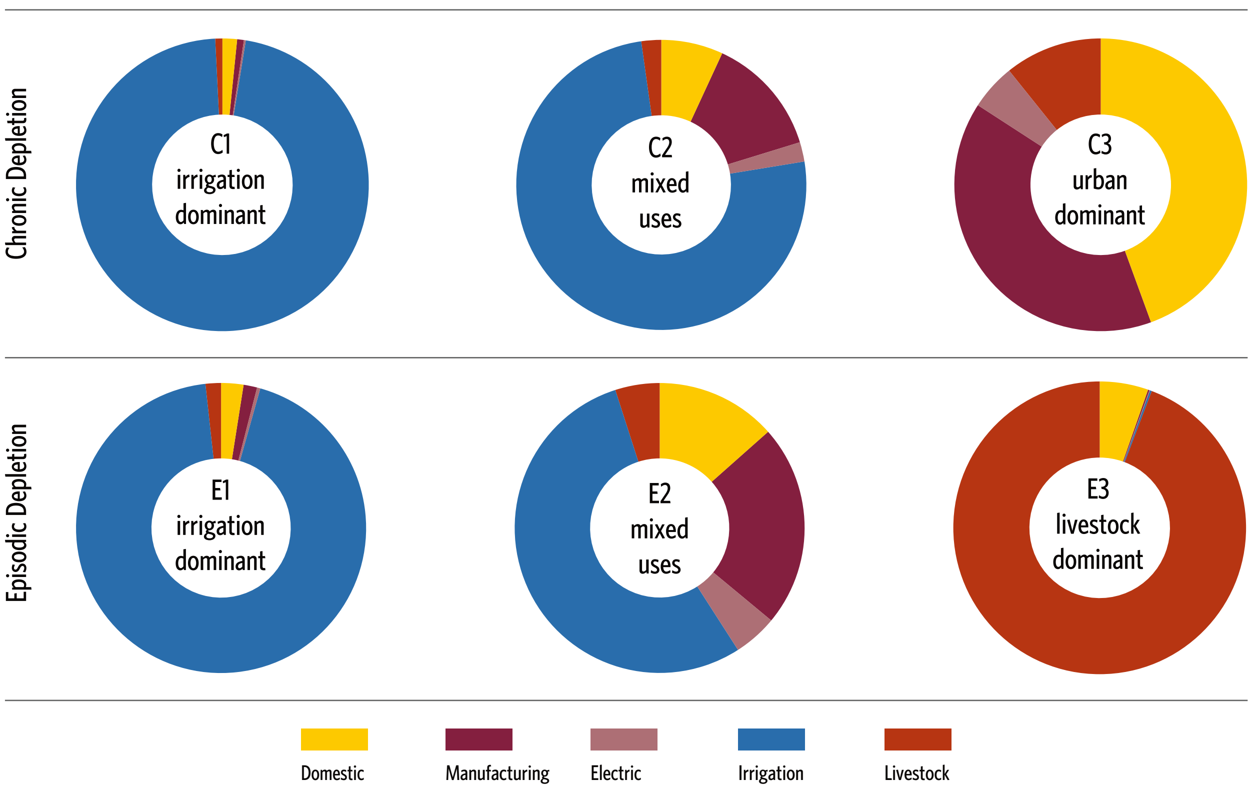
- *Strategy C2 – Facilitate long-term (permanent) trades between farmers and cities.* This strategy is designed for basins experiencing chronic scarcity with mixed uses of water. The intent would be to facilitate rural-to-urban water exchanges, either through regional water markets or through bilateral transactions between cities and farming communities. Three urban case studies in Appendix I (San Diego, Austin and San Antonio) document that rural-to-urban water market transfers have spurred GDP growth of 3 to 6 percent per annum in these water-challenged cities over the past decade.

- *Strategy E-1 – Facilitate short-term (temporary) trades within farming communities.* This strategy will be particularly helpful in basins presently experiencing only episodic (dry-year) scarcity with heavy dominance of irrigation water use. During dry years or droughts, mechanisms are needed to substantially reduce or curtail water use on lower-value or annual crops on farms that will not suffer long-term damage from temporary fallowing or deficit irrigation. With proper compensation given to those water users or producers who are able to reduce their water use, this strategy will encourage higher-value crops to be produced. A case study of the Murray-Darling Basin of Australia in Appendix I documents that short-term market trades averted losses in the gross value of agricultural production of 20 to 25 percent in the worst two years of the Millennium Drought. In recent years, approximately 44 percent of all water use has come from trading of annual water allocations, helping to realize gains in agricultural revenues estimated at AUD$2.6 billion each year.[4]

- *Strategy E-2 – Facilitate short-term exchanges between farmers and cities.* In basins with episodic scarcity caused by mixed water uses, carefully designed drought management plans will be essential in averting drinking water or electricity shortages, or economic damage due to lost industrial production. Opportunities for short-term lease options with irrigation farmers to free up water supply should not be overlooked as the cost-effectiveness of paying farmers to curtail water use during drought years may look even better than urban conservation strategies.

Figure ES-2. Water scarcity conditions and dominant categories of consumptive water use

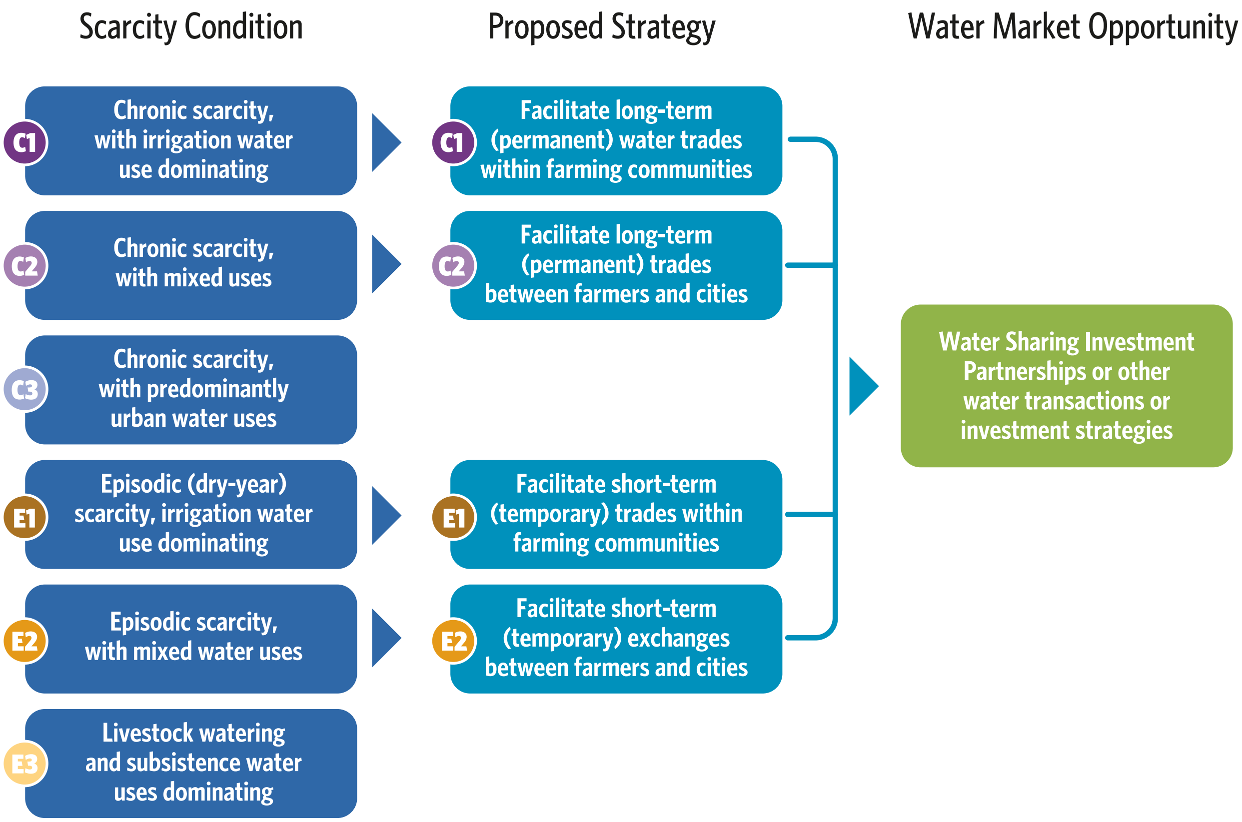




The map above indicates the global distribution of the six water scarcity condition categories described in this report. The pie charts above indicate the proportion of total consumptive water use going to each sector, for each of the six scarcity categories. Relative proportions of sectoral water consumption are averaged across all basins within each scarcity category. (Source: model outputs from WaterGAP3)

Drying Peppers, Chilean Matorral ecoregion, Chile. © Tom Crowley

Figure ES-3. Market strategies for addressing water scarcity



Four water market strategies are offered in this report, addressing four of the scarcity conditions found in water-stressed basins around the globe. Market strategies are not offered for scarcity conditions C3 and E3, for reasons explained in the text.

If all four of these strategies could be fully implemented – in just the countries with existing water-rights systems and some evidence of water trading already taking place – they could collectively generate total annual water sales of USD$13.4 billion per year, equating to market assets of USD$331 billion (Table ES-1).

Unleashing the benefits of water markets will require bold leadership and concerted action on the part of non-governmental organizations (NGOs), irrigation farmers, political leaders, private investors and urban water managers. Specific recommendations are offered for each group.

Table ES-1. Potential water sales and market asset values of four water market strategies

Strategy	Potential Annual Water Sales (USD$ billions)	Potential Market Value (USD$ billions)
C1	3.8	37.7
C2	1.0	6.7
E1	0.6	18.7
E2	8.0	268.2
TOTAL	**13.4**	**331.3**

Colorado River Delta, Mexico. © Nick Hall

Chapter One

Running Out of Water

Introduction

It has been said that necessity is the mother of invention. This is perhaps nowhere more evident than in our relentless pursuit of water to serve a rapidly growing human population.

From the moment early nomadic tribes began to settle into sedentary, agriculturally-based lifestyles more than 10,000 years ago, the prosperity of human communities has been tightly connected to the presence and reliability of their water sources.

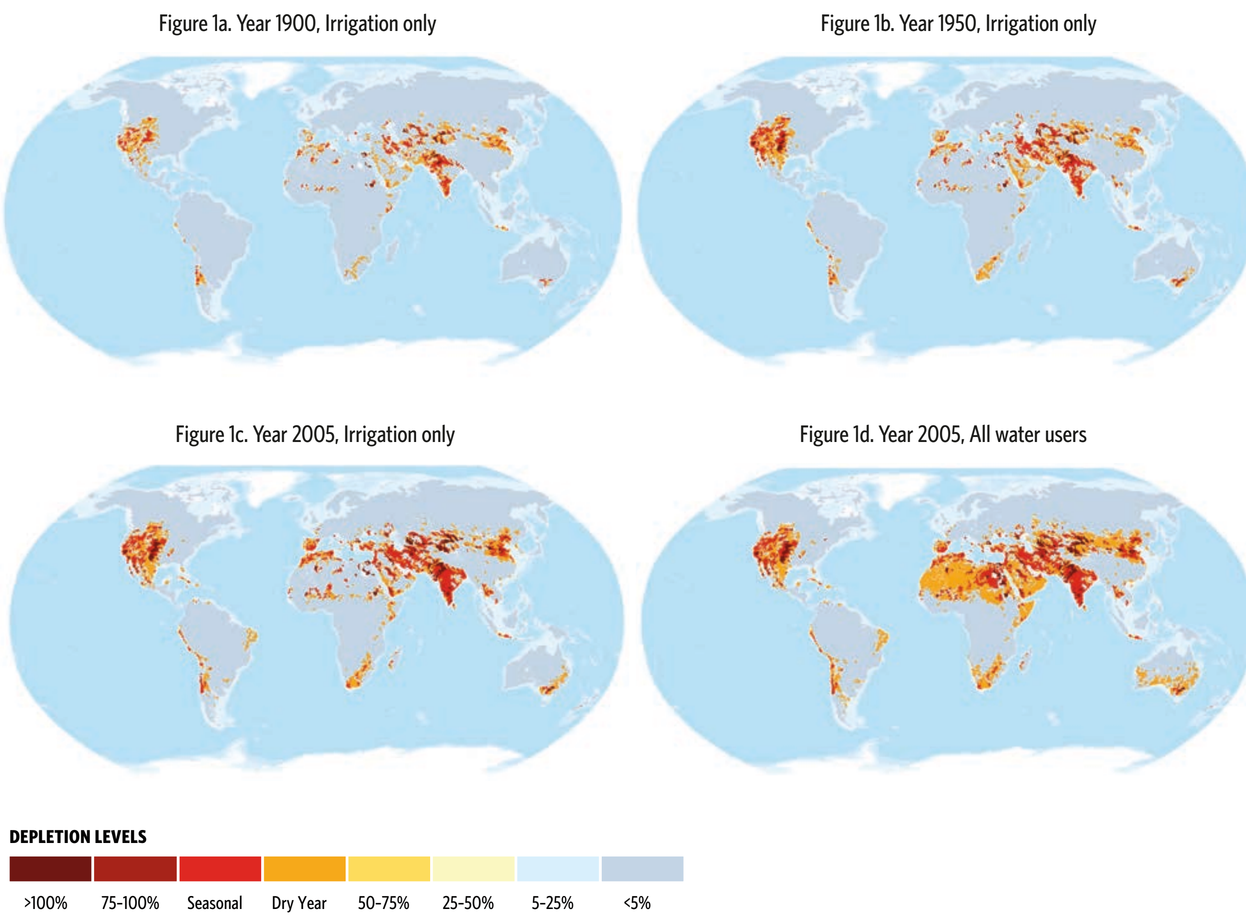
The annual flooding of the Tigris and Euphrates Rivers – which saturated and spread nutrient-rich sediments across a vast floodplain – set the stage for the rise of a farming-based society in the Fertile Crescent. At the mouth of the Nile, ancient Egyptians diverted the river's water onto crops using earthen dykes. Far upriver, in what is now known as the Sudan region, the Nubians invented a waterwheel-like device called a *sakia* to lift the river's water onto their farms. In China, some of the earliest known hydraulic engineers transformed a vast area of the Chengdu Plain along the Min River into the Dujiangyan irrigation system. It is still in use today to grow crops across more than 5,300 square kilometers.


Nairobi, Kenya. © Nick Hall

As the human population grew and spread around the globe, so too did the practice of diverting rivers and other water sources to irrigate crops. Many smaller rivers and shallow groundwater aquifers were fully drained for irrigation use by the early 20th century (Figure 1), but when engineers gained the ability to construct large dams beginning in the 1930s, they harnessed some of the largest rivers on the planet and diverted the water onto farms (see "Aral Sea" sidebar). Similarly, the use of groundwater – which began with shallow hand-dug wells in ancient times but rapidly intensified with the invention of industrial-scale pumps in the mid-20th century – has extended the reach of agricultural irrigation into aquifers thousands of feet beneath the Earth's surface.

Today, with the world's population exceeding 7 billion and growing, irrigated agriculture remains essential to our well-being, supplying nearly 40 percent of the global crop harvest. Our food security and our global economic prosperity are now at serious risk because one-third of the water sources on our planet are being over-exploited – to near exhaustion – and additional water supplies are beyond affordable reach in many of those basins.[5] In thousands of rivers, lakes and aquifers around the globe, more than three-quarters of the water that naturally replenishes their hydrologic systems is being consumed for human use, damaging the planet's freshwater and estuarine ecosystems and leaving many farms, cities and industries at serious risk of water shortages during droughts. More than 90 percent of water consumption in water-scarce regions takes place on irrigated farms, and 20 percent of that irrigation is supplied with non-renewable groundwater.[6]

Figure 1. Global water depletion



Figures 1a-d. Many water sources are being heavily depleted by consumptive water use. The percentage categories (e.g., 75-100 percent, and >100 percent) indicate the level to which consumptive water use is depleting the annual renewable water supply. 'Seasonal depletion' means that heavy depletion (>75 percent) occurs primarily in certain months of the year, and 'Dry year depletion' occurs only during drier years or droughts. As evidenced by Figure 1a, water scarcity has been a challenge for human societies for a very long time. Farmers in the Middle East, Asia and western North America were exhausting many of their local water supplies by the turn of the 20th century, a condition that spread and worsened over the past century. The first three maps (Figures 1a, 1b and 1c) show depletion attributable solely to irrigation. Figure 1d is based on all water uses in 2005. As can be seen by comparing the two maps for 2005, much of the water depletion globally is attributable to irrigation (adapted from Brauman et al. 2016[5] and Siebert and others, 2015[7]).

The Aral Sea: Turning a Lake into Cotton

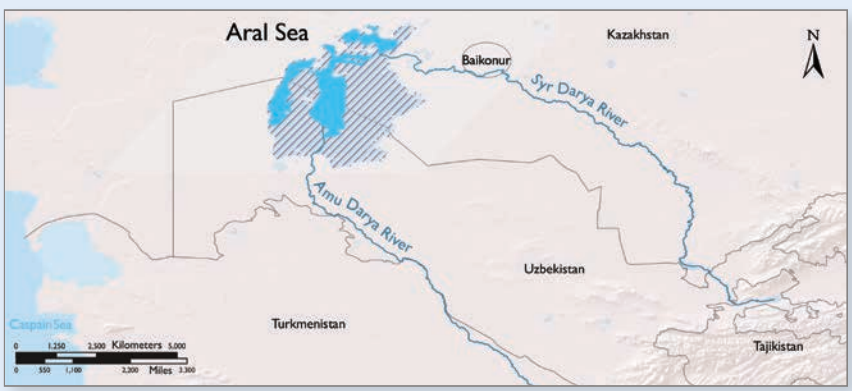
A century ago, the Aral Sea of Central Asia was one of the four largest freshwater lakes in the world (Figure 2), covering more than 67,000 square kilometers. Its name means “sea of islands,” referring to the more than 1,100 islands that historically could be found in the lake. For thousands of years, with no outflow from the lake, water levels fluctuated from year to year in response to the inflow of water from two rivers – the Amu Darya and the Syr Darya – and the loss of water to evaporation. Those natural variations changed dramatically when the former Soviet Union began diverting both rivers for farming.

In the 1920s, under the Soviet leadership of Joseph Stalin, a decision was made to grow cotton in the area. This decision was, in part, predicated on the belief that the Aral Sea was a “useless evaporator” and a “mistake of nature.”[8] The Soviets would instead produce “white gold” (cotton) by diverting the rivers flowing into the lake. By 1988, Uzbekistan had become the world’s largest exporter of cotton.

The irrigation canals built in the region until 1960 diminished the lake only slightly, but the Soviets then embarked on an ambitious expansion of the cotton farms. By the early 1980s, the waters of the Amu Darya and Syr Darya no longer reached the Aral Sea. By 1987, the water level in the lake had lowered so much that the lake split into a northern and a much larger southern portion (see Figure 3a). By 2002, the southern portion had split apart into an eastern and western half. In July 2014, the eastern half of the southern portion dried up entirely (see Figure 3b).

The shrinking of the Aral Sea has been called “one of the planet’s worst environmental disasters.”[9] The region’s once-prosperous fishing industry supporting 60,000 jobs and harvesting up to 50,000 tons of fish each year has been destroyed, bringing severe economic hardship.[10] The salinity concentration of the sea has increased ten-fold, and now provides habitat suitable only for brine shrimp, whereas 84 fish species once inhabited the lake and its tributary rivers. As the lake began to dry up, toxic levels of sodium chloride and pesticides began swirling into dust storms, affecting every level of the lake’s food chain, including human residents of the area. Local communities now suffer from esophageal cancer at a rate 25 times higher than the rest of the world due to inhalation of toxic wind-blown dust lifted from the now-dry lake bed.

Figure 2. Aral Sea



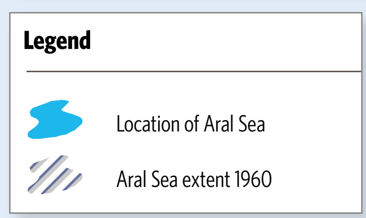


Figure 3. Declining water levels in the Aral Sea

Figure 3a. Aral Sea, Year 2000

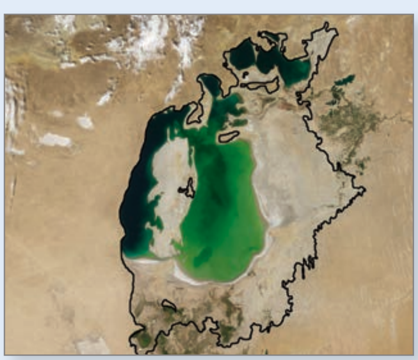
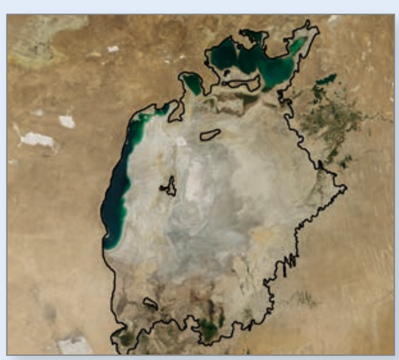


Figure 3b. Aral Sea, Year 2014



The Aral Sea has been shrinking since the 1960s due to diversion of the rivers flowing into the lake for use in irrigating cotton and other crops. The lake’s extent in 1960 is shown with hashed shading in Figure 2 and in black outline in Figure 3. (Photos: NASA Earth Observatory)

The fact that irrigation is the dominant consumptive user of water explains why the strategies for alleviating water scarcity presented in this report are so heavily focused on reducing water consumption on farms. There are many good reasons for saving water in every type of water use. For example, any use of water has the potential to reduce its quality and temperature before the water is returned to a freshwater source, thereby reducing the suitability of the water for subsequent uses or for ecosystem support. It also takes a great deal of energy to move water around, or to treat it to an acceptable water quality after use, so all reductions in water use can lessen energy requirements or pollution. But – as explained further in later chapters of this report – there are few places in the world where water scarcity can be alleviated without substantially reducing the volume of water being consumptively used in agriculture.[11]

Accounting for Water: Withdrawals versus Consumptive Use

The ultimate physical cause of water scarcity is easy to understand: just as with a bank account, when more money or water is being removed than is being deposited, the account will eventually go dry.

This simple reality has been obscured by the way water use has been accounted for in most countries and water-use reports. The most commonly reported water-use statistic is *water withdrawals* – the volume of water that is withdrawn (extracted) from freshwater sources. However, a large proportion of the withdrawn water is returned to the original freshwater source after use, meaning it is redeposited in the water account and doesn't permanently deplete the source – it remains available for other users. In the United States, for example, more than half of all water withdrawn from rivers, lakes and aquifers is returned to these water sources after use (see Table 1). The water that is not returned to the original source after use is referred to as *"consumptive use"* (i.e., the water that is lost from the original source after use). When trying to understand the causes of water scarcity, and designing strategies for alleviating scarcity, it is the consumptive use of water that matters most. If the rate of consumptive use approaches or exceeds the rate of water replenishment, water shortages can be expected.

Unfortunately, the volumes of consumptive use are rarely accounted for, or reported, for most of the world's water basins. This has generated widespread misunderstanding of the root causes of water scarcity, and has often diverted attention away from the types of water use that consume the greatest volumes of water. For example, in the United States, the largest volume of water withdrawal goes to electricity production at power plants, accounting for nearly 50 percent of all water withdrawn from freshwater sources (Table 1). However, less than 10 percent of water used in these power plants is consumptively used, meaning that this type of water use is seldom a major cause of water scarcity.[12] By comparison, irrigation water use on farms in the United States consumptively uses twice the volume of water consumed for all other purposes. Globally, irrigation consumes 10 times more water than all other uses combined.

Table 1. A comparison of annual water withdrawals and consumptive water use in the United States

	Volume of withdrawals*	Percent of total withdrawals	Volume of consumptive use*	Percent of total consumptive use
Domestic use	57 BCM	10 percent	10 BCM	6 percent
Industrial and mining use	57 BCM	10 percent	10 BCM	6 percent
Thermoelectric use	278 BCM	49 percent	5 BCM	3 percent
Irrigation and livestock use	176 BCM	31 percent	141 BCM	85 percent
TOTALS	**568 BCM**	**100 percent**	**166 BCM**	**100 percent**
		Global Water Use		
Domestic use	380 BCM	10 percent	42 BCM	4 percent
Industrial and mining use**	780 BCM	21 percent	38 BCM	4 percent
Irrigation and livestock use	2,600 BCM	69 percent	945 BCM	92 percent
TOTALS	**3,760 BCM**	**100 percent**	**1,025 BCM**	**100 percent**

*Reported in BCM = billion cubic meters

**Includes thermoelectric use

(**Source:** *Chasing Water: A Guide for Moving from Scarcity to Sustainability*, by Brian Richter, 2014. Island Press, Washington, D.C.)

As illustrated by the time series of maps in Figure 1 (see page 18), water scarcity tends to accumulate gradually and insidiously, as more water is consumptively used each decade, until water-user communities are confronted with the limits of their renewable water supplies and begin to experience harmful water shortages. Ultimately, water shortages and the over-extraction of water from freshwater ecosystems represent a failure of governance – whether formal or communal – to control cumulative water demands within the limits of renewable supply. As the authors of the United Nations' 2015 report, "Water for a Sustainable World," wrote: "Over-abstraction is often the result of outdated models of natural resource use and governance, where the use of resources for economic growth is under-regulated and undertaken without appropriate controls."[13]

The graphs of historical water supply and use in Figure 4 illustrate this problem. Typical of most water-stressed basins around the world, the volume of consumptive water use gradually increased over time in both the Murray-Darling Basin of Australia and the Colorado River of the western United States, largely without restraints. Governments and private interests constructed extensive systems of pipelines and canals to deliver water to farms, cities and industries. Large water storage reservoirs were also built in both river basins to capture and more fully utilize the water flowing through these river systems.

As the recent decades have shown in both of these basins, there is great risk in allowing water consumption to grow too close to the limits of water availability. In drier times, the result is serious economic and ecological consequences.

Figures 4. Historical water supply and use

Figure 4a. Water availability and use in the Murray-Darling Basin of Australia

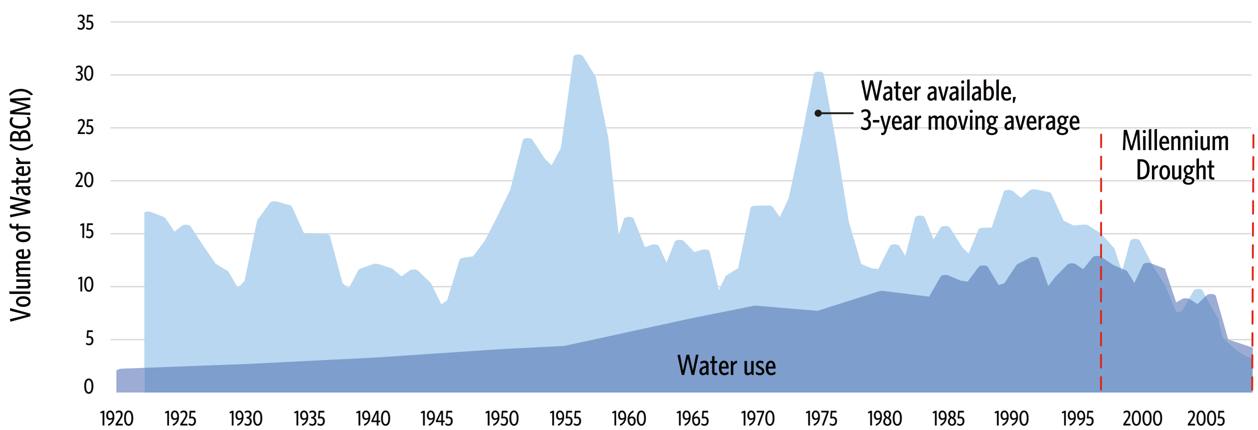
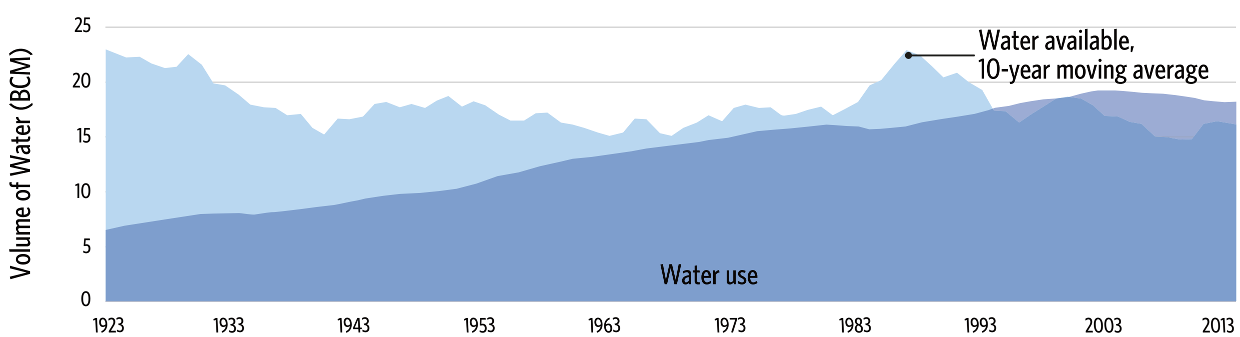


Figure 4b. Water availability and use in the Colorado River Basin of the United States



Typical of rivers and aquifers in water-scarce regions around the globe, consumptive water use in the Murray-Darling Basin of Australia (upper graph) and the Colorado River Basin in the western United States (lower graph) increased gradually over time, eventually reaching the limits of water availability. Note that in the Colorado River Basin, the use of stored water in large reservoirs, along with overdraft of groundwater aquifers in the basin, has enabled consumptive water use to exceed the river's supply in recent years. (Sources: Murray-Darling Basin Authority, U.S. Bureau of Reclamation, Colorado River Research Group)

Taking stock of scarcity in the world today

The balance of water supply and demand within each of the world's water basins has been assessed by numerous research groups, using a variety of global hydrology models. Model outputs from the newest version of "Water – A Global Assessment and Prognosis" (referred to as the WaterGAP3[14] model) have been used in this report as the basis for understanding where water scarcity exists around the globe and how water is being used in each water basin. This information is also used in formulating recommendations for action that will be discussed in the concluding chapter of this report.

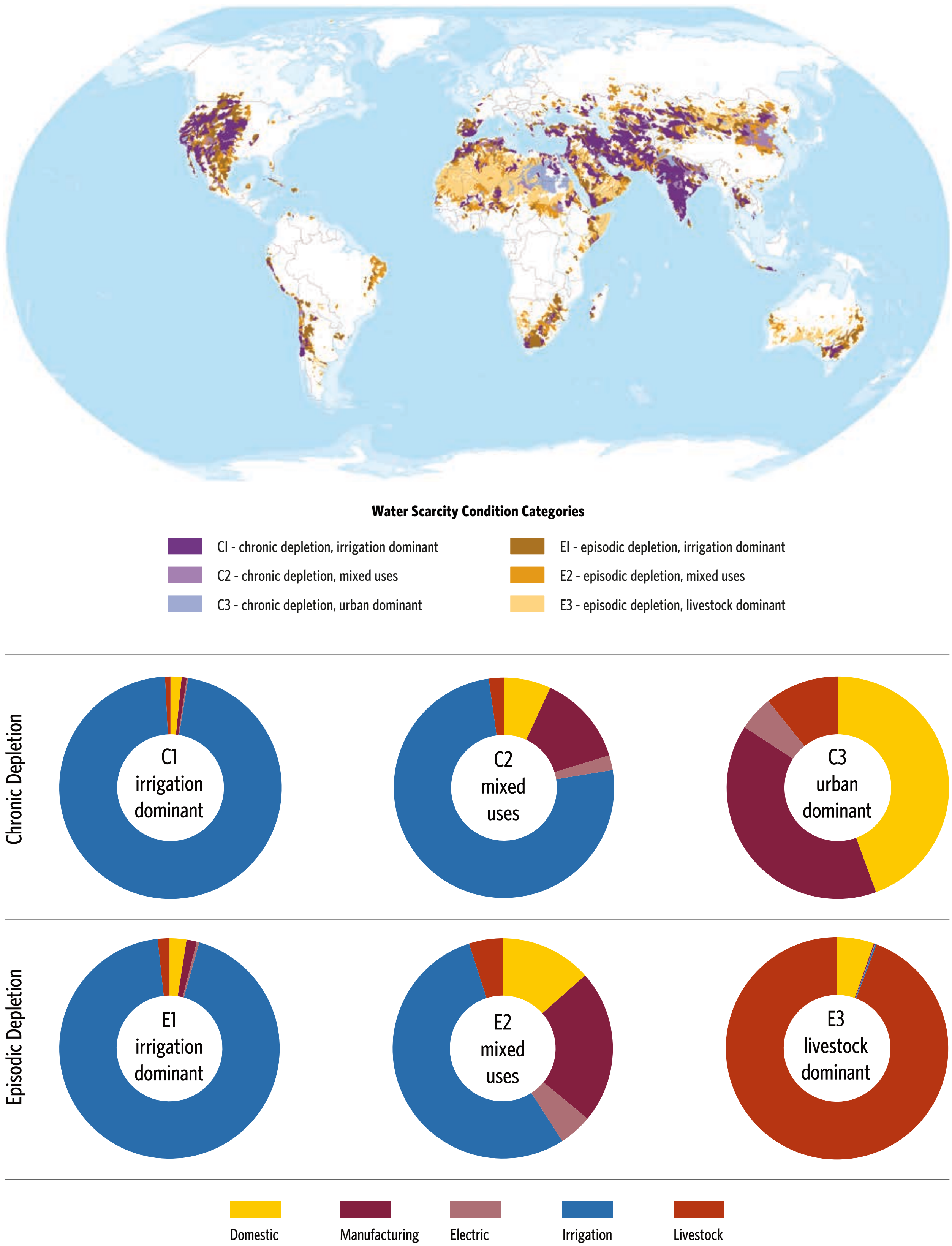
WaterGAP3 calculates water balance outputs for 143,653 individual water basins globally. Following the approach taken in Brauman and others[15] (2016) for data reliability reasons, only the 15,091 of these water basins larger than 1,000 square kilometers, constituting 90 percent of total land area, are used in developing conclusions and recommendations.[16]

Renewable water flows are being heavily depleted in nearly one-third (approximately 4,800) of the water basins assessed (Figure 5). Among these depleted basins:

- Approximately 1,700 basins (35 percent) are ***chronically*** depleted, meaning that more than 75 percent of the renewable water replenishment is consumptively used on either an annual or seasonal basis.
  - » The consumptive water use in two-thirds of these chronically-depleted basins is dominated by irrigated agriculture (condition category C1).
  - » A blend of irrigation and other uses, including municipal and industrial, can be found in one-fifth of these basins (condition category C2).
  - » Irrigated agriculture is nearly or fully absent in nearly one-fifth of these basins, and urban (municipal and industrial) water uses are dominant (condition category C3).
- Approximately 3,100 basins (65 percent) are ***episodically*** depleted, meaning that consumptive use exceeds 75 percent of the renewable water replenishment only during drier years or droughts.
  - » Irrigated agriculture is dominant in one-quarter of these episodically-depleted basins (condition category E1).
  - » A blend of irrigation and other uses can be found in one-quarter of these basins (condition category E2).
  - » In nearly half of these episodically-depleted basins, annual rainfall is relatively low, and livestock grazing and subsistence uses of water account for the majority of water use (condition category E3).


Smallholder farmers, India. © Brian Richter

Figure 5. Water scarcity conditions and dominant categories of consumptive water use



The map above indicates the global distribution of the six water scarcity condition categories described in the text. The pie charts above indicate the proportion of total consumptive water use going to each sector, for each of the six scarcity categories. The relative proportions of sectoral water consumption are averaged across all basins within each scarcity category. (Source: model outputs from WaterGAP3)

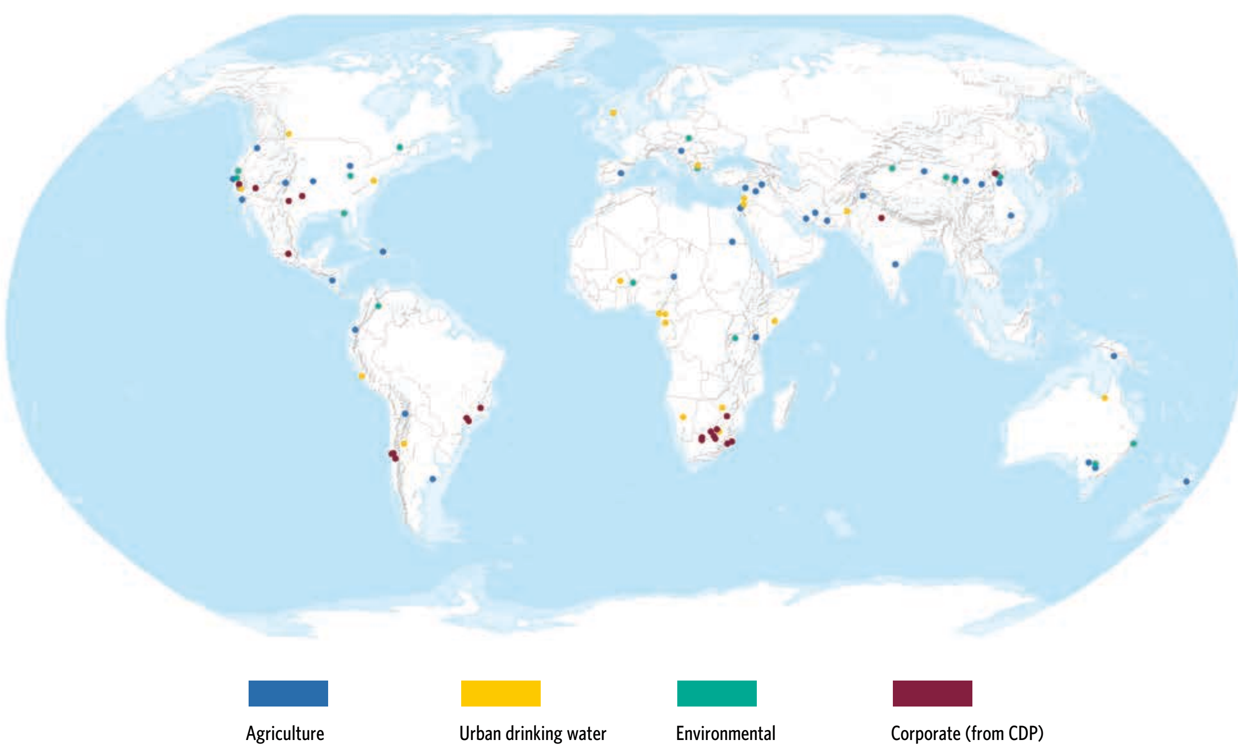
Increasing the risk of water shortage

The World Economic Forum has recognized water shortages as being among the greatest risks to the global economy[17] – and for good reason. The map in Figure 6 highlights 112 recent water shortage events compiled by The Nature Conservancy and CDP.[18] While droughts are commonly blamed as being the cause of water shortages, Figure 7 documents the fact that the likelihood of water shortages is much greater in regions where existing levels of consumptive use are nearing or exceeding the limits of their renewable water supplies. While the onset of a drought certainly reduces available water supplies, droughts only create shortages for people and the environment when the water source is already being too heavily exploited on a regular basis.

Some recent examples of water shortage events include:

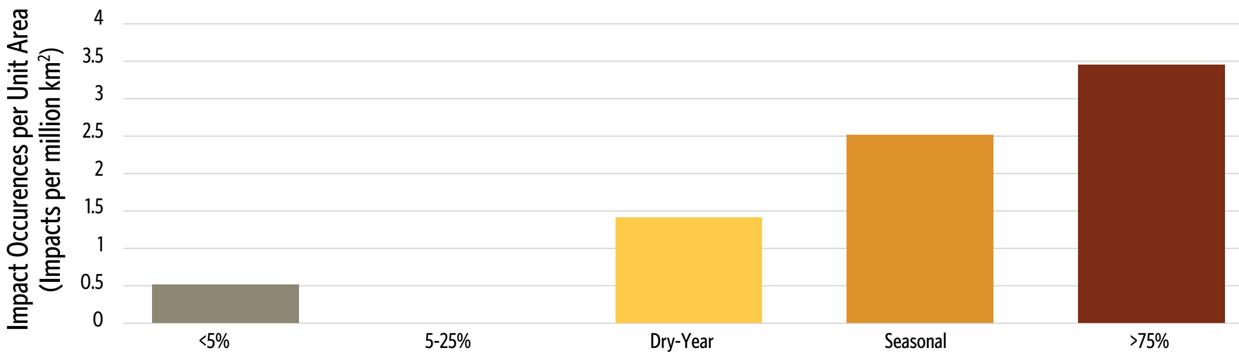
- *Agriculture:* Water shortages in the Badin District of Pakistan in 2013 left 27,000 hectares of rice farms without water, impacting 100,000 farmers and causing an economic loss of PKR1.3 billion (USD$12.4 million).
- *Manufacturing:* Water shortages in the Yellow River basin in 2000-2007 caused industrial losses in Gansu Province of over CNY 1.8 billion (USD$278 million).
- *Mining:* Water shortages in 2014 at the Los Bronces mine in Chile caused loss of 30,000 tons of copper production.
- *Electricity generation:* Water shortages in the Tana River basin of Kenya in 1999-2000 led to the loss of hydropower generation and associated industrial production, resulting in losses of over USD$2 billion.
- *Urban water supply:* Water shortages in Cameroon in 2011 left household water taps dry, forcing the city's residents to line up for hours at groundwater wells and carry their water to their homes.
- *Fisheries:* Insufficient freshwater inflows to Florida's Apalachicola Bay (United States) in 2013 led to a 60 percent decline in oyster populations, resulting in revenue losses of 44 percent in the shellfish industry.
- *Tourism:* Low water levels in Lake Mead on the Colorado River in the United States during 1999-2003 led to 900,000 fewer tourist visits, 680 lost jobs, a USD$28 million loss in visitor spending and USD$9.6 million loss in personal income.

Figure 6. Location of 112 water shortage events



(Sources: The Nature Conservancy, University of Virginia and CDP)

Figure 7. Water shortage impacts



The likelihood of experiencing water shortage impacts is much greater when renewable water supplies are being depleted by 75 percent or more on a regular basis, as indicated by the 'Dry-Year,' 'Seasonal' and '>75 percent' annual depletion categories. One-third of all water basins evaluated fall into these heavily-depleted categories. All other water basins are <25 percent depleted on an annual average basis. (Sources: The Nature Conservancy, University of Virginia and CDP)

The early exhaustion of renewable water supplies for agricultural irrigation presents enormous challenges for the growth of cities and industries in water-scarce regions.[19] As cities expanded and consumed any remaining local water supplies not already being extracted for agriculture, many began reaching far and wide into distant water basins to bolster their supplies. More than 40 percent of the water now used in the world's 100 largest cities is accessed through inter-basin transfers.[20]

Cities are facing increasingly difficult obstacles to importing water to solve urban water shortages. Moving water over long distances and pushing it uphill against gravity requires tremendous energy. Large-scale water transport pipelines are now the biggest electricity users in many regions. The energy-intensive nature of water importation makes this water-supply option very expensive, and its widespread use can boost climate-damaging carbon emissions. Another serious hurdle is that fewer communities are willing to allow others to raid their local water supplies, potentially robbing them of their own water futures.

Many cities are instead turning to desalination, a technology that removes salts from ocean water or saline groundwater. Desalination remains very expensive, however, due to its high energy requirements, making it unaffordable for many users.[21] Other cities are investing in water reuse or recycling, but it is energy intensive as well and some reuse of treated water – particularly when proposed for drinking water supply – has met with public resistance. None of these options for boosting water supply come without daunting environmental, economic and political challenges (see "Phoenix, Arizona" sidebar).

Irrigation canal, Colorado, United States. © Gaston Lacombe

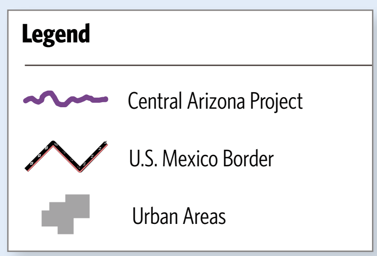
Phoenix, Arizona (United States): Living at the Brink of Shortage

When farmers of European descent first settled in the Gila River valley of central Arizona in the 1860s, they found extensive marshes and floodplain forests along the Gila River and its tributaries including the Salt and Verde Rivers (Figure 8). They also found an extensive system of irrigation canals built hundreds of years earlier by the Hohokam people who disappeared from the area around 1450 AD. The Hohokam used stone and wooden tools to build more than 800 kilometers of irrigation ditches that sustained a population of almost 50,000 for hundreds of years. The system was, in fact, the largest prehistoric irrigation system in North America. The reactivation of the Hohokam ditches after 400 years of non-use inspired the city's naming as Phoenix, after the mythological bird that arose again from its ashes.

Industrious settlers quickly expanded the irrigation system of the valley with small dams and canals and planted water-intensive crops such as corn, barley and wheat. Their diversions of water soon dried the Gila River completely during the growing season, a situation that largely persists to this day, except in reaches that are watered by discharges from wastewater treatment plants or agricultural drainage.

Early settlers described the city as "an oasis" known for "eight months of heaven," but an undependable water supply and searing summer heat also meant "four months of hell."[22] From 1911 to 1949, engineers built six large water storage reservoirs in the river basin, providing substantial enhancement of the area's water security and enabling agriculture to flourish in the Salt and Gila River valleys.

Figure 8. Phoenix, Arizona and the Central Arizona Project



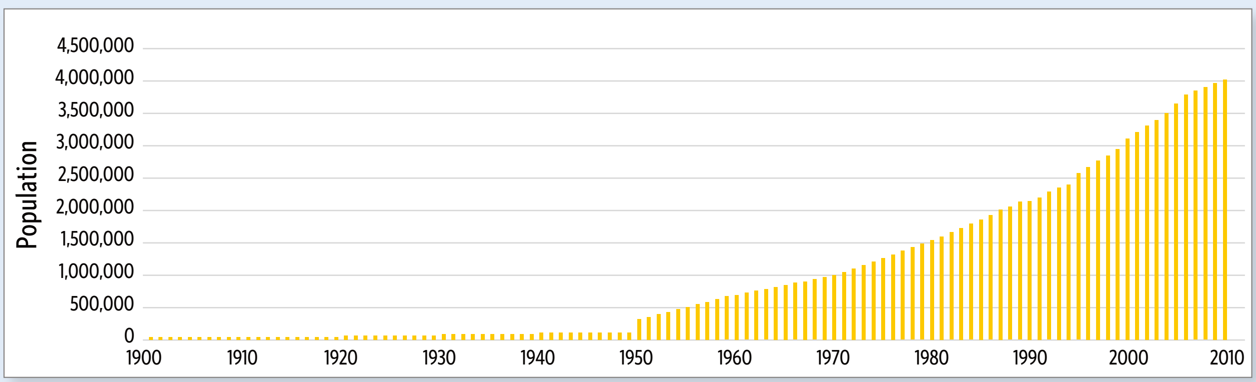
The Central Arizona Project (CAP) canal draws water from the Colorado River for use in cities and farms across the state.

With a bolstered water supply and the arrival of air conditioning in the 1950s, the population of the Phoenix metropolitan area skyrocketed (Figure 9). As the local rivers became fully utilized and groundwater over-pumping caused aquifer levels to decline, competition between the city and farmers for limited water supplies intensified, and both city leaders and farmers soon desired tapping the Colorado River for additional supply. In 1968, the U.S. Congress authorized funding for a huge water importation project to draw water from the Colorado River, substantially augmenting water supplies for farms and growing cities in the state (Figure 8). The 528 kilometer aqueduct, known as the Central Arizona Project (CAP), was built at a cost of USD$12.8 billion (in 2016 dollars), making it the most expensive water delivery project in American history. Its ongoing operations are very energy-intensive, making the project the single biggest electricity user in Arizona. The aqueduct has proven an essential source of water for the rapidly growing metropolitan area, providing more than one-quarter of the area's water supply today.

Phoenix and its neighboring cities have made important investments in further securing their future water supply as their populations have continued to grow rapidly. Phoenix residents have lowered per-capita water use by 25 percent since 1990, and additional progress is anticipated in coming decades. The city is investing in water recycling and has also been 'banking' CAP water not needed for immediate use in its local groundwater aquifers. These measures have provided an important safety buffer against dry times.

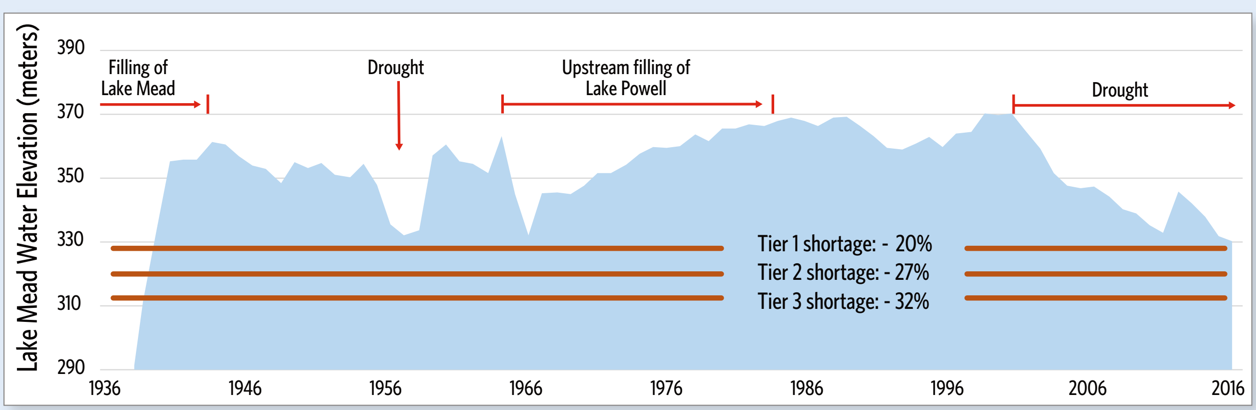
Projections for a warming and drying climate across the southwestern United States presage increasing water challenges in coming decades. The Colorado River – the source of water for the CAP canal – is now heavily exploited, to the point that the river now only rarely reaches its delta, and groundwater is being over-pumped in many areas of the basin. To make matters worse, the region is presently experiencing a persistent drought thought to be the worst in more than 1,200 years, causing water levels in the Colorado River's massive storage reservoirs to drop precipitously (Figure 10).[23] With further drops in Lake Mead water levels, Arizona's supply of the Colorado River will be cut by 20 percent, 27 percent and 32 percent as lake levels reach 328, 320 and 312.5 meters, respectively.

Figure 9. Population growth, Phoenix metropolitan area



The population of the Phoenix metropolitan area has grown rapidly since the 1950s. (Source: U.S. Census Bureau)

Figure 10. Water levels in Lake Mead



The water level in Lake Mead, one of two very large storage reservoirs on the main channel of the Colorado River, has been dropping precipitously in recent years. In early 2016, the lake dropped below 40 percent of its total capacity. If the lake levels drop below 328 meters (Tier 1), Arizona's supply of the Colorado River will be reduced by 20 percent, with additional cutbacks if the lake goes even lower. (Source: U.S. Bureau of Reclamation)

Nature is the silent and unseen victim of water scarcity

Sonora sucker, Arizona, United States. © Justin Bailie

The consequences of scarcity for nature

The plants and animals living in freshwater and estuarine ecosystems depend upon habitat conditions that are strongly influenced by the volume and timing of water flow.[24] That flow – whether it is moving downriver or into a lake or wetland where it influences water levels – can vary considerably over the course of a year and from year to year, forming an ever-changing, dynamic mosaic of habitat. Over centuries or millennia, freshwater species have adapted to the changing habitats created by naturally-fluctuating water levels.

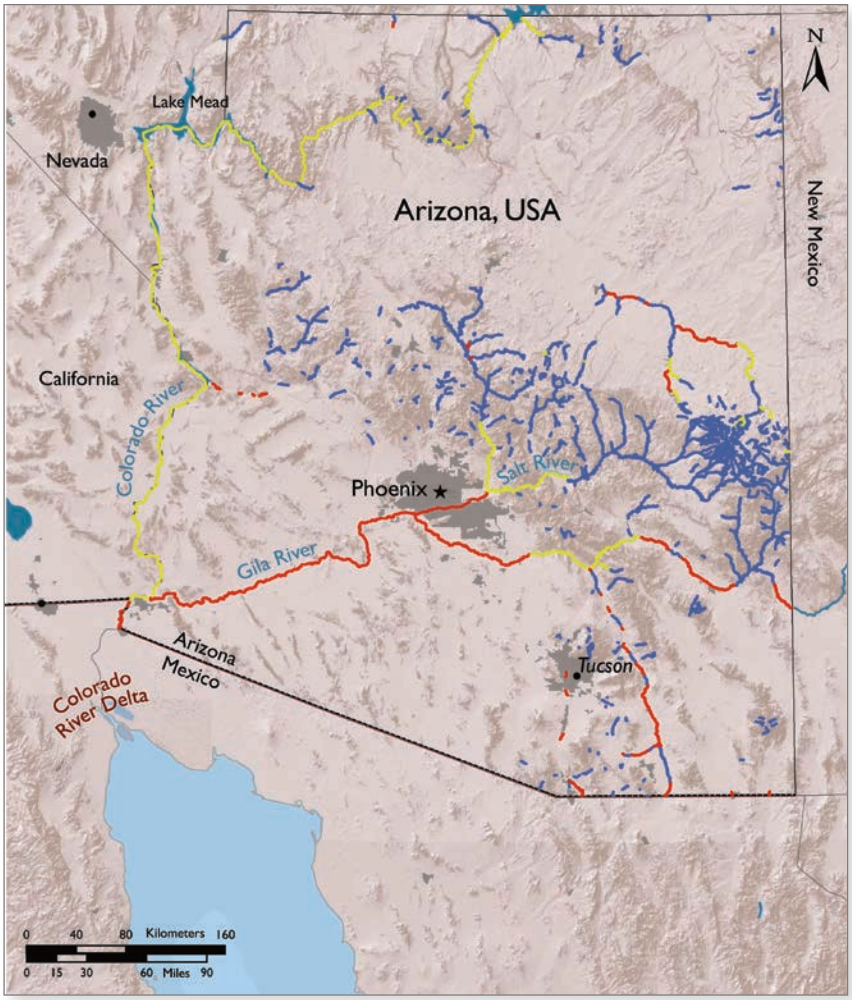
Each freshwater-dependent animal or plant has different habitat needs or preferences, which typically vary during their life cycles, as well as different tolerances for unfavorable conditions. Freshwater species have been tested by nature's variability over thousands of years. If individuals are able to grow and reproduce adequately when conditions are favorable, and their population does not lose too many members during hard times, the species is able to persist.

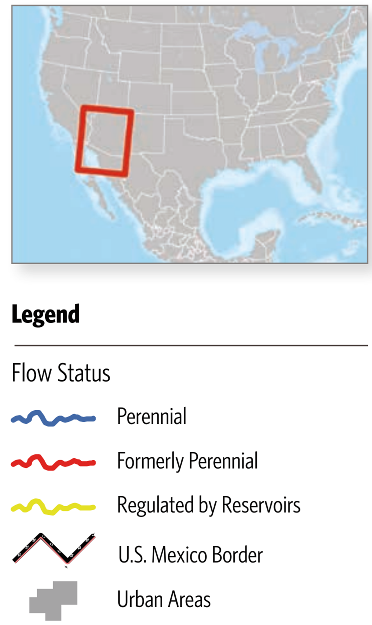
When humans heavily alter the natural variations in river flow, however, they change the probabilities of survival for each species. The excessive extraction of water from freshwater ecosystems and groundwater aquifers has become a leading cause of imperilment for freshwater species, whose populations declined by an estimated 76 percent globally between 1970 and 2010, according to the *Living Planet Report*.[25] As illustrated in Figure 1 (page 18), freshwater habitats have been severely dewatered in at least one-third of the world's water basins, and in many cases water extractions have caused complete drying of rivers (Figure 11).

The International Union for the Conservation of Nature (IUCN) has been tracking the status of plant and animal populations around the world since the 1960s. The organization ranks and publishes the status of each species in its regularly-updated, "Red List." Water flow alterations are reported as a cause of decline for nearly 20 percent of all imperiled freshwater species.[26] Figure 12 illustrates the correlation between water depletion in freshwater ecosystems with the occurrence of well-documented imperiled species from the Red List.

The risks to humanity posed by the loss of aquatic species extend far beyond the loss of the species themselves, because water depletion is leading to the degradation of entire ecosystems that provide critically important services to our societies and economies (Table 2). When the removal of water from freshwater or estuarine ecosystems degrades their functional capabilities, the ecosystem services they support will be greatly diminished or lost altogether.

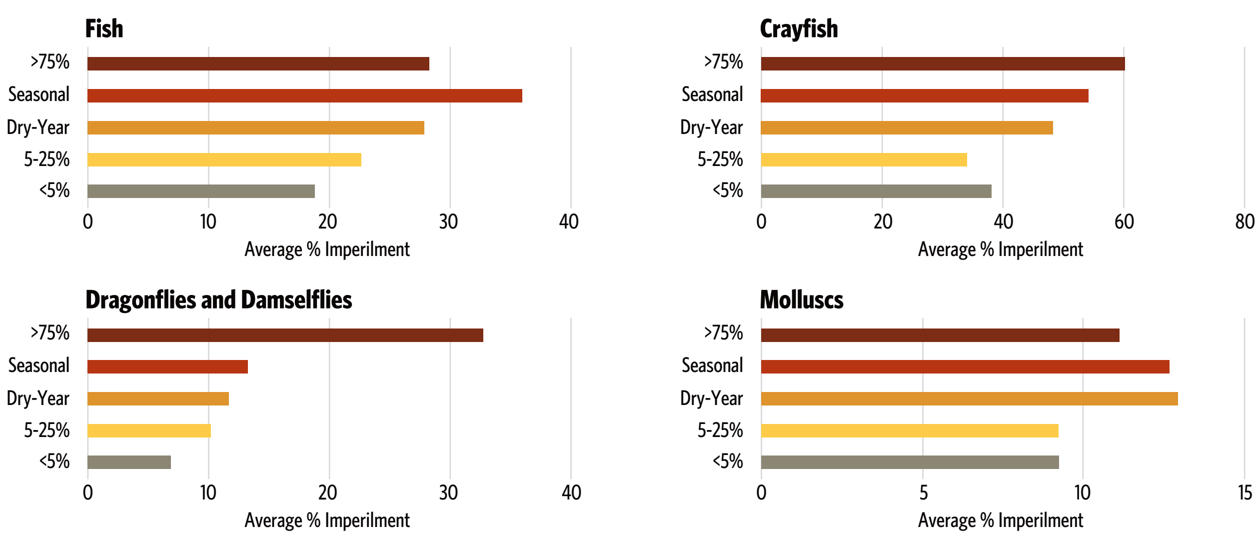
Figure 11. Depleted river flows in Arizona





More than one-third of the perennial rivers in Arizona (United States) have been dried by water extractions (red zones reflect river drying, yellow zones reflect substantial changes in river flow regimes due to upstream reservoirs). The proportion of native freshwater species at risk in Arizona is higher than in any other state within the United States. One species, the Santa Cruz pupfish, is already extinct, and of the 35 remaining native fish species in the state, 21 are listed under the federal Endangered Species Act. (Source: Turner and List, 2007)[27]

Figure 12. Water depletion and imperilment of species



When too much water is removed from freshwater or estuarine ecosystems, the species inhabiting these ecosystems suffer. These graphs show the relationship between water depletion category and the average percent imperilment of species, by water basin, for different freshwater animal groups. As can be seen from these graphs, the percent of imperiled species to be found in a water basin goes up sharply as freshwater sources become heavily depleted, as indicated by the 'dry-year,' 'seasonal' and '>75 percent' annual average depletion categories. Also of note is the fact that relatively low levels of water depletion can have adverse effects on certain species groups. (Source: IUCN Red List)[26]

Table 2. Ecosystem services threatened by water depletion

Ecosystem Service	Benefits
Provision of food	Fish, waterfowl, mussels, clams, etc. are important food sources for people and wildlife
Water purification/waste treatment	Healthy wetlands and rivers filter and break down pollutants, protecting water quality
Flood mitigation	Healthy watersheds and floodplains absorb rainwater and river flows, reducing flood damage
Drought mitigation	Healthy watersheds, floodplains and wetlands absorb rainwater, slow runoff and help recharge groundwater
Provision of habitat	Rivers, streams, floodplains and wetlands provide homes and breeding sites for fish, birds, wildlife and numerous other species
Soil fertility maintenance	Healthy river-floodplain systems constantly renew the fertility of surrounding soils through flooding
Nutrient delivery	Rivers carry nutrient-rich sediment to deltas and estuaries, helping maintain their productivity
Maintenance of coastal salinity zones	Freshwater flows maintain the salinity gradients of deltas and coastal marine environments, a key to their biological richness and productivity
Provision of cultural and spiritual values	Natural rivers and waterscapes are sources of inspiration and deep cultural and spiritual values; their beauty enhances the quality of human life
Recreational opportunities	Swimming, fishing, hunting, boating, wildlife viewing, water-side hiking and picnicking all rely on healthy natural environments
Biodiversity conservation	Diverse assemblages of species perform the work of nature (including all the services in this table), upon which societies depend. Conserving genetic diversity preserves options for the future

(Table adapted from *Rivers for Life: Managing Water for People and Nature*," by Sandra Postel and Brian Richter, 2003. Island Press.)

More than 90%

of water consumption in water-scarce regions goes to irrigated agriculture

United States and Mexico border. © Nick Hall

Imperial Irrigation District, California, United States. © Brian Richter

Chapter Two

It is Time for New Approaches in Water Management

The primary challenges in managing against water scarcity are to ensure that available water supplies are always greater than needs and adequate water remains within natural ecosystems to protect their health and diversity. When bumping up against the limits of their available water supplies, water-user communities seek to rebalance their water budgets by pursuing one, and sometimes both, of two strategies: increase water supply, or reduce demand.

Historically, communities and governments have focused heavily on the supply side by, for instance, building water storage reservoirs or importing water from other river basins or aquifers.[28] In recent decades, a growing volume of wastewater is being treated for reuse, and ocean water or salty groundwater is being desalinated in efforts to increase water supplies, particularly for urban and industrial uses. Globally, capital expenditures for water and wastewater reached nearly USD$250 billion in 2015 alone.[29]

It is highly unlikely, however, that these supply-side, infrastructure-based approaches will be able to resolve water scarcity at its current levels, nor prevent further expansion and intensification of water scarcity, for three major reasons:

- There is no more surplus water to be found in most water-scarce regions.
- The renewable water supply is declining due to climate change in many regions.
- The costs to secure more water are too high.

Surplus water is hard to find

As illustrated by Figure 1 (see page 18) and discussed throughout this report, the renewable water supply is being nearly or completely exhausted in one-third of the water basins on the planet. Some of the largest rivers in Asia, North America, the Middle East and Australia are already exploited to near exhaustion, and one-third of the largest aquifers on the planet are being rapidly depleted.[30] An estimated 20 percent of all irrigated farmland is watered with non-renewable groundwater.[31] The over-extraction of water has severely degraded aquatic, riparian, and estuarine ecosystems, endangering large proportions of their plants and animals.

The construction of water-storage reservoirs will likely be of little help in heavily water-stressed regions where nearly all of the renewable water supply is already being consumed in most years (i.e., basins with 75-100 percent and >100 percent annually-averaged depletion, as shown in Figure 1, page 18). Reservoirs cannot create new water in these regions. Instead, they will only capture what little water is still flowing through already-depleted basins, more fully exhausting any remaining water. By making even more water available for consumption, and by losing water to evaporation, reservoirs can actually worsen water scarcity in these areas. However, in places where 'seasonal' depletion (Figure 1, page 18) is the primary challenge, such as in areas where additional irrigation water is needed during drier months of the year, temporary water storage using reservoirs could be helpful in capturing wet-season rains and holding the water for use during drier times of the year. Any infrastructure investments must be weighed against the economic and food security gains that could be realized with such investment.
Other options for increasing food productivity, such as by improving soil management and other on-farm cultivation practices, should be given full consideration, along with potential environmental impacts associated

with infrastructure projects.[32] The expense of reservoir construction is unlikely to be justifiable in regions afflicted with 'dry-season' depletion (Figure 1, page 18), where shortages occur only episodically during droughts, or in drought-prone areas where livestock watering and subsistence uses of water dominate, such as across much of northern Africa.

Similarly, interbasin transfer of water is a waning option due to the reality that water-scarce basins are clustered regionally and expanding geographically. Water-stressed communities can no longer reach into other water basins to supplement their local water supplies without exacerbating scarcity in other basins and drawing hostility from communities dependent upon those other sources.

Even water reuse or recycling, which may appear to be an environmentally-friendly option for extending water supplies, can actually worsen water scarcity within a stressed basin by making more water available for consumptive use, instead of returning wastewater to its original source after use. This can have the undesirable consequence of further diminishing environmental flows.

The renewable water supply is declining

The challenge of balancing water demands with water availability will grow in coming decades due changing climatic conditions. Mounting evidence indicates that the temperatures of both air and water are already increasing in many areas, along with changes in the volume and seasonal patterns of precipitation, river flows, snowmelt runoff and groundwater recharge. These on-going changes and projections of future change have important implications for both water availability and demand in coming decades. Perhaps most importantly, the uncertainty of what the future will look like suggests the need to maintain maximum flexibility to respond to water shortages.

Attempts to predict whether water scarcity will worsen in any particular place due to climate change are very difficult. The accuracy and resolution of global climate forecast models have been improving rapidly, providing better capabilities for predicting changes in water availability and demand in many regions, but our ability to predict changes for individual river basins or aquifers remains weak. Even more challenging is the difficulty of anticipating how governments, water managers and water users will respond to changing water availability and needs in each water basin. As stated in the Fourth Report on Climate Change prepared by the International Panel on Climate Change (IPCC): "To evaluate how climate change will affect the balance between water demand and water availability, it is necessary to consider the entire suite of socially-valued water uses and how the allocation of water across those uses is likely to change … The institutions that govern water allocation will play a large role in determining the overall social impacts of a change in water availability, as well as the distribution of gains and losses across different sectors of society."[33]

Changing climate conditions over the past half-century, and those projected for coming decades, certainly have played, and will continue to play, a role in many water shortages and impacts on freshwater and estuarine ecosystems,[34] as suggested by these general cause-and-effect relationships:

- *Reductions in runoff and river flows*: Of all the projected impacts of climate change during this century, the prospect of lessened water availability – expressed as decreases in river flow and groundwater recharge – is among the most worrisome, particularly given the heavy depletion of water sources that is already occurring. Due to rapid and widespread increases in water use over the past century, it is quite difficult to ascertain the portion of past river flow and aquifer declines that can be attributed to climate changes. However, climate model projections for the rest of this century forecast substantial decreases in water availability in many of the regions that are already experiencing the heaviest levels of water depletion (Figure 13): The Middle East, the western United States, southern Europe, southern Australia, Chile and Argentina and southern Africa. As just one illustration of the potential impacts of decreased river flows, 20-50 percent decreases in hydropower production have been projected for Portugal, Spain, Ukraine and Bulgaria.[35]
- *Changes in precipitation and temperature:* Notable decreases in precipitation have occurred during the past 30-40 years within the latitudinal band from 10° South to 30° North, with pronounced regional drying in the western United States, Chile, northwestern India, southern Australia, western Europe, eastern Brazil and northeastern China.[36] Decreases in annual rainfall, or changes in the seasonality or frequency of rainfall or drought, can have large consequences for the viability of both irrigated and rain-fed agriculture, as water deficits


Dried wetland, Colorado River Delta, Mexico. © Erika Nortemann

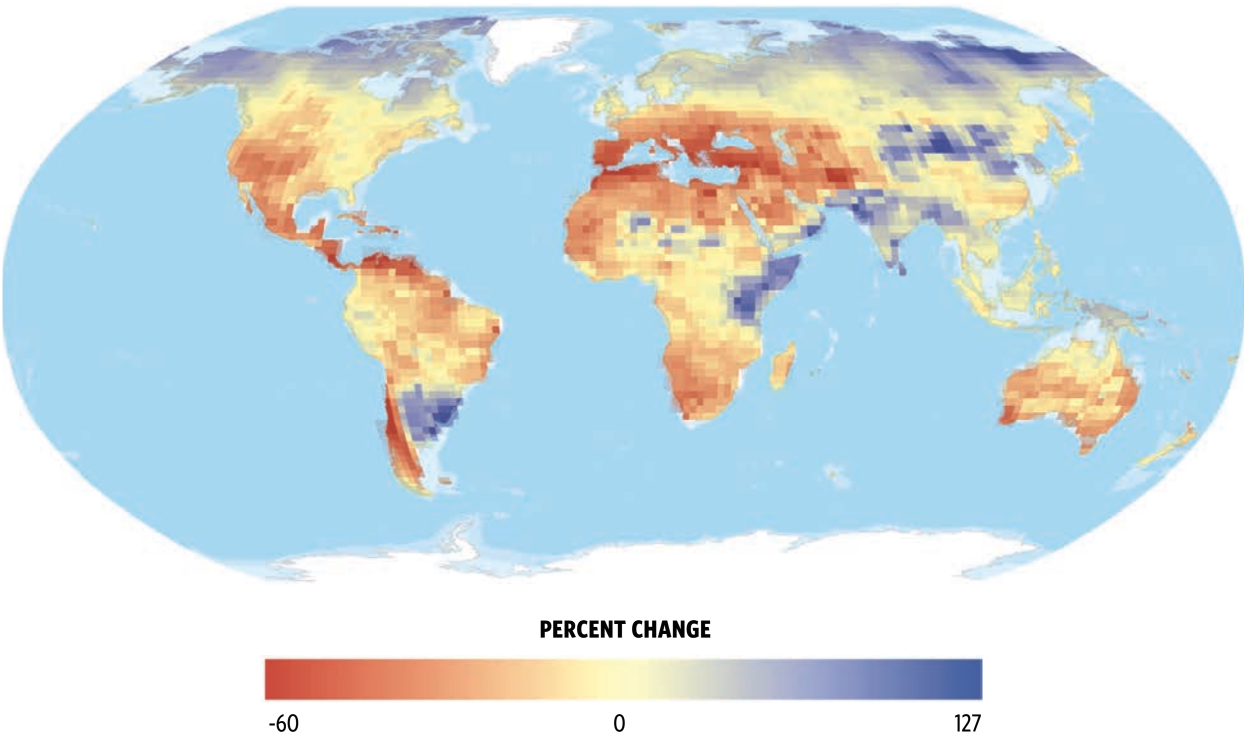
are damaging to all crops. Also, with warming temperatures, yields for many crops will decline unless rainfall increases or supplemental irrigation can be applied to maintain suitable growth conditions or to avoid heat stress; eventually, the temperature tolerance for many crops will be exceeded and their suitable range will move to higher latitudes. A longer growing season resulting from warmer temperatures will also require more water to support many crops. Lessened rainfall, warmer temperatures, and increased drought frequency and duration is leading many farmers to begin irrigating for the first time, and causing irrigation farmers to need more water for their crops. In 2011, farmers in Texas that were not able to access sufficient irrigation supply collectively lost an estimated USD$7.6 billion in a single year.[37]

- ***Warming air and water temperatures:*** As air temperatures have warmed (Figure 14), many cities have experienced growing demand for electricity to cool homes and businesses. The capacity of thermoelectric power plants to meet this increased electricity demand can be severely affected by the temperature and volume of water available for cooling the power plant. As rivers become depleted by drought and excessive water use, the temperature of the remaining water often rises sharply. During a record-breaking heatwave in 2003, for example, the French power utility Électricité de France was forced to shut down or reduce electricity production at 17 of its nuclear reactors when the water temperature of rivers used for cooling soared. The utility was forced to buy power from neighboring countries on the open market, costing the utility an extra €300 million.[38]

- ***Rising sea levels:*** The global mean sea level has been rising as a result of the thermal expansion of the ocean as well as melting glaciers, ice caps, and the Greenland and Antarctica ice sheets. Climate models project another 0.2-0.6 meter rise during this century, but with substantial geographic variability.[39] In addition to threatening coastal areas with increased storm surges on low-lying lands, elevated sea levels will, along with groundwater over-pumping, place coastal aquifers at increasing risk of saltwater intrusion, causing freshwater sources to become too saline for many uses or causing increased costs for desalination. In May County, New Jersey (United States), more than 120 water supply wells have been abandoned because of saltwater contamination.[40]

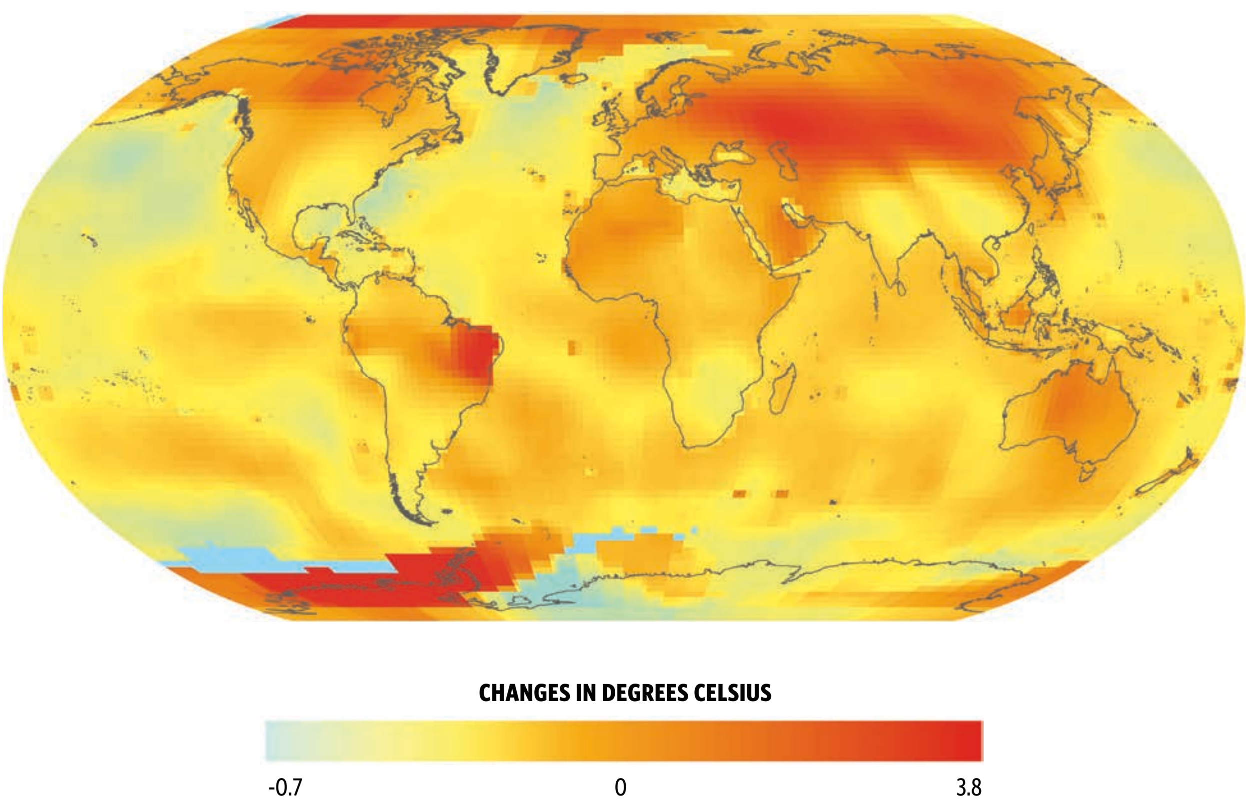
- ***Shifts to earlier snowmelt runoff:*** Global forecasts for the 21st century indicate widespread reductions in snow and ice cover, presenting worrisome implications for long-term water supplies in regions dependent upon the predictable and slow release of meltwater. Across the northern hemisphere, the onset of the snow accumulation season is projected to begin later, the melting season to begin earlier, and net snow coverage over the winter to decrease.[41] A volumetric loss of 60 percent in glaciers has been projected by 2050, and many will disappear completely. Another robust finding of climate models is that warming will lead to changes in the seasonality of river flows where winter precipitation currently falls mostly as snow, with spring and summer runoff decreasing because of the reduced or earlier snowmelt, while winter flows will increase, with winter peak flows occurring at least a month earlier on average by 2050. These effects have already been seen in the European Alps, Scandinavia, the Baltics, Russia, Himalayas and across North America. Shifts in the timing of annual snowmelt can present unique challenges for water managers as they face trade-offs between lowering reservoir levels to enable flood control during peak snowmelt runoff in winter or early spring, while needing to retain as much of the snowmelt as possible to offset much-lessened water flows later in the summer months.

Figure 13. Changes in runoff due to climate change



Climate change is expected to cause significant changes in water runoff into rivers and lakes by the late 21st Century. This map shows predicted increases in runoff in blue, and decreases are in brown and red. (Source: Map drawn using data from Chris Milly, NOAA Geophysical Fluid Dynamics Laboratory)

Figure 14. Change in temperature, 1940-2010



Rising global temperatures have increased water demand for agriculture and have displaced or eliminated aquatic species populations requiring cooler water habitats. Map shows change (in degrees Celsius) in 1970-2010 as compared to a baseline in 1940-1970. (Source: National Aeronautics and Space Administration[42] (U.S.))


Hoover Dam, Arizona/Nevada border, United States. © Brian Richter

The costs to secure more water are too high

The World Commission on Dams has estimated that approximately USD$2 trillion was spent to construct some 45,000 large dams during the past century.[43] About 17 percent of those dams were built primarily for irrigation supply, and another 3 percent for urban water supply. Those expenditures, however, amount to only a tiny fraction of what is now being spent on water infrastructure and its maintenance and operations. In 2015 alone, nearly USD$250 billion was spent in the water sector on capital expenditures.[44]

If communities continue trying to meet water needs using traditional, supply-dominated approaches, the price tag can be expected to continue rising sharply. The Organization for Economic Co-operation and Development (OECD) estimates that by 2025 water will make up the lion's share of global infrastructure investment. For just the 34 OECD countries plus Russia, China, India and Brazil, water spending will top USD$1 trillion that year.

Water infrastructure projects involve a high initial capital outlay, followed by very long payback periods from long-lived assets. As a result, the risk of repayment default is very high relative to many other investments.[45] This risk becomes particularly acute during economic downturns. The World Bank has documented that infrastructure investments often bear the brunt of shrinking public expenditures during crises such in 1997 in Asia, and more broadly during the recent economic recession.[46] According to the Bank: "Public resources are more limited and tariff revenues fall as poverty deepens, weakening the financial position of utilities, and decreasing their ability to access private finance (i.e., loans, bonds, and equity). As predicted, private investment (stocks, bonds, and project finance) in the water infrastructure and services of developing countries has taken a hit since 2008."[47]

Two financial signs point to an urgent need to shift strategy in managing water scarcity. One is the fact that many countries are already amassing a huge and growing backlog of infrastructure maintenance and rehabilitation costs. As one example, the American Water Works Association has projected that within the United States, "… restoring existing water systems as they reach the end of their useful lives and expanding them to serve a growing population will cost at least $1 trillion over the next 25 years. The level of investment required to replace worn-out pipes and maintain current levels of water service in the most affected communities could in some cases triple household water bills."[48]

Desalination plant, Israel. © Cody Sheehy

A second financial bellwether points to the inability of the citizenry to pay these mounting infrastructure debts, along with the ongoing costs of securing additional water supplies using infrastructure-dominated systems. Many countries have adopted "affordability ratios" as guidelines for keeping housing, education and other public services within the financial capabilities of its families. Households paying an amount for water that exceeds an affordability threshold are considered to be paying a cost that is unaffordable and a "high burden." For instance, affordability ratios for spending on water and sewage as a proportion of household budgets in Western Europe are in the 1-1.5 percent range, around 1 percent in Northern Europe, and 3 percent in England. In the United States, the ratio has been set at 2-2.5 percent.[49] However, the costs of water and sewer have in many countries already soared far above these affordability targets. In some areas of England, retired citizens are already paying as much as 7 percent of their annual incomes on water and sewer services. A 2015 survey of monthly water and sewage rates in the United States conducted by Circle of Blue documents that in cities such as Atlanta and Seattle, citizens pay USD$3,700-3,900 per year for these services.[50] Those rates represent 5 percent of the median household income for Seattle residents, and 7 percent in Atlanta, suggesting that many families may be experiencing difficulties in paying for these services. A new report titled, "The Invisible Crisis: Water Unaffordability in the United States," documents that the cost of water and wastewater services has increased at a rate nearly double the rise in household incomes, leading the report authors to conclude: "Rising prices for water and sanitation have left low-income people in the United States without the services they need to maintain their health and dignity."[51]

The Organization for Economic Co-operation and Development (OECD), in its report on "Infrastructure to 2030," pointed to the writing on the wall for water management going forward: "Only when resource constraints, economic factors, and environmental concerns started to become significant issues did it occur that traditional approaches such as large dams and reservoirs may no longer be the solution … New water infrastructure projects have become increasingly expensive compared with other alternatives, placing a strain not only on existing budgets but also on future income streams. There has been a growing appreciation that issues of social equity and ecosystem integrity have to be included in decisions."[52]

The World Economic Forum, in its 2016 Global Risks report, put it even more directly: "Unless current water management practices change significantly, many parts of the world will face growing competition for water between agriculture, energy, industry, and cities."[53]

Fortunately, cost-effective alternatives are available to rebalance water budgets in water-stressed regions (Table 3). Numerous studies have compared the costs of supply-side versus demand-side options, repeatedly showing that investments to lower water demands can be one-half to one-twentieth the cost of increasing supply.[54] Among the broad array of available demand-management options, investments in water-saving measures in irrigated agriculture are particularly cost-effective.

The key to a more water-secure future is to enable cities, industries and conservation interests to form collaborative partnerships with irrigation farmers that can drive investment in water-saving strategies on farms, redistribute the saved water to other water uses and return water to depleted ecosystems. It is time to unleash the potential of water markets.

Table 3. Cost comparisons of water supply options (adapted from Richter and others, 2013[55])

	$ per m^3 (USD)
Texas Water Planning Regions (16 plans)[56]	
Desalination: seawater	0.85 – 1.85
Desalination: brackish	0.28 – 0.62
Water importation	1.06 – 1.91
Water recycling	0.03 – 0.77
Groundwater wells	0.02 – 1.06
Surface water reservoirs	0.33
Urban water conservation	0.04 – 0.46
Industrial water conservation	0.17
Golf course water conservation	0.23
Agricultural irrigation efficiency	0.02 – 0.18
Reduced leakage irrigation canals	0.01
Lower Colorado River Authority[57]	
Desalination: seawater	2.34
Desalination: brackish	0.91
Surface water reservoir	1.99
Dredge existing reservoirs	13.79 – 213.30
Water importation (surface and ground)	0.97 – 1.54
Groundwater wells and storage/recovery	0.96 – 1.81
Water recycling: wastewater	0.36
Urban water conservation	0.36
Agricultural water conservation	0.11 – 0.15
Transfer/conversion of agricultural rights to urban	0.02 – 0.04
Brush management	0.01 – 0.23
Southern California Water Strategies[58]	
Desalination: seawater	0.81
Desalination: groundwater	0.61 – 0.97
Agriculture to urban water transfers	0.57
Water recycling	0.81
Surface water storage	0.62 – 1.14
Groundwater storage	0.47
Local stormwater capture	0.28
Urban water conservation	0.17

	$ per m^3 (USD)
Charting Our Water Future[59]	
Desalination (reverse osmosis)	0.76
Rainwater harvesting: agricultural	0.38
Removal of alien vegetation	0.36
On-farm canal lining	0.07
Municipal leakage repair	-0.28[60] to +0.16
Water importation	0.07 – 0.50
Deep groundwater	0.06 – 0.08
Municipal reservoirs	0.06 – 0.19
Large infrastructure	0.04
Shallow groundwater	0.04
Wastewater reuse	0.04 – 0.35
Artificial recharge	0.04 – 0.14
Sprinkler irrigation	0.04 – 0.22
Small-scale irrigation infrastructure	0.03
Irrigation scheduling	0.10 to +0.01
Drip irrigation	0.01 – 0.05
Industrial conservation	-0.01
Reduced over-irrigation	-0.02
No-till farming	-0.05 to -0.1
Efficient faucets (domestic)	-0.46 to -0.10
Efficient showerheads (domestic)	-0.60 to -0.25
Industrial reuse	-0.5

(negative values represent cost savings)

Water markets offer a **powerful mechanism** for alleviating water scarcity, restoring ecosystems and driving sustainable water management

Salmon in Battle Creek, California, United States. © Ian Shive

Chapter Three

The Promise of Water Markets

Water markets as instruments of efficient allocation between nature and people

Many cities, farms and industries have in recent decades begun to give demand management much greater attention. Typical approaches to demand management include installation of water-saving plumbing devices or more efficient irrigation systems, fixing leaks in water-distribution systems, use of more water-efficient cooling technologies in power plants, implementing effective pricing and water-rate structures that discourage over-use and changing the water-use behaviors of urban residents and farmers. Thanks to growing investment in water conservation and improved water-use efficiency, and the changing structure of the U.S. economy towards a service economy, water withdrawals in the United States have stopped increasing.[61] They are today lower than they were in 1970, despite the fact that the country's population has grown by more than one-third.[62] In Japan, water withdrawals have dropped by 25 percent since the 1970s, in spite of increasing industrial output.[63]

While water-saving measures and the changing structure of the economy have slowed or stopped long-term increases in water withdrawals in many places, existing levels of consumptive use remain far too high to avoid recurring water shortages during drier seasons or droughts, and only modest volumes of saved water have been returned to nature during recent decades. As illustrated by Figure 4 (page 21), consumptive water use in the Colorado River Basin (United States) – and in hundreds of other river basins and aquifers around the world – remains near or above the limit of renewable water supplies, leaving the users and ecosystems supported by these water resources at great risk of shortage.

Sustainable water management in the 21st century will require more than just stopping scarcity from worsening. The volume of consumptive use must be lowered below current levels to alleviate the water scarcity problems discussed in the previous chapter. This will require that governments, or communal water systems, such as irrigation districts, set firm limits or 'caps' on consumptive water use to avoid exhausting the available water supply, and to help ensure that sufficient water remains available in freshwater and estuarine ecosystems to sustain their health and productivity.

Water use remains highly inefficient in many places, and far too much water is being used for low-value or wasteful purposes, dampening the water productivity and economic prosperity of many regions. For example, most of the water extracted from the over-drafted Central Valley Aquifer of California (United States) goes to watering low-value grass hay and corn for cattle feed that could be grown elsewhere, while cities and industries in the state are struggling to find additional water supplies.[64] Given the pressing need to feed and clothe a growing global population, the productivity of water – meaning the production of crops or other goods, or the economic returns gained per unit of water use – must rise sharply in coming decades.

Lowering existing levels of consumptive water use while increasing water's productivity will require both strong governmental leadership and game-changing innovation in the private sector.[65] The establishment of high-functioning, well-governed water markets – in which a cap on total consumptive use is set, rights to use water are legally defined, and in which rights can be exchanged among water users within the limit of the cap – can provide a powerful integration of public and private efforts to alleviate water scarcity. A well-functioning water market can provide the institutional framework for those willing to consume less water to be rewarded by those needing more water, or wanting to return water to the environment. By so doing, water markets open up pathways for entities wanting to access more water to do so in a highly cost-effective manner that is far less environmentally damaging than building new infrastructure.[66]

Water markets are built on the 'currency' of water rights (i.e., the right to use a specific volume of water each year). (See Table 4 for typical attributes of water rights.) These water rights are usually issued by an agency of government, such as a state-, provincial- or national-level water management agency. Importantly, a water right is usually an entitlement to use water, but does not convey ownership of the water itself.[67] The water remains a public resource, owned and managed by governments in the public interest.[68] This is an important legal distinction because it provides governments the opportunity to adjust or otherwise restrict the volume of water that can be used during times of shortage.

The nature and language of the water currency being exchanged in a water market can be quite different across geopolitical jurisdictions, even within countries. For instance, in the western United States, a permanent water right can be sold or it can be temporarily leased (rented). In contrast, within Australia, permanent rights are referred to as "water entitlements," and entitlement holders receive differing volumes of "water allocations" each year, according to water availability. To further complicate matters, the reliability of permanent water rights can differ across geographies. In the western United States, the reliability of each water right is tied to its "priority date," which is based on the date the water was first applied to a beneficial use. Older or "more senior" water rights have first priority when there is not enough water available to satisfy all rights. In Australia, water entitlements come with different "security" levels that determine their reliability, such as high-security versus general-security entitlements.

A water market brings together willing buyers and sellers wanting to exchange water rights. Buyers are looking for the right to use more water. Sellers are willing to trade some of their water rights for monetary compensation. In some places, such as Australia, water markets function much like a stock exchange: willing sellers advertise their water for sale or lease on an internet bulletin board, at a specified price. The parties involved in water market trades typically include city water utilities, energy-generating facilities, irrigation districts or individual farmers, manufacturers or conservation organizations.

There exists a wide variety of different transactions or exchanges of water taking place around the world that do not fit the traditional economic definition of a "market," and many of these transactions do not even involve monetary compensation. For simplicity's sake, any trading of rights to use water is generically bundled under the term 'water markets' in this report.

Table 4. Typical attributes of a water right

Quantity:	The amount of water the holder of the water right may withdraw and/or consumptively use, or the area of land and crops that can be irrigated
Source:	The specific water source and location from which the water right is granted
Timing:	Restrictions on the time that the water right applies (i.e., times that the volume may be withdrawn or consumptively used and possibly daily extraction limits)
Assurance:	Some water rights are more absolute, meaning their volume is almost always fulfilled, while other rights have variable assurance of supply depending on how much water is available each year
Type of Use:	The specific use for which the water is to be withdrawn or consumptively used (e.g. irrigation, mining, etc.)
Duration:	The duration for which the holder is entitled to the water right. Some water rights are issued in perpetuity, while other rights are authorized only for a specified number of months or years

Before further discussing the merits of water markets, some important cautions and caveats need to be stated. Many concerns have been expressed about the unintended consequences that can arise in water markets, and these issues need to be given careful consideration.[69] Most of these concerns center on the possibility that water rights will be bought up by wealthy entities – water speculators, big corporations or cities – leaving poorer people or freshwater and estuarine ecosystems without water. This is a very real possibility if appropriate regulatory controls and other essential water governance functions are not put into place explicitly and early.

Every individual or family must be guaranteed an inalienable entitlement to enough affordable water to meet their basic needs. Those entitlements – whether they are secured as water rights or as public deliveries to residents – should not be tradable. Similarly, when establishing new water markets, serious consideration must be given to the volume and patterning of water flows needed to sustain the ecological and ecosystem service values of freshwater and estuarine ecosystems.


Corn harvest, California, United States. © Erika Nortemann

In an ideal, properly-designed water market system, the water needed to support basic human needs and to protect ecosystems would be reserved from market trading. For instance, the basic principle of withholding some portion of the renewable water supply from commercial uses or market trading is firmly and explicitly embedded in South Africa's National Water Act (1998). Specifically, the Act establishes a water allocation known as the "Reserve," consisting of two parts. The first part is a non-negotiable allocation to meet the basic water needs of all South Africans for drinking, cooking, sanitation and other essential purposes. The second part of the Reserve is an allocation of water to support ecosystem functions in order to conserve biodiversity and secure the valuable ecosystem services they provide to society.[70] This bold vision from South Africa strongly influenced recommendations adopted at the 2002 World Summit on Sustainable Development held in Johannesburg, which included the statement that "the value of ecosystems should be recognized in water allocation and river basin management," and that "allocations should at a minimum ensure flows through ecosystems at levels that maintain their integrity."[71]

Most importantly, nobody should ever be forced to sell their water entitlement, or have it taken from them unwillingly.

Water trading can also create undesirable impacts on agriculture or rural communities if not properly anticipated and managed. One direct effect of transferring water out of agricultural use can be a reduced capacity for food production that can have both local and far-reaching implications. Diversion of water away from agriculture may financially benefit individual farmers receiving payments for their water rights, but when a large volume of water is removed from a farming community, or when too many farmers leave the community after selling their rights, adverse impacts can ripple through rural communities, affecting incomes and employment in both farm-related and non-farm businesses. If the farmers selling their water rights are members of a communal water-supply system, such as an irrigation district that maintains shared water infrastructure, the loss of too many irrigators due to water sales can place a heavy burden on the irrigators who remain, as they must bear the ongoing maintenance costs for the infrastructure.

These cautions about markets highlight the critically important need for strong water governance wherever water markets exist, and for making water markets and water management an integral part of economic development. If the potential risks are properly addressed and managed well, the ability to trade water rights can be quite beneficial in improving economic, social and ecological conditions. In places where basic human needs are not being met, or where freshwater and estuarine ecosystems have been excessively depleted, water markets may provide a mechanism for reallocation of water to these needs.

The necessary governance (enabling) conditions to support high-functioning water markets exist in only a few countries presently, and problematic impediments to water trading can be found in all existing water markets. **The intent of this report is therefore aspirational: to make the case that water markets offer a powerful mechanism for alleviating water scarcity, restoring ecosystems and driving sustainable water management.**

Reaping the benefits of water markets

Six benefits of water markets are particularly noteworthy:

- ***Stimulating water savings –*** By establishing a monetary value for water, water markets can provide strong stimulus for reducing consumptive water use because a water-saving entity can be rewarded financially by selling or leasing the portion of its water right that is no longer needed. When water is appropriately priced it also discourages waste.
- ***Increasing water availability –*** By accessing additional water through a market, a community or government can avoid expensive, time-consuming and environmentally-damaging alternatives for increasing their water supplies.
- ***Improving community flexibility –*** The transfer of water between users and end uses enables individuals and communities to quickly adapt to changing conditions and personal preferences. This includes providing farmers with new revenue-generating opportunities and options for averting irrigation shortages during droughts.
- ***Improving water's productivity and allocation efficiency –*** By discouraging wasteful or low-value uses of water, the trading of water facilitates reallocation of water rights to more productive uses, commonly resulting in more revenue generation in local economies.
- ***Returning water to nature –*** Markets offer opportunities for conservation interests and government agencies to restore water flows in depleted freshwater and estuarine ecosystems by purchasing water in the market and then dedicating its use to environmental purposes.
- ***Improving accounting for water use and availability –*** When water is appropriately priced, water users are more willing to participate in transparent water measurement practices.

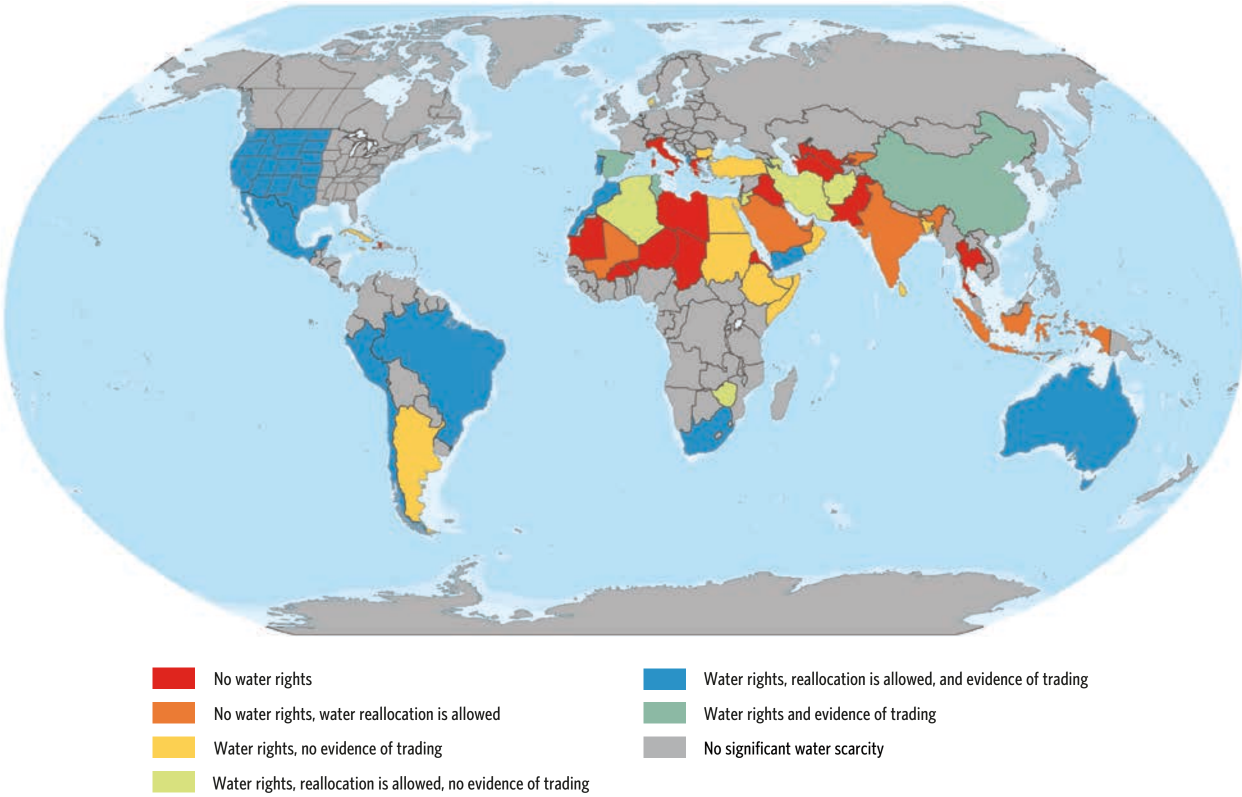
Appendix I of this report presents four case studies demonstrating many of the water-related benefits that can be gained through water market trading. These case studies illustrate not only the potential for reducing consumptive water use on irrigated farms, but also for transferring the rights to the saved water to other uses. The first three case studies highlight recent water trading in the American cities of San Diego, Austin and San Antonio to increase or secure their urban water supplies. In these stories, the water trades did not directly improve water flows in freshwater ecosystems, but environmental protection was a central consideration in each case. In the fourth case study – focusing on the Murray-Darling Basin of Australia – securing water rights for environmental restoration is an integral component of water market trading.

Water market opportunities already exist in many countries

Water-scarce basins can be found in more than 60 countries, but unfortunately, nearly half of these countries lack any formal regulatory means of controlling water use, such as through the issuance of water-use rights or permits (Figure 15). In the absence of governmental regulation or community-based laws or norms, water tends to be underpriced, undervalued, wasted and overused to the great detriment of society and freshwater and estuarine ecosystems. Lacking well-defined and enforceable water-use rights, water markets cannot function properly because anyone can use water without restraint and there is no asset value to be exchanged in a market. Additionally, water rights holders must be allowed to share or trade their water entitlements or allocations with other users on a temporary or permanent basis for water markets to function efficiently.

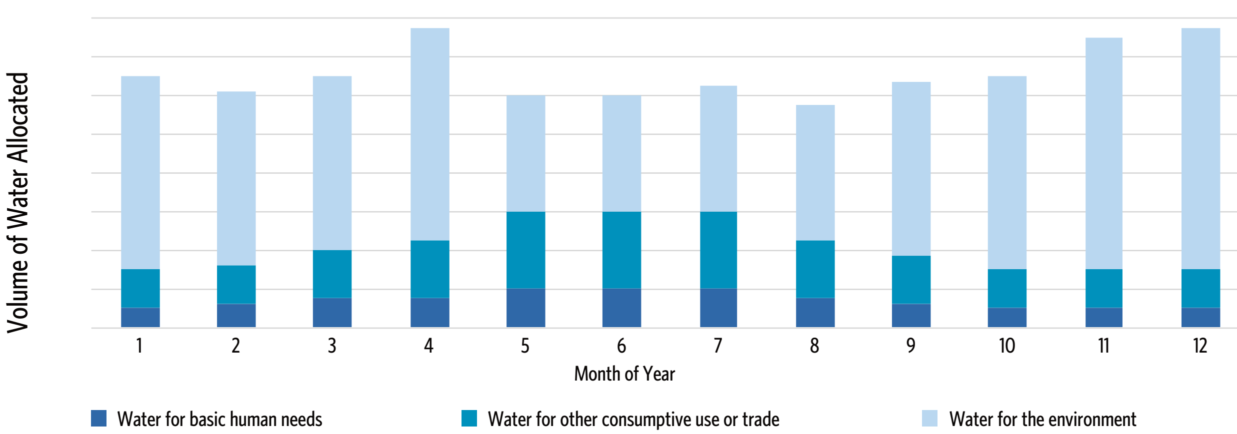
A number of additional enabling conditions are essential or desirable to make water markets function optimally, but one additional consideration will be discussed here.[72] The implementation of a legally imposed limit, or 'cap', on the total volume of consumptive use in a water basin is highly desirable in a water market setting. Once the volume of available water available is fixed, the right to use that water takes on a firm value driven by transparent supply-demand dynamics. That value motivates both efficient use as well as trading in water-scarce settings. A cap on water use can also be highly beneficial in protecting reserves of water to meet basic human needs, while supporting freshwater and estuarine ecosystems (Figure 16). Arguably, a cap on consumptive water rights provides a more effective and more easily implemented strategy for protecting basic human and ecosystem needs, as compared to the set-aside of a water reserve or environmental flow allocation, because regulatory limits on water rights can be more easily enforced. Additionally, by fixing limits on water consumption and allowing the remainder of water within a basin to fluctuate with climatic variability, ecosystems retain some semblance of the natural variability in water flows essential to their ecological health.

Figure 15. Water rights and trading in countries experiencing water scarcity



A cursory assessment of governance conditions and water rights trading in water-scarce states and countries undertaken by The Nature Conservancy.

Figure 16. Meeting human and environmental needs using water markets



This idealized, conceptual representation of a water allocation approach illustrates how both basic human needs and environmental water could be sustainably allocated within a water market context. The volumes of water provided for basic human needs would remain relatively fixed from year-to-year. The maximum volume of water rights allocated for other uses or market trading is capped, although it could vary from month-to-month to account for seasonal variation in water demand. This would allow the remaining water left for ecosystem support to vary considerably over the years in response to climatic conditions, providing some semblance of the much-needed natural variability required to sustain ecological health. Note that this idealized scenario of reserving water for basic human needs and the environment as part of water market design has been discussed often, but has not been successfully implemented anywhere to date (adapted from "Chasing Water: A Guide for Moving from Scarcity to Sustainability" by Brian Richter, 2014).

Water markets can enable restoration of water flows for nature

Unfortunately, very few governments around the world have set limits on consumptive water use sufficient to protect freshwater species and their habitats. Even in basins that have been closed to further water allocation, or where caps have been set, insufficient water remains in the system to support ecological values. Very little or no water has been set aside for nature in most countries, and governments are rarely willing to take back water for environmental benefit once it is being used for other purposes.

The failure to protect some portion of the available water for the environment has led to widespread imperilment of freshwater species, and caused great damage to the health of freshwater and estuarine ecosystems and the important natural services they provide to society. While the adoption of appropriate limits on consumptive use can help protect still-healthy ecosystems in basins where water use remains relatively low, new approaches are needed to facilitate the return of water to already-depleted ecosystems.

When water use is regulated through the issuance of water rights, and where those rights can be traded in a water market, it may be possible for governmental or private interests to acquire water rights and then redirect some or all of the water associated with the rights back to the environment (see Table 5). Two noteworthy examples of governmental action in this regard include: 1) the Australian Commonwealth government's appropriation of more than AUD$3 billion for the direct buyback of water rights in the Murray-Darling Basin, and an additional AUD$5.8 billion for rural water use and infrastructure projects to improve the efficiency of water use on farms, with a portion of the saved water to be returned to the environment;[73] and 2) the Bonneville Power Administration's (United States) efforts to mitigate the impacts of hydropower dams in the Columbia River Basin by providing more than USD$42 million to date to return water to depleted rivers and streams through its Water Transactions Program (Table 5).

Table 5. Water savings in irrigated agriculture can be used to restore environmental flows or serve other purposes

Program Name	Location	Year Started	Year Ended	Permanent or Temporary Transfers	Total Volume of Water Transferred (BCM)	Original Water Use	New Water Use
United States							
Colorado Instream Flow Program	State of Colorado	1973	On-going	Permanent	0.369	Various	Environmental flow
Colorado Instream Flow Program	State of Colorado	1973	On-going	Temporary	0.071	Various	Environmental flow
Colorado Water Trust	State of Colorado	2001	On-going	Both	0.023	Primarily agricultural or municipal	Environmental flow
Columbia Basin Water Transaction Program	Columbia River Basin (many states)	2002	On-going	Permanent	0.099	Various	Environmental flow
Columbia Basin Water Transaction Program	Columbia River Basin (many states)	2002	On-going	Temporary	1.3	Various	Environmental flow
Great Basin Land and Water Trust, Truckee River Program	Truckee River Basin (states of Nevada, Utah, and California)	1998	On-going	Permanent	0.01	Irrigation	Environmental flow
Idaho Water Transaction Program	Upper Salmon River Basin (State of Idaho)	2003	On-going	Temporary	0.024	Various	Environmental flow
Imperial Irrigation District - Transfers to San Diego County Water Authority	Imperial Valley (State of California)	2003	On-going	Temporary	0.86 (2003-14) 0.12 (2014)	Irrigation	Municipal
Imperial Irrigation District - Transfers to Coachella Valley Water District	Imperial Valley (State of California)	2003	On-going	Temporary	0.15 (2003-14) 0.04 (2014)	Irrigation	Municipal

Table 5. (continued)

Program Name	Location	Year Started	Year Ended	Permanent or Temporary Transfers	Total Volume of Water Transferred (BCM)	Original Water Use	New Water Use
Imperial Irrigation District - Transfers to Salton Sea	Imperial Valley (State of California)	2003	On-going	Temporary	0.48 (2003-14) 0.11 (2014)	Irrigation	Municipal
New Mexico Strategic Water Reserve	State of New Mexico	2005	On-going	Temporary	0.006	Various	Environmental flow
San Joaquin River Exchange Contractors Water Authority	San Joaquin River Basin (State of California)	2005	On-going	Temporary	1.623	Irrigation	Agriculture, municipal, and environmental
Scott River Water Trust	Scott River Basin (State of California)	2007	On-going	Temporary	0.004	Irrigation	Environmental flow
Swalley Irrigation District Piping Project	Deschutes River Basin (Oregon)	2005	2007		0.003	Irrigation	Environmental flow
The Freshwater Trust's Flow Restoration Program	Deschutes River Basin (Oregon)	1996	On-going	Permanent	0.029	Irrigation	Environmental flow
Trans Pecos Water and Land Trust	Rio Grande river Basin (State of Texas)	2005	On-going	Temporary	0.002	Irrigation	Environmental flow
Tumalo Irrigation District Bend Feed Canal Piping Project	State of Oregon	1999	2002	Permanent	0.005	Irrigation	Environmental flow
Walker Basin Restoration	Walker Lake Basin (State of Nevada)	2010	On-going	Permanent	0.022	Irrigation	Environmental flow
Walker Basin Restoration	Walker Lake Basin (State of Nevada)	2012	2015	Temporary		Irrigation	Environmental flow
Australia							
On-Farm Irrigation Efficiency Program, Rounds 1-3	Murray-Darling Basin (many states)	2010	2013	Permanent	0.02	Irrigation	Environmental flow, irrigation
On-Farm Irrigation Efficiency Program, Round 4	Murray-Darling Basin (many states)	2013	2014	Permanent	0.019	Irrigation	Environmental flow, irrigation
Private Irrigation Infrastructure Program for South Australia, Round 2	South Australia	2012	On-going	Permanent	0.002	Irrigation	Environmental flow, irrigation
China							
Chaobai Water Trust	Miyun Reservoir in Chaobi Watershed	2006	On-going	Permanent	0.02942	Irrigation	Municipal
Zhangye Water Reallocation	Heihe River Basin	2000	On-going	Permanent	0.07	Irrigation	Industrial
Japan							
Agricultural Water Reorganization Measures	Tone River Basin	1968	2003	Permanent	0.347	Irrigation	Municipal
Taiwan							
Petrochemical Corporation	Taiwan	1997	2003	Temporary	0.341	Irrigation	Industrial

Summary of programs that have realized savings in consumptive water use in irrigated agriculture and transferred water savings to the environment or other users. (Adapted from "Opportunities for Saving and Reallocating Agricultural Water," by Brian Richter and seven other authors. In review, Water Policy. Documentation available from The Nature Conservancy.)


Tana River, Kenya. © Brian Richter

However, it is unlikely that governmental water acquisitions will be undertaken in many other depleted river basins, or conducted at the scale necessary to effect ecological restoration. A recent assessment of conservation funding gaps conducted by Credit Suisse, WWF and McKinsey and Company[74] concluded that there is a significant unmet demand for the funding of conservation programs to preserve or restore ecosystems at the global scale, and a huge shortfall will remain even if current governmental and philanthropic funding is doubled. Instead, private investment will be required to make up the shortfall, at a level estimated to be 20-30 times greater than is being privately invested in conservation-related activities today. The ability for global conservation solutions to reach the scale of the climate and development challenges we face – especially with the global population heading toward 9 billion people by 2050 – will depend on driving new funding resources to this work.

Opportunities for private investment in water markets

In 2014, The Nature Conservancy proactively addressed this opportunity with the launch of NatureVest, a division of the Conservancy specifically dedicated to designing investment opportunities that deliver conservation results and financial returns for investors. The opportunity presented by investor-funded conservation solutions, or 'impact investing,' is immense. A research report co-authored by NatureVest, *Investing in Conservation: A Landscape Assessment of an Emerging Market*, found that there is currently USD$23 billion committed to conservation impact investing around the world and that capital is expected to increase to USD$69 billion by 2018. Meanwhile, total annual philanthropic giving to the environmental and animal sector remains around USD$11 billion.[75]

The appetite for conservation impact investments, however, outpaces the development of investable deals. The *Investing in Conservation* report also found that a substantial amount of potential private capital had not been deployed, demonstrating a need for a significant increase in the number of risk-adjusted investment opportunities. Private investors expect to deploy USD$1.5 billion of already-raised capital by 2018, and to raise and invest an additional USD$4.1 billion.

The Nature Conservancy is addressing this market void by structuring more of its conservation projects so they deliver a cash flow that can provide a return for investors. Additionally, many of the organization's impact investing projects are designed to do more than just deliver conservation results and generate financial returns. They also improve quality of life for local communities, ensuring that these projects achieve conservation, financial and social outcomes in balance. With respect to water projects, The Nature Conservancy is pursuing a wide variety of transactions using philanthropy, government grants and impact investment, as well as engaging in dialogues over needed water policy reforms. One new initiative is highlighted here.

A private initiative to restore nature – Water Sharing Investment Partnerships

Given that irrigation is consuming the vast majority of the renewable water supplies in water-scarce basins, transformative solutions to alleviating water scarcity and returning water to freshwater and estuarine ecosystems should: a) find ways to reduce consumptive water use in irrigated agriculture, while sustaining revenue generation; and b) facilitate transfers of saved water to freshwater ecosystems, underserved communities and other water-use sectors such as municipal and industrial uses.

A common misconception is that any removal of water rights from irrigated agriculture would necessarily result in a loss of agricultural productivity or revenue generation. To the contrary, there are many practical and cost-effective ways and opportunities to reduce consumptive water use in agriculture without compromising economic returns or crop production (see "Saving Water in Irrigated Agriculture" sidebar).

Saving Water in Irrigated Agriculture

In recent years, there has been growing debate – played out most actively in the scientific literature[76] – around the issue of how much water can realistically be saved in irrigated agriculture and released to other uses. Due to the strong emphasis in this report on the need to reduce consumptive water use in irrigated agriculture, some illustration of how this could be accomplished is warranted. For simplicity and clarity, a hypothetical situation is described.

Imagine a farming area in which 10,000 hectares of land is being irrigated. The farmers consumptively use 100 million cubic meters (m^3) of water each year, on average. A local non-governmental organization (NGO) is concerned that the removal of this large volume of water from the local river is damaging the river ecosystem used by the farmers. The farmers and the NGO enter into a "Water Sharing Investment Partnership" for the purpose of enhancing the fishing and other recreational values of the river and the associated ecosystems.

Under this arrangement, the farmers agree not to increase the area being irrigated. Further, they commit to reducing their total consumptive use to 85 million m^3, and convey any associated rights to the remaining 15 million m^3 to the NGO. To ensure that no more than 85 million m^3 of water can be consumed in the area, the farmers agree to allow local water authorities to reduce water deliveries accordingly. The farmers are at liberty to select the methods and practices they will use to attain their 15 percent reduction goal. They will consider an array of possible strategies to reduce "non-beneficial consumptive uses" on their farms (Figure 17), including use of regulated deficit irrigation, improved soil management (e.g., mulching, no-till), shifts to new crop types, temporary fallowing of some fields and other proven approaches.[77] Importantly, they will apply strategies to maintain or increase their revenues from agricultural production.

The NGO agrees to secure government grants and private impact investment to cover the costs borne by the farmers to reduce their consumptive use. The NGO dedicates 5 million m^3 of the saved water each year to river flow restoration. The NGO also engages in water trading, using the remaining 10 million m^3 to earn revenue from water sales and leases. Half of the NGO's water revenue goes back to the farmers to incentivize their participation in the Water Sharing Investment Partnership, and the other half enables annual returns to impact investors.

In summary:

- The farmers benefit from expanding their income stream to include a "water product" along with a "crop product."
- The NGO benefits from seeing water restored to the river.
- The impact investors receive annual returns on their investment.
- With 15 percent savings in consumptive water use, 5 percent goes back to the river, 5 percent goes to farmers and 5 percent goes to investors.[78]

Closing note: While a 15 percent savings in consumptive irrigation use may not seem like much, this level of savings at the global scale could free enough water to nearly double all other uses of water and at the same time return flows to depleted rivers and other freshwater and estuarine ecosystems (see "Accounting for Water" sidebar on page 20).

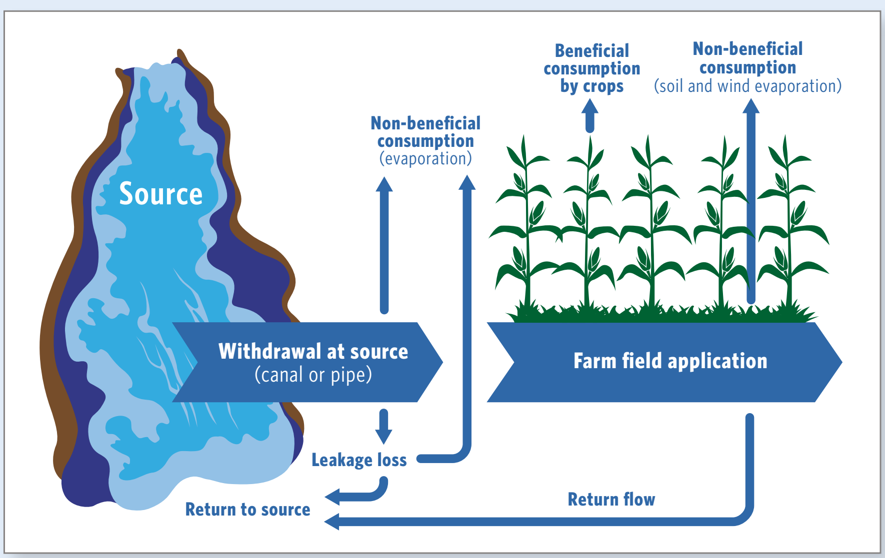
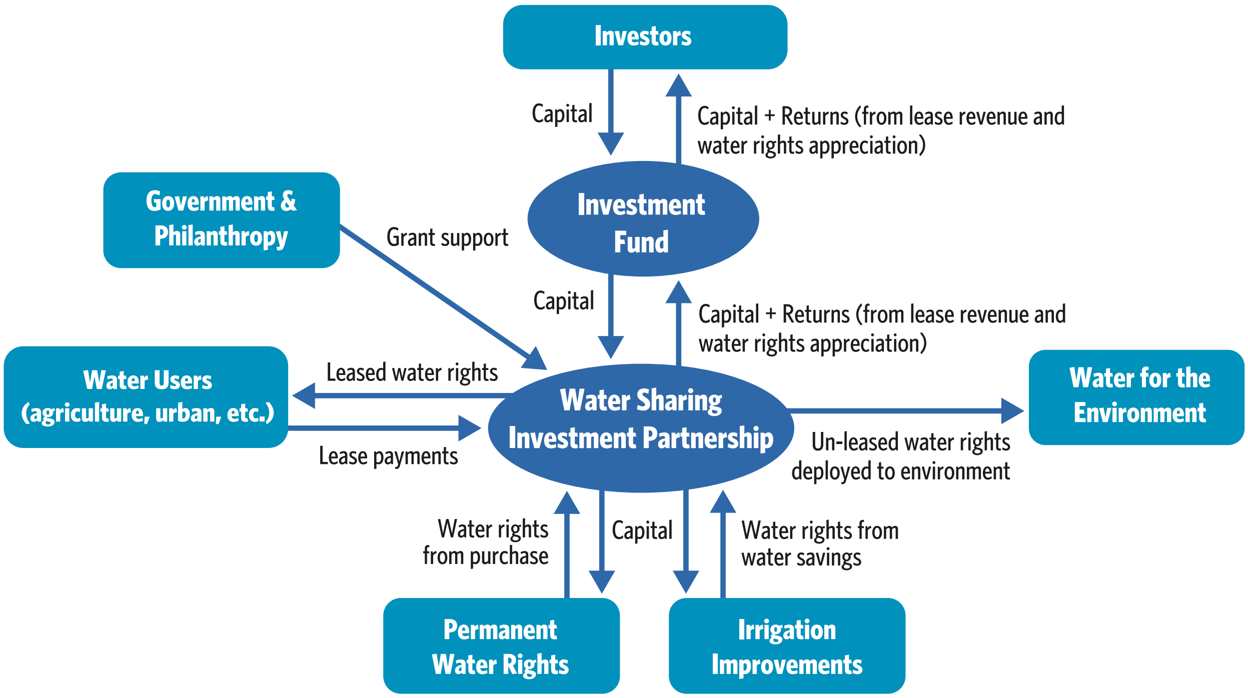


Figure 17. Pathways of water flow in irrigated agriculture

The typical pathways of water flow in irrigated agriculture. When striving to reduce consumptive water use, farmers will focus on reducing the volumes of water lost to "non-beneficial" consumption, and may in some instances reduce beneficial consumption to some degree by switching to alternate crop types. (Source: adapted from "Opportunities for saving and reallocating agricultural water," by Brian Richter and seven other authors. In review, Water Policy.)

The Nature Conservancy is now advancing an aspirational new concept[79] called "Water Sharing Investment Partnership," based upon the strategic trading of water-use rights within select river and lake basins. The overarching purpose of a WSIP is to acquire a pool of water-use rights that can subsequently be reallocated to the environment, provide on-going water security through lease agreements to water users in the community and generate financial returns to investors (Figure 18).

Figure 18. Water Sharing Investment Partnership – How it works



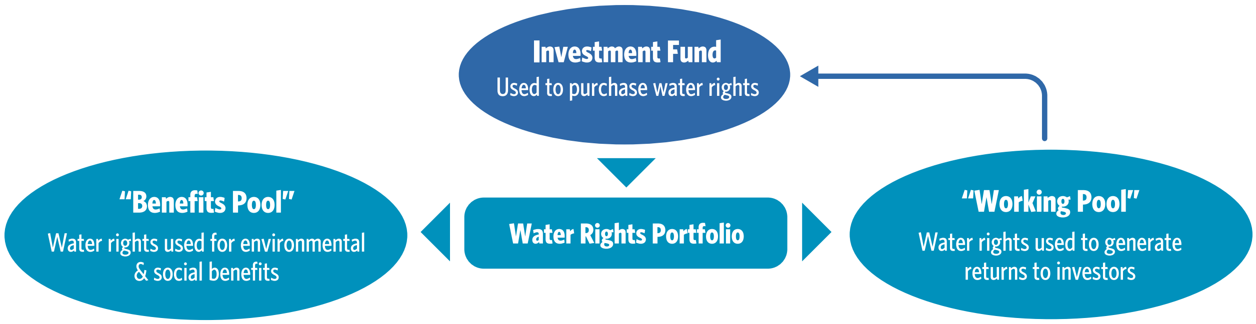
The operations of a WSIP can be supported with funding from impact investors, philanthropic contributions, and/or government grants. A WSIP can use this funding to acquire water rights in two primary ways: 1) outright purchases of water rights from willing sellers in a water market; or 2) by collaborating with irrigation farmers to implement water-saving measures that enable farmers to transfer some portion of their unneeded water rights to the WSIP (see "Saving Water in Irrigated Agriculture" sidebar). The WSIP can then reallocate the acquired water rights to depleted freshwater ecosystems and to other water users seeking greater supply.

A WSIP could generate returns for investors through various means. Figure 19 illustrates one way to view the use of water rights by a WSIP, in which some portion of the total portfolio of the acquired water rights is used to meet environmental and social outcomes, and another portion is used to generate returns for investors. In some instances, the WSIP may also generate returns for investors from improved agricultural revenue generation. The distribution strategy for the water rights held by a WSIP can be custom tailored, depending on the environmental, social and economic needs of a given basin.

Because of the need to generate returns for investors, a Water Sharing Investment Partnership will have an added benefit of making water available for other users through leases or sales of water rights held by the WSIP. Water can be leased to other farmers, or to cities or industries that are in need of additional water supply, thereby averting the need to access water in costlier and environmentally-damaging ways, such as through building new reservoirs or water importation pipelines. These water users would also gain reputational value from associating with a program that is clearly promoting sustainable water management.

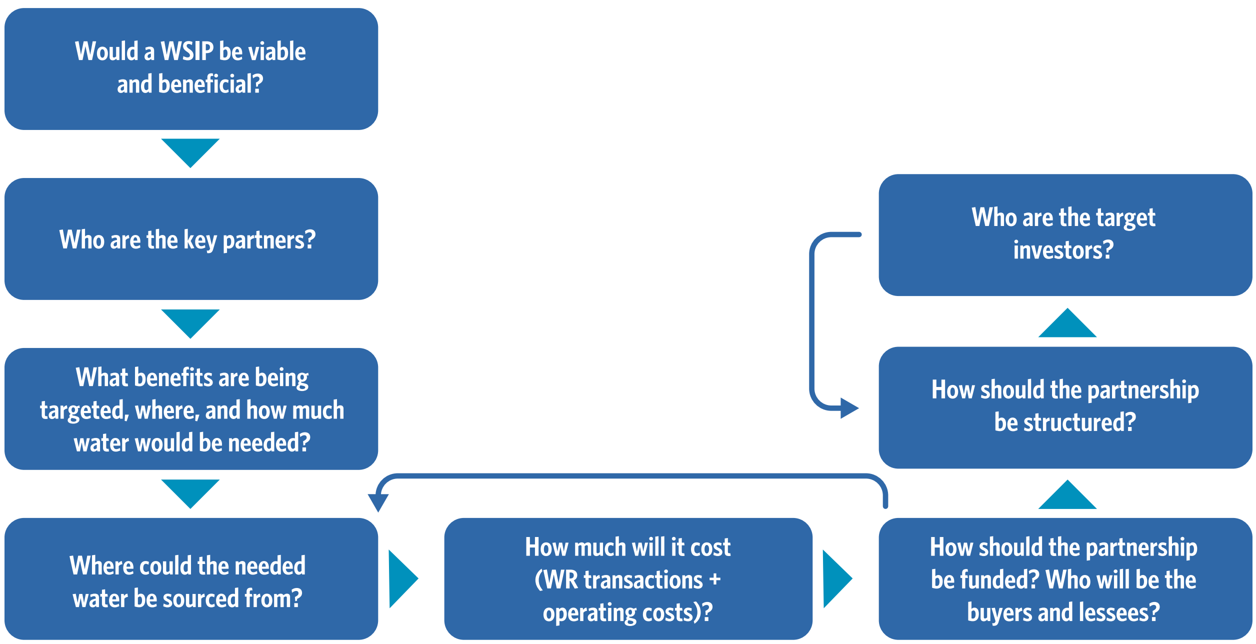
While the development of each new WSIP will present unique challenges, The Nature Conservancy has found that the process illustrated in Figure 20 will generally need to be undertaken in each case.

Figure 19. How Water Sharing Investment Partnerships use water rights



Once the Water Sharing Investment Partnership has acquired a portfolio of water rights, it uses some portion of those rights each year to generate returns for its investors, leaving the remainder of the water rights to be used for environmental and social benefits, such as leaving the water instream to improve fisheries.

Figure 20. Water Sharing Investment Partnership design process



While each WSIP will present unique challenges, these steps will likely be needed in all cases.

As documented in Table 5 (page 46), both governmental and non-governmental entities have successfully transferred water saved in irrigated agriculture for other uses, including river flow restoration. These programs have been implemented using either government funds or philanthropic contributions. The novelty of the Water Sharing Investment Partnership concept presented here is the utilization of funding from impact investors, which is expected to greatly increase the potential for river flow restoration.

In late 2015, The Nature Conservancy successfully launched its first Water Sharing Investment Partnership in Australia, as discussed below. Already, early ecological and financial outcomes are illustrating the potential benefits of this approach. In turn, the Conservancy has been assessing the feasibility of implementing similar WSIPs or other investor-funded solutions in other basins and countries, including Latin America and the western United States. These early feasibility evaluations are confirming that while the majority of geographies do not have as robust a water markets framework as the Murray-Darling Basin, WSIPs will still be feasible in basins with key enabling conditions.[80] Moreover, in basins where the legal, political and administrative conditions are currently

prohibitive to WSIPs, The Nature Conservancy and other actors can use creative investor-funded solutions to facilitate the rebalancing of water use in these water-scarce regions. Key enabling conditions necessary to facilitate WSIPs and other potential investor-driven solutions in water markets are listed in Table 6.

Table 6. Key enabling conditions for pursuing market-based solutions to water scarcity

Enabling Condition	Water Sharing Investment Partnership	Other Creative Financing Solution
Existence of legally-defined and enforceable water rights	Required	Required
Adequate measurement, monitoring, and enforcement systems to assure compliance with rules and regulations	Required	Required
Existence of limitations (e.g., a cap) on total allowable consumptive use	Required	Not Required
Strong science to inform environmental and social outcomes	Required	Required
Agricultural Community Buy-in	Required	Required
Ability to protect environmental water to achieve desired benefits	Required	Required
Holistic community buy-in	Required	Not Required
Ability to transfer permanent and unbundled water rights efficiently	Required	Not Required
Ability to conduct short term transfer of water access from user to user or sector to sector	Required	Not Required
Inefficient agriculture in the basin	Required in many settings	Not Required
Ability to monetize and/or trade conserved water	Required	Not Required

The world's first Water Sharing Investment Partnership: Murray-Darling Basin, Australia

Thousands of floodplain wetlands exist in the Murray-Darling Basin, but nearly all of them have been starved for water since the construction of large reservoirs during the 20th century. These reservoirs, which effectively capture all flood runoff and channel it to irrigators, have prevented many wetlands from being inundated for decades. A large proportion of these wetlands exist on private lands, including Aboriginal heritage lands, where they are integral to the spirituality and livelihoods of indigenous peoples.

State and federal (Commonwealth) governments in Australia have made excellent progress in restoring 'iconic' wetland areas, especially larger wetlands on public lands situated along the main river courses, using water rights (known in Australia as entitlements) obtained through outright purchases of entitlements from willing sellers and investments in irrigation efficiency projects. However, many wetlands of critical importance to indigenous peoples and biodiversity conservation are not yet being restored by these governmental efforts.

The Nature Conservancy, working in close collaboration with Murray Darling Wetlands Working Group, a local wetland conservation organization, and Kilter Rural, an Australian-based asset management firm, launched a first-in-the-world Water Sharing Investment Partnership (WSIP) in late 2015. The WSIP is comprised of two primary entities: an "Environmental Water Trust" and a "Murray-Darling Basin Balanced Water Fund." As of May 2016, the effort has invested approximately AUD$27 million (USD$20 million) in the Murray-Darling Basin Balanced Water Fund (the Fund), with a goal of scaling to AUD$100 million (USD$76 million)[81] within the next four years.

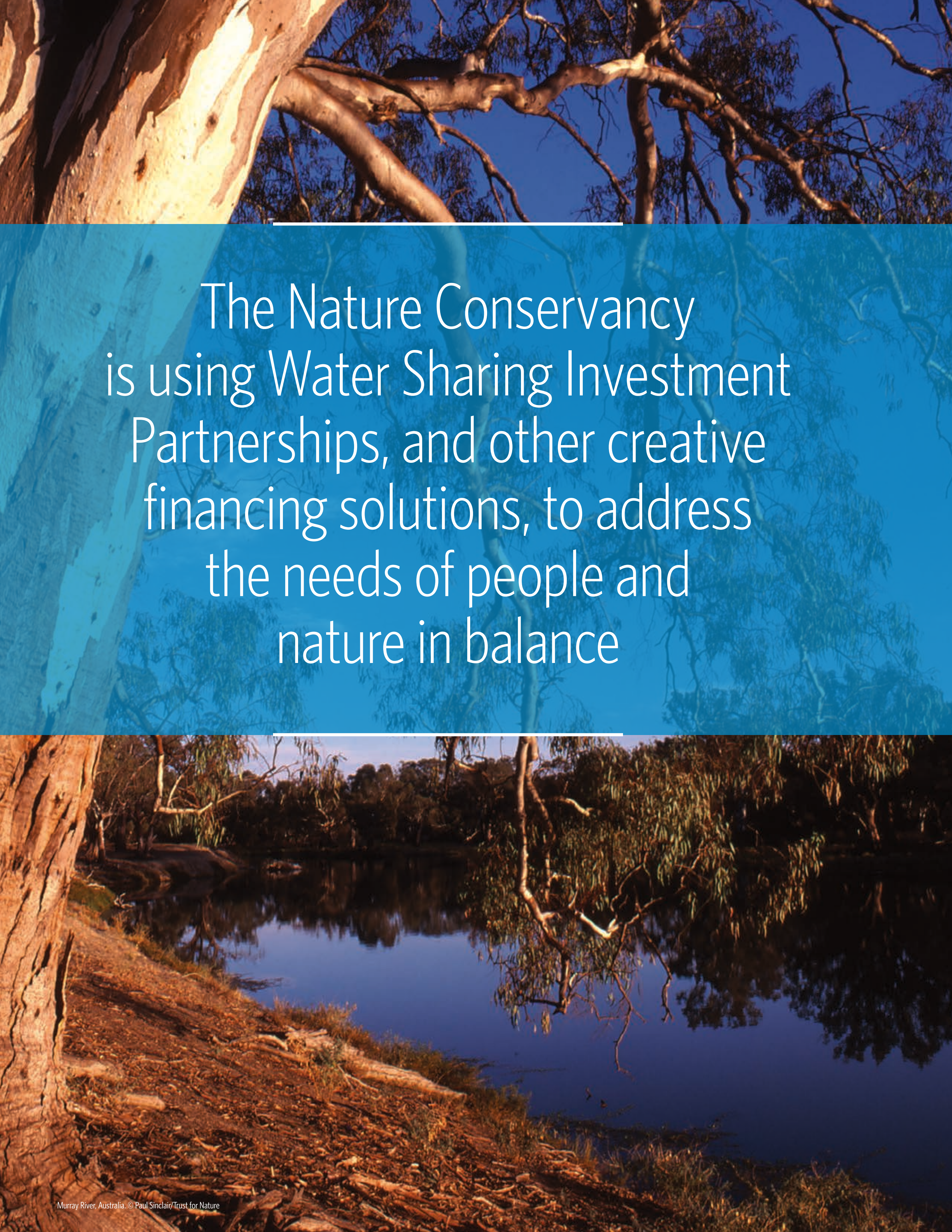
The Fund is working with farmers to acquire and hold a portfolio of permanent water entitlements. It will then sell or lease the majority of the annual water allocations associated with its water entitlements back into the agricultural community, while donating the remainder of the water allocations to the Environmental Water Trust (EWT) for wetland restoration efforts each year. Environmental watering activities undertaken by the EWT will target areas of high ecological and Aboriginal cultural significance. The Fund is structured in such a way that the majority of the environmental donations will occur in years of high rainfall, consistent with natural patterns of wetland inundation, which are also years when farmers least need the water.

The establishment of the EWT and an associated investment fund demonstrates how an impact investment solution can generate environmental and social benefits at a far greater scale than could be achieved under a traditional philanthropy-funded model. Current projections indicate that the WSIP will be able to restore thousands of hectares of wetlands over the coming decade to the great benefit of people, frogs, fish, turtles and waterfowl. Investment of AUD$100 million will enable the purchase of approximately 40 gigaliters (40 million cubic meters) of water entitlements.[81] The WSIP will be entirely self-funding, including coverage of all ecological monitoring and other operational costs, while projecting a return of 7 to 9 percent to wholesale investors.[82]

The annual lease of permanent water entitlements, the trade of annual water allocations during the course of each year and the long-term capital appreciation of the Fund's portfolio of water entitlements will generate financial returns to investors. Kilter Rural is managing the portfolio. Environmental watering is being carried out by the EWT, a registered environmental organization and charity, and managed by the Murray Darling Wetlands Working Group, which has more than 20 years of experience delivering environmental watering programs in the Murray-Darling Basin.

As a limiting factor in virtually all agricultural systems, investments in water assets are positioned to benefit from structural trends impacting both climate and the global food and fiber markets. As an alternative real asset class, water assets provide opportunities for diversification and risk mitigation for investors. Water has a low correlation with traditional assets, making it one of the few asset classes able to provide a true source of alternative opportunities for investors. The Australian water market provides one of the very few opportunities globally for investors to obtain a direct exposure to this most vital of assets.

Leopard frog during drought in Missouri, United States. © Mark Godfrey



The Nature Conservancy is using Water Sharing Investment Partnerships, and other creative financing solutions, to address the needs of people and nature in balance

Murray River, Australia. © Paul Sinclair/Trust for Nature

Chapter Four

Conclusions and Recommendations for Action

One solution will not fit all situations, custom-tailoring will be essential

Any market-based strategies for alleviating water scarcity should be carefully tailored to the underlying uses of water in water-scarce basins. The first chapter of this report described six different typologies of basin-level water scarcity:

Chronically depleted (35 percent of all water-scarce basins):

- Condition C1 – Agricultural irrigation dominant (23 percent of basins)
- Condition C2 – Multiple sectors consuming water (6 percent of basins)
- Condition C3 – Urban water use dominant, with little to no irrigation (6 percent of basins)

Episodically depleted (65 percent of all water-scarce basins):

- Condition E1 – Agricultural irrigation dominant (15 percent of basins)
- Condition E2 – Multiple sectors including cities consuming water (20 percent of basins)
- Condition E3 – Livestock watering and subsistence uses dominant (30 percent of basins)

These typologies suggest that fundamentally different strategies will be needed to combat water scarcity, as appropriate to both the frequency and root causes of water depletion. Four market-based strategies – addressing Conditions C1, C2, E1, and E2 – are outlined here (Figure 21).

A market strategy is not offered here for Condition C3, in which urban water uses are the primary cause of scarcity. A strong shift toward demand-management (water conservation) strategies is urgently needed in these basins to enable cities to reduce their vulnerability to water shortages. Hundreds of well-documented case studies on urban water conservation provide lessons learned from around the world and the literature on proven, cost-effective strategies is vast and growing.[83] The challenge here is to effectively apply those proven approaches at a scale commensurate with the need. Water market strategies or other transactions may very well be helpful in encouraging demand management, but those strategies are outside of the scope of this report.

Similarly, a market strategy is not offered for Condition E3, which involves episodic scarcity resulting primarily from livestock watering and subsistence uses. Resolution of scarcity in these basins will likely require a diverse mixture of strategies, ranging from pastoral herd management, to soil management, to alternative food production systems, to improving the productivity of rain-fed grasslands.[84]

Successful implementation of each of the four market-based strategies presented here will likely require substantial water policy or administrative reforms in each country to enable water markets to function optimally, as discussed previously. The nature of needed reforms will vary greatly among political jurisdictions, depending upon the enabling conditions already in place.[85] Generally, the basic governance underpinnings of well-designed markets include a clearly-defined water rights system that explicitly protects environmental water and basic human needs, the ability to readily exchange water rights on both a temporary and permanent basis and a cap on the total volume of rights to be issued.

Rice fields, California, United States. © Drew Kelly

Given that environmental water needs have been inadequately addressed in all water-scarce regions, the ability to return water to the environment – on both a temporary and a permanent basis, through purchases, leases or donations – will also be essential. So, too, will be the ability to trade any water no longer needed by water rights holders who implement water-saving measures, thereby incentivizing conservation and efficiency investments. Trading activity will also be greatly enhanced by making standardized information about past transactions readily available – including their volumes and costs – as well by communications systems that can help bring interested buyers and sellers together. Finally, administrative restrictions and the time for transactions to be approved by governmental authorities should be kept to the absolute minimum necessary to protect other water rights, the environment and basic human needs for water.

Strategy C1 – Facilitate long-term (permanent) water trades within farming communities

There is tremendous potential for alleviating water scarcity for farmers, and gaining substantial economic and ecological benefits within farming communities, through permanent and temporary water trading within these basins. Local "farmers' water markets" can be designed by farming communities and their governments in a manner that is custom-tailored to the physical layout of the local catchment and aquifers, irrigation infrastructure, the irrigation needs of the farmers and the water needs of local ecosystems. Expected benefits of permanent trades would include increased economic productivity as water rights are traded to farmers who can generate greater incomes per unit of water used. Many farmers will benefit from capital earned from sales of any water rights they no longer need, such as when they invest in irrigation efficiency improvements that reduce consumptive water use. The benefits of farm-based water markets are very well illustrated by the Murray-Darling Basin in Australia, where in recent years nearly 10 percent of all water entitlements, worth nearly AUD$2 billion, have been exchanged each year on average.

If this strategy could be fully implemented – in just the countries with existing water-rights systems and some evidence of water trading already taking place (see Figure 15, page 45) – it could generate annual water sales of USD$3.8 billion per year, equating to market assets of USD$37.7 billion (see Appendix II).

Strategy C2 – Facilitate long-term (permanent) trades between farmers and cities

Great potential exists for alleviating water shortages in cities if water-sharing partnerships can be established collaboratively with irrigation farmers. Rural-to-urban water exchanges can be facilitated through regional water markets or through bilateral transactions between cities and farming communities. Three case studies in Appendix I (San Diego, Austin and San Antonio) demonstrate the tremendous benefits that can be achieved when farmers are incentivized to implement water-saving measures on farms, and then transfer rights to some or all of the saved water to urban users and to freshwater ecosystems. Expected benefits include increased water productivity (dollars generated per unit of water consumed), an infusion of capital into farm communities, and ecosystem protection or restoration. The three case studies in Appendix I document that rural-to-urban water market transfers have spurred GDP growth of 3 to 6 percent per annum in these water-challenged cities over the past decade.

If this strategy could be fully implemented – in just the countries with existing water-rights systems and some evidence of water trading already taking place (see Figure 15, page 45) – it could generate annual water sales of USD$1.0 billion per year, equating to market assets of USD$6.7 billion (see Appendix II).

Strategy E1 – Facilitate short-term (temporary) trades within farming communities

Short-term or temporary adjustments in water allocation are needed in episodically-depleted basins. During dry years or droughts, market mechanisms are needed to substantially reduce or curtail water use on lower-value or annual crops on farms that will not suffer long-term damage from temporary fallowing or deficit irrigation, with proper compensation given to those water users or producers that are able to reduce their water use to enable higher-value crops to be produced. This is facilitated through the creation of farmers' water markets as described for Strategy C1, or it can be exercised through bilateral farmer-to-farmer exchanges. Strict attention is required to protect adequate low flows in freshwater ecosystems during droughts, as the needs of nature are commonly overlooked in the heat of a drought-induced water shortage.

The benefits of farm-based water markets are very well illustrated by the Murray-Darling Basin in Australia, where approximately 44 percent of all water use in recent years has come from trading of annual water allocations. This traded water produces agricultural goods worth an estimated AUD$2.6 billion each year.[86] The case study for the Murray-Darling Basin of Australia in Appendix I documents that short-term market trades averted losses in the gross value of agricultural production of 20 to 25 percent in the worst two years of the Millennium Drought (2008 and 2009).

If this strategy could be fully implemented – in just the countries with existing water-rights systems and some evidence of water trading already taking place (see Figure 15, page 45) – it could generate annual water sales of USD$560 million per year, equating to market assets of USD$18.7 billion (see Appendix II).

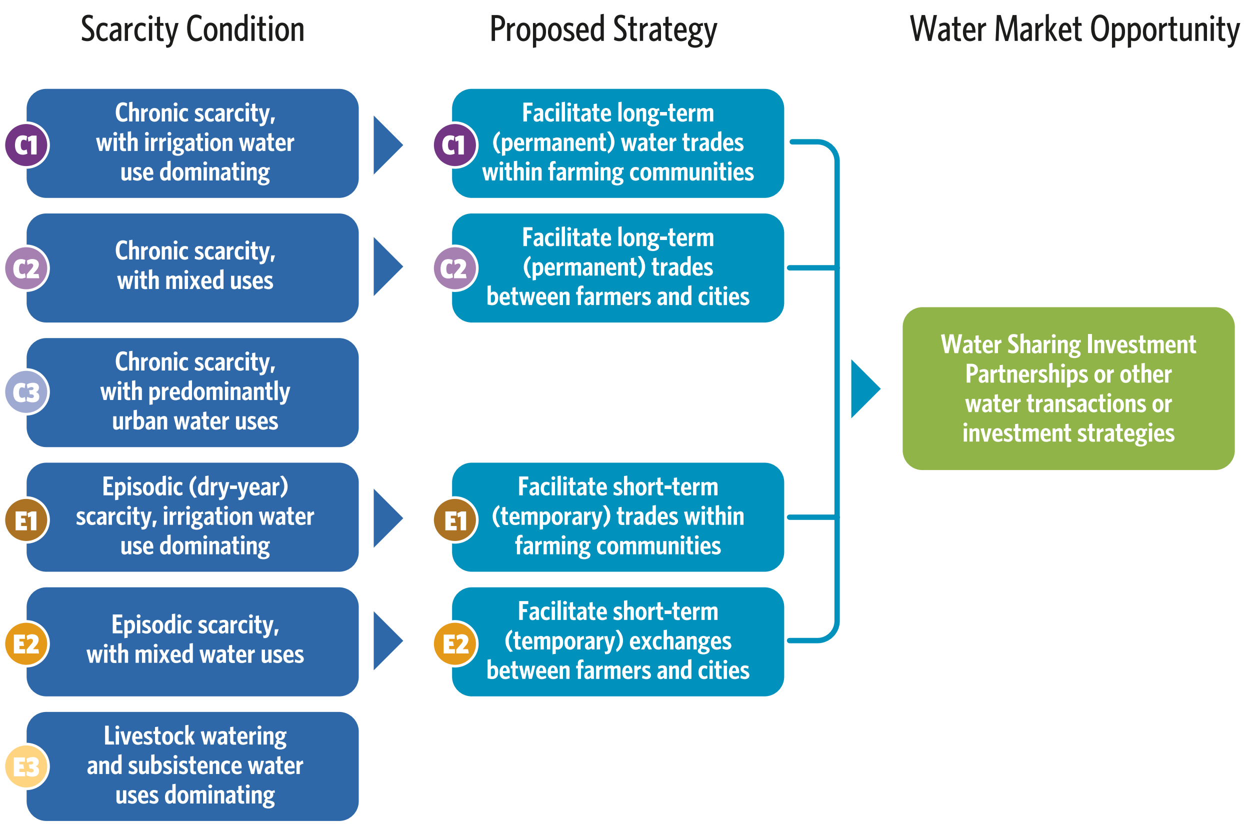
Strategy E2 – Facilitate short-term (temporary) exchanges between farmers and cities

In urban areas, carefully-designed drought management plans will be essential in averting drinking water or electricity shortages, or economic damage due to lost industrial production.[87] Both mandatory water-use restrictions and temporary water pricing structures that discourage overuse of water should be considered. Again, strict protection of minimum environmental flows requires explicit attention, as in all strategies outlined here. Opportunities for short-term lease options with irrigation farmers to free up water supply should not be overlooked, as the cost-effectiveness of paying farmers to curtail water use during drought years may look very good even when compared to urban conservation strategies.[88]

If this strategy could be fully implemented – in just the countries with existing water-rights systems and some evidence of water trading already taking place (see Figure 15, page 45) – it could generate annual water sales of USD$8.0 million per year, equating to market assets of USD$268 billion (see Appendix II).

If all four of the strategies outlined previously could be fully implemented, they could generate total annual water sales of USD$13.4 billion per year, equating to market assets of USD$331 billion.

Figure 21. Market strategies for addressing water scarcity



Four water market strategies are offered in this report, addressing four of the scarcity conditions found in water-stressed basins around the globe. Market strategies are not offered for scarcity conditions C3 and E3, for reasons explained in the text.

Table 7. Potential water sales and market asset values of four water market strategies

Strategy	Potential Annual Water Sales (USD$ billions)	Potential Market Value (USD$ billions)
C1	3.8	37.7
C2	1.0	6.7
E1	0.6	18.7
E2	8.0	268.2
TOTAL	13.4	331.3

These solutions are within reach, but we must act now

Unleashing the full potential of water market solutions discussed in this report will require water policy and regulatory reforms, mobilization of unprecedented levels of public and private investment and inspired leadership from both non-governmental organizations and political decision-makers. Some of the highest-priority activities that can help seize the potential of water markets are outlined here.

Non-governmental (NGO) community

Implementing any of the strategies outlined above will require bold, collaborative efforts by private as well as public actors. The NGO community has a particularly important role to play as brokers of water-sharing agreements, such as through Water Sharing Investment Partnerships. NGOs can bring together the key players in the governmental, agricultural, urban and private sectors, and direct their capacities and activities in a focused manner to achieve carefully-designed outcomes. The following tasks are particularly needed in water-scarce basins:

- ***Prepare scarcity reports:*** In collaboration with relevant governmental agencies, academic institutions and other researchers, compile a detailed scarcity report for the basin(s) of concern. The report should include accounting for water availability and consumptive uses by sector, ideally with documentation of historic trends and inter-annual variability, to advance understanding of how water is being used and the level of water depletion that is occurring. Additionally, document impacts of past water-shortage events, including ecosystem degradation, and provide forecasts of likely future scenarios if necessary actions are not undertaken. Articulate the most promising solutions for saving water in various sectors, and the economic, social and environmental benefits that could accrue from shifts in water use, such as through the transfer of water rights among sectors. Publicize and interpret study results with decision-makers and community and business leaders to build support for action.

- ***Define environmental water needs:*** If scientifically-credible assessments of the environmental water needs in the basin are not available, it will be important for NGOs to help mobilize the funding and expertise needed to define these needs so they can be fully integrated into the design of scarcity solutions.

- ***Design and launch Water Sharing Investment Partnerships and other creative investor-driven solutions:*** The basic action steps are illustrated in Figure 20 (see page 51). In order for a solution to be effective and successful it must be designed at the scale necessary to resolve water scarcity and ensure adequate water flows for degraded ecosystems. This consideration of scale is essential to the setting of water-acquisition targets and the structure of the solution. Additionally, engaging key stakeholders with a deep knowledge of the basin, and earning the trust of essential partners in the basin, will be imperative to success.

- ***Advocate for water policy and regulatory reforms:*** The preparation of scarcity reports for basins of concern will provide a sound platform for identifying shortcomings in existing policy and legal frameworks that need to be resolved before the benefits of water markets and WSIPs can be realized. Successful implementation of Water Sharing Investment Partnerships will demonstrate the potential benefits to be gained from high-functioning, well-governed water markets.

Irrigation farming communities

The dire situation presented by water scarcity and the threat of water shortages could surprisingly provide opportunities for proactive farming communities to reinvent their future. Because farmers typically hold the vast majority of water rights in water-scarce basins, they hold great power to influence the creation and shaping of water markets and ensure that market rules work toward the betterment of the overall community, and avoid the many unintended consequences that can arise when markets are not designed and governed properly. The establishment of high-functioning, well-governed water markets can provide increased flexibility for generating farm revenue (i.e., by 'growing water'), while at the same time protecting the livelihoods and social fabric of rural farm communities. Some key decisions facing farm communities include:

- ***Proactively decide how much water should ideally be held within the farm community or sector:*** Water is the most important input to irrigated agriculture (no water, no crop), and the volume of water available within a farm community ultimately defines the potential size and economic productivity of the community. At the same time, any targets for agricultural water retention or acquisition should fully account for the potential to intentionally reduce consumptive use within the farming community, which can enable trading of surplus (saved) water rights, at profit to farmers. By proactively defining how much volume should be held within the overall community to maintain its vibrancy and culture, and how much could be traded outside or into the community, farmers will be better able to secure the future they desire.

- ***Invest in infrastructure that facilitates trading:*** The ability to move water into, within or outside of a farming community can greatly influence opportunities for trade. Carefully-designed infrastructure improvements can benefit many farmers and the overall farm economy. Financial assistance from governments to fund infrastructure improvements can help in many countries, but financing agreements with the private sector – such as in a Water Sharing Investment Partnership in which some portion of water rights are exchanged for financing infrastructure and other farm improvements – can certainly help fill the gap.

- ***Look for opportunities to maximize farm revenues by 'growing water':*** Investments in strategies to reduce consumptive water use can generate attractive returns on investment, particularly if saved water can be traded with other farmers or with other sectors, such as in a Water Sharing Investment Partnership. Demand reduction can also help to reduce farm costs associated with infrastructure maintenance, electricity, etc.

Political leaders

Water policy reforms and regulatory adjustments will be needed in every water basin or country afflicted by water scarcity. The nature of the governance challenges will vary greatly across the more than 60 countries and nearly 5,000 water basins experiencing water scarcity, but these are some of the key issues to be addressed by political leaders:

- ***Define water rights:*** Half of the countries presently experiencing water scarcity appear to lack any formal or effective means for controlling water use (see Figure 15, page 45). Rights or permits to use water, characterized by attributes such as those listed in Table 4 (page 42), will need to be formally institutionalized before the market-based solutions described in this report can be implemented. Of particular concern in the establishment of any new water rights system will be ensuring that basic human needs and ecosystem health are explicitly accounted for, and that caps on consumptive use are adopted.

- ***Facilitate trade in water rights:*** Even in the best-functioning water markets in the world, further refinement in trading rules are needed to optimize the benefits of water markets and prevent against undesirable consequences for disadvantaged populations and ecosystems. Of particular concern here is reducing transaction costs, i.e., the time and expense associated with approving water transactions. This includes streamlining of review and approval processes as well as enhancement of the transparency of water trading, such as by making records of trades publicly available and creating mechanisms for buyers and sellers to connect with each other, such as through online bulletin boards or exchanges. Additional trading impediments, common to many countries, should be addressed, including:

    » Water rights holders must be allowed to sell or lease some or all of its water rights holdings. Rights holders must be able to lease or donate water to any party for any purpose at any time, as long as it is physically possible to do so.

    » Water rights holders must have the ability to dedicate water to the environment, on both a temporary and a permanent basis, through either leases, dedications or donations.

    » Water rights must be unbundled from land ownership.[89] Water rights holders will need the ability to buy, sell or lease water to other parties without being encumbered by a requirement that water must be applied to a specific parcel of land.

    » Water rights holders must be allowed to invest in water-saving measures without risk of losing all or a portion of their water right due to non-use. Additionally, water rights holders must be able to transfer the saved portion of their water right to other users or the environment.

Private investors, fund managers and financial consultants

Given expected near-term shortfalls in public funding and philanthropy needed to address water scarcity at a meaningful scale, the attraction of private investment to the water scarcity solutions highlighted in this report will be essential. Some recommended action steps for the investment community include:

- ***Serve as advisors to the NGO community:*** Water markets offer promising opportunities for mutualistic relationships between investors and the NGO community. Many NGOs have experienced, knowledgeable water experts on staff that can provide the data, knowledge base and political insights that can enable investors to better understand opportunities and risks around water markets. NGOs can help investors understand how much water is needed to serve various objectives, and the legal and physical mechanisms through which water transactions can be achieved. In turn, given that many NGOs lack sophisticated understanding of investor perspectives and even the language of investment, collaboration should prove to be mutually beneficial. Investors can help attune NGOs to investor concerns or risks that need to be addressed in the design of a Water Sharing Investment Partnership, or other creative financial solution, and the likelihood of attracting sufficient investment to the project.

- ***Provide financial modeling and prospectus development:*** Many NGOs lack the financial expertise to build appropriate financial models that can be used to communicate potential investment returns and risks. They may also need help in formulating a compelling investment prospectus.

- ***Familiarize themselves with water risks and opportunities, and commit funding to good projects:*** When an investment fund has been designed with expert input and sound financial analysis, investors will be much more inclined to commit funds to the project. In particular, it will be important for investors interested in environmental and social outcomes to give serious consideration to Water Sharing Investment Partnerships and other innovative financials solutions.

Urban water managers

Water markets can provide opportunities for urban water managers to gain access to additional water supplies in ways that are highly cost-effective and often less environmentally damaging than infrastructure-based supply-side options. Water markets can also provide important stimuli for investment in demand management by compensating water users that are willing to implement water-saving measures. Urban water managers can stimulate use of water markets by doing the following:

- ***Give serious consideration to demand management and market transfers in water supply planning:*** Many cities have given insufficient consideration to the cost-effectiveness and other positive attributes of these options in their long-term water-supply plans. In particular, attractive opportunities may be available to enter into partnerships with irrigation farmers, such as through Water Sharing Investment Partnerships or bilateral transactions.

- ***Educate city leaders and other decision-makers on the opportunities to pursue a secure water future using alternatives to infrastructure projects:*** Moving toward new strategies for balancing urban water demands with available supplies can be politically challenging. Urban water managers will need to formulate a compelling case to move outside of business-as-usual, and that may require engaging expert consultants and NGOs to help make the case.

The path forward

Water scarcity has emerged as one of humanity's greatest challenges of the 21st century, and it has become a leading threat to the freshwater biological diversity of our planet. In retrospect, it is rather easy to understand how this water crisis – which now touches the lives of more than half of all people on the planet – came into being. With very few localized exceptions, governments around the world have been unable to control the growing depletion of available freshwater sources, and as a result, communities are bumping up against, or have already exceeded, the limits of their renewable, affordable water supplies.

Drying rivers and lakes and rapidly depleting aquifers are warning signals of disasters pending. The fact that half of all large cities on Earth and three-quarters of all irrigated farms are likely already experiencing recurring water shortages should be of concern to every government and every individual.

Whereas it is easy to understand in hindsight the emergence of this crisis, it is exceedingly difficult to envision a way forward, a pathway out of trouble. The complicated tapestry of differing cultures, political and legal systems, economies, and hydrologic regimes found across nearly 70 water-scarce countries eludes monolithic solutions. Ultimately, water solutions must be localized, tailored to context.

In this report, the promise of local water markets has been articulated, but in truth, what has been described is the beginning of an exploration. The benefits of water markets can, at this time, only be proffered as being aspirational. In many countries, the creation of enabling conditions for high-functioning water markets would require nothing short of a revolution in water policy and law.

But The Nature Conservancy believes that in many places experiencing water scarcity, the potential benefits justify the difficult work that will be required to enable water markets, as well as the risks that will be incurred. Herein we describe one of our own experiments in this regard, known as Water Sharing Investment Partnerships. We invite your reactions, and your partnership.

Appendices

Colorado River Delta, Mexico. © Erika Nortemann

Appendix I: Water Market Case Studies

San Diego, California (United States)

Background

When Juan Cabrillo landed his Spanish sailing ship on the shores of what is now known as the City of San Diego in 1542, his soldiers found a large population of Native Americans living on wild game, fish and acorns growing in the San Diego River valley. More than 200 years passed before a permanent mission settlement would be established in the valley; by the late 1700s, thousands of Native Americans were growing crops alongside Spanish missionaries and other settlers, using hand-dug wells in the river's floodplain for irrigation. As the mission population continued to grow, a small diversion dam was built in 1816 to divert water directly from the river. By the early 1900s, six large water-storage reservoirs had been built in the river basin to provide irrigation to expanding farmlands and drinking water for the 18,000 residents of the burgeoning city.

Continued growth of the urban population motivated the San Diego City Council in 1926 to authorize construction of a water importation canal, spanning nearly 400 kilometers to tap the Colorado River (Figure 22). World War II temporarily disrupted construction plans for the aqueduct, but San Diego's important role as a naval base brought a huge influx of new residents, increasing the population to over 500,000 and seriously over-taxing available water supplies. Aided by an emergency Act of Congress, the Colorado River Aqueduct was finally constructed and began delivering water to San Diego in 1947.

The city's population rose ever-more strongly after the war, creating the need for more reservoirs and another long-distance import of water. This time the new water came from northern California's Feather, American and Sacramento Rivers as part of the State Water Project, completed in 1978. By the early 1990s, 95 percent of the city's water supply was being imported from far-distant water sources.

The role of water market transfers

By the late 1990s, the city was becoming increasingly concerned with the reliability of its imported water. Competition for water was intensifying throughout California and the western United States as the region entered into what has now become one of the most severe and persistent droughts during the past 1,200 years.[90]

Early in 2003, the Secretary of the United States Department of the Interior issued an order mandating that California immediately reduce its use of the Colorado River by 40 percent, thereby forcing the state to begin living within the limits of its 4.4 million acre-foot (5.4 billion cubic meter) allocation. The Secretary had become concerned about the implications of the drought on the equity and availability of water across all seven states sharing the river, and the time had come to reel in California's over-use of its share.

Fortunate for San Diegans was the fact that their San Diego County Water Authority (SDCWA) was already deep into water-sharing negotiations with the Imperial Irrigation District (IID), located along the Colorado River in the far southeastern corner of the state. The IID holds rights to 70 percent of the state's entire share of the Colorado.[91] The SDCWA and IID had entered into a Water Conservation and Transfer Agreement in 1998, but this agreement – representing the largest rural-to-urban water transfer in U.S. history – was not implemented until added impetus from the federal government came in the form of a 'Quantified Settlement Agreement' signed in late 2003. This agreement enables California to reduce its historic over-dependence on the Colorado River by incentivizing reductions in consumptive water use in the IID, which in turn enables transfer of saved water to San Diego to offset and reduce the metropolitan area's direct use of the river.

The reductions in consumptive use needed to support the water transfer from IID to San Diego are being achieved using multiple strategies, including canal lining, temporary fallowing of farm fields and installation of sophisticated monitoring systems. As illustrated by Figure 23, the transfer of water saved on IID farms and from canal lining already makes up more than a third of SDCWA's water supply, and that proportion is expected to grow to 37 percent by 2021.

Other important factors in the urban area's water security is that fact that its residents and businesses have reduced their water use by more than 20 percent during the past 15 years, and water recycling is a small (approximately 5 percent) but growing portion of the area's water supply. The agriculture-to-urban water transfers and other conservation measures have enabled the SDCWA to reduce its dependence on water importation from northern California rivers as well.

Environmental outcomes

California's Salton Sea is a fertile freshwater oasis in the arid desert of southeastern California, providing critically-important habitat for millions of birds migrating along the Pacific Flyway. Fish and insects in the sea feed enormous numbers of pelicans, cormorants, skimmers, herons, egrets, rails and other birds. In all, more than 400 species of birds – the second highest bird count in the country – have been seen at the lake.

The water level in the Salton Sea – the largest lake in California by surface area – has for decades been sustained primarily by agricultural drainage from the IID. Unfortunately, with the water efficiency measures being implemented in the IID, less drainage runoff reaches the lake, causing it to shrink because inflows can no longer keep up with evaporation from the lake surface.

The Quantified Settlement Agreement expressly mandates the State of California to prepare and implement a restoration plan for the Salton Sea as an integral component of the water-sharing plan between farms and cities. However, the restoration plan delivered to the legislature in 2007 carried a USD$9 billion price tag and has not been acted upon by legislators. Many organizations, individuals and agencies have criticized the legislature for inaction, claiming that further delays will lead to growing costs associated with public health impacts from blowing lakeshore dust, declines in property values and recreational revenues and the region's habitat value for birds and other wildlife.[92]

Economic outcomes

The water transfer agreement has provided a new revenue stream for IID farmers by providing payments approaching USD$60 million per year in recent years. Those revenues are projected to double as the water-sharing agreement reaches it full implementation.[93] These funds have enabled farmers to make water-saving infrastructure improvements to their farms and provided a new revenue stream to supplement crop income. Over the course of the first decade of the program, irrigated farm acreage in the area decreased by 5 percent, but crop revenues rose by more than 40 percent, suggesting that farmers were able to save substantial volumes of water while increasing their economic productivity.[94]

The infusion of more secure water supplies from the IID into the San Diego metropolitan area has helped enable the metro population to grow by 14 percent and its real GDP to expand by 70 percent from 2001-2014 (Figure 23).

Potential role for Water Sharing Investment Partnerships

While the transfer of water savings from the irrigated farms of the Imperial Irrigation District has helped to secure San Diego's water future, the shrinking of the Salton Sea suggests that this water transfer has not produced ecologically sustainable outcomes. Additionally, the Colorado River remains heavily depleted throughout its lower reaches, and the river is dried completely by additional water use in northern Mexico before reaching its delta at the Sea of Cortez.

There is excellent potential for the establishment of one or two Water Sharing Investment Partnerships in the lower Colorado River basin. As this case study illustrates, there is both an ability to conserve substantial volumes of water on irrigated farms, and there are urban populations in this region that would likely be

willing to lease additional water from a Water Sharing Investment Partnership. Successful WSIPs operating both immediately north and south of the U.S.-Mexico border could substantially restore water to both the Salton Sea and the Colorado River Delta.

Figure 22. San Diego, the Colorado River and the Imperial Irrigation District

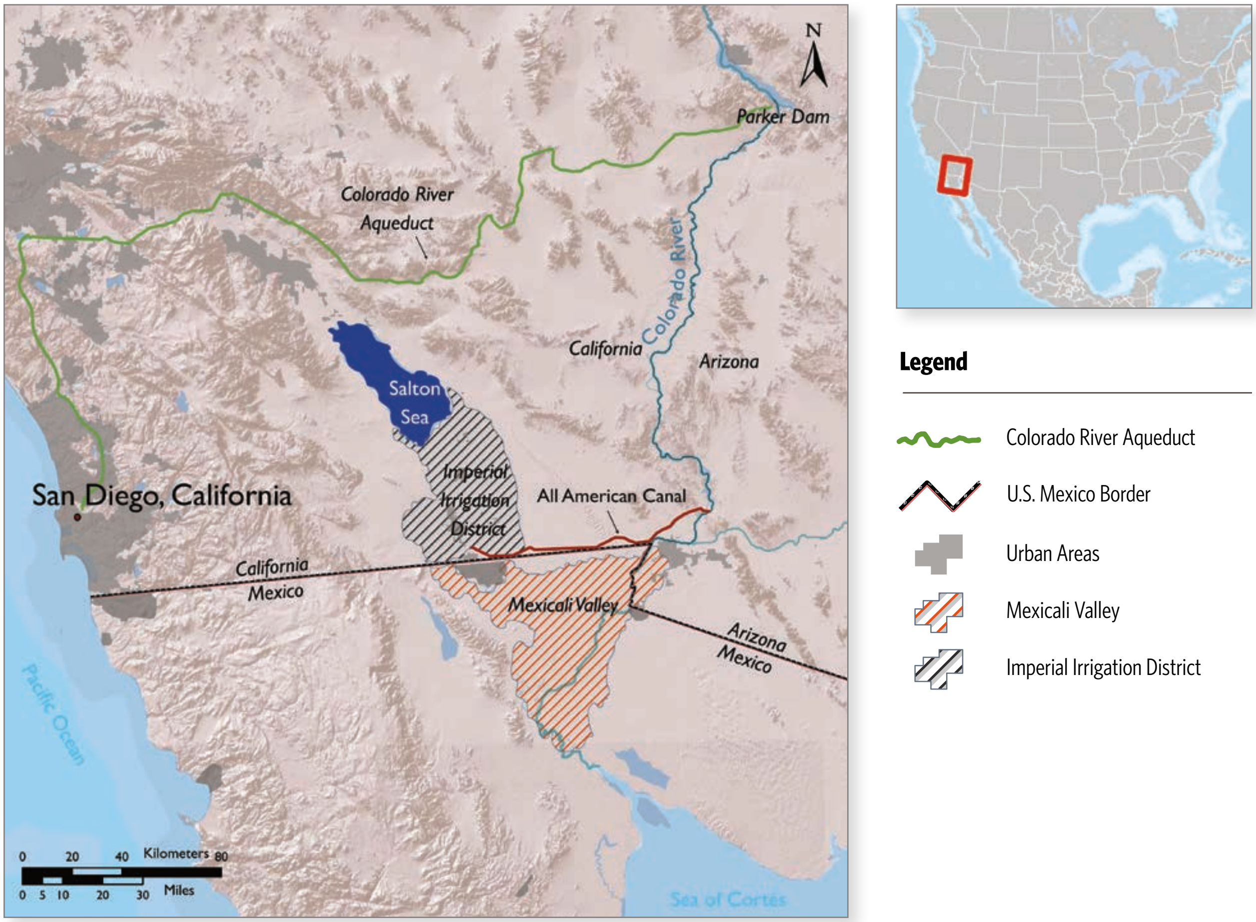
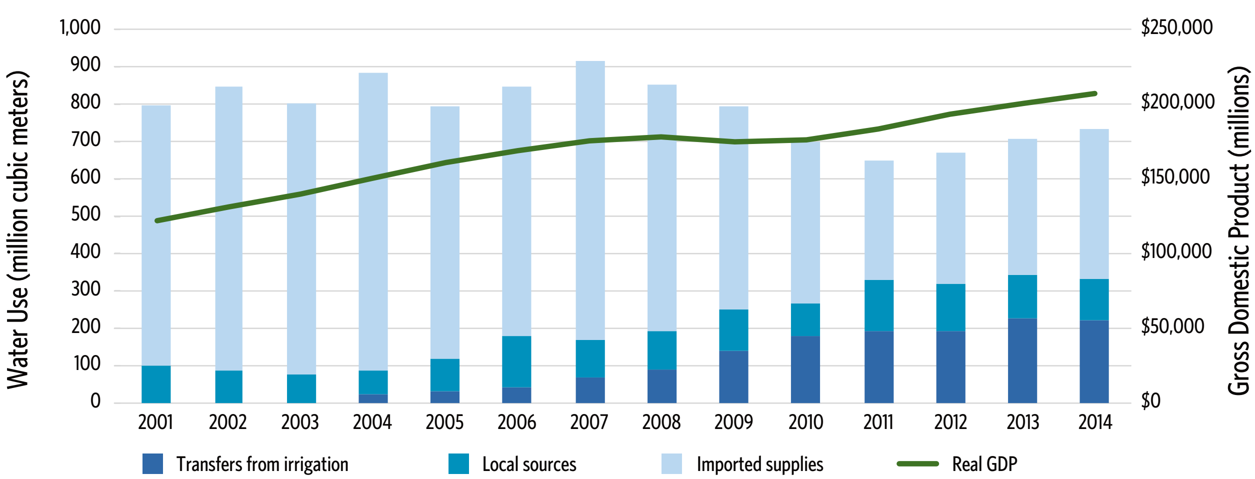


Figure 23. Water transfers from the Imperial Irrigation District to San Diego



Water transfers from the Imperial Irrigation District are integral to the San Diego metropolitan area's water security. By 2021, these transfers will make up nearly 40 percent of the area's water supply. (Sources: San Diego County Water Authority, U.S. Department of Commerce)

Austin, Texas (United States)

Background

For thousands of years, nomadic tribes gathered in the vicinity of the Colorado River of central Texas (no relation to Colorado in previous case study) to hunt and fish, or to cool off in the prolific groundwater springs feeding the river (Figure 24). The first permanent settlement – which would soon thereafter become known as Austin – was established in 1837 along the river's banks, and by 1871 a private company had begun supplying water from the river to the growing community. At the turn of the 20th century, the private water company was purchased by the City of Austin, and Austin Water has now been the city's primary water supplier for more than 100 years. The Colorado River of Texas has always been the sole source of supply for the city while its population has grown to nearly 900,000 residents.

The right to use water in Texas – as is the case in other states of the western United States – is regulated through the issuance of water rights. The reliability of these water rights is dictated by the 'priority date' assigned to each right. The priority date is set according to the time at which the water was first put to beneficial use. During drier years, those holding 'junior' (more recent) water rights are sequentially cut off from water use according to their priority dates. The oldest (most senior) water rights therefore have the highest reliability of being satisfied during dry years.

In many river basins in the western United States, state governmental authorities have issued water rights for a much greater volume than can be supplied during drier years. As an example, the total volume of all water rights issued in Texas's Colorado River basin are four times the long-term median flow of the river. This means that in dry to average years, most water rights holders are left without any water at all, unless they are able to lease water from more senior water right holders or have entered into contracts to purchase water from water suppliers with storage reservoirs. In Texas's Colorado River basin, water right holders with a priority date after 1922 and lacking reservoir storage would receive water in less than half of all years.

The role of water transfers

Austin Water holds a large volume of water rights in the Colorado River. In fact, the city's water right holdings of 0.36 billion cubic meters (nearly 300,000 acre-feet) per year is double the volume the city has used, on average, in recent years. However, during drier years, the Colorado River's flow is insufficient to fully meet the needs of many water rights holders, including Austin Water. During those periods, only water users with the most senior (oldest) water rights or with the ability to store water will be able to access the water they need. During times when there is inadequate flow in the river to meet Austin Water's needs, the city is able to purchase stored water from the Lower Colorado River Authority (LCRA).

LCRA is a state entity which owns and operates two large water storage reservoirs in the basin. LCRA was established in 1934 to provide water supply, flood control and hydroelectricity throughout Texas's lower Colorado River basin.

During dry years, Austin Water purchases water from LCRA under long-term contractual agreements. Access to this supplementary supply is of critical importance to the city during drought years such as 2011, when LCRA provided 40 percent of the water used in Austin (see Figure 25).

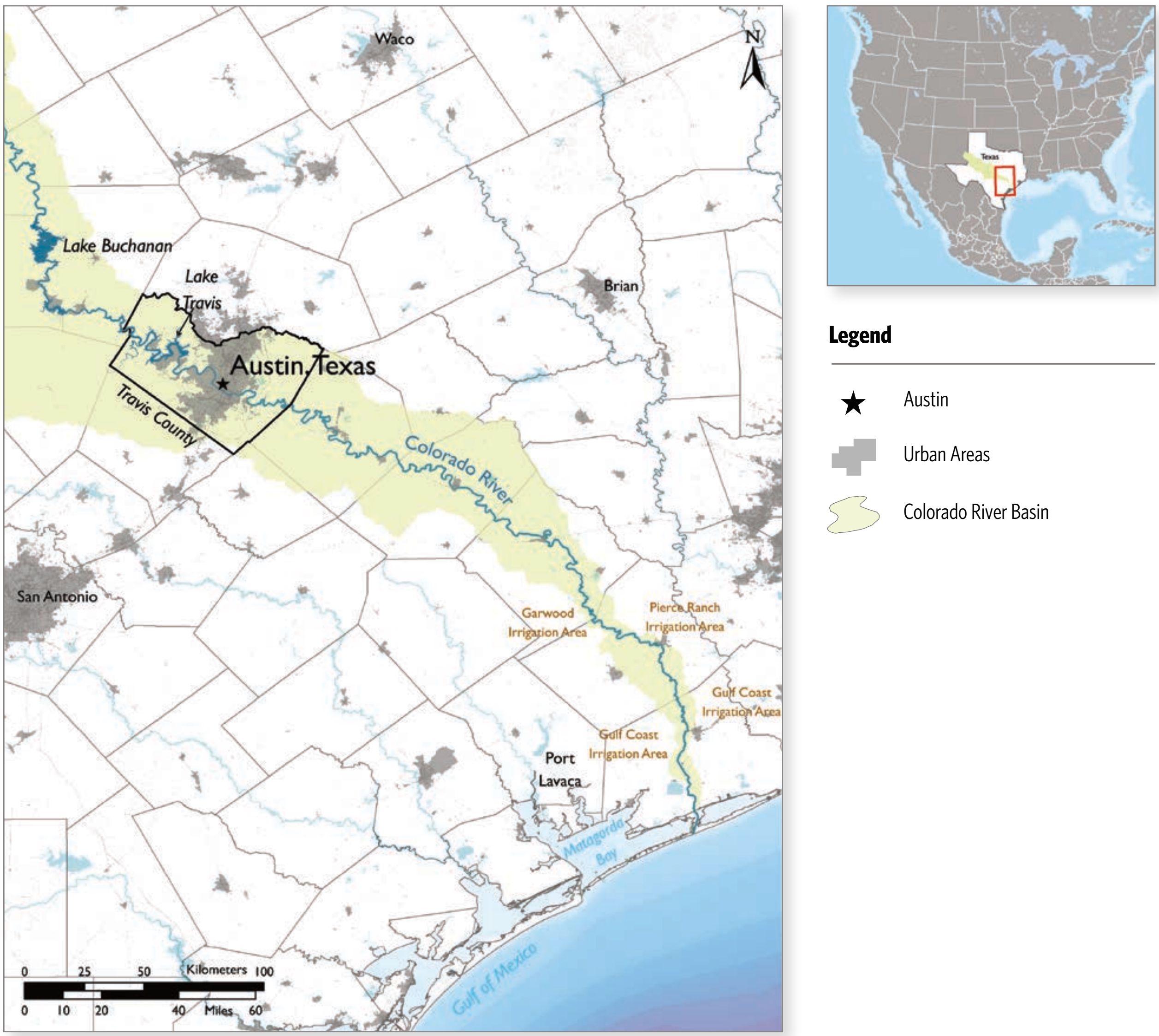
In turn, LCRA's ability to provide a reliable, supplementary water supply to Austin and other water users in the future has been greatly strengthened by LCRA's purchase of senior water rights from irrigators (Table 8). Prior to its acquisitions of water rights from farmers, LCRA's oldest water rights had a priority date of 1926. With the purchases listed in the table below, LCRA was able to jump to near the front of the seniority line in the Colorado River basin, substantially improving the reliability of its water supply (Figure 26).

However, LCRA is still not immune to shortages during severe drought periods, during which the volume of water stored in LCRA's reservoirs will be reduced as reservoir withdrawals exceed replenishment. During 2012-2015, with its reservoirs at one-third of capacity, the agency sought and received emergency permission to cut off its irrigation customers so that the basic needs of cities and industries could be met. LCRA was able to provide water to only one of four irrigation divisions along the lower river during those years.

Environmental outcomes

LCRA's Water Management Plan governs the agency's operation of its reservoirs to supply water to users throughout the lower Colorado River basin in Texas. The plan also requires LCRA to provide water from its reservoirs to help meet environmental flow needs in the lower Colorado River and Matagorda Bay. The 2015 revision of the water management plan commits to providing 0.41 BCM (33,430 acre-feet) per year, over a long-term average, for environmental flow releases into the lower river and estuary.[95] In 2014, following seven years of below-average river flows, the LCRA reservoirs had dropped to one-third of capacity. In that year, LCRA for the first time petitioned the Texas Commission on Environmental Quality for emergency relief from a portion of its environmental release requirements. Only 0.06 BCM (4,582 acre-feet) were released for environmental purposes in 2014.

Figure 24. City of Austin, Travis County and the Colorado River of Texas



Economic outcomes

LCRA paid more than USD$158 million (in 2016 dollars) to acquire senior water rights from irrigators over the past 55 years. These water right acquisitions have enabled the agency to secure the most reliable rights in the basin. The prices paid for these rights have risen sharply over time. The price paid for their most recent acquisitions was approximately 14 times higher than paid in 1959, after adjusting for inflation.

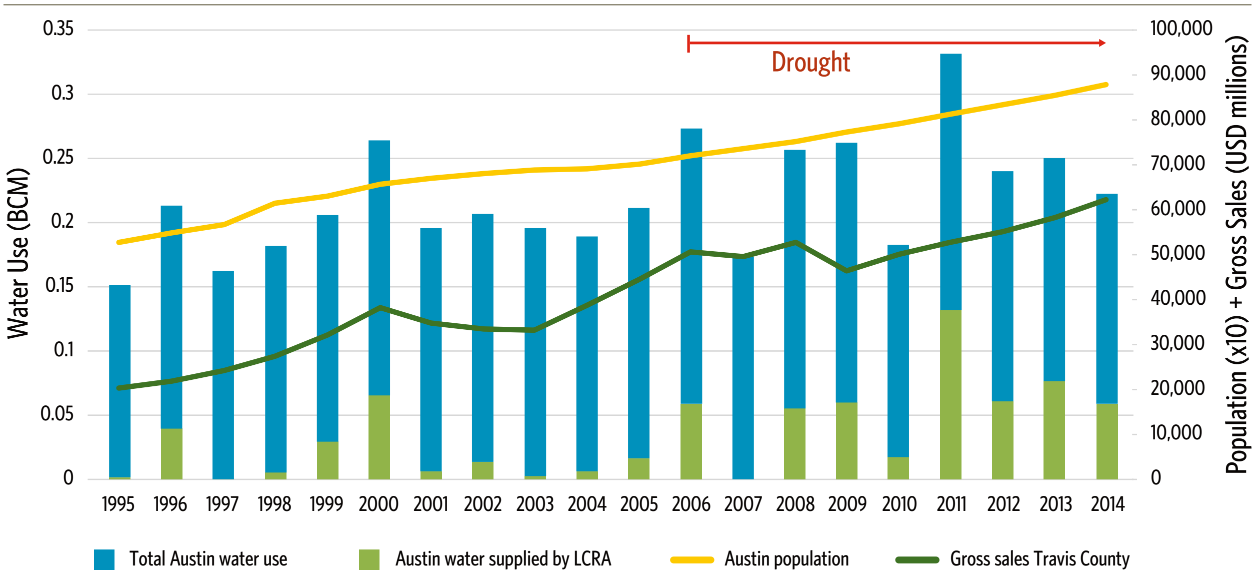
LCRA's water rights acquisitions will be essential to the future water security of many of LCRA's contract customers, including the City of Austin. The city's long-term sales contract with LCRA will become ever-more important in future decades if the city's needs for LCRA water increase more than 20 percent by 2030, as projected.[96] The infusion of water supplies from LCRA into the city has helped enable the urban population to grow by 67 percent and its economy to double over the past two decades (Figure 25). At the same time, the city has made great strides in improving its water productivity, as measured by revenue generation per unit of water. The city's water productivity doubled over the past two decades.

Not all needs are met during severe droughts, however, and the recent shortfalls in river flow and depletion of reservoir storage hit farmers pretty hard. When LCRA was forced to cut off most of its deliveries to farmers during 2012-2015, crop production and revenues were sharply reduced.[97]

Potential role for a Water Sharing Investment Partnership

The recent difficulties in meeting environmental flow targets for Texas's lower Colorado River – as well as drying of smaller tributary streams that flow into the Colorado – suggest the need for environmental flow augmentation in this basin. Given existing shortfalls in water supplies for both urban populations and farmers, the potential for a Water Sharing Investment Partnership to secure water rights will likely depend upon the cost of purchasing stored water from LCRA, or opportunities to realize reductions in consumptive water use on irrigated farms and directing saved water toward supplementing environmental flows and to meet other needs.

Figure 25. Population growth and water supplies in Austin, Texas



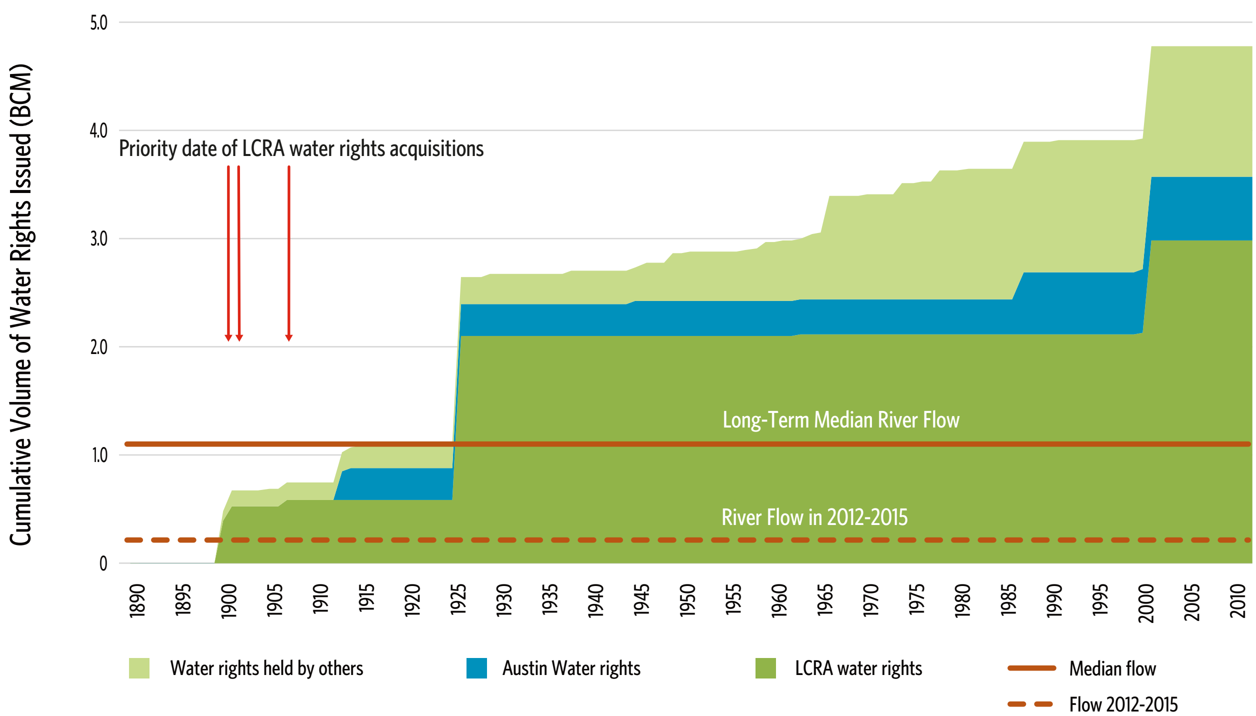
The Lower Colorado River Authority – which owns and operates two large water storage reservoirs in the Colorado River basin of Texas – provides supplementary water to the City of Austin when the city's own water rights are inadequate to meet its needs. For instance, water supplied by LCRA to the city in 2011 comprised nearly 40 percent of the city's water supply. Eighty percent of the residents of Travis County, Texas, live in the City of Austin. During the past two decades (1995-2014), the city's population has grown by 67 percent and the Travis County economy has more than doubled. (Sources: Austin Water, Lower Colorado River Authority, Texas Comptroller of Public Accounts and U.S. Census Bureau)

Table 8. LCRA's water rights purchases

Original Water Rights Holder	Water Right Priority Date	Date Acquired	Volume in acre-feet/year (BCM)
Gulf Coast Irrigation Division	1900	1959	262,500 (0.32 BCM)
Lakeside Irrigation Division	1901	1983	131,250 (0.16 BCM)
Pierce Ranch Irrigation Company	1907	1993	55,000 (0.07 BCM)
Pierce Ranch Irrigation Company	1907	2000	55,000 (0.07 BCM)
Garwood Irrigation Division	1900	1999	133,000 (0.16 BCM)

(Source: Lower Colorado River Authority)

Figure 26. Water rights in the Colorado River Basin, Texas



During 1959-2000, the Lower Colorado River Authority (LCRA) purchased a large volume of very senior water rights from farmers as a strategy for improving the reliability (priority date) and volume of their water supplies. These water right purchases enabled LCRA's water rights priority to jump ahead of many other rights holders, providing greater assurance that LCRA's water rights would be satisfied even in dry years. (Source: Texas Commission on Environmental Quality)

San Antonio, Texas (United States)

Background

San Antonio was named by a Spanish expeditionary party in 1691 while camping beside a crystal-clear spring that bubbled effusively from a limestone (karst) rock formation later known as the Edwards Aquifer (Figure 27). This site had been occupied by Native Americans for more than 11,000 years. The Spanish did not settle in the area until 1720 when a mission was established.

The Spanish missionaries and area natives immediately began excavating an extensive system of irrigation canals, diverting water from the San Antonio Springs and nearby San Pedro Springs. In early years, the diverted water powered waterworks and mills, fed irrigation ditches, provided drinking water, helped fight fires and carried sewage downstream. This water distribution system served as San Antonio's water supply for almost 200 years.

By 1890, numerous wells had been drilled into the Edwards Aquifer around San Antonio, and soon thereafter the city began to rely on wells rather than the canal system for its water supply. The city grew rapidly throughout the 20th century, averaging 36 percent growth in population each decade. The total volume of pumping from the aquifer quintupled from the 1930s to the late 1980s, causing aquifer levels to drop precipitously during dry periods and causing spring flows emanating from the aquifer to decline. During the drought of record in 1956, Comal Springs – the largest spring system remaining in the state – ceased to flow for several months.[98]

Pumping from the Edwards Aquifer increased in a largely uncontrolled manner until 1993 when a management entity called the Edwards Aquifer Authority was created. This authority was established in response to a federal lawsuit that determined that endangered species living in the aquifer and springs were not being adequately protected as required by the U.S. Endangered Species Act. The aquifer harbors a remarkable diversity of species, including blind, colorless catfish and salamanders found nowhere else. The court decision forced the State of Texas to limit aquifer withdrawals and guarantee minimum spring flows to protect the endangered species.

The role of water transfers

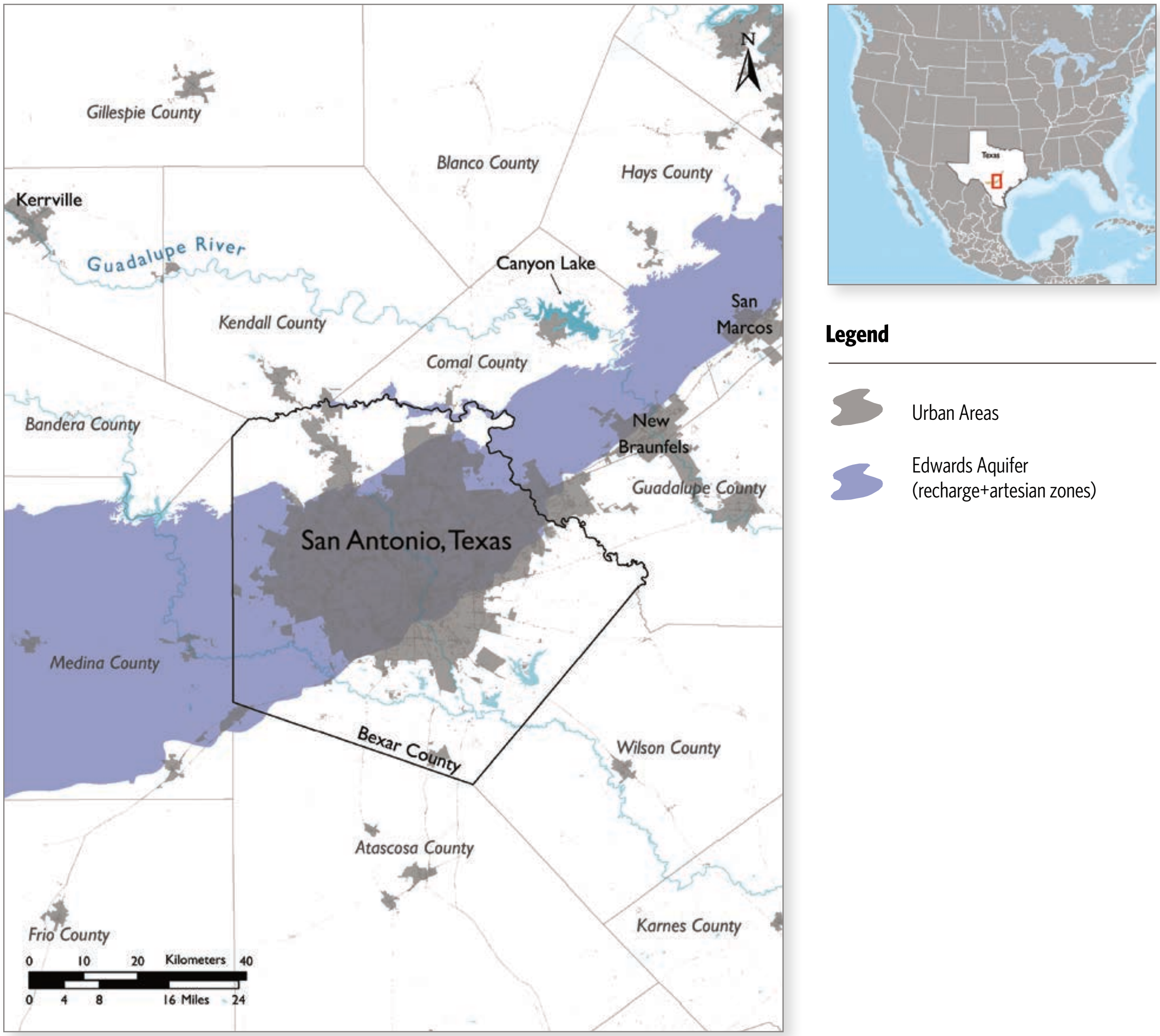
With the creation of the Edwards Aquifer Authority, water rights were issued to groundwater users, both assuring and limiting the volume of their use according to historic use patterns. These rights can be sold or leased, giving rise to an active water market.

Because the volume of water allocated to San Antonio by the Edwards Aquifer Authority was based on historic use levels, the city's allocation left little room for growth in the city's water demand. The San Antonio Water System (SAWS) began purchasing additional water rights from other aquifer users beginning in 1998 (Figure 28). The Edwards Aquifer remained the sole source of drinking water for San Antonio until 2003. Since then, the city has also begun investing in other water supplies such as tapping into additional aquifers (the Trinity and the Carrizo), and has begun developing a brackish groundwater desalination project to enable the city to further reduce its reliance on the Edwards Aquifer. The agency also began purchasing water from an existing reservoir (Canyon Lake) on the Guadalupe River, beginning in 2006. This Canyon Lake water is acquired from the Guadalupe-Blanco River Authority, which holds surface water rights in the adjacent Guadalupe River basin.

The combined purchases of water – through acquisition of water rights in the Edwards Aquifer, contract purchases from Canyon Lake, and multi-year leases of water from other parties – now makes up more than 50 percent of the city's water deliveries.

The Edwards Aquifer water market has also created a strong stimulus for investment in water conservation because any water saved can be sold to other water users. When the Edwards Aquifer Authority was created, irrigators were granted rights to use approximately 6,000 cubic meters of water per hectare (2 acre-feet per acre) each year. Half of each farmer's water allocation can be sold to other users if the irrigators don't need it, providing considerable incentive for agricultural water conservation. SAWS purchased more than 80 million cubic meters of water from farmers, amounting to more than 15 percent of its total water supply.

Figure 27. San Antonio, Texas and the Edwards Aquifer



Environmental outcomes

Limits on withdrawals from the Edwards Aquifer have been expressly set for the purpose of protecting endangered plant and animal species dependent on aquifer levels or outflows at springs. Because San Antonio is the largest user of the aquifer, the city's participation in the "Edwards Aquifer Habitat Conservation Plan," along with other aquifer users, plays a critical role in maintaining aquifer levels within targeted limits. Since the late 1990s, SAWS has been implementing an aggressive urban water conservation program that is keyed to specified water levels in the aquifer. As the aquifer level drops, increasing regulatory controls are exercised on water use in the metropolitan area (Figure 29).

During 2013-14, the aquifer dropped to its lowest level since 1989, but then rebounded with heavy rains in 2015. Monitoring of endangered species populations suggests that while some species were clearly impacted by the low aquifer levels and their populations remain low, the population of other endangered species appear to have rebounded to average or above-average levels.[99]

Economic outcomes

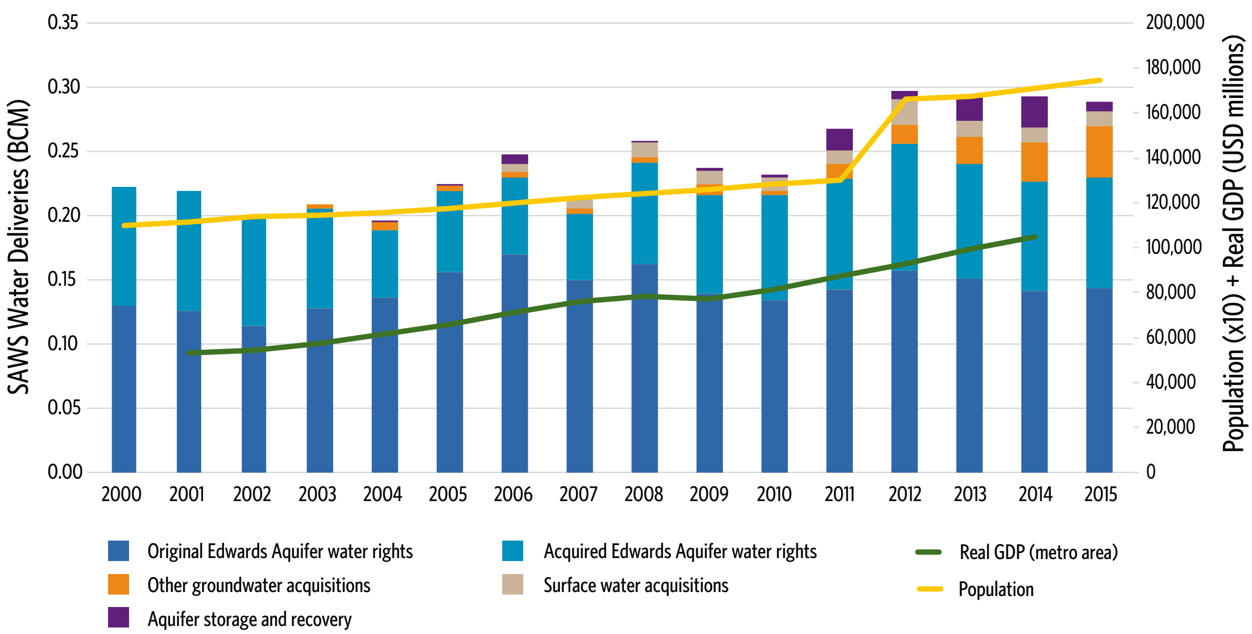
The acquisition of additional water supply through purchases of water rights, as well as multi-year leases and an industry-leading municipal conservation initiative since the 1990s, has enabled San Antonio's population and economy to grow while maintaining adequate water levels in the Edwards Aquifer to protect endangered species. During the past 15 years, the population of the San Antonio metropolitan area has grown by 40 percent and its economy has more than doubled (Figure 28).

Potential role for a Water Sharing Investment Partnership

The limits on water extractions from the Edwards Aquifer thus far appear to be sustaining the endangered species living in the aquifer and in springs emanating from the aquifer. However, the groundwater level did drop into Stage IV (Figure 29) during 2014, reducing spring outflows to a trickle.[100] While insufficient time has passed to determine any impacts on the endangered species populations, this situation should be avoided to the extent possible in the future.

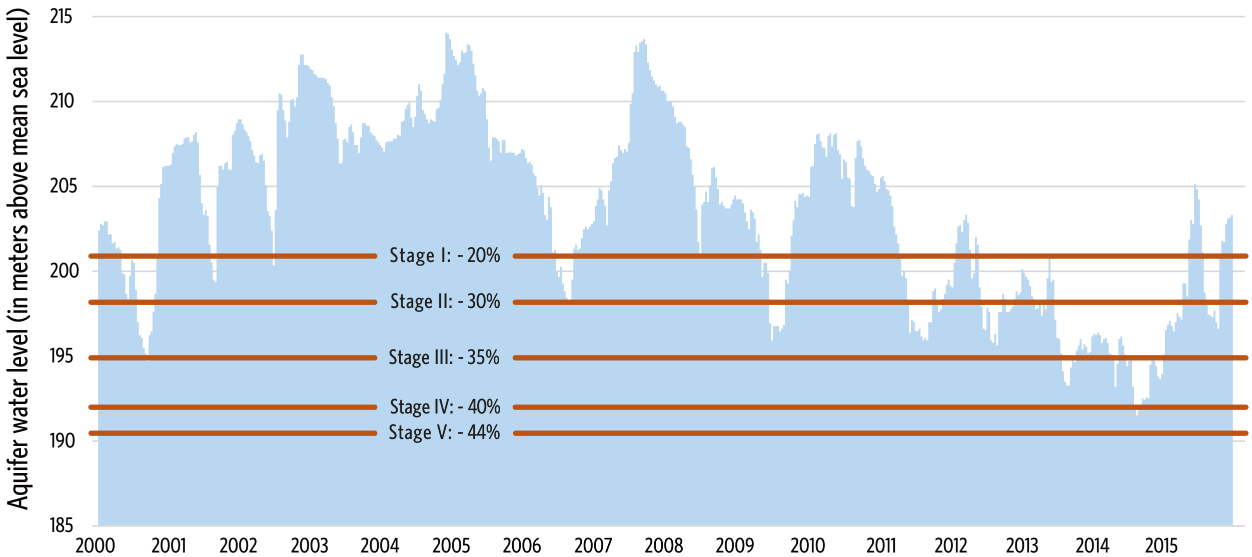
A Water Sharing Investment Partnership (WSIP) could potentially strengthen protection for the endangered species by acquiring groundwater rights for this purpose. These rights could be acquired from farmers, either through outright purchases or by implementing water-saving measures on irrigated farms. This could reduce pressure on the aquifer and the aquatic species during very dry periods by simply leaving the water in the aquifer, instead of extracting it. During wetter periods, the WSIP's water rights could be leased to an entity such as SAWS, which has the capability of storing reserves of water in another aquifer, to be 'recovered' (pumped) when needed, thereby helping to supplement the city's water supply and generating returns for investors in the WSIP.

Figure 28. Water supplies and population growth in San Antonio, Texas



Over the past 15 years, the San Antonio Water System (SAWS) has bolstered its available water supply through a variety of water rights purchases and multi-year leases. These water acquisitions have helped the water utility's service population to grow by 60 percent and the metropolitan area's economy to more than double over this time period. Note: SAWS acquired another water utility in 2012, causing a jump in the population served and the volume of water deliveries. (Sources: SAWS, U.S. Department of Commerce)

Figure 29. Edwards Aquifer levels, 2000-2015



Water extractions from the Edwards Aquifer in Texas – the primary drinking water source for the San Antonio metropolitan area – are curtailed to an increasing degree as aquifer levels fall. These withdrawal restrictions protect the aquatic habitats of endangered species living in springs flowing from the aquifer. San Antonio has been able to meet these restrictions by implementing an active urban water conservation program, and by accessing water supplies from alternate sources other than the Edwards Aquifer. (Source: Edwards Aquifer Authority)

Murray-Darling Basin, Australia

Background

The Aboriginal peoples of Australia have lived with fickle and harsh climatic extremes for tens of thousands of years. Their understanding of weather fluctuations among seasons and years is reflected in their calendars, their language, their art, and their nomadic migrations. They have long known where to find edible plants or fish when the rains do not come.

European settlement in southern Australia began in 1836 with establishment of the colony of South Australia on the Adelaide plains, not far from the mouth of the Murray River (Figure 30). Within a couple of decades, paddle-wheeled steamboats were pushing upstream more than 2,000 kilometers into the upper reaches of the Murray and Darling rivers to haul wool, timber and other resources to Adelaide's port. The discovery of gold in the 1850s brought thousands of new settlers into the river basin along with rapidly growing demand for agricultural goods.

Unpredictable rains and highly variable water supplies have challenged Australian farmers from the very beginning. Of the 460 millimeters of average annual rainfall in the river basin, only about 6 percent ends up in the river system because of the severe heat and aridity that evaporates water quickly from the landscape. River flow can vary enormously from year to year: 118 billion cubic meters (BCM) of water rushed downstream in 1956, but in 2006 only a paltry 7 BCM of water was available.

The early farmers in the Murray-Darling Basin quickly came to appreciate that irrigation was essential to their success. To overcome their water limitations, the farmers of the late 1800s built hundreds of small dams to capture river water for use during the summer growing season. Much larger reservoirs were built in the 20th century, providing greater certainty and stability in agricultural production. By the 1980s, three full years of river flow could be stored in reservoirs, supplying water to an extensive network of farms and rural towns across the basin. The Murray-Darling Basin – known today as Australia's food bowl – accounts for nearly two-thirds of all irrigated farmland in Australia, and generates nearly half of all farm revenue in the country. More than 90 percent of the consumptive use of Murray-Darling water goes to irrigating cotton, rice, cereals, pasture, fruits and nuts, wine grapes and nurseries (mostly cut flowers and turf grass).

The role of water transfers

In contrast with the water rights management system in the western United States – in which the reliability of a water right is tied to its priority date of first use – the Australian system is based on an approach in which the volume of water allocated to each water right over the course of each year is determined by water availability. In wet years, each water right holder is allocated more water as a percentage of their total water right, and in dry years, each holder receives less. In the Australian water market, both permanent rights (known as 'entitlements') as well as temporary (i.e., seasonal) allocations can be bought and sold.

Water market transfers have been taking place in Australia for decades, but trading activity prior to 2006 was quite modest compared to volumes being traded today. Prior to 2006, only 10-20 million cubic meters of water were being traded each year among different farming regions in the basin. However, with the country suffering in the grips of a record-breaking Millennium Drought that lasted from 1997 to 2009, a series of water market reforms were put into place to better facilitate water trading, with the intent to optimize water use and productivity. By 2008-2009, nearly 1.4 billion cubic meters of annual water allocations were being traded, along with sales of more than 700 million cubic meters of permanent rights, even though water prices had risen sharply. In the 2012-2013 irrigation season, temporary allocation trading approached 6 billion cubic meters, and permanent trades exceeded 960 million cubic meters.[101] In recent years, 50 to 60 percent of the total annual water allocations have been traded (Figure 31).

Over the past decade, farmers in the basin have quickly adapted their strategies for owning versus leasing water, as reflected by rapidly increasing seasonal trade in water allocations (Figure 31). Each season, farmers holding water entitlements decide whether it will be more profitable to grow crops with their water, or to sell some water in the market and produce lesser or no crop yields. Consequently, sales of seasonal water allocations are now an

important new revenue stream for many. Other farmers have sold a portion of their permanent water entitlements to earn capital that can be invested in farm improvements, pay off debts, or used for other purposes. Water prices play an important role in these decisions, with prices fluctuating in response to water availability.

The buying and selling of water entitlements, as well as short-term allocations, have been extremely important to the farm economy of the Murray-Darling Basin because it allows water to move temporarily from use on annual crop fields – which can be fallowed without consequence for future years – to perennial crops such as fruit and nut trees or grape vines, which cannot tolerate years without water (Figure 32). Additionally, water entitlements have gradually moved from use on lower-valued crops to those of higher value, maximizing agriculture's economic output. During the peak of the Millennium Drought, farmers producing rice, cereal grains and cotton sold huge volumes of water – where the economic returns on water use ranged from AUD$0.2 to AUD$0.6 million per BCM – to farmers who could generate AUD$1.7 to AUD$15 million with every BCM by growing grapes or other fruits, vegetables or cut flowers and turf grass at nurseries (Table 9 and Figure 32).

Figure 30. The Murray-Darling Basin in Australia

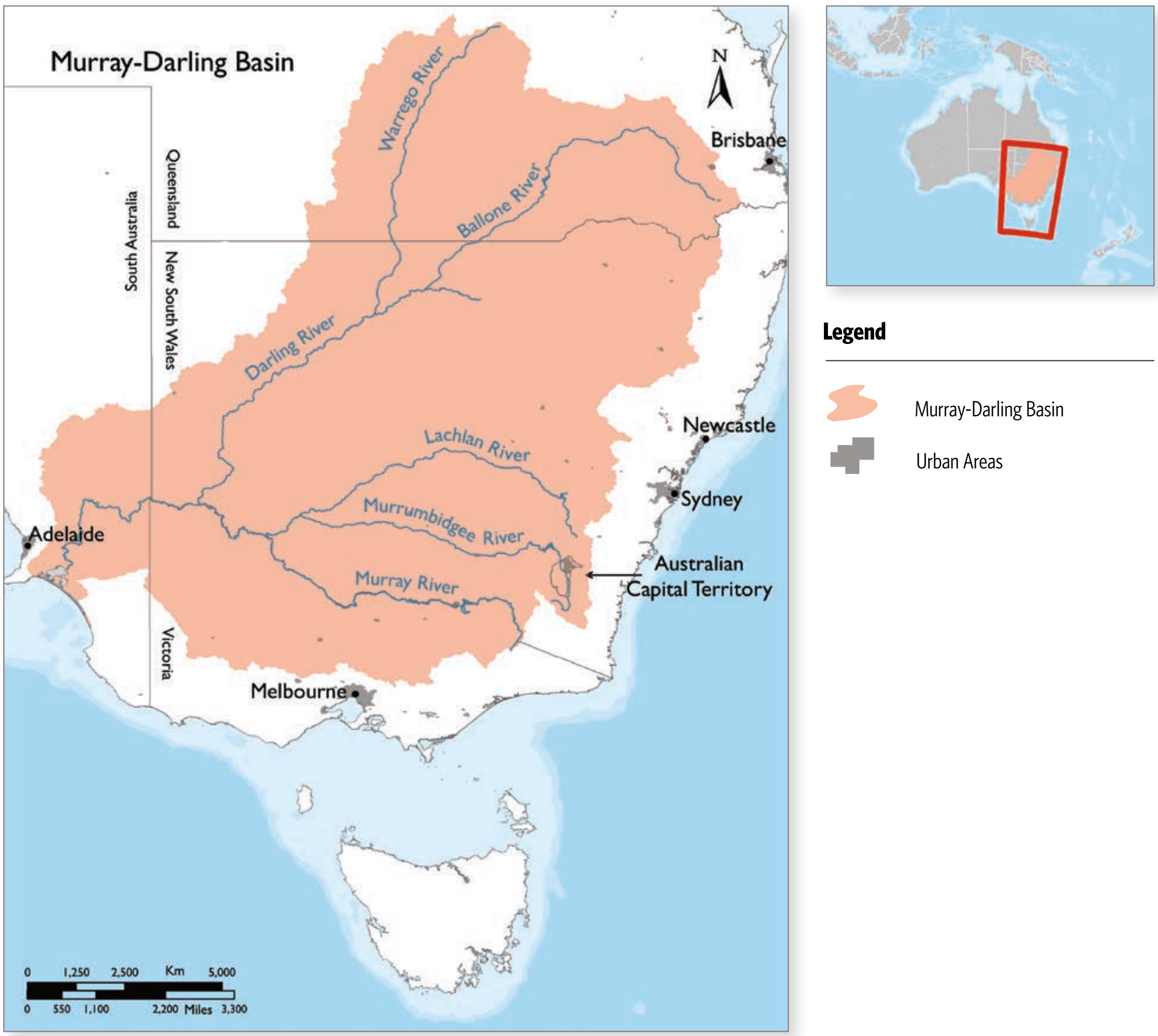


Table 9. Crops and associated water productivity in the Murray-Darling Basin

Crop Type	Water Productivity (AUD$/gigaliter of water[102])
Nurseries	15.5
Vegetables	4.6
Fruit & Nuts	2.9
Grapes	1.7
Cotton	0.6
Pasture (hay)	0.3
Cereals	0.3
Other broadacre crops	0.3
Rice	0.2

Environmental outcomes

The greatly diminished river flows during the Millennium Drought took a heavy toll on the freshwater and estuarine ecosystems of the Murray-Darling Basin, but signs of ecological stress had been apparent for decades. A 'Sustainable Rivers Audit' conducted in 2007 found only one of the 23 river ecosystems in the river basin to still be in good ecological shape, with 20 being rated 'poor' or 'very poor.'[103]

In response to the ecological and economic crisis unfolding in the river basin during the Millennium Drought, the federal government passed the Water Act of 2007. The Water Act created a Murray-Darling Basin Authority and directed the Authority to prepare a 'Basin Plan' for the integrated management of water resources throughout the basin. In concert with the Act, the Australian government announced a new national initiative, 'Water for the Future,' and committed AUD$12.6 billion over 10 years to its implementation. The funds were earmarked to deliver AUD$5.8 billion for rural water use and infrastructure projects to improve the efficiency of water use on farms, and AUD$3.1 billion more for direct buy-backs of water entitlements from willing sellers.

Both the farm efficiency improvements and the entitlement buy-backs were designed to help reduce consumptive irrigation use in the basin to the level of the 'Sustainable Diversion Limits' set for 42 individual planning areas evaluated in the Basin Plan.[104] The water market reforms discussed earlier helped to facilitate the entitlement buy-backs, which, along with entitlements to saved water resulting from the government's farm water efficiency program, would then be managed by a Commonwealth Environmental Water Office for environmental restoration purposes. As of March 2016, a total of 2,410 gigaliters (GL) out of a targeted 2,750 GL has been returned to environmental use. The ecological outcome of these water restoration efforts is summarized each year as 'Outcomes Snapshot' reports.[105]

Economic outcomes

The graph of the gross value of agricultural production in Figure 31 shows a pronounced drop in agricultural revenues during the heart of the Millennium Drought. However, the annual revenue generated during the drought tells only a part of the story.

During the drought, river flows across the entire basin fell to 40 percent below average, but much of the (southern) Murray River portion of the basin experienced river declines of nearly 60 percent. By 2007, the largest storage reservoirs were nearly drained. Due to the lack of rain and depletion of reservoirs, farmers were receiving on average only one-third of the water that they had been using before the drought, and some farms with lower-priority entitlements received no water allocation at all during the worst three years. Overall, dairy production in the watershed fell by an average of 14 percent, cotton fell by 25 percent, meat by 50 percent and rice farming stopped almost entirely.[106]

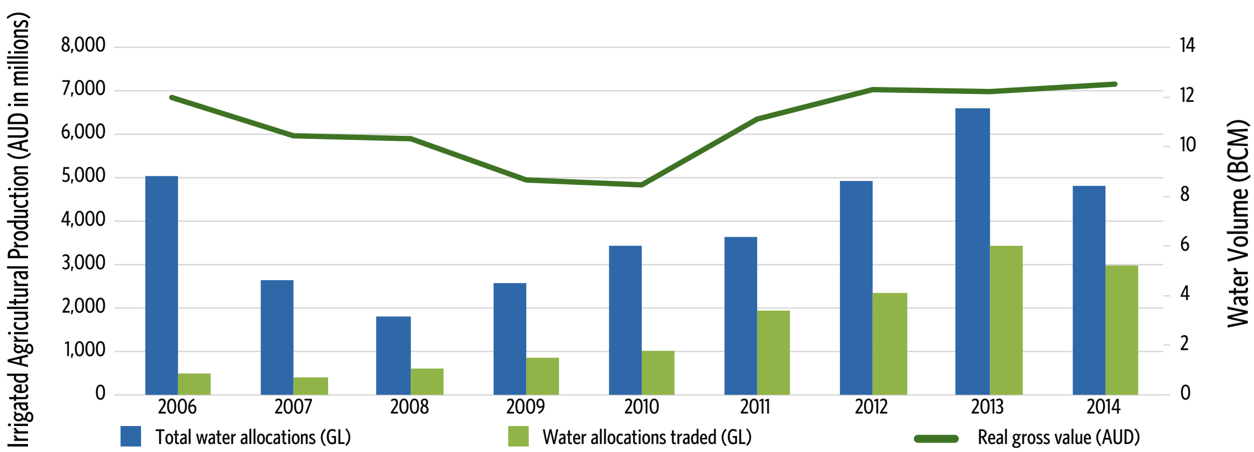
Detailed economic modelling performed by the National Water Commission in Australia has revealed that water market trading substantially reduced the potential economic impacts of the drought.[107] The Commission's report suggests that water trading reduced losses in the regional gross domestic product (GDP) in the Southern Murray River portion of the basin from AUD$11.3 billion to AUD$7 billion over the five-year study period, which included four years of drought followed by a year of significantly increased water availability.

The study pointed out that most of the benefits of trading accrue in dry years, when the need to reallocate water is greatest. In the exceptionally dry years of 2007–2008 and 2008–2009, total benefits of trading were estimated at AUD$1.05 billion and AUD$1.2 billion, respectively. Whereas total benefits in the relatively wet year of 2010–2011 were less than AUD$0.5 billion.

Potential role for a Water Sharing Investment Partnership

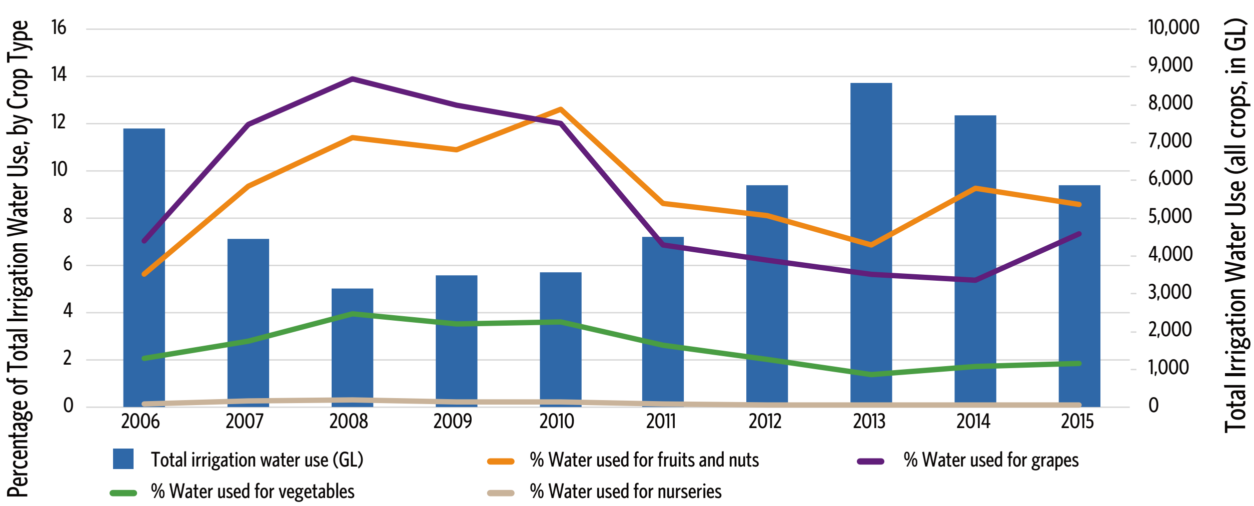
As discussed earlier in this report, The Nature Conservancy and its partners launched its first-ever Water Sharing Investment Partnership in the Murray-Darling Basin in late 2015. The partnership is explicitly intended to supplement the water dedicated to the environment by governmental entities and, in particular, to deliver that water to wetlands that have not been receiving governmental water. Importantly, the Water Sharing Investment Partnership will generate returns for investors by leasing its water allocations back into the farming community, thereby enabling most of the water to continue to be used for agricultural production, particularly during the driest years, when farmers most need the water. During wetter years, more water will be donated to the wetlands in keeping with natural patterns of inundation that would have occurred historically.

Figure 31. Water trading and agricultural revenues in the Murray-Darling Basin



In the worst years (2007-09) of the Millennium Drought, water available for irrigated farming dropped by 40-60 percent across the Murray-Darling Basin. The water reductions had a pronounced impact on agricultural revenues, but these losses would have been much greater in the absence of water trading. (Sources: Australian National Bureau of Statistics, Australian National Water Commission, and Australian Bureau of Meteorology)

Figure 32. Irrigation water use in the Murray-Darling Basin



During drier years when water supplies are inadequate to meet all agricultural demands, water allocation trades in the Murray-Darling Basin of Australia help move water to higher-value crops, including the perennial crops shown here. This bolsters the regional agricultural economy, while providing many farmers with a new source of revenue from water allocation sales. (Source: Australian Bureau of Statistics)

Appendix II: Methodology For Global Economic Projections

To generate global projections of the potential economic benefits of water markets, it was necessary to determine values for each of five variables for each of the four market-based strategies presented in this report:

- Total annual consumptive water use within each water basin
- The likely percentage of total consumed water that might be traded each year for each of the four strategies
- The likely price per unit of water traded for each of the four strategies
- A GDP adjustment ratio to enable currencies in each country to be normalized
- Traded-to-assets ratio (market turnover)

The approach used to estimate each of the above variables is described below. Once estimated, the following equations were applied for each of the four strategies:

- Volume traded = total consumptive use x percentage traded, by basin
- Annual water sales = Volume traded x price per unit of water x GDP ratio, by basin
- Market value = Annual water sales / traded-to-assets ratio, by basin

Estimated total annual consumptive water use

This estimate, in cubic meters per year, is taken directly from the output of the WaterGAP3 model as described in Brauman and others (2016).[108]

Estimated percentage of total consumed water that is traded

It was assumed that under high-functioning market conditions, water-scarce basins around the globe would reach a trading volume similar to what has been documented in two of the case studies in Appendix I. Specifically, these percentages were based on the Murray-Darling Basin case study for irrigation dominated basins and the San Antonio case study for mixed-use basins.

For Strategy C1, in which chronic depletion is attributable largely to irrigated agriculture, the recent 5-year average of trade in volume of permanent entitlements in the Murray-Darling Basin was divided by the total volume of entitlements on issue, producing an estimate of 8 percent. A conservative estimate of 5 percent was adopted for use in the global projections for Strategy C1.

A similar approach was applied for Strategy E1, for episodically-depleted basins, with reference to the volume of trade in annual water allocations in the Murray-Darling Basin as a percentage of the total volume of allocations consumed. The recent five-year average in the Murray-Darling Basin has been approximately 44 percent traded (Figure 31), but a more conservative 25 percent temporary trading volume was applied to the global estimates for Strategy E1.

The estimate for Strategy C2, in which episodic depletion is attributable to mixed uses of water, was made with reference to documented trades in the Edwards Aquifer in the vicinity of San Antonio. Annual trade of permanent water rights in the Edwards Aquifer over 2008-2013 averaged 1 percent per year, which was adopted as the estimate for Strategy C2.

No directly suitable reference case could be found for estimating trading percentages for Strategy E2. An estimate of 25 percent was used, which seems reasonable and conservative when compared with the recent history of agricultural trading in the Murray-Darling Basin (44 percent), and the fact that San Antonio now relies on trading for more than 50 percent of its annual water deliveries to urban customers.

Estimation of the likely price paid per unit of water traded

The prices for both permanent and temporary trades in the Murray-Darling Basin are well documented (see Murray-Darling Basin case study in Appendix I). These MDB prices were applied to the global projections for C1 and E1.

Prices for permanent sales in Strategy C2 were based on prices reported in Debaere and others (2014) for the Edwards Aquifer in the vicinity of San Antonio.[109]

No directly suitable reference case could be found for estimating a price for Strategy E2. However, given that this strategy would be invoked only during droughts, would primarily involve short-term agricultural-to-urban sales, and given the willingness and ability of cities to pay high prices during short-term needs, a price slightly less than half the price of permanent sales under Strategy C2 seems reasonable.

Estimating the GDP adjustment ratio

Due to vastly different economies found across the more than 60 countries experiencing water scarcity, a GDP adjustment ratio was applied to all water sales estimates in an effort to normalize these estimates. All estimates of GDP were referenced to the year 2014 and the majority of these estimates came from the World Bank. Notable exceptions were the following countries: Yemen, Venezuela, Syria, South Korea, North Korea, Greece, Eritrea, Cuba and Angola. In the event these countries did have data from World Bank, but not at 2014 level, an inflation adjustment was applied to bring their most recent available GDP to a 2014 value. If data was not provided by the World Bank it was obtained from tradingeconomics.com. Once all countries in the study area had a value that represented a 2014 GDP they were compared to the United States GDP (2014) to create the adjustment ratio (GDP of country divided by GDP U.S.).

Estimating the traded-to-assets ratio

This ratio was estimated for Strategy C1 (10 percent) using the recent 5-year average of sales of permanent entitlements in the Murray-Darling Basin and estimates of the total market value of all entitlements on issue as reported by the National Water Accounts database maintained by the Bureau of Meteorology in Australia. This ratio was estimated for Strategy E1 (3 percent) using the recent five-year average of sales of annual allocations in the Murray-Darling Basin and the total market value of all entitlements on issue.

No directly suitable reference case could be found for estimating the traded-to-assets ratio for Strategies C2 and E2. Estimates were, therefore, conservatively adopted at 15 percent for Strategy C2 and 3 percent for Strategy E2.

Glossary

Barton Springs, Texas, United States. © Blake Gordon

Glossary of Terms

Consumptive water use – the volume of water that is not returned to its original source after use

Desalination – a technology that removes salt from ocean water or saline groundwater to create fresh water

Water markets – the rights to use water are traded among water users, government agencies, water utilities or non-governmental organizations; this trading is facilitated by governance conditions including formally defined water rights with associated monitoring and enforcement, and a fixed cap on total water use

Water productivity – the production of crops or others goods, or the economic returns gained, per unit of water use

Water scarcity – the result of excessive human use of water relative to the renewable water supply, resulting in shortages and disruption to ecosystems and human endeavors

Water Sharing Investment Partnership – institutions that operate within existing water markets, using investor capital and other revenue sources to acquire a pool of water-use rights that can subsequently be reallocated to the environment, or sold or leased to other water users to enhance water productivity or generate financial returns for investors

Water shortage – the result when the rate of consumptive use approaches or exceeds the rate of water replenishment

Water withdrawals – the volume of water that is withdrawn (extracted) from freshwater sources

Endnotes

Irrigation canal along Limari River, Chile. © Brian Richter

Endnotes

1 "Nonsustainable groundwater sustaining irrigation: A global assessment" (2012) by Yoshihide Wada, L. P. H. van Beek, and Marc F. P. Bierkens. *Water Resources Research* 48.

2 This is based on trends in 3,066 populations of 757 freshwater mammal, bird, reptile, amphibian and fish species as recorded in the *Living Planet Report: Species and Places, People and Places* (2014), by WWF International, Gland, Switzerland.

3 The need for very strong governance to enable high-functioning water markets is explicitly recognized here. This includes the need for formal legislation and supportive political leadership; legally-defined water rights registries supported by diligent and accurate water measurement and accounting, monitoring, and enforcement of rights; detailed hydrologic measurement and modeling; full consideration of the vulnerabilities of underserved and poorer communities, ecosystem water needs, and the direct and indirect impacts of trading water out of communities or sectors; and numerous other administrative rules and considerations.

4 This is not an estimate of the additional economic benefit of trading, which would require evaluation of each individual transaction to understand the increased revenue gained as measured against the previous use. Instead, this estimate is based on the overall economic productivity of water in the basin multiplied by the portion of water that is traded.

5 'Water Depletion: An improved metric for incorporating seasonal and dry-year water scarcity into water risk assessments,' (2016) by Kate Brauman, Brian Richter, Sandra Postel, Marcus Malsy, and Martina Floerke. *Elementa* doi: 10.12952/journal.elementa.000083

6 "Nonsustainable groundwater sustaining irrigation: A global assessment" (2012) by Yoshihide Wada, L. P. H. van Beek, and Marc F. P. Bierkens. *Water Resources Research* 48.

7 "A global data set of the extent of irrigated land from 1900 to 2005," (2015) by Stefan Siebert, M. Kummu, M. Porkka, P. Döll, N. Ramankutty, and B. R. Scanlon. *Hydrology and Earth System Sciences* 19.3: 1521-1545.

8 "Sins of the Aral Sea," by Mark Synnott, *National Geographic*, June 2015.

9 "Aral Sea one of the planet's worst environmental disasters," *Daily Telegraph* (London), April 5, 2010.

10 "Irrigation systems and their fisheries in the Aral Sea Basin, Central Asia," by T. Petr, K. Ismukhanov, B. Kamilov, D. Pulatkhon, and P.D. Umarov, undated. Food and Agriculture Organization of the United Nations (FAO).

11 The terms 'water scarcity' and 'water shortage' are used in this report to denote a condition in which human livelihoods and well-being, or freshwater or estuarine ecosystems, are harmed by a shortage of water. Scarcity is defined here not just by the volume of available water supply; many ecosystems and species have in fact evolved in the presence of aridity. Instead, water scarcity is a result of excessive human use of water relative to the renewable water supply, resulting in shortages and disruption to ecosystems and human endeavors.

12 There are other potential problems with water use in power plants, however, including possible increases in the temperature of water released after use in plant cooling, as well as entrainment of aquatic organisms on intake pipes.

13 *The United Nations World Water Development Report 2015: Water for a Sustainable World* (2015). United Nations World Water Assessment Programme, UNESCO, Paris.

14 WaterGAP3 is an integrated water resource model developed at the University of Kassel in Germany.

15 The water scarcity statistics used in this report are based largely on an analysis summarized in 'Water Depletion: An improved metric for incorporating seasonal and dry-year water scarcity into water risk assessments,' (2016) by Kate Brauman, Brian Richter, Sandra Postel, Marcus Malsy, and Martina Floerke. Elementa: Science of the Anthropocene doi: 10.12952/journal.elementa.000083

16 This excludes a large number of small coastal watersheds.

17 *The Global Risks Report 2016,* World Economic Forum, Geneva

18 These data on water shortage impacts include 25 events reported by companies responding to CDP's Water Questionnaire in 2015.

19 "Tapped out: how can cities secure their water future?" (2013) by Brian D. Richter, D. Abell, E. Bacha, K. Brauman, S. Calos, A. Cohn, C. Disla, S. Friedlander O'Brien, D. Hodges, S. Kaiser, M. Loughran, C. Mestre, M. Reardon, and E. Siegfried. *Water Policy* 15 (2013) 335-363.

20 *Urban Water Blueprint: Managing Conservation Solutions to the Global Water Challenge' (2014),* The Nature Conservancy.

21 "Tapped out," see note 19.

22 *A History of the Salt River Project*, by the Salt River Project (Phoenix, Arizona), 2012

23 *"Colorado River Drought Forces a Painful Reckoning for States,"* by Michael Wines, New York Times, January 5, 2014.

24 *Rivers for Life: Managing Water for People and Nature* (2003), by Sandra Postel and Brian Richter. Island Press, Washington D.C.

25 This is based on trends in 3,066 populations of 757 freshwater mammal, bird, reptile, amphibian and fish species as recorded in the *Living Planet Report: Species and Places, People and Places* (2014), by WWF International, Gland, Switzerland.

26 "Global patterns of freshwater species diversity, threat and endemism," (2014), by Ben Collen, Felix Whitton, Ellie E. Dyer, Jonathan E. M. Baillie, Neil Cumberlidge, William R. T. Darwall, Caroline Pollock, Nadia I. Richman, Anne-Marie Soulsby and Monika Böhm. *Global Ecology and Biogeography* 23, 40–51.

27 'Habitat mapping and conservation analysis to identify critical streams for Arizona's native fish,' (2007), by Dale Turner and Michael List. *Aquatic Conservation: Marine Freshwater Ecosystems* 17: 737-748

28 "Tapped out," see note 19.

29 *Market Profile: Global trends in water spending* (2015), by Global Water Intelligence.

30 "Quantifying renewable groundwater stress with GRACE," (2015), by Alexandra S. Richey, Brian F. Thomas, Min-Hui Lo, John T. Reager, James S. Famiglietti, Katalyn Voss, Sean Swenson, and Matthew Rodell. *Water Resources Research* 51: 5217-5238.

31 "Nonsustainable groundwater..." see note 6.

32 See for example, "Improvements in crop water productivity increase water sustainability and food security—a global analysis" (2013), by Kate A. Brauman, Stefan Siebert, and Jonathan A. Foley. *Environmental Research Letters. Also, Water for Food, Water for Life: A Comprehensive Assessment of Water Management in Agriculture* (2007), by the International Water Management Institute, Sri Lanka, and Earthscan, London.

33 "Freshwater resources and their management," (2007), by Z.W. Kundzewicz, L.J. Mata, N.W. Arnell, P. Döll, P. Kabat, B. Jiménez, K.A. Miller, T. Oki, Z. Sen and I.A. Shiklomanov. In *Climate Change 2007: Impacts, Adaptation and Vulnerability.* Contribution of Working Group II to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change, M.L. Parry, O.F. Canziani, J.P. Palutikof, P.J. van der Linden and C.E. Hanson, Eds., Cambridge University Press, Cambridge, UK.

34 These cause-and-effect relationships are based on IPCC 2007 cited in note 33, as well as *Global Climate Change Impacts in the United States* (2009) by Thomas R. Karl, Jerry M. Melillo, and Thomas C. Peterson, (eds.). Cambridge University Press.

35 "The impact of global change on the hydropower potential of Europe: a model-based analysis," (2005) by B. Lehner, G. Czisch, and S. Vassolo. *Energy Policy* 33: 839–855.

36 "Climate Change and Water," (2008) by B.C. Bates, Z.W. Kundzewicz, S. Wu and J.P. Palutikof, Eds. *Technical Paper of the Intergovernmental Panel on Climate Change*, IPCC Secretariat, Geneva.

37 http://today.agrilife.org/2012/03/21/updated-2011-texas-agricultural-drought-losses-total-7-62-billion/ accessed 1 July 2016.

38 "Climate change puts nuclear energy in hot water," (2007) by James Kanter. *The New York Times,* May 20, 2007.

39 "Climate Change and Water" see note 36.

40 "Saltwater intrusion into fresh groundwater supplies, southern Cape May County, New Jersey, 1890-1991," (1992) by P.J. Lacombe and G.B. Carleton. In *The Future Availability of Ground Water Resources: Proceedings of the National Symposium,* Raleigh, N.C., April 12-15, 1992, American Water Resources Association, Bethesda, Maryland.

41 "Climate Change and Water" see note 36.

42 http://data.giss.nasa.gov/gistemp/maps/, accessed 1 July 2016.

43 *Dams and Development: A New Framework for Decision-Making,* (2000) by the World Commission on Dams, Earthscan, London.

44 *Market Profile: Global trends in water spending.* See note 29.

45 *Infrastructure to 2030: Telecom, Land Transport, Water and Electricity,* (2006) by the Organization for Economic Co-operation and Development.

46 *Infrastructure Recovery and Assets Platform – a response to support infrastructure during the crisis,* (2009) by the World Bank, Washington, D.C.

47 *Investing in Water Infrastructure: Capital, Operations and Maintenance,* (2012) by Diego J. Rodriguez, Caroline van den Berg, and Amanda McMahon. The World Bank, Washington, D.C.

48 *Buried No Longer: Confronting America's Water Infrastructure Challenge,* by the American Water Works Association.

49 *Water Rates: Water Affordability,* by the Pacific Institute, California.

50 "Price of water 2015: Up 6 percent in 30 major U.S. cities, 41 percent rise since 2010," by Brett Walton, *Circle of Blue,* April 22, 2015.

51 *The Invisible Crisis: Water Unaffordability in the United States,* (2016) by Patricia A. Jones and Amber Moulton, Unitarian Universalist Service Committee.

52 *Infrastructure to 2030.* See note 45.

53 *The Global Risks Report 2016.* See note 17.

54 See for example "Tapped Out" (note 19) and *Charting Our Water Future: Economic Frameworks to Inform Decision-Making,"* (2009) by the 2030 Water Resources Group.

55 "Tapped out." see note 19.

56 *Water for Texas 2012: State Water Plan – Appendix A.2: Recommended Water Management Strategies and Cost Estimates, Regions A-O* (2012), by the Texas Water Development Board, Austin, Texas.

57 *Water Supply Resource Plan* (2010) by the Lower Colorado River Authority (LCRA), Austin, Texas.

58 *Where Will We Get the Water? Assessing Southern California's Future Water Strategies* (2008) by the Los Angeles County Economic Development Corporation.

59 *Charting Our Water Future.* See note 54.

60 Negative values represent net cost savings

61 "Decomposing US water withdrawal since the 1950s," by Peter Debaere and Amanda Kurzendoerfer, *Journal of the Association of Environmental and Resource Economists,* in press.

62 *Estimated Use of Water in the United States in 2010* (2014) by the U.S. Geological Survey, Circular 1405, Reston, Virginia.

63 *Infrastructure to 2030.* See note 45.

64 "Linking groundwater use and stress to specific crops using the groundwater footprint in the Central Valley and High Plains aquifer systems, U.S." (2014) by Laurent Esnault, Tom Gleeson, Yoshihide Wada, Jens Heinke, Dieter Gerten, Elizabeth Flanary, Marc F.P. Bierkens, and Ludovicus P.H. van Beek. *Water Resources Research* 50: 4953–4973.

65 The need for very strong governance to enable high-functioning water markets is explicitly recognized here. This includes the need for formal legislation and supportive political leadership; legally-defined water rights registries supported by diligent and accurate water measurement and accounting, monitoring, and enforcement of rights; detailed hydrologic measurement and modeling; full consideration of the vulnerabilities of underserved and poorer communities, ecosystem water needs, and the direct and indirect impacts of trading water out of communities or sectors; and numerous other administrative rules and considerations.

66 "Tapped out." See note 19.

67 This is not always the case, however. Land ownership in many geographies implies ownership of underlying groundwater resources, and perhaps entitlement to surface water flowing over or adjacent to the private property. But even in these cases, such private use of water is commonly restricted under law from impacting the use of the same water resource by others.

68 *Chasing Water: A Guide for Moving from Scarcity to Sustainability (2014)* by Brian Richter. Island Press, Washington, D.C.

69 *Chasing Water* (note 68)

70 *Rivers for Life.* See note 24.

71 *Water – A Key to Sustainable Development: Recommendations for Action* (2001). International Conference on Freshwater, Bonn, Germany, December 3-7, 2001.

72 See for example: *Tapping Water Markets* (2012) by T. Anderson, B. Scarborough, and L. Watson, Resources for the Future, New York; "Water markets and trading," (2006) by H. Chong and D. Sunding, *Annual Review of Environmental Resources* 31: 239–264; "The evolution of water markets in Chile," (2012) by Guillermo Donoso, In *Water Trading and Global Water Scarcity;* "An integrated assessment of water markets: a cross-country comparison," (2011) by R.Q. Grafton, C. Landry, G.D. Libecap, S. McGlennon, and R. O'Brien, *Review of Environmental Economics and Policy* 5: 219–239; and "Water markets as a response to scarcity" (2014) by Peter Debaere, B.D. Richter, K.F. Davis, M.S. Duvall, J.A. Gephart, C.E. O'Bannon, C. Pelnik, E.M. Powell, and T.W. Smith. *Water Policy* 16: 625-649.

73 "*Securing our Water Future*" (2010), by the Commonwealth of Australia.

74 *Conservation Finance: Moving beyond donor funding toward an investor-driven approach,* (2014) by Credit Suisse, WWF and McKinsey and Company.

75 *Giving USA 2016: The Annual Report on Philanthropy for the Year 2015* (2016), a publication of Giving USA Foundation.

76 See for example "Increasing productivity in irrigated agriculture: Agronomic constraints and hydrological realities," by Chris Perry, Pasquale Steduto, Richard G. Allen, and Charles M. Burt (2009). *Agricultural Water Management* 96: 1517–1524.

77 See for example "Opportunities for saving and reallocating agricultural water," by Brian Richter and seven other authors. In review, *Water Policy*

78 Note that these percentages would need to be custom-tailored in each Water Sharing Investment Partnership as necessary to provide adequate incentives for farmers, modest returns to investors and important ecosystem benefits. Percentages suggested here are for illustrative purposes only.

79 This concept remains largely "aspirational" for many reasons, not the least of which are the absence of adequate governance (enabling) conditions in most countries and severe impediments to water trading, which are discussed in greater detail later in this report.

80 See for example *Unbundling Water Rights: A Blueprint for Development of Robust Water Allocation Systems in the Western United States* (2015), by Michael Young. Nicholas Institute, Duke University.

81 Based on market prices as of July 15, 2016. All conversions from AUD to USD also as of July 15, 2016.

82 As of the date on which the Fund was launched in 2015, past performance of the fund is no indication of future performance. All information about the Murray-Darling Basin Balanced Water Fund set forth herein is provided for discussion purposes and not as an offering of any investment. The information provided herein may not be accurate and complete and definitive information about the fund should be obtained from Kilter Rural.

83 See for example publications by Alliance for Water Efficiency, Pacific Institute, International Water Association, American Water Works Association, and other organizations.

84 *Water for Food, Water for Life.* See note 32.

85 See for example *Better Access, Healthier Environment, Prosperous Communities: Recommended Reforms for the California Water Market* (2016) by the Environmental Defense Fund; and Unbundling Water Rights, note 80.

86 Based on recent average for gross value of irrigated agriculture, assuming that 44 percent of this irrigation was enabled by water trading.

87 See for example *Drought Preparedness and Response* (2011) by the American Water Works Association, and *Considerations for Drought Planning in a Changing World* (2014) by the Alliance for Water Efficiency.

88 "Tapped Out." See note 19.

89 *Unbundling Water Rights.* See note 80.

90 "A 1,200-year perspective of 21st century drought in southwestern North America," (2010) by Connie Woodhouse, David Meko, Glen MacDonald, Dave Stahle, and Edward Cook, *Proceedings of the National Academy of Sciences* (PNAS) 107: 21283-21288.

91 The IID rights total to 3.1 million acre-feet, or 70 percent of California's entitlement of 4.4 million acre-feet from the Colorado River.

92 *Hazard's Toll: The Costs of Inaction at the Salton Sea, (2014)* by Michael Cohen. Pacific Institute, California.

93 *Quantification Settlement Agreement Implementation Report 2010-2013,* Imperial Irrigation District, California.

94 *2012 Census of Agriculture, County Profile, Imperial County, California.* U.S. Dept. of Agriculture. Note: 2012 is the most recent year for which agricultural census data are available. Much of the growth in crop revenues is likely attributable to increases in crop commodity prices during this period.

95 This represents only the firm amount that LCRA is required to provide; during wetter years, the agency is required to release additional water.

96 *Lakes Buchanan and Travis Water Management Plan and Drought Contingency Plans,* (2015) by the Lower Colorado River Authority, Austin, Texas.

97 Based upon a comparison of crop revenue data for Colorado and Wharton Counties, from *USDA Census of Agriculture for 2007 and 2012.*

98 *Habitat Conservation Plan Biological Monitoring Program: Comal Springs/River Aquatic Ecosystem, Annual Report 2015,* prepared by Bio-West Inc. for the Edwards Aquifer Authority.

99 See note 98.

100 See note 98.

101 *Australian Water Markets Report 2012-2013,* National Water Commission, Australian Government.

102 Average of 2005-2008 data from Australian Bureau of Statistics, Gross Value of Irrigated Agricultural Production.

103 *Sustainable Rivers Audit: A Report on the Ecological Health of Rivers in the Murray-Darling Basin, 2004-2007* (2008) by the Murray-Darling Basin Commission, Canberra, Australia.

104 The targeted reduction in irrigation use averaged over the entire basin is approximately 20 percent.

105 See for example the 2014-15 report at http://www.environment.gov.au/node/40837, accessed 1 July 2016.

106 Much of this economic summary is based on *The Economic Impact of Water Reductions During the Millennium Drought in the Murray-Darling Basin* (2012) by Mac Kirby, Jeff Connor, Rosalind Bark, Ejaz Qureshi, and Scott Keyworth, paper presented at the 56th Australian Agricultural and Resource Economics Society's annual conference, Fremantle, Western Australia, February 7-10, 2012.

107 *Impacts of Water Trading in the Southern Murray-Darling Basin between 2006-07 and 2010-11* (2012) by the National Water Commission, Canberra, Australia.

108 "Water Depletion." See note 5.

109 "Water markets as a response to scarcity." See note 72.

If all regions with defined water rights functioned in a similar manner to the Australian market, the markets could collectively generate total annual water sales of USD$13.4 billion per year, equating to market assets of USD$331 billion

Onlookers watch the Colorado River pulse flow, Mexico. © Nick Hall

It is time to **unleash the potential** of water markets

www.nature.org/watershare

The Nature Conservancy
Protecting nature. Preserving life.

The Nature Conservancy

4245 North Fairfax Drive, Suite 100
Arlington, VA 22203-1606

Phone: 703-841-5300
Website: www.nature.org

Front cover: Central Arizona Project near Phoenix, Arizona, United States. © Peter McBride

Back cover: Colorado River, Mexico. © Nick Hall