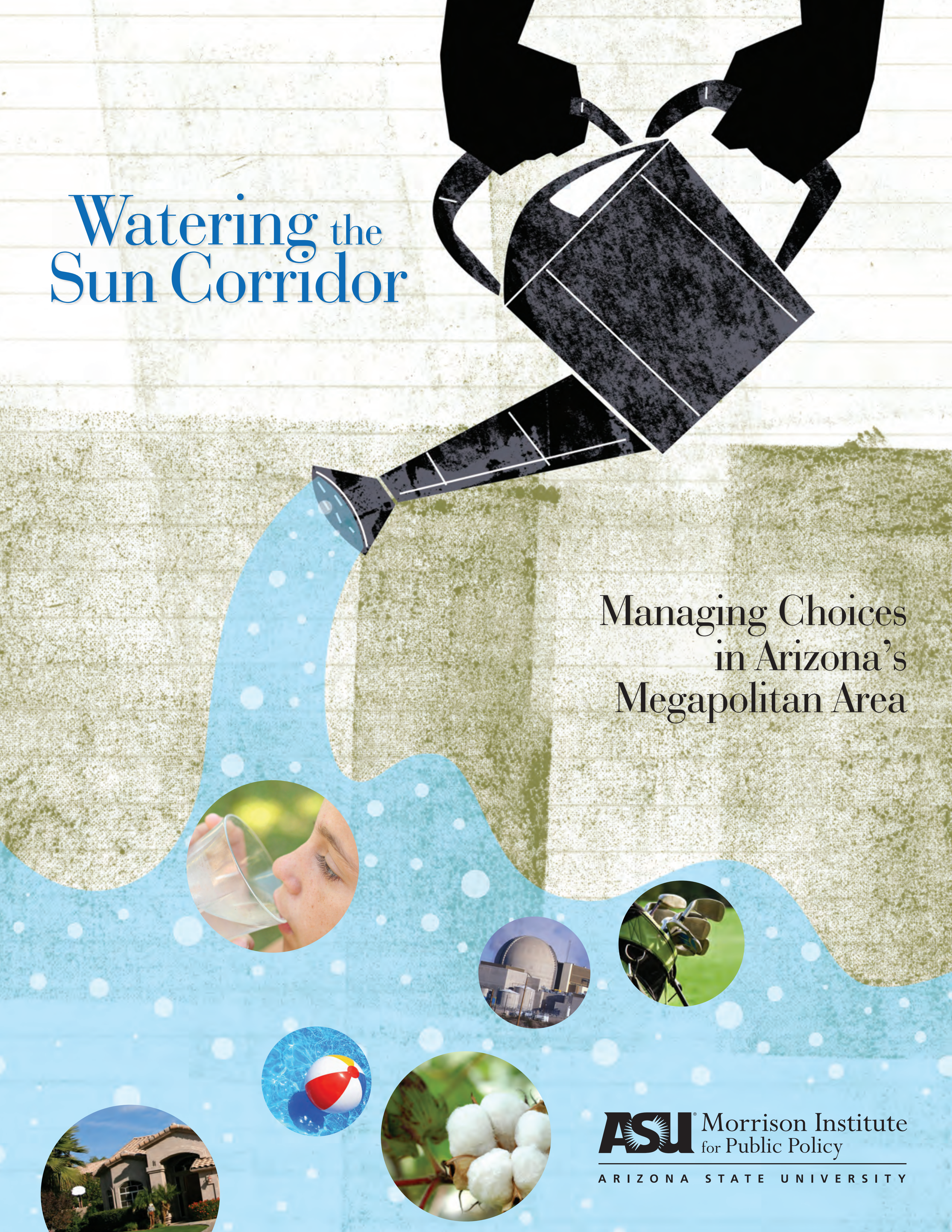
Watering the Sun Corridor

Managing Choices in Arizona's Megapolitan Area



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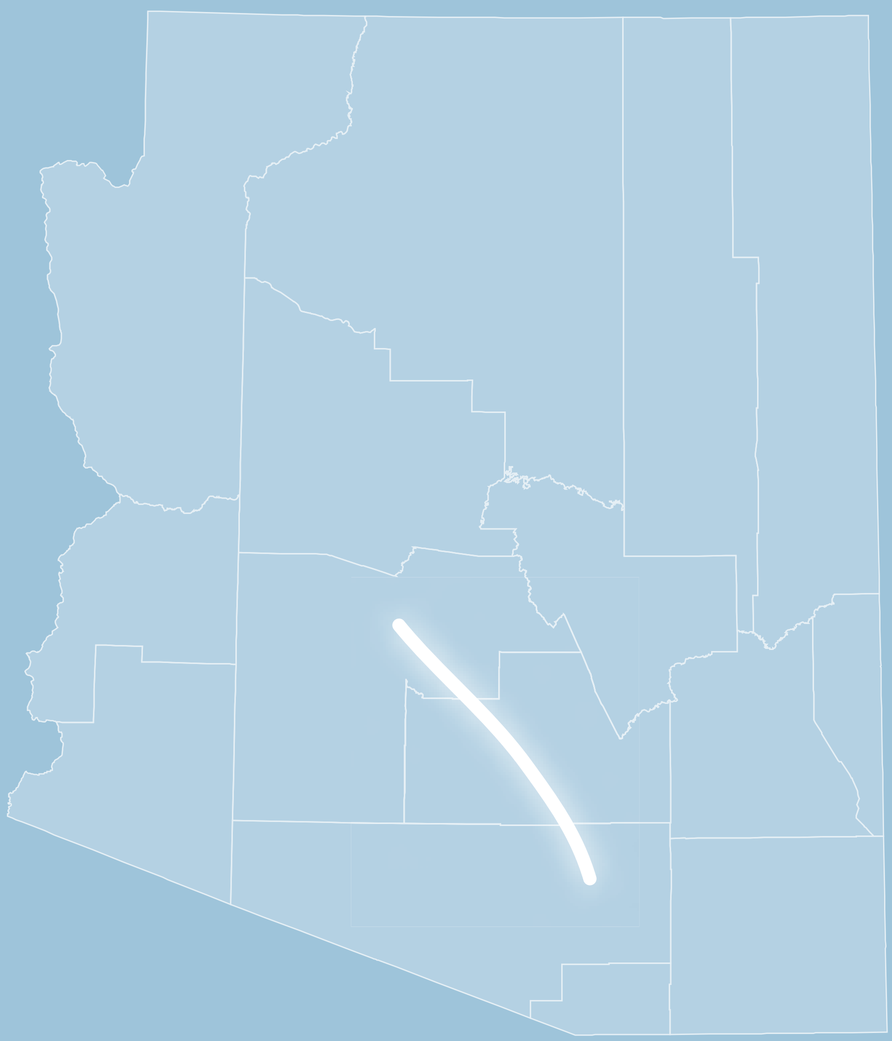

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August 2011

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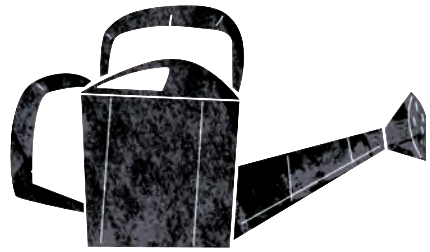
Watering the Sun Corridor



Introduction

Running out of water must be among the oldest of human fears. Today, this ancient dread still lingers in the rich green croplands and sprawling new housing developments of the American Southwest. Life is good in these warm, sunny, roomy places. But life there also brings the reminder of relentless and inescapable challenge. The challenge of water. The fear of running dry.

Arizona's Sun Corridor—the Central Arizona Urban Region including Phoenix and Tucson—is one of these places. In the summer of 2010, residents read in *The Arizona Republic* that their region was among the most threatened in the U.S. from global warming.[1] A study for the Natural Resources Defense Council (NRDC) found the Sun Corridor at "extreme risk" because of a likely widening gap between precipitation and water demand.[2] A few months later *The New York Times* announced that "Water Use in the Southwest Heads for Day of Reckoning," highlighting the dropping water level of Lake Mead.[3] In October, the *Times* summarized a study by an organization called Ceres about the risk to municipal bonds of water and electric utilities.[4]

The view that large populations should not settle in places of little rainfall sounds reasonable, yet it is clearly at odds with the choices made by millions of migrants to the Southwest over the past hundred years. In response to their arrival, water in this region has been pumped, dammed, moved, hoarded, litigated, and fought over to the point that it has come to define the American West—"Beyond the Hundredth Meridian.[5]"

Some insist that Phoenix and Tucson should never have been built. Others assure us with equal certainty that there is plenty of water if managed carefully. Both, it seems, cannot be right.

"What about the water?" was one of the questions Morrison Institute for Public Policy asked in its 2008 study, *Megapolitan: Arizona's Sun Corridor*. That report looked at the potential growth of the Sun Corridor as Tucson and Phoenix merge into one continuous area for economic and demographic purposes.

The clearest conclusion of *Megapolitan* was that no "Sun Corridor-wide" thinking was taking place. Metro Phoenix and metro Tucson are consistently regarded as utterly separate places—separate statistically, culturally, politically, and economically. One significant goal of the report was to foster "Corridor wide" thinking about issues.

The challenge of water supply and use is the best place to start this kind of regional thinking. The three core counties of the Sun Corridor—Maricopa, Pinal, and Pima—are already bound together by the Central Arizona Project and the limitations of the Groundwater Management Act.

With its brief review of the water situation in urban Arizona, *Megapolitan* left a number of questions unanswered:

- Are population projections for the Sun Corridor still meaningful in light of the current economic downturn?
- How many people can be supported by the Sun Corridor's water supplies?
- What happens if the conventional assumptions about water availability prove inaccurate?
- How should the impact of climate change be assessed?
- How would lifestyles have to change by dramatically decreased water use?
- Does more efficient water reuse stretch existing supply?
- What water supplies are available for the future?

This report will consider questions like these in more detail in order to examine the Sun Corridor's water future. This topic has received less sophisticated public discussion than might be expected in a desert state. Arizona's professional water managers feel they are relatively well prepared for the future and would like to be left alone to do their job. Elected officials and economic-development professionals have sometimes avoided discussing water for fear of reinforcing a negative view of Arizona. Public campaigns about water conservation—by brushing our teeth differently or shutting off public fountains—leave many residents worried that Arizona faces an immediate shortage.

The result of these different viewpoints has often left the public confused: Is there a current crisis or not? Why do we keep encouraging growth if there is no water? For the most part, as long as water comes out of the tap, there is not a widespread discussion of where our water supply comes from, how much there is, how it is used, and what will happen in the future. *Watering the Sun Corridor* seeks to contribute to this understanding, and to a more open and informed conversation about the relationship of water and future growth.

I

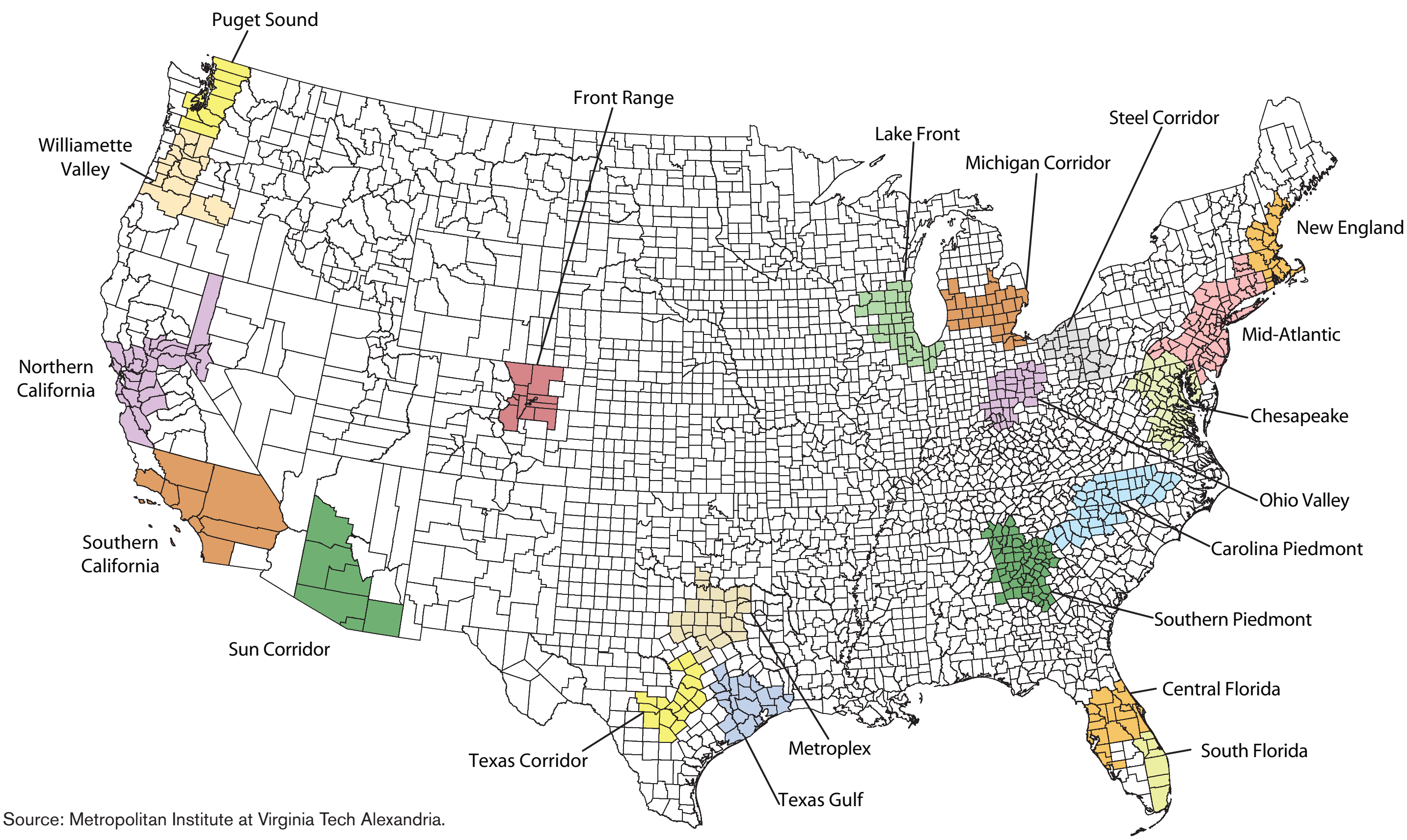
The Sun Corridor

Megapolitan Redux

For generations, Arizonans have talked about the potential merger of Phoenix and Tucson into a single urban area. The expectation was that the two would blend together seamlessly, much the way Phoenix and Mesa did, or like the continuous metropolis now lining the nation's East Coast. This has not happened. It probably will never happen, due to some of the realities Western cities face, such as the Indian reservations and public lands that lie between Phoenix and Tucson.

More recently, researchers have concluded that an actual physical merger may not be as significant as an economic one. The real question, they say, is what constitutes a single functioning economy. It was in this context that scholars at the Metropolitan Institute at Virginia Tech took up the "more than metro" banner while trying to determine where the next hundred million U.S. residents might live. Their conclusion was that most growth would be in 20 "megapolitan" areas that together would account for roughly 60% of the U.S. population living in 10% of its land area. Virginia Tech's megas reflect areas that by 2040 are expected to have the U.S. Census Bureau's "combined statistical area" designation. The main criterion for this category is economic interdependence among two or more metropolitan areas as shown by overlapping commuting patterns. The working definition is when two or more adjacent metropolitan counties have an "employment interchange measure" of at least 15%. Electronic commuting is obviously becoming more prevalent by the day. But urban areas are necessarily defined by geographic proximity, so the "employment interchange factor" of overlapping commuting is the best current thinking on a reasonable means of defining the limits of a "megapolitan area."

A MEGAPOLITAN NATION IS TAKING SHAPE



Source: Metropolitan Institute at Virginia Tech Alexandria.

In its 2008 report, *Megapolitan: Arizona's Sun Corridor*, Morrison Institute applied this methodology to the Phoenix-Tucson area and concluded that by 2030 the Sun Corridor would include five Arizona counties: Yavapai, Maricopa, Pinal, Pima and Santa Cruz.

By 2030, the report projected nearly 8 million people living in a 32,000 square-mile region, an 82% increase over the 2000 population.

The report's principal purpose was to provoke more regional thinking about the future of urban Arizona. For too long, Phoenix and Tucson have competed with each other, not realizing that their real competitors are other urban areas in the U.S. and the world. By beginning to cooperate in analyzing demographic and economic trends, Tucson and Phoenix may be able to set aside this historic rivalry and begin to think about their shared identity in an increasingly global economy.[6]

Megapolitan identified two critical issues related to the environmental sustainability of the Sun Corridor: water resources and the tradeoff between population growth and quality of life. Both of these concerns focus on resource limitations, an issue that animates much of the current discussion about sustainability and the future of the planet.[7] Without massive human intervention to move water and air-condition buildings, Arizona's urban growth would have stopped far short of its current size.

MEGA PLACES ARE FOUND ACROSS THE U.S. FROM EAST TO WEST AND NORTH TO SOUTH

Regions and Areas	Anchor Metros	2005 Population	Square Miles	2000 Population	Projected 2030 Population	Projected Increase	% Change
Northeast		**51,601,118**	**62,612**	**49,948,064**	**62,427,070**	**12,479,006**	**25.0**
New England	Boston/Providence	8,276,116	12,320	8,133,219	9,873,668	1,740,449	21.4
Mid-Atlantic	New York/Philadelphia	33,527,905	31,027	32,656,309	39,072,196	6,415,887 1	9.6
Chesapeake	Washington/Baltimore/Richmond	9,797,097	19,265	9,158,536	13,481,206	4,322,670	47.2
Great Lakes		**34,267,189**	**68,992**	**33,641,220**	**39,536,775**	**5,895,555**	**17.5**
Steel Corridor	Cleveland/Pittsburgh	7,067,896	16,320	7,140,287	7,434,689	294,402	4.1
Ohio Valley	Cincinnati/Columbus	5,344,052	15,256	5,198,100	6,374,776	1,176,676	22.6
Michigan	Corridor Detroit	8,969,861	19,313	8,835,742	10,070,142	1,234,400	14.0
Lakefront	Chicago/Milwaukee	12,885,380	18,103	12,467,091	15,657,168	3,190,077	25.6
Piedmont		**13,953,787**	**47,226**	**12,633,926**	**19,096,474**	**6,462,548**	**51.2**
Carolina Piedmont	Charlotte/Raleigh	7,012,769	26,175	6,460,338	9,431,809	2,971,471	46.0
Southern Piedmont	Atlanta	6,941,018	21,051	6,173,588	9,664,665	3,491,077	56.5
Florida		**13,823,188**	**26,189**	**12,474,423**	**20,312,554**	**7,838,131**	**62.8**
Central Florida	Tampa/Orlando	7,851,525	18,126	6,975,772	11,352,506	4,376,734	62.7
South Florida	Miami	5,971,663	8,063	5,498,651	8,960,048	3,461,397	62.9
Texas Triangle		**18,187,772**	**70,842**	**16,525,203**	**25,598,697**	**9,073,494**	**54.9**
Texas Gulf	Houston	6,247,170	20,801	5,699,704	8,535,961	2,836,257	49.8
Texas Corridor	San Antonio/Austin	3,965,018	16,690	3,573,621	5,870,470	2,296,849	64.3
Metroplex	Dallas-Fort Worth/Oklahoma City	7,975,584	33,351	7,251,878	11,192,266	3,940,388	54.3
Front Range	**Denver**	**3,880,126**	**20,880**	**3,582,688**	**5,594,523**	**2,011,835**	**56.2**
Sun Corridor	**Phoenix/Tucson**	**4,988,564**	**31,906**	**4,295,516**	**7,839,873**	**3,544,357**	**82.5**
Cascadia		**7,350,438**	**35,746**	**6,901,160**	**9,927,217**	**3,026,057**	**43.8**
Puget Sound	Seattle	4,106,956	14,628	3,892,016	5,556,154	1,664,138	42.8
Willamette Valley	Portland	3,243,482	21,118	3,009,144	4,371,063	1,361,919	45.3
Northern California	**Bay Area/Sacramento**	**11,288,313**	**24,644**	**10,788,599**	**15,057,719**	**4,269,120**	**39.6**
Southern California	**Los Angeles/San Diego**	**21,720,656**	**49,301**	**20,326,831**	**27,796,900**	**7,470,069**	**36.7**
Megapolitan Total		**181,061,151**	**438,338**	**171,117,630**	**233,187,802**	**62,070,172**	**36.3**
U.S. Total (lower 48 states)		**296,410,404**	**3,007,400**	**282,193,477**	**378,302,736**	**96,109,259**	**34.1**

Megaregions are shown in bold. Anchor Metros rank in the top 50 U.S. Metropolitan Areas.

Source: Metropolitan Institute at Virginia Tech, U.S. Bureau of the Census, ESRI and Woods & Poole Economics, Inc. Morrison Institute for Public Policy, ASU.

What Happened to the Growth?

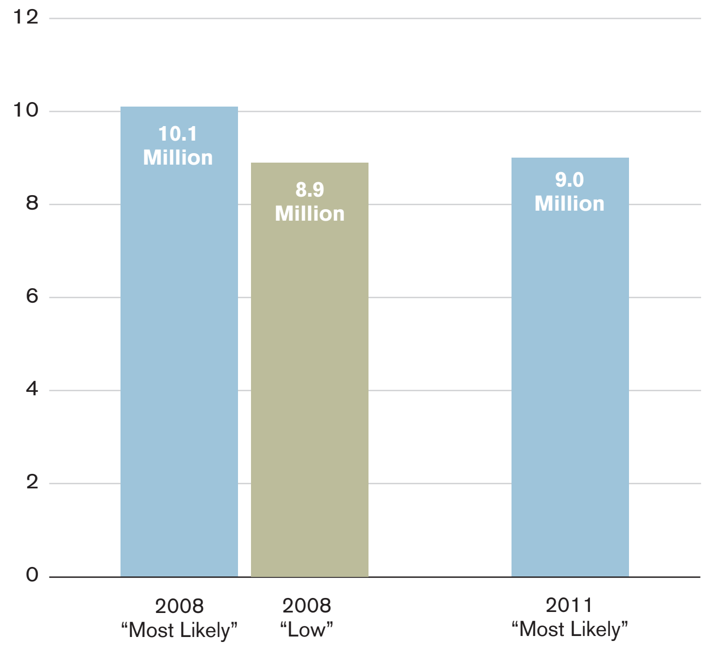
The 2008 Sun Corridor report was written as the scope of the national economic collapse was emerging. But population projections for Arizona and the Sun Corridor were based on "boom time" numbers, still reflecting the assumption that the state's growth would always outstrip even optimistic projections. Then the magnitude of the economic bust became clear. From 2005 to 2010, the prices of homes in Metro Phoenix, for example, fell by almost 50%[8]. Arizona as a state went from creating 121,000 jobs between October 2005 and October 2006 to losing 183,000 jobs in 2009[9]. The Sun Corridor's traditionally homebuilding-based economy saw housing construction plummet.

In light of the realities of the 2008 economic collapse, Morrison Institute commissioned Marshall Vest, director of the Economic and Business Research Center at the University of Arizona's Eller College of Management, to revisit the population projections. This is a tricky task. The 2010 census numbers had not been released when Vest did his projections. Even in normal economic times, Arizona's population is unsettled, dynamic, and transient. It is clear, however, that population growth has dramatically slowed. But whether the trend line has changed slope, or just suffered a blip, is not entirely clear.

Vest's 2008 projections for Maricopa, Pima, and Pinal counties called for 10.1 million residents in 2040 as the "most likely" population projection. The "low" scenario was 8.9 million. The new projection is for a "most likely" 9.0 million—virtually identical to the old "low" number. Vest concludes that overall population growth will ultimately return to the Sun Corridor at about a 2% annual rate from 2015 to 2040. Net migration—people moving into the Sun Corridor minus those moving out—will return to an "average" of 80,000 per year by 2015. In March 2011, census data was released showing that from 2000 to 2010 Arizona's population grew by 25%, but housing supply increased by 30%. Housing stats have tended to be viewed as a proxy for population growth, leading in this decade to an overestimate. Phoenix, which had touted itself as the fifth largest city in the country, fell back below Philadelphia when the numbers were counted.

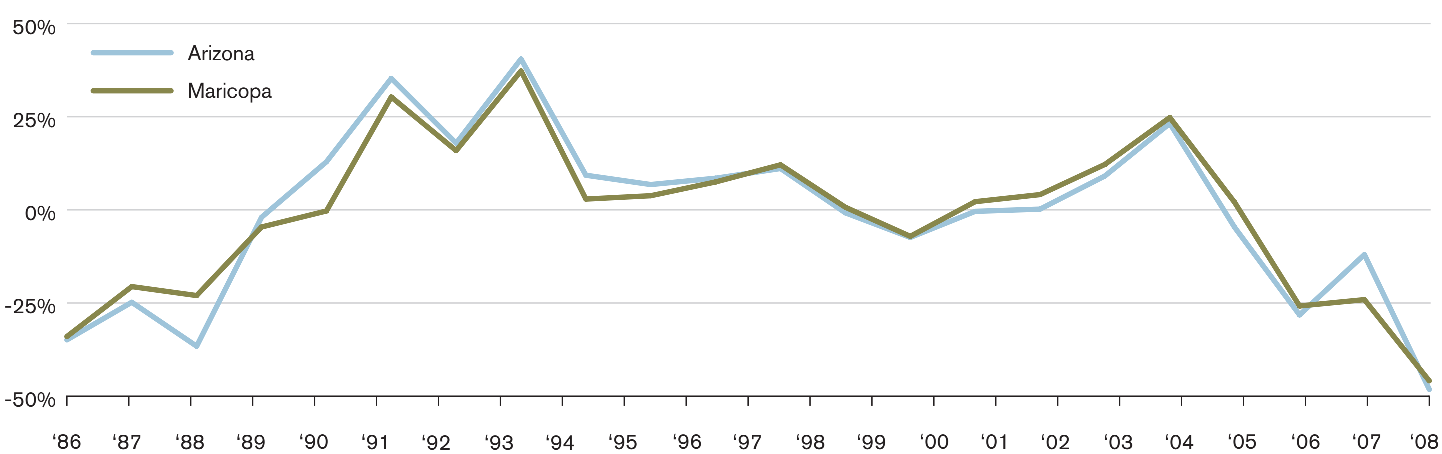
Despite the slowdown, the projection of a 9 million person Sun Corridor by 2040 remains the most likely possibility.

9 MILLION PERSON SUN CORRIDOR BY 2040 REMAINS MOST LIKELY POPULATION PROJECTION



Source: Morrison Institute for Public Policy, ASU.

HOUSING UNITS AUTHORIZED, PERCENT CHANGE FROM PRIOR YEAR



Source: Arizona Indicators, 2009, Morrison Institute for Public Policy, ASU.

Challenges of Geography and Time Frame

Like Vest's population projections, this report will focus on the three big counties at the heart of urban Arizona: Maricopa, Pima, and Pinal. The original Sun Corridor report included Santa Cruz and Yavapai, and both of those counties are likely to fit the megapolitan's employment-interchange factor in the near future. However, given the current growth of central Arizona, its three principal counties pose the biggest challenge. Maricopa, Pima and Pinal are also the counties with the best relevant statistical data and with locations in the Central Arizona Project service area. Indeed, the CAP is the closest thing there is to a Sun Corridor-wide institution. *In this report, the term "Sun Corridor" will generally refer to the more focused three-county area*.

Is there enough water for the Sun Corridor to continue to grow? To answer that question, we will focus primarily on the three counties as a single unit. Questions of allocation of water within the Corridor among competing areas and uses are obviously of huge importance in shaping urban Arizona.

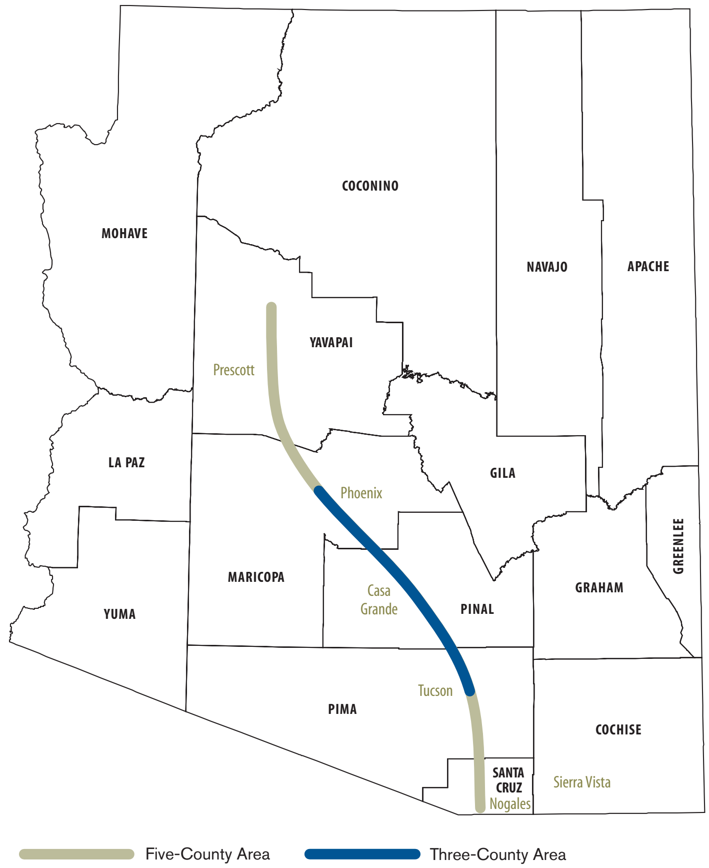
Knowledgeable "Water Buffaloes" (as they often call themselves) are likely to find this report's overview simplistic, as it avoids the complexity of issues in different parts of the Corridor. They will also argue that it ignores legal constraints that prevent all water from being equal. These are valid concerns—some water is usable only in certain locations, or only for certain purposes, or only by a particular party or only after decades of negotiation.

The clearest example is the Salt River Project (SRP). SRP, one of the two big suppliers of water to the region, is legally limited to delivering to an area referred to as "on project," which covers only a portion of the Phoenix Metro area, and therefore only a fraction of the Sun Corridor. Limiting the size of SRP's irrigable area was a deliberate step taken in the early twentieth century to assure adequate water supplies. Due to these early efforts, and consistent defense of the limits, this area has the most robust water supplies in all of Arizona.

By aggregating all of the water supplies together and viewing the three-county "Corridor" as a whole, this report significantly understates the intra-region challenges which will arise. Will people move to living at higher densities in the water-rich areas? Will water supplies migrate to less water-rich areas? Will tension arise between have and have-nots? How will long-distance infrastructure systems be financed? These internal equities will be sorted out over coming decades.

The appropriate time frame for analysis is another major consideration. Most analysis of the Sun Corridor's water situation has tended to look out to about 2030. Up to that point, known supplies seem generally adequate to most observers. Beyond that point, population projections are extremely speculative, as are assumptions about lifestyle, commuting patterns, industrial and economic development, climate change, and virtually any other variable.

ARIZONA'S MEGAPOLITAN: THE SUN CORRIDOR



Source: Morrison Institute for Public Policy, ASU.

Many urban areas—perhaps most in the arid West—do not even look as far as 2030 in planning water supply. Urban Arizona has been able to feel responsible, maybe even proud, for its willingness to plan decades into the future.

Today it is important to look beyond 2030, despite how difficult projections become. The stress from climate change alone probably makes that horizon insufficient. Between now and 2030 every assumption will likely be challenged and changed—including the classic formulation of "predict and plan" that underlies water management. We now need to derive multiple scenarios, not just a "most likely" alternative, and will need to constantly adapt to new conditions.

10 Things Residents of the Sun Corridor Should Understand About Water

Recent national media reports echo a number of popular misconceptions about Arizona's water and water future. In brief, here are 10 things every Sun Corridor resident should understand:

1. Rainfall in the Sun Corridor has little to do with water supply. Water is brought to this desert from the mountains, where it rains and snows a lot more. Rainfall does directly impact demand for water use for landscaping.

2. The renewable water supplies to the Sun Corridor provide "on average" 2.5-3 million acre feet (an acre foot is 325,851 gallons) of water which could theoretically support a population of 8-10 million people. But "average" in the context of water supply does not mean "reliable." Water supply in an arid region is highly variable, which is why water management has been so important.

3. The Sun Corridor's plumbing systems include reservoirs in Arizona, bigger reservoirs on the Colorado River and groundwater banking. Together, these can typically store 4 to 5 years' worth of urban Arizona's water demands.

4. Climate change will probably increase variability of supply, and may reduce the "average" number by as much as 15%. One bright spot is that our watering systems are designed to handle high variability.

5. More than half of Sun Corridor water is still used to grow crops. Agricultural use has provided a buffer during droughts, when water for farming can be cut back to protect urban use.

6. Groundwater is subject to far more regulation in urban Arizona than in most states. We have purposefully put significant amounts of water back underground for the last decade. Even so, the long-term goal of "safe yield" is a challenge to achieve and sustain.

7. Per capita use of water has been declining since the 1980s. The Phoenix area uses much more water for landscaping than Tucson. This reflects historical and climate differences in the two cities. But both urban areas have been consistently reducing consumption.

8. Reuse of urban water will be an important means of stretching water supplies in the future. Cities in the metro Phoenix area are among world leaders in reusing effluent, both for landscaping and for cooling water at the Palo Verde Generating Station.

9. 2.4 million acre feet of average annual water supply appears to be a reasonable estimate for planning. At the current rates of consumption, 2.4 million acre feet of annual water could support about 9.5 million residents in the Sun Corridor. That level includes no commercial agriculture.

10. The Sun Corridor won't run out of water, but it faces serious challenges about how to strike the right balance between population growth and lifestyle.

II

Sources of Water for the Sun Corridor

Three Concepts: Supply, Stationarity, and Variability

SUPPLY. There are almost as many ways of defining water supply as there are reports written on the subject. Sometimes it is thought of as being the amount of rain that falls within a geographic area. By this measure, the Sun Corridor long ago outgrew its "water supply." Some places treat lakes as water supply. If you are sitting on the shore of Lake Michigan, the availability of that vast body of fresh water would seem to resolve any questions about water for Chicago's future. In Arizona, major lakes are really reservoirs, man-made impoundments of water. They are not limitless, or natural, and are designed to go up and down. In this sense they are not really "supply," but rather a management device to store water in times of plenty for use in times of need.

Groundwater presents another conundrum. Groundwater is pumped from below the earth's surface, having percolated there over millennia. Most of urban Arizona has existed in a state of overdraft—using groundwater in excess of the amount naturally recharged every year.

Some reports consider effluent reuse a potential water supply (generally, a significantly unused water supply) for future needs. But effluent does not represent new water; rather, its use is a management technique to make existing water supplies go further. Similarly, conservation does not represent a new water supply, but rather a form of "demand" management to stretch available water.

In this report, we will define the Sun Corridor's water supply as physical water inputs. These include rain, surface water that can be transported and made available, and the amount of pumped groundwater that is naturally replaced every year. Everything else—lakes, effluent, artificial groundwater recharge, conservation—will be treated as management techniques.

STATIONARITY AND VARIABILITY. Water managers have long operated under an assumption of "stationarity." This means that natural systems operate within a fixed range. Based on historical data about rainfall, river flows, temperature and so on, reasonable predictions about system behavior can be made. The stationarity principle includes such concepts as the 50- or 100-year flood event and the "standard record drought." Based on stationarity, flood control systems have been designed, water rights allocated and reservoirs built. The notion that the past helps to predict and plan for the future is deeply embedded in water management culture and technology.

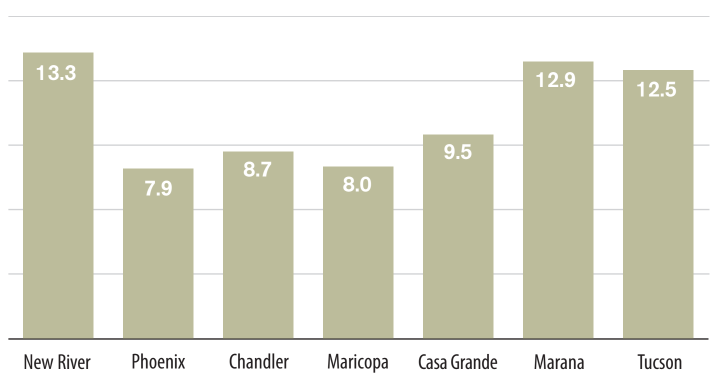
In the arid climate of central Arizona, stationarity includes a very high degree of variability. Sometimes rivers are dry and sometimes they are at flood. This is the main difference between Arizona and many other, wetter, parts of the U.S. In places where it rains a lot more, the stationarity assumption has a much narrower range of variability. In Arizona, we are used to, and have built our systems upon, wild swings in conditions. But more recent thinking has challenged even that highly variable stationarity assumption. One obvious example is the potential "over allocation" of the Colorado River. When the cases, statutes, and compacts divided up the Colorado River among Western states in the 1920s and 1930s, it was assumed that on average the river would flow at about 17½ million acre feet[10] per year. But analysis of tree ring records now suggests that the 17½ million figure was inaccurate. The actual average annual flow of the Colorado may be only 12-15 million acre feet or less.[11]

The Water Sources

Rain

It does not rain much in the Sun Corridor. The average annual rainfall at several points throughout the Corridor is shown in the chart below.

AVERAGE ANNUAL RAINFALL IN INCHES



Source: Federal Research Division, Library of Congress, Country Studies-Arizona Weather.

Throughout the Sun Corridor, the average is probably about 8-9 inches per year. Analysts looking at the sustainability of places like the Sun Corridor tend to focus on the balance between rainfall and water use within a geographic area. This is the formulation used in the 2010 Tetra Tech report *Climate Change, Water, and Risk: Current*

Water Demands are Not Sustainable, commissioned by the Natural Resources Defense Council (NRDC). That report looks at each county in the United States and analyzes how much water is used in that county compared to how much rain falls in that county. The report then goes on to add some assumptions about the impact of climate change on the differential between "use" and "supply," defined as rainfall. By this metric, Maricopa County may be among the most challenged places in the United States from climate change. The reality is that Maricopa County's water use already far exceeds annual rainfall. Any urban area is by definition a concentration of people who draw upon a larger area of resources for support. Urban areas consume many commodities from a larger geographic base. In the arid West, this includes water.

In the Sun Corridor, like most large metro areas, the average annual rainfall has little to do with the actual water supply serving the area. Rainfall levels are more dramatically felt on the "demand" side of the equation: In times of drought we need more water delivered for landscape and irrigation. However, in this report we will ignore rainfall within the Corridor itself as a source of water supply. Rather, rainfall will be built into the calculus in two ways. First, to the extent that rainfall replenishes groundwater aquifers on an annual basis, we will consider the amount of natural groundwater recharge available to the watering systems. Second, some amount of annual rainfall is captured by the surface water flows that are managed within the Sun Corridor. We will therefore analyze water supply in terms of groundwater and surface water supplies and not add input for other rain sources.

The Salt and Verde Rivers

The Sun Corridor got its start as an urban area when the Hohokam began settling on the banks of the Salt River. The Salt, as it flows through Phoenix, has already merged with its principal tributaries, the Verde River and Tonto Creek. Well west of the Phoenix metropolitan area, it flows into the Gila River, which ultimately reaches the Colorado. The flow of the Salt River is highly variable. Its water comes from the mountains of central and eastern Arizona, a watershed of about 13,000 square miles. The watershed is fed by both rainwater and snowmelt. The highly variable runoff in the Salt River, Tonto Creek, and Verde River watershed is shown by the graph below for the period from 1913 through 2008. During that 100-year period, flows ranged from less than 300,000 acre feet to more than 4,200,000.

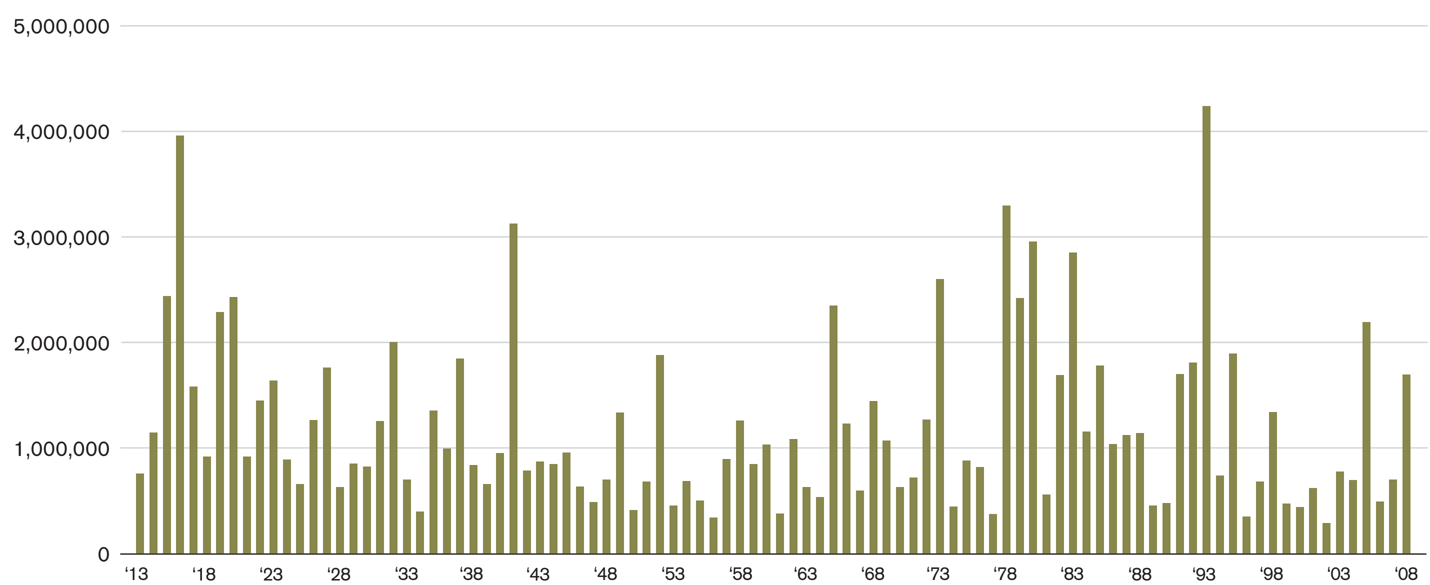
The average combined flow during this period was 1,199,000 acre feet. The highly variable nature of this flow may have been part of what ultimately doomed the Hohokam civilization. Building a society based on an average flow with this degree of variability is very risky without storage to "normalize" the flow.

Based on historical stationarity and variability assumptions, however, it seems reasonable to assume that the Salt and Verde system delivers on average approximately 800,000 acre feet each year to the Sun Corridor.

Other Surface Water

One of the least thought-about pieces of the Sun Corridor's water supply is the potential availability of other surface water sources.

SALT RIVER, TONTO CREEK, AND VERDE RIVER COMBINED ANNUAL INFLOW, IN ACRE FEET 1913-2008



Source: Salt River Project.

These resources, like all surface water flow in the desert Southwest, are extremely volatile. Variability goes beyond even that of the Salt River system because many of these sources are ephemeral washes, which often have no flow at all. This extreme variability means most of these sources would not be appropriate candidates for dams, reservoirs, or other intensive human management. Furthermore, many of these sources have environmental benefits in creating the part-time riparian environments so critical to the life of the Sonoran Desert. Many, if not all, of these flows also disappear into the ground, thereby recharging aquifers.

From a variety of sources, a conservative estimate of these other surface water supplies emerges:

- **PHOENIX ACTIVE MANAGEMENT AREA (AMA)** Within the Phoenix AMA, surface water not counted within the Salt and Verde system includes the Agua Fria River, New River, the Hassayampa River, Skunk Creek, Centennial Wash, Cave Creek, Queen Creek, and the Indian Bend Wash. These are estimated to produce around 50,000 acre feet in mean annual flow.[12]
- **TUCSON AMA** In the Tucson AMA, additional surface water resources include the Santa Cruz River, Sonoita, Tanque Verde, and Rincon Creeks, the Canada del Oro, Pintano, Sabino, Rillito, Aravaica, Brawley, and Altar Washes. These may total around 50,000 acre feet of mean annual flow.
- **PINAL AMA** The largest potential additional water supply to the Sun Corridor is the upper Gila River, before it joins with the Salt. The river is currently diverted at the Ashhurst-Hayden Dam. From 1930 to 1986, diversions averaged 230,000 acre feet per year. Kohlhoff and Roberts[13] indicate that as much as 110,000 acre feet of upper Gila River water exists that might theoretically be available for urban uses. Virtually all of this water is currently dedicated to agriculture in Graham and Greenlee counties. Pre-development flows on the Gila River into the Pinal AMA are estimated to have been as high as 500,000 acre feet per year.[14] This suggests that somewhere between 100,000-200,000 acre feet might be available for the Sun Corridor from the upper Gila, though using this water for urban growth would be very politically controversial.

In the aggregate, other surface water supplies available to the Sun Corridor are probably in the total range of 200,000-300,000 acre feet per year. For simplicity's sake, we will estimate these at 250,000 af/yr.

Groundwater

Groundwater use in the Sun Corridor began with the Spanish and Anglo-American settlements. Some of the earliest wells were drilled in Tucson. Water was abundant there when the U.S. Army established Fort Lowell in 1873. The area had a system of canals that brought water from the river, windmills that pumped groundwater from nearly 35 feet below, and storage tanks sufficient to supply water to all of the Fort's major buildings. Several additional wells were installed in the area by the early 1890s.[15] Significant groundwater use in the Sun Corridor did not occur until the widespread adoption of the turbine pump after the Second World War. There are now more than 50,000 wells in the Sun Corridor.[16]

The groundwater supplies in the Sun Corridor have been estimated by Arizona Department of Water Resources (ADWR) down to a depth of 1,000 feet at approximately 180 million acre feet.

Phoenix AMA	80 million acre feet
Pinal AMA	35 million acre feet
Tucson AMA	65 million acre feet
TOTAL	**180 million acre feet**

This estimate is not especially reliable, however, because the science of groundwater measurement is not particularly well understood. Fully "dewatering" aquifers causes severe negative consequences such as subsidence, fissuring, and degraded water quality. In the three-county Sun Corridor area, approximately 1.6 million acre feet (MAF) of groundwater were withdrawn for all purposes in 2006. At the 2006 rate of withdrawal, and based on the estimated 180 MAF of groundwater available, existing groundwater would be exhausted in about 112 years if no recharge took place. However, if we treat groundwater the same as surface water from a sustainability standpoint, the only safe level of groundwater withdrawal would be that equal to the annual natural and incidental recharge. DWR estimates this number for the three AMAs to be about 260,000 acre feet.[17]

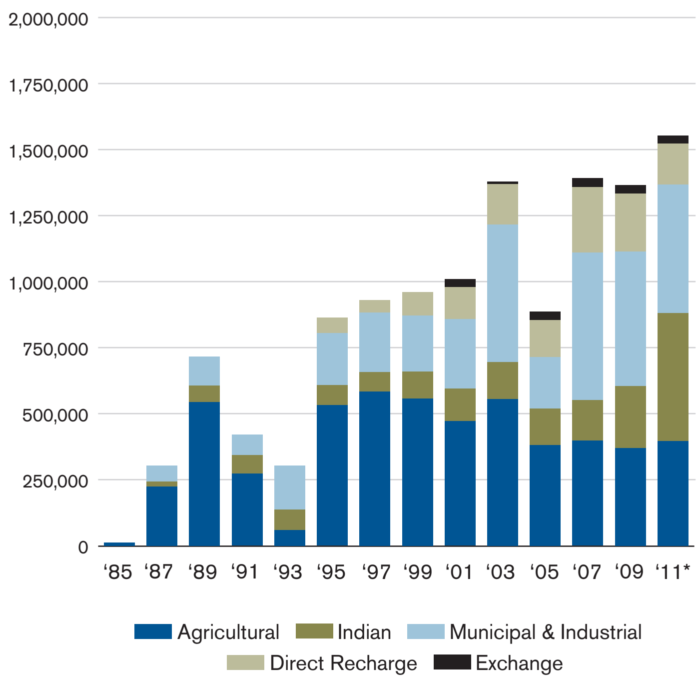
The Sun Corridor has thousands of miles of infrastructure serving commercial agriculture, such as this irrigation headgate in Marana.

Colorado River Water

The Colorado River does not flow anywhere near Arizona's Sun Corridor, yet it represents a relatively sustainable source of water for it. In fact, over 30 million people in seven Western states[18] and over 3 million acres of land—producing some 15% of the nation's crops and about 13% of its livestock—rely on Colorado River water. Fourteen million acre feet of Colorado River water is used in the United States and Mexico each year.

Bringing Colorado River water to the Sun Corridor was the dream of generations of Arizonans. It became reality when the Central Arizona Project canal started delivering water to central Arizona in 1985.[19] Through a long series of Congressional acts, interstate compacts and court decrees, Arizona has won the right to 2.8 million acre feet per year from the Colorado River. Of that total, uses along the river itself amount to about 1.2 million acre feet per year; the CAP receives the balance. The CAP canal was designed to move approximately 1.5 million acre feet to Maricopa, Pinal, and Pima counties. Actual deliveries since full operation of the canal began are shown in the chart below. Based on this relatively brief history, 1.5 million acre feet appears to be a reasonable assumption to use for Colorado River supplies, at least before delving further into CAP issues.

CAP DELIVERIES BY END USER IN VOLUME OF ACRE FEET, 1985-2011



* Forecasted.

Source: Central Arizona Project.

The Need for Better Numbers on the Colorado

One of the most critical pieces of research needed for planning Arizona's water future is an assessment of the probable long-term water supply from the Colorado River. The original assumption used to allocate the flow among the seven basin states and Mexico is universally acknowledged to have been unrealistic even when it was made, and the potential challenges of climate change may well throw the river even further into a condition of "over allocation."

A multi-state cooperative effort led by the U.S. Bureau of Reclamation is developing a comprehensive new study of Colorado River supply and demand. The Colorado River Basin Water Supply and Demand Study is designed to provide a long-term look at demand and supply among the seven basin states in the context of historic, observed and future conditions that could be associated with climate change.

Each of the basin states is working with the Bureau throughout 2011 to refine water supply and demand information. The study will develop scenarios for water availability based on hydrologic projections and the projected demands of other Colorado River users, including the amount of water likely to be available to central Arizona via the Central Arizona Project. The first interim report was released in June of 2011. The final report is expected by the end of 2012.[20]

This effort may result in the best estimates to date of what the water future of the Colorado basin states really looks like.

Arizona's participation in the Basin Supply and Demand study has been largely the result of an effort by a group of private funders working with ADWR. For information on the study, or to help fund its completion, contact ADWR at www.azwater.gov.

The conclusions of the completed study may well prompt Arizonans to revisit the question of water supply for the future of the Sun Corridor.

Summary of Existing Sun Corridor Supplies

Based on conventional stationarity (meaning with no adjustment for climate change) assumptions, the supplies of "sustainable" water available to the Sun Corridor can be summarized as follows:

Salt/Verde	800,000 Average Af/Yr
Other Surface Water	250,000 Average Af/Yr
Natural Groundwater Recharge	260,000 Average Af/Yr
Colorado River	1,500,000 Af/Yr
TOTAL	**2,810,000 Af/Yr**

This summary undoubtedly includes some overlap; much of the "other" surface water, for example, is likely currently viewed as "natural recharge." Another caveat: This number is a potentially misleading average produced by widely varying amounts of rain and runoff. The best historical data on variability is probably that from the SRP system, which has varied from 30% to 400% of average. The challenge of managing this variability is discussed in Section III.

Climate Change

The classic stationarity assumptions made about water supply in places like the Sun Corridor did not consider the potential effects of long-term climate change. A 2008 article in *Science* magazine declared "Stationarity is dead" because climate change may produce results well outside of historic ranges.[21] Stationarity may indeed be dead, or merely challenged; underlying assumptions may have to be changed, or not. In any case, it seems clear that a greater range of variability has to be assumed in the future.

Some studies suggest that the Colorado River system yield could be reduced by as much as 30% over the coming decades. A recent work by the National Oceanic and Atmospheric Administration and the National Center for Atmospheric Research suggests a range of decline of 10-20%.[22] The most recent Colorado River projection of the possible impact of climate change suggests a 9% decline in flow by mid-century.[23] There is a tendency to assume that, because the Sun Corridor is already so hot and dry, "global warming" will disproportionately negatively impact the area. Certainly if summertime temperatures continue to rise, at some point Arizona becomes a less attractive place to live, regardless of how much water there is. But on the other hand, the Sun Corridor is better prepared to deal with highly variable rain and snowfall conditions than most places on the planet. As noted above, this is the underlying principle upon which the water supply of the Sun Corridor has been built.

Besides increasing variability, climate change may well reduce the long-term average amount of available water. If an aggressive 15% decline in the average Colorado River flow is also applied to the Sun Corridor's other water sources, the nearly 2.8 million acre feet of "average" annual input to the Corridor could drop to 2.4 million.

Arizona occupies a "junior position" for Colorado River water entitlement, which puts it at greater risk. Together, California, Nevada, and Arizona are entitled to 7.5 million acre feet (MAF) from the Colorado. The Sun Corridor's rights—to 1.5 MAF of CAP water—is assigned the lowest priority position among all these uses.[24] Theoretically then, ignoring storage, a major reduction in Colorado River supply could severely curtail CAP water deliveries to the Sun Corridor.

Future Water Supplies for the Sun Corridor

Because of Arizona's dramatic growth, its historic challenges and the potential impact of climate change, water managers have begun analyzing where future Sun Corridor supplies might come from. The Central Arizona Project has conducted a long-term dialogue, called "ADD Water," engaging numerous stakeholders in the region.[25] Future supplies were analyzed with regard to physical, legal, and political constraints, and compared against a series of various contractual and political demands for future supply. Implementation of any effort to obtain new supplies means a multi-decade effort in the complex diplomacy of western water.

One analysis of future supplies created "tranches" of future supplies labeled "highly likely," "likely," and "possibly available."[26] One large potential source—though one with huge political ramifications—would be moving some Colorado River water from western Arizona agriculture to the Sun Corridor. There may be 200,000 acre feet or more available annually. Another potential source is groundwater imported from places in Arizona that are unlikely to urbanize; there may be another 200,000 acre feet or more available annually from such isolated sources. Though, like all groundwater, it is exhaustible, and its transportation controversial.

The ultimate solution for the arid West is generally assumed to be de-salinization plants built on the Pacific Ocean. This is usually touted as a way to bring vast additional supplies to Los Angeles or San Diego—or even to Las Vegas, which could use more of California's Colorado River supplies if California could pull from the ocean. These cities are more immediately challenged for future supply than is the Sun Corridor. De-salting the ocean is an expensive proposition. Reverse osmosis, the most commonly considered technology, uses huge quantities of electricity to force seawater through a membrane, leaving behind the salt. Costs can run in the $1,500-$2,000 range for each acre foot produced.[27] As technology improves, the cost of desalted seawater will drop—in some parts of the world it is now below $1,000/af. As total water supplies grow scarcer, existing costs will rise. The lines will eventually converge, reflecting once more that, in the history of the urban West, "water flows toward money." But desalted ocean water will not be coming to the Sun Corridor anytime soon.

A Cautionary Note for Sun Corridor Water Planners

Ray Quay and Patricia Gober, Decision Center for a Desert City (DCDC), Arizona State University

At first glance, this report's message about the Sun Corridor water supply appears positive. But water managers and urban planners should proceed with caution. That's because first, climate change may reduce supplies in the long term; and second, because our region does not depend upon one big bucket of water, but on many smaller pails linked to individual water providers. The Sun Corridor thus confronts two quite distinct futures: Will it emerge as a cooperative region in which surpluses are shared and risks from drought and climate change are more evenly distributed? Or will it succumb to the challenges posed by an uncertain climate, unsure supplies, and a concentration of risk in places of rapid growth?

Climate change should be on water planners' radars, but no easy answers come from climate models, which are notoriously uncertain about the impacts of climate change on surface supplies at local and regional levels. They tend to agree that the future climate will be warmer, but disagree about future rainfall and runoff conditions. DCDC's analysis of the Intergovernmental Panel on Climate Change's 2001 model finds an estimated temperature rise for central Arizona of between 2.4 to 5.6°C, using 2050 greenhouse gas emissions. These increases, along with widely varying rainfall estimates, suggest future ranges in runoff for the Salt-Verde watershed between 50% and 127% of historical levels. Similar studies for the Colorado River showed flow ranging between a decrease to 61% and an increase to 118% of historical flows, averaging around 90% of mean flows.

However, recent DCDC work does point to the differing impacts of shortages on individual providers in Maricopa and Pinal counties. Some will be able to manage even the most extreme shortages; others would be seriously challenged by only moderate shortages. Nor will water-sharing resolve all problems. Another DCDC study showed that spot shortages can be largely ameliorated through cooperation during moderately severe climate-change conditions. But such strategies have little effect under the most extreme scenarios because no communities have surpluses to share.

The second critical issue facing the region is the fragmented nature of water governance—the fact that myriad providers make individual and generally uncoordinated decisions. The Sun Corridor's water budget hardly consists of one big bucket. Instead, there are 285 water providers, ranging from major players to irrigation districts. The municipalities that rank as the largest of the Phoenix-area providers supply in excess of 50,000 acre feet annually. At the other end are providers delivering a few thousand acre feet to outlying communities. Their vulnerability to future climate change varies enormously depending upon our supply portfolios, lifestyle and landscaping preferences, and potential for future growth.

Irreducible uncertainties—about drought-induced water shortages, regional growth patterns and climate change impacts—suggest that the future could be far from normal for all parts of the Sun Corridor. Looking 20 to 40 years ahead, water shortages from long-term drought could have temporary but significant impacts on the region's groundwater supply. In the 40-to-60-year horizon, climate change could increase temperatures and decrease stream flows, enhance the length and severity of drought conditions, and boost the intensity of storms. It's clear that under these changing conditions the Sun Corridor faces serious water challenges. These sobering possibilities require us to think seriously about the adequacy of existing infrastructure, the relevance of operational rules and the sustainability of projected growth patterns and lifestyles.

The old adage of "predict and plan" worked well when the systems were stable, time periods were 20 years or less, the impact of being wrong was not catastrophic, and financial resources were fairly plentiful. None of these conditions now holds true. New decision-making strategies that envision and plan for a wide range of futures are thus needed today more than ever. Individual planning will not do it. Indeed, the Sun Corridor's fragmented form of water management risks creating winners and losers rather than sharing risk and benefit. Recent studies by the City of Phoenix and the East Valley Water Forum showed that communities that rely heavily on groundwater may face significant problems during long-term drought conditions. The interconnected nature of the groundwater system means that such communities could in turn jeopardize the water future of neighbors that had planned judiciously for their future. This may or may not be considered legal, or fair, but it's clearly not the future Sun Corridor any of us want.

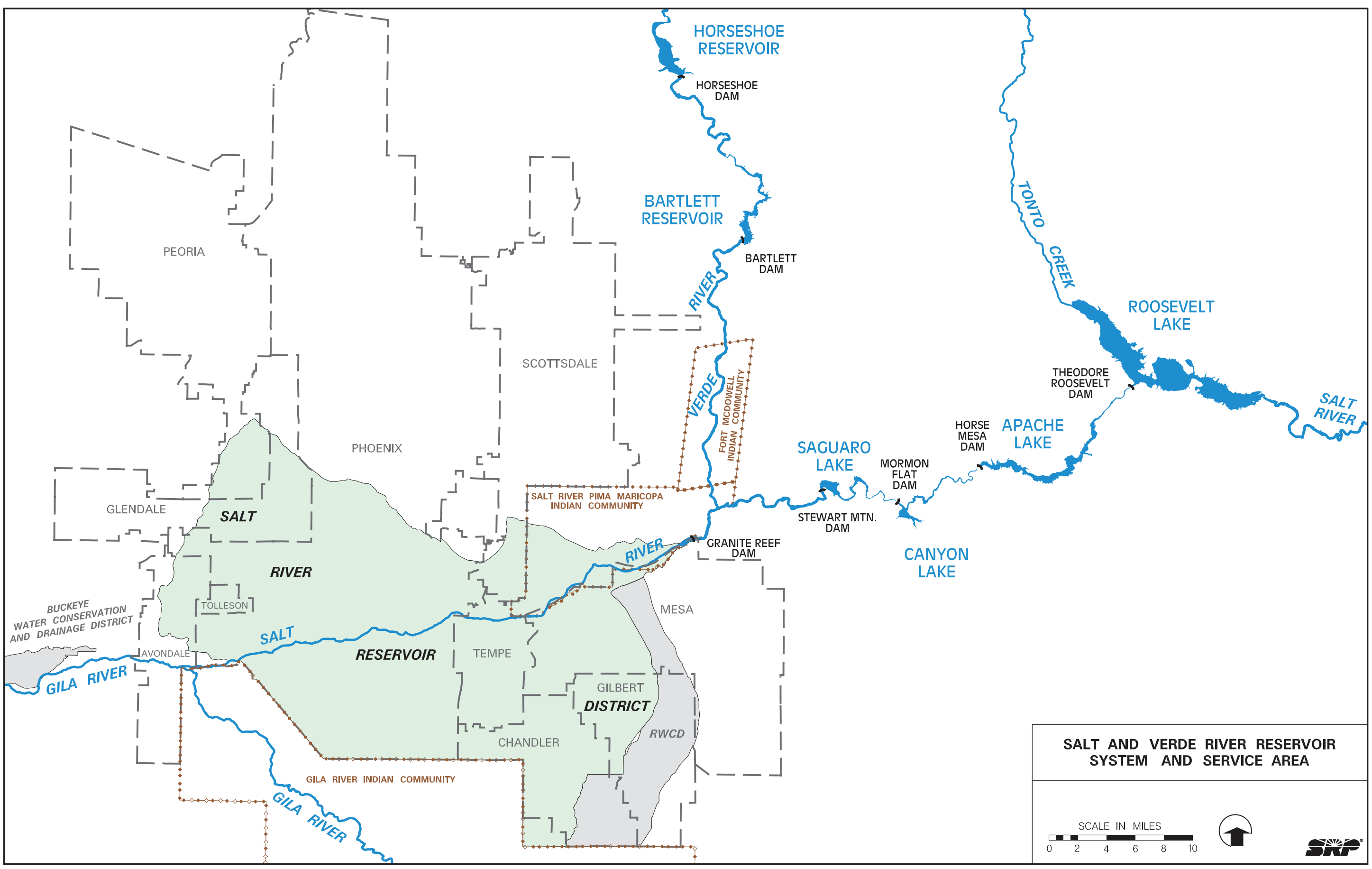
III

Managing a Desert Water Supply: From Variable to Reliable

The Sun Corridor's challenge has been to create a water supply for desert cities that is reliable and sustainable. With abundant sunshine and plenty of arable land, the Sun Corridor attracted its earliest Native American inhabitants because it was a good place to grow crops. The Hohokam built an extensive irrigation system in central Arizona based on the waters of the Salt and Gila Rivers, but their system lacked a large-scale means of storing water. This meant that their delivery system was subject to both drought and flood—a fact that may well have been the ultimate source of their demise. In the late 19th century, Jack Swilling and other early settlers built an irrigation system atop the Hohokam canals. But until the creation of large-scale storage by the federal government early in the 20th century, the variability swings remained a serious challenge.[28]

Today, three key elements of the Sun Corridor's water supply are intensely managed toward a goal of smoothing variability. These are the surface waters of Central Arizona (managed through the Salt River Project), the Colorado River (managed by the Central Arizona Project), and groundwater (managed under the Groundwater Management Act).

SRP RESERVOIR SYSTEM, SALT RIVER RESERVOIR DISTRICT, AND CITY BOUNDARIES



Source: Salt River Project.

The Salt River Project

The Salt River Project is one of the great water-management success stories of the United States. It also is a notable legacy of the federal government's "reclamation" policy to advance settlement of the arid West by storing and moving water. Landowners in the Salt River Reservoir District put their land up as collateral in the early 20th century to build a series of dams. Establishing the reservoir district and water rights within it helped to ensure the Valley's water supplies for more than 100 years. The first of SRP's storage dams, Theodore Roosevelt, was the largest in the world at the time.[29] Today, SRP is both a water provider and an electrical utility; it operates eight dams, 251 groundwater wells, and 1,300 miles of canals and laterals serving about 250,000 acres. The area was once agricultural, but is now more than 90% urbanized. SRP water must be used within the SRP service area, including deliveries to a host of cities. These deliveries give users with SRP rights robust water portfolios and management flexibility.

In 2010, SRP's reservoirs were at 96% of capacity.[30] In total, they can store about 2.3 MAF of water, or about two years' worth of runoff from the watershed.[31] More than 70% of this is stored in Roosevelt Lake.

The chart below shows SRP surface water deliveries for the period from 1950 to 2009.

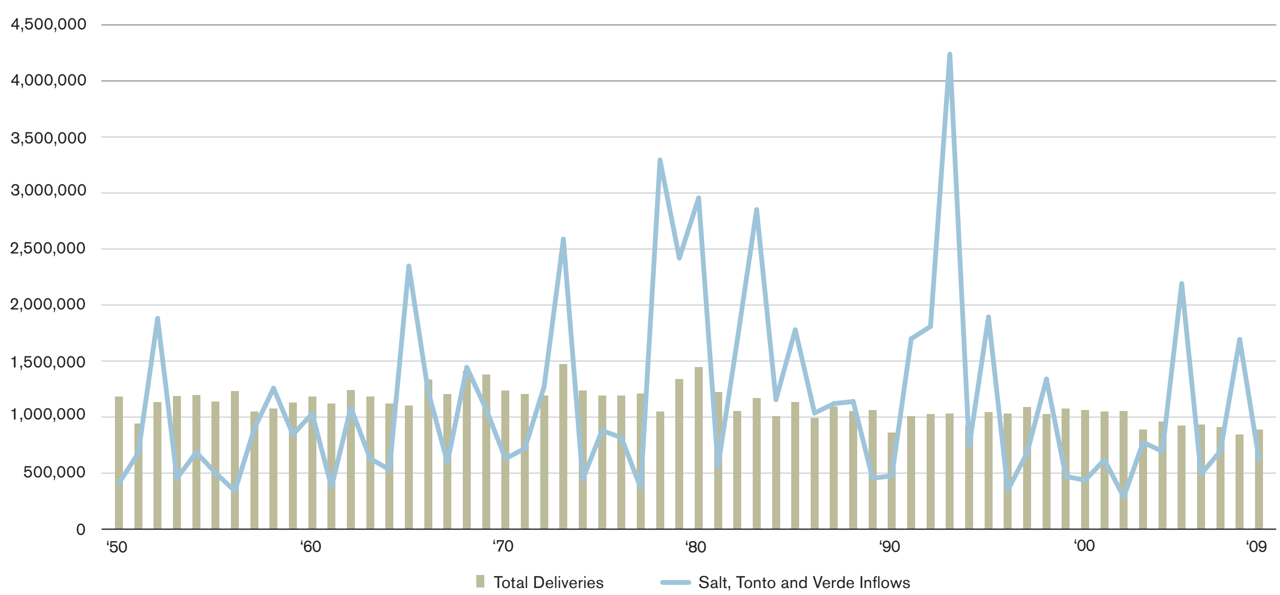
The Salt River Project also controls significant groundwater resources within its territory. For planning purposes, this groundwater is operated like another "reservoir" with a current annual maximum delivery capacity of about 325,000 acre feet, or just over 1/3 of the annual water demand in the SRP service area.[32] Operationally, SRP uses mainly surface water when the reservoir system is full, thereby enabling it to store as much water as possible for future use. As storage levels decrease, groundwater pumping is increased until a productive runoff season refills the reservoirs. If storage levels continue to decrease, deliveries by SRP are reduced to save the surface water for as long as possible. As agriculture in the SRP territory has declined, so generally has groundwater pumping.[33] Balancing deliveries of water in this way has made the Salt River Project supply very reliable. During the last 60 years, SRP has been able to deliver a full allocation of water to its shareholders 93% of the time. In four of the 60 years, SRP reduced the allocation for two years in a row, during the worst droughts in the Project's 100-year history. Deliveries to water users from SRP's system have totaled, on average, about 950,000 acre feet per year.

The Central Arizona Project

The CAP system is also a surface water-delivery system, but on a scale quite different from SRP's. The Colorado River serves multiple states, including some of the fastest-growing and driest urban and industrial areas in the United States. The futures of these communities and economies is tied, in whole or part, to water availability from the Colorado River. Over the next 40 years, the population dependent on the Colorado River could grow by 25 million or more, leading to an increase in water demand of perhaps 5 million acre feet.

The Central Arizona Project is only one piece of the Colorado River delivery system, and does not even represent all of Arizona's demand on the Colorado. The overall system has truly vast reservoirs, Lake Powell and Lake Mead, each of which can store about 25 million acre feet. Theoretically, storage on the Colorado amounts to more than three years worth of average annual flow. In order to win federal authorization for the CAP, Arizona had to agree that its CAP alloca-

SRP DELIVERIES FROM COMPLETION OF HORSESHOE DAM THROUGH THE PRESENT



Source: Salt River Project.

tion would be the "junior most" priority on the river and, therefore, the most susceptible to interruption in times of shortage. This concern has animated much of Arizona's recent policy in dealing with the Colorado. While a shortage has never been declared in the lower basin, negotiations among the basin states have resulted in guidelines for shortage sharing among the lower basin states. Shortage sharing is triggered based on year-end water level elevations in Lake Mead as indicated below.

SUMMARY OF REDUCTIONS IN COLORADO RIVER FOR ARIZONA AND CAP

Year-End Lake-Level Elevation (Feet above Sea Level)	Reduction in Acre-Feet
Below 1075 but Above 1050 Feet	333,000 Arizona's Share: 320,000 CAP's Estimate Share: 288,000
Between 1050 and 1025 Feet	417,000 Arizona's Share: 400,000 CAP's Estimate Share: 360,000
Below 1025 Feet	500,000 Arizona's Share: 480,000 CAP's Estimate Share: 432,000
Below 1000 Feet	Secretary Consults with Basin States

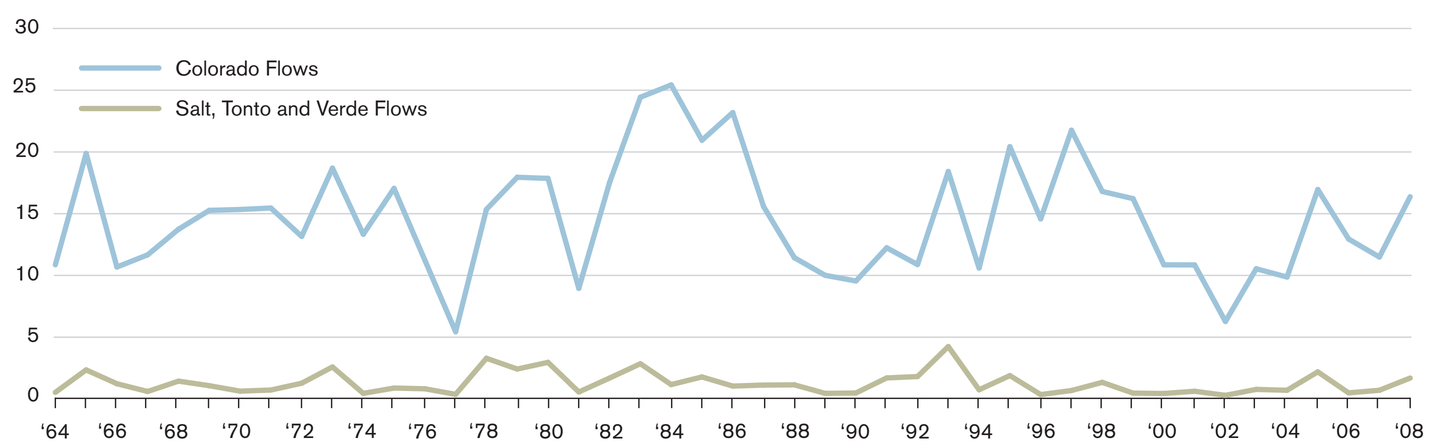
Lake Mead's elevation was approximately 1,092 feet as of January 2011.[34] This means that it was only about 41% "full."[35] The prolonged drought on the Colorado River has left Lake Powell at about 57% full.[36] Recent releases from Powell to Mead will rebalance the reservoirs, and the large 2010-11 snowfall will rebound both reservoirs somewhat. The Colorado system has been considered in drought conditions for over ten years, and yet deliveries have not been curtailed, demonstrating the intended function of these huge reservoirs. The contrast between the Colorado system and the Salt system is an inherent part of the reliability and sustainably strategy of the Sun Corridor.[37] Deriving water from two different geographic areas (the mountains of central Arizona and the Rockies in Utah, Colorado, and Wyoming) was long thought to create a more balanced and sustainable supply. Tree ring data analysis shows a higher degree of drought correlation between central Arizona and the Colorado system than was previously thought.[38]

Colorado River water users, led by the U.S. Bureau of Reclamation, produce models of the operation of the Colorado in an attempt to determine the probability of shortage. Recent model runs (August 2010) indicate there is no more than a 20% probability of shortage in 2012. Current models project that shortages would not impact CAP municipal and industrial or Native American contractors until about 2020 and then only under "worst case" conditions.[39] Even with a reduction of 432,000 acre feet, the highest level of reduction considered in the current shortage sharing guidelines, CAP would still receive around one million acre feet. Today, CAP's long-term (mainly municipal) contractors use just over 800,000 acre feet. "Excess" contractors, including most farmers, use another nearly 800,000 acre feet of water. So most reductions—even severe ones—would be absorbed by agriculture.

Despite this huge cushion of agricultural use, however, CAP's junior position means that in times of shortage, it would take most of the first cut—before California agricultural use, before Nevada, and before Arizona on-river use. While there have been suggestions to change this system, it remains in place. A decrease in availability on the Colorado could greatly impact the Sun Corridor.

A highly variable system, the Colorado River is subject to dramatic change in runoff from year to year. CAP may experience some level of shortage during the next 20-25 years. While the magnitude and duration of a shortage cannot be predicted, CAP's own analysis suggests that its municipal users are not likely to experience a significant reduction in supply during this period. However, a prolonged shortage would seriously reduce the amount of water available for agricultural users and limit the ability to bank water for future use.

COLORADO AND SALT, TONTO AND VERDE FLOWS, IN MILLION ACRE FEET



Source: U.S. Bureau of Land Reclamation, Current Natural Flow Data 1906-2008 and Salt River Project.

The Future of ADWR

Water management is frequently cited as something Arizona has done exceptionally well. Indeed, water issues have historically been dealt with by a broad, non-partisan consensus of Arizona leaders and institutions. But the state's precarious budget situation has put that strong legacy in jeopardy.

The Arizona Department of Water Resources was created in 1980 in the Groundwater Management Act. In the 30 years since, ADWR has:

- quantified and protected groundwater rights
- adopted conservation plans
- facilitated groundwater storage
- ensured that new residential developments have a 100-year supply
- defended Arizona's Colorado River rights against other users
- protected endangered streams and rivers
- acted as the focal point for discussion of state water issues.

Since 2008, ADWR's budget has been cut by 70%. In 2011, its budget has dropped below 1984 levels. Full-time-equivalent employees have declined from more than 235 to 95. Programs have been completely eliminated; offices outside of Phoenix have been closed. Some $47 million in funds collected to store water for future shortages, implement Indian water settlements and protect remaining streams was "zeroed out" by the Legislature and shifted to general state operating funds.

Ultimately, a legislative bargain was struck through which cities agreed to pick up a major share of DWR funding. These costs will be built into municipal water bills.

Public funds are unquestionably scarce. Still, shrinking ADWR and potentially jeopardizing our history of careful water management do not seem the best way to celebrate Arizona's centennial.

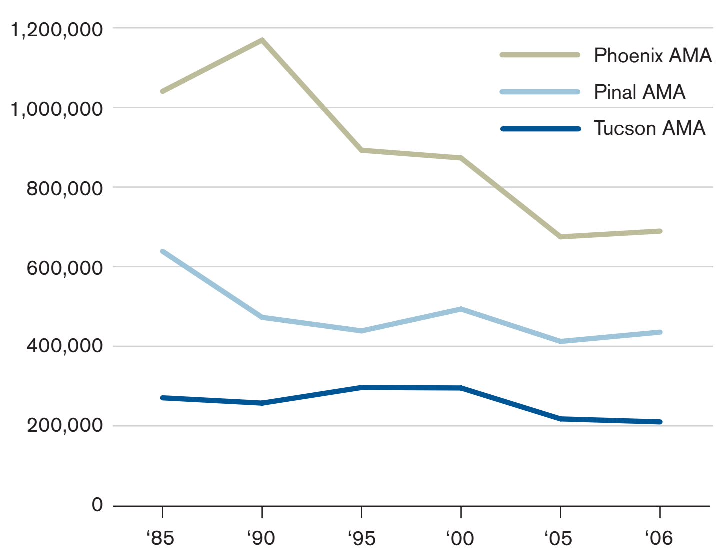
Managing Groundwater

For decades in Arizona, groundwater was simply treated as a resource available to anyone who wanted to pump it from beneath their land. Legally, groundwater was thought of as being separate and distinct from surface water and was largely unregulated. This remains true today in most of the United States. But excessive and continuous groundwater pumping raises a number of problems. Groundwater depth in a place as dry as Arizona is often great enough that drilling is expensive and risky. Excessive and continuous groundwater pumping can lower the water table; as water is removed, the soil can collapse and damage buildings and infrastructure. At some point excessive pumping of groundwater leads to the depletion of a finite resource that accumulated over hundreds of thousands of years. Groundwater is in this sense similar to oil.[40]

In 1980, due to years of pumping for agriculture and to meet increasing urban demands, the Arizona State Legislature adopted the Groundwater Management Act (GMA) and created the Arizona Department of Water Resources (ADWR) to protect groundwater supplies for the future. The GMA was also insisted upon by the U.S. Secretary of the Interior before agreeing to fund the Central Arizona Project. In fact, part of the rationale for the CAP was to replace long-term groundwater pumping with renewable surface water. The GMA ranks among the most innovative policy initiatives undertaken by Arizona.

The GMA designated areas of the state where groundwater pumping was heaviest as "*Active Management Areas*" (AMAs). The Sun Corridor, as we use the term here, lies within these AMAs. The chart below shows the change in the rate of groundwater withdrawal for the three counties since passage of the GMA.

CHANGE IN THE RATE OF GROUNDWATER WITHDRAWAL FOR THE THREE COUNTIES SINCE PASSAGE OF THE GMA, IN ACRE FEET



Source: ADWR.

In Pima and Maricopa counties, the GMA was intended to reduce pumping toward a "safe yield" condition and thereby end groundwater mining. The Pinal AMA, however, was originally designed to allow groundwater depletion to preserve agriculture for as long as possible while reserving a supply for future urbanization.

Safe yield represents a balance in groundwater supplies in the aquifer between what leaves (generally through pumping) and what is returned to the aquifer (through natural or artificial recharge). The goal of safe yield has proved to be elusive. As of 2006, 45% of the three-county supply still comes from groundwater pumping.

While current evaluations indicate that safe yield has been achieved in the Phoenix AMA, and that the Tucson AMA has come close, long-term projections indicate that without more aggressive water management, the ability to maintain safe yield will not be realized.

Part of this shortfall derives from a water-accounting anomaly: water being artificially "recharged" back into the aquifer (which is discussed below) is not counted against withdrawals, but is "banked" for future use. In addition, because physical delivery of CAP water is too difficult in many areas, the CAP supply has not always replaced groundwater pumping in the direct manner that was probably originally envisioned. But the biggest reason is probably simple economics: pumping groundwater is cheap. We still live under long-standing federal policies that provide low-cost electricity for agricultural pumping, a remnant of the reclamation era.

Arizona continues to be among the most active and innovative states in groundwater management. One important tool for securing groundwater supplies in the AMAs has been the requirement that new developments demonstrate secure physical, legal, and continuous access to a 100-year assured water supply . This is a stricter standard than California's, which requires a 20-year access (and only for large subdivisions).[41] The 100-year supply in Arizona should generally come from surface water, preserving groundwater for when surface water is not available. In practice, this provision was designed to push development in the Sun Corridor to areas with access to municipal water based on a municipal system with a CAP contract. Theoretically, this should have resulted in containing and compacting development in the Sun Corridor and making it more difficult to develop far outside of municipal boundaries.[42]

Since 1993,[43] developers have been able to meet the renewable supply requirement by enrolling in the Central Arizona Groundwater Replenishment District (CAGRD). This program allows groundwater to be pumped for a new development as long as it is replaced with water from the CAP or other non-groundwater supplies through artificial recharge. This enables development to continue without investing in expensive water acquisition and transmission facilities or water treatment plants.

The CAGRD has been criticized as a "shell game" that allows groundwater pumping in the expectation that replacement water will be available to be recharged somewhere else in the AMA; but this recharge could occur so far from the development that in practice it circumvents the requirement of renewable water availability for development.[44] At the height of the development boom, the CAGRD proved much more successful than originally envisioned, with nearly 265,000 lots entitled through this mechanism. The downturn in development has dramatically slowed enrollment, but it is likely that either the availability of this mechanism will be curtailed in the future, or the costs will dramatically increase, or both.

Arizona has also been at the forefront of large-scale institutional groundwater recharge. Starting in 1986,[45] the state began recharging underground aquifers with available surface water. The initial impetus was to use the otherwise unused portions of Arizona's CAP allocations to keep them away from California. In addition, in order to satisfy California's thirst, the U.S. Secretary of the Interior in the late 1990s declared a series of "surplus conditions" on the Colorado River resulting in the release of additional water that Arizona could take for its own purposes. Because Arizona's population had not grown enough at the time to consume even its base CAP allocation, a series of mechanisms for using extra water were created. Spreading basins were built in dry riverbeds where water can be poured out onto the desert, allowing it to percolate back into the aquifers. Another mechanism—indirect recharge—displaces legal and cheap groundwater for agriculture with surface water. The surface water is used to water crops, and the un-pumped groundwater is counted as indirectly recharged surface water which can be recovered in the future.

Since the mid-1990s, the Arizona Water Banking Authority (AWBA) has been storing excess CAP water to shore up supplies during a shortage. The AWBA has even banked water on behalf of Nevada. When Nevada needs that water, it will withdraw directly out of Lake Mead, and Arizona can pump the banked water to satisfy needs that would otherwise have been met directly with CAP deliveries.[46] These various mechanisms have resulted in more than 4 million acre feet of water being put back underground in central and southern Arizona.[47]

Groundwater banking is ultimately a management technique just like reservoirs: a means of smoothing out a highly variable water supply. But it is a less flexible and longer-term solution. Getting the water exactly where and when it's needed in the future may pose challenges. But the fact that urban Arizona has managed to save millions of acre feet of groundwater for future use clearly improves the reliability of the Sun Corridor water supply.

Reclaimed Water

The issue of reusing wastewater from urban households is becoming increasingly important—but remains a tricky category of water to think about. Some commentators discuss it as a significant new source of water "supply" that is more effectively and readily developed than other new sources.[48] But this is really not "new" water. Rather, it is a management technique for stretching an existing supply.

There are several different categories of wastewater that can be reclaimed in urban areas: storm water runoff, power plant cooling water, agricultural return flows, household gray water (dishwashing or showers), and sewage. Techniques for treating and reusing effluent are becoming more sophisticated. Some effluent—like city sewage—is better treated on a large scale, while other types may be reclaimed by individual households. Additional questions include: Is the reclaimed water to be used for landscaping? Fiber crop irrigation? Food crops? Aesthetic purposes like fountains or artificial lakes? Can the water be reused for body contact? What about for flushing toilets?

In 2009, Governor Jan Brewer appointed the Arizona Blue Ribbon Panel on Water Sustainability. That panel reviewed water reuse by area around the state, and concluded that the percent of treated wastewater reused or recharged in the Sun Corridor was:

Pinal AMA	58%
Phoenix AMA	49%
Tucson AMA	15%

The Panel also noted that Arizona's gray water rules have been referred to throughout the U.S. by gray-water advocates as the "model to emulate."

Because so much Sun Corridor water is used for landscaping, the most readily available reuse is effluent treated to the level that it can be used on plants and supplant the use of potable water. This approach became prominent in the Sun Corridor in the 1980s and 90s with the use of reclaimed effluent on golf courses. Scottsdale and Tucson pioneered this use. A large effluent line specifically serving golf course development has been built in north Scottsdale, and throughout the city about 12 million gallons per day of reclaimed water is used to irrigate golf courses. But even this reuse poses some problems. For example, another source of water must periodically be used to flush from the soil the salts concentrated in reclaimed water. It is thus difficult for any landscape use to exist on 100% effluent. A second problem, particularly for some golf courses, is that the seasonal demand for water and the seasonal production of reclaimed water do not always coincide. Snowbirds produce effluent in the wintertime, but golf courses need most water in the summer.

It is also important to note that there is an inverse relationship between interior conservation and effluent production. As household plumbing fixtures become more efficient in conserving water that is initially used, the per capita amount of effluent produced decreases. With the advent of ever lower-flush toilet fixtures, waterless urinals and other appliances, in-home per capita production of available wastewater has been falling.

As water has become more valuable, an initial concern was ownership and control over effluent. In an Arizona Supreme Court decision,[49] the court determined that treated wastewater would be the property of the entity that treats it, since it is no longer of the same character as the source water. The court also found that treatment facilities are not obligated to discharge treated effluent for any downstream user even if it initially came from surface water.

A recent master's thesis at ASU, which extensively examined reclaimed water issues, estimates that the Phoenix AMA in 2006 generated approximately 315,000 acre feet of effluent.[50] This would suggest that the total Sun Corridor effluent production today may be approaching 500,000 acre feet. The Sun Corridor is one of the nation's better-performing urban areas with regard to the reclamation of urban water. The City of Phoenix asserts that well over 90% of its effluent is reused. This includes delivery to turf facilities for irrigation contracts and, most importantly, for cooling at the Palo Verde Nuclear Generating Station. The multi-city 91st Avenue Treatment Plant delivers annually about 60,000 acre feet of effluent to Palo Verde.[51] Other treated effluent from the plant is discharged into the Salt riverbed, where it forms the Tres Rios Riparian Area. In fact, because in Arizona effluent cannot be discharged into the ocean or another huge body of water, it is in some ways appropriate to think of all effluent as being "reused"—as it ultimately winds up recharging underground aquifers.

Conclusions on Supply and Reliability

As noted, the most sustainable water supply for the Sun Corridor is surface water. Because precipitation within the Sun Corridor is low, most of its surface water supply is imported. Arizona law since the 1980 Groundwater Management Act has strongly preferred that urban growth occur based on this surface water supply. However, the high variability of surface water supplies poses risks. The solution has been to smooth out the water supply through large-scale storage. In Section II, we concluded that annual water inputs to the Sun Corridor total an average of about 2.8 million acre feet. Preliminary climate-change assumptions currently suggest possibly reducing that level by 15%, to 2.4 million. But variability makes such "averages" risky to rely upon. The junior status of CAP rights further exacerbates that risk.

Storage systems are designed to increase reliability. The SRP system can theoretically store nearly one full year of the Sun Corridor's supply—2.3 million acre feet. Arizona's "share" of the Colorado River reservoirs is not separately quantified; but, if full, they theoretically impound almost 4 years' worth of lower basin entitlement. So the aggregate reservoir system serving the Sun Corridor is capable of storing between five and six years of the "average" annual input. Artificial groundwater recharge to date adds another 1 ½ years.

Is this enough? Should we save more? Should we be comfortable with the current low levels on the Colorado but a full SRP system? Given the watering systems of the Sun Corridor, we typically store 4-5 years' worth of supply—maybe as much artificial storage as any place on the planet. Metro Atlanta, in contrast, had less than thirty days of water supply on hand at one point in 2008.[52]

The Sun Corridor reservoirs have functioned successfully, and the public seems to understand the general concept. But Arizonans are less clear on how to think about the role of groundwater. We have shifted our thinking from an era which regarded groundwater as hydrologically separate from surface water which could be used whenever needed. Today, by contrast, there is a tendency to believe that groundwater should never be used as a water supply. If reservoirs are the "savings," we should think of recharged groundwater the same way, though perhaps more like a "certificate of deposit"—slightly harder to withdraw. In this analogy, prehistoric groundwater is our "inheritance"—a kind of trust fund that is available in emergencies, but that we would prefer to leave for future generations. In the face of past assumptions about variability—a storage system of five years supply or so has been reasonable and sufficient. But in the face of potentially much greater future challenges from climate change and altered assumptions, our savings are starting to feel a bit thin. Looking out to 2060 and beyond, as population and urban demand increase and harden, the margin becomes troubling.

So does the Sun Corridor have enough water for the future? Does your family have enough money for the future? The answer to these questions is the same: it all depends.

Spreading basins, such as the Granite Reef Underground Storage Project above, allow water to percolate into the soil and are used to recharge the groundwater tables.

IV

Demand: Where Does the Water Go?

Urban Water Use

Where does the Sun Corridor's water go? While there are many different ways to slice the pie, the most typical one separates water use into three categories: municipal, agricultural, and industrial. Most Arizona water still goes to irrigated agriculture.

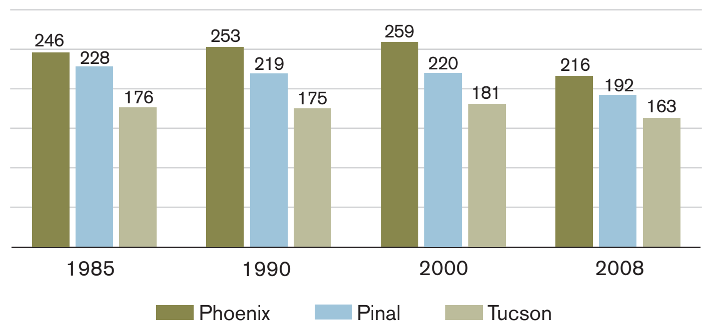
The "industrial" category includes a range of users like electronic chip manufacturing plants and electric power generation. In Arizona, "industrial" also includes some golf courses, because direct groundwater pumping by a golf course requires an industrial permit. But many manufacturing and employment-related water uses are not actually captured by the "industrial" category because these uses are directly served by municipal water providers. It seems more useful, therefore, to group water use into two categories: "urban" (municipal and industrial) and agricultural (meaning commercial irrigated agriculture). The urban category represents the Sun Corridor as an emerging megapolitan region.

Each of the three principal counties in the Sun Corridor has a different water use profile.

Since the 1980 Groundwater Management Act, the shorthand way of explaining municipal water use has been in gallons per capita per day or "GPCD." GPCD takes the water delivered by a municipal utility and divides it by the population the utility serves. The chart to the right shows the GPCD rate as usually compared for the three central Arizona AMAs.

Based on these typical numbers, each acre foot of non-agricultural water in the Sun Corridor appears to support about 5 people (4.2 in the Phoenix AMA; 5.5 in the Tucson AMA in 2008).

GALLONS PER CAPITA PER DAY RATES FOR CENTRAL ARIZONA AMAS

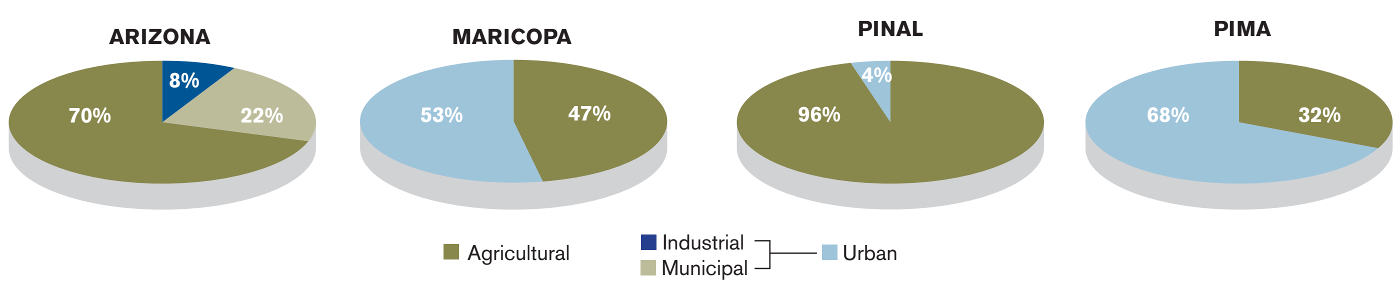


Source: ADWR.

The downward trend in GPCD water use in all three AMAs is significant. This is in large measure the intended result of the Groundwater Management Act. More efficient use of water has been achieved through education, increased water rates, and a variety of regulations on specific uses.

It is difficult to compare per capita water use from one region to another. Different cities, states and countries include different uses in their calculations and a huge difference results simply from the variation in rainfall in different places. The U.S. Geological Survey cites the U.S. national average as 150 GPCD, with Vermont the lowest state at below 100.[53] Of urban arid regions, Australia, in the depths of a drought crisis, dropped residential use from 70 GPCD to 34 in 2007-08.[54] Urban Arizona's decreased GPCD has been

WATER USE PROFILES FOR ARIZONA AND THREE COUNTIES



Source: *Arizona Water Atlas*, Vol. 8 (2010). Arizona Department of Water Resources.

the result of deliberate incremental changes over three decades, not an immediate response to a crisis. We can expect to see continuing improvement in these numbers.

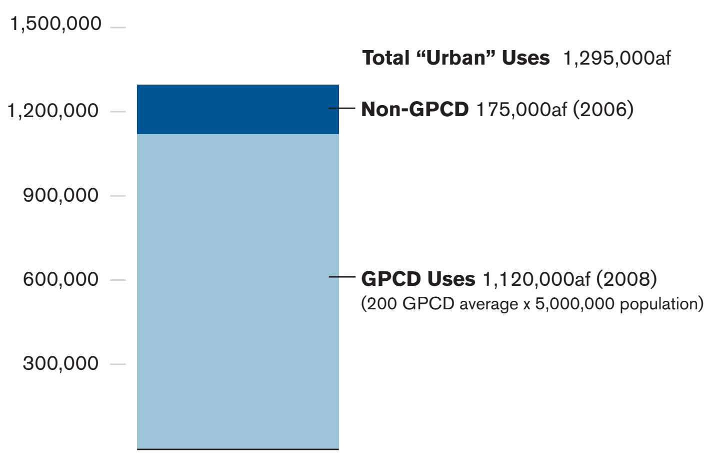
There is a tendency to take these per capita numbers and use them as a proxy for all "urban" water use. So if an acre foot/year supports about 5 people, 1,000,000 acre feet should support a population of 5,000,000? Not exactly.

In the Sun Corridor, there are non-farming water uses which are *not* included in GPCD calculation. These include things like factories and mining supplied by their own pumps, rather than city water. Untreated water delivered for flood irrigation of homeowners' lawns, a feature of some parts of metro Phoenix within the SRP boundaries, is also left out. Golf courses with their own water supply are not counted. Dairies, high water users, are also omitted. These uses should be grouped into the "urban" category.

These other urban uses cannot simply be inserted into the per capita numbers and rebalanced. Some of them have little or no relationship to population growth. Copper mining, for example, occurs in the Sun Corridor because of ore locations. Water use for copper mining is independent of local population, and fluctuates with global demand. Sand and gravel mining, on the other hand, is related to nearby construction, and it does therefore correlate more closely to increased population. Using untreated water for flood irrigation of lawns is largely a historic remnant and is likely to decline over time. While these uses all have different characteristics, the most convenient shorthand is to treat them as "non GPCD" uses distinct from commercial agriculture. In 2006, the latest year for which aggregated figures are available, the non GPCD uses for the three AMAs totaled about 175,000 acre feet.[55]

Using the 2008 GPCD numbers and the 2006 non GPCD "urban" consumption, the Sun Corridor's urban water uses, including everything but commercial irrigated agriculture, can be approximated.

CURRENT APPROXIMATE "URBAN" WATER USE IN THE SUN CORRIDOR



Residential

Tucson is one of the most water conservation conscious communities in the United States. Per capita water use rates in the Tucson AMA have long been among the lowest in the arid states. Phoenix has also made significant progress in reducing its urban water use, though it remains far more water consumptive than Tucson. The difference between the two communities is largely historic. Phoenix has always been a farming town with immediate access to a flowing river that, while highly variable, generally had a low flow rate nearly four times that of Tucson's local natural surface water supply.[56] Even though Phoenix is both drier and hotter than Tucson, it was this difference that made Phoenix a location for irrigated agriculture.

As Phoenix urbanized, it generally transformed flat, agricultural land into subdivisions. This made the importation of non-native species and a Midwestern landscape palette of grass and deciduous trees a logical choice for early settlers. As the city grew, the Hohokam canal system became a template for providing agricultural water. The Salt River Project was the nation's first use of federal funding for creating an ever greater capacity for irrigated agriculture. The size and reliability of that water supply continued to support the urbanization of land in an "oasis" urban form.

Tucson, by contrast, consciously urbanized as a desert environment rather than an oasis. Its more meager water supplies meant that agriculture was never an important part of its economy. Its milder climate, higher elevation, and more varied topography gave Tucson a "desert living" character that Phoenix lacked. The result of these differences is the dramatically different water consumption of the two cities: *It is all about the landscape*. Interior home water use is now approximately 60 gallons per capita per day in both cities. In newer subdivisions, because of advances in water conservation technology in bathrooms and kitchens, this number is even lower. It is likely that inside home water use will continue to decline slowly on a per capita basis.

In the Phoenix metro area, about half of residential water use occurs in the landscaping outside the home. This ratio used to be higher, with estimates as high as 60-70%,[57] but smaller lots, xeriscaping, higher water prices, and educational efforts have consistently reduced the percentage in recent years. New subdivisions use markedly less outdoor landscaping water than older parts of town. The most recent City of Phoenix estimates place outdoor use citywide at 46%.[58] Some other cities in the metro area are likely higher, because of larger lots, higher overall GPCD numbers, and older landscape. In the Tucson AMA, the ratio is significantly lower, with outside use arguably below 30%.[59]

On a Sun Corridor wide basis, there is no clear way to estimate exactly what percentage of residential use is going into outdoor landscaping, but it is likely to average about 45-50%.

Many Sun Corridor cities have created educational and regulatory programs to encourage a desert or "xeriscape" landscape palette.

Pima and the Politics of Water

Sharon B. Megdal, Water Resource Research Center, University of Arizona

The adage "local policies reflect local values" is certainly true in Tucson, where front lawns are rare, xeriscape is common and water conservation has long been an intense public concern. In truth, of course, every community within the Sun Corridor is distinct, with different histories, cultures and local challenges. Yet our destinies are inextricably, and increasingly, linked. This is why it's crucial for all of us to develop an understanding of each others' resources and needs.

It's equally crucial that we understand local political and economic landscapes. Water management, especially in semi-arid regions, can be a complex and high-stakes affair.

Lines of ownership, authority and jurisdiction are often scrambled. Tucson Water, for example, serves about 80% of the municipal water demands, but more than one-third of its customers reside outside the city limits. These residents do not elect the Mayor and Council, who set the water rates, nor vote on water bonds or initiatives that would change the City Charter. Several other public and private water providers exist in the region. Pima County provides wastewater treatment for most of the region, but the City owns a large portion of the treated wastewater in an arrangement unique in Arizona. Finally, the U.S. Secretary of the Interior controls 28,200 acre feet of the region's effluent, which it manages for the benefit of the Tohono O'odham Nation.

Against this complex backdrop, the arrival of CAP water in Tucson made the early 1990s a turbulent time. Tucson Water had planned to be the regional provider of CAP water, but this was derailed by the formation of several new smaller utilities by residents outside the Tucson city limits as well as by nearby municipalities of Oro Valley and Marana. Local control of water assets and supply became a focus of citizen activism. The real trouble came when Tucson Water first delivered treated CAP water to its customers. The overnight switch to treated CAP water for over half the utility's customers was disastrous. Pipes burst, water was brown, and fish died. In 1995, city voters approved a citizen-developed initiative that forced Tucson Water to abandon plans for direct delivery of CAP water after treatment. Instead, a strategy dependent on recharge and recovery has taken hold, and recharge basins have been built to the northwest and south of Tucson. In other words, the landscape—literally as well as politically—sharply changed.

But all was not conflict. Several efforts to think and plan regionally about water were launched during the 1990s, with mixed outcomes. A legislatively authorized regional water district was not made permanent. The Southern Arizona Water Users Association (SAWUA), an affiliation of water interests, established itself as a regional voice for water providers and large water users. The Water Conservation Alliance of Southern Arizona (Water CASA) formed so that the smaller utilities could collaborate on water conservation programs. The northwest area water providers began to collaborate on efforts to utilize CAP water. The key issue of CAP reliability was resolved in 2010 with a plan based on recharge rather than a surface storage facility. Yet several other CAP issues still remain unresolved, such as a pipeline to bring this renewable water supply to the Sahuarita-Green Valley area.

Effluent remains another unresolved issue. The City of Tucson and Pima County have had their differences regarding how treated wastewater should be reclaimed and reused. They agreed to set aside a pool of effluent for environmental purposes; yet nearly 10 years later the use of the pool appears undetermined. The city and county also worked together for three years to develop water and wastewater recommendations that would benefit the region, including its natural environment. In addition, the multiple owners of effluent have worked collaboratively on effluent recharge in the Lower Santa Cruz River.

The people of Pima County realize how critical water management is for their future and know that they must work together on shaping that future. Citizen awareness of water scarcity is widespread and intense, as is residents' desire for water policies that balance human and environmental needs. But while Tucson is "different," this same need for collaboration among water interests, public decision-makers and citizens exists throughout the Sun Corridor. Harmonizing the water policies of the Sun Corridor's distinct regions will require the time and effort necessary to acknowledge our differences as well as recognize our commonalities. Tucson's experience is showing that, with patience, persistence and public education, it can be done.

While Phoenix has moved toward a more desert landscape palette, a large percentage of homes still include grass and non-native trees. The houses of Tucson have long embraced a more indigenous landscape. Tucson Photo Source: Community of Civano, LLC.

The results have been significant, if not always as dramatic as expected. An ASU study concluded that drip irrigation systems often do not save as much water as anticipated because of their high maintenance problems, frequent leaks, and the tendency of homeowners to overwater desert plants.[60]

Commercial/Industrial Uses

Cities and municipal providers have also sought to encourage conservation by commercial and industrial users, and have incorporated water use into their economic-development policies. Arizona became a magnet for silicon chip manufacturing in the 1970s because Motorola and Intel found it a good environment for building clean rooms and for attracting a skilled workforce. Chip manufacturing uses large amounts of water, though the industry has promoted extensive conservation and reuse techniques.

Scottsdale and other Valley cities encouraged construction of golf courses for another major economic-development activity and "export" industry—tourism. Over time, water-use regulations have prompted a significant decrease in the amount of turf planted, the development of new kinds of turf and the use of recycled wastewater.

Nationally, the most water-intensive industry is arguably electric power generation, which diverts about 48%[61] of the nation's annual supply. But this number includes cooling water that flows through plants and is returned to streams and rivers. In Arizona, only about 5% of the water supply goes to power plants, and much of it is reclaimed water to begin with.

Mining is a significant industry in Arizona and a significant water user—about 1% of the state's general usage and somewhere around 40,000 acre feet in three counties. There are proposals to significantly expand mining in the Tucson and Pinal AMAs. Historically, mining has primarily used groundwater.

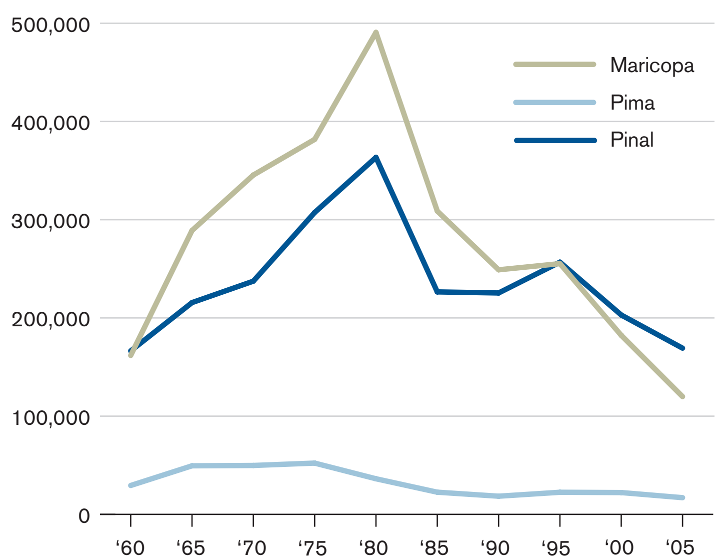
Agriculture

Since at least the time of Marc Reisner's *Cadillac Desert*[62] it has been politically expedient to criticize most large-scale irrigated western farming as wasteful. A recent Stockholm Environment Institute report[63] continues this view, and is especially critical of Arizona's situation, which on a statewide basis the authors see as 77% of water supply going to agriculture, with 54% of that share being used for high-water/low-value hay production. Reisner's own bleak vision predicted that massive confrontations between agricultural and urban interests would potentially devastate western politics.[64]

Arizona has been fortunate to avoid such cataclysmic confrontation because as the Sun Corridor has urbanized, farm land and water have been converted to subdivisions in the same place: the Sun Corridor. This land use evolution has seemed natural, logical, market driven, and relatively sustainable, since houses often use less water than crops.

Within the Sun Corridor, about 1,800,000[65] acre feet of water per year are still used for irrigated agriculture. Agriculture in Maricopa and Pinal counties peaked in the late 1980s and has been declining since then, but more than 95%[66] of Pinal County water still goes to farming.

TOTAL NUMBER OF ACRES PLANTED FOR ALL AGRICULTURAL PURPOSES BY COUNTY



Source: Morrison Institute for Public Policy, ASU; data from the U.S. Department of Agriculture, National Agriculture Statistics Service, 2007.

Pinal Perspective: Life in Transition
Agriculture, Depletion, and Urbanization

David Snider, Pinal County, District 3 Supervisor

One of Arizona's more enduring items of conventional wisdom has been that Phoenix and Tucson will grow together just like most of southern California. Ground Zero for that projected growth is, of course, Pinal County. The time frame was vague. The concept, depending on where you lived, was greeted with healthy skepticism (and mild distaste) or a shrug of inevitability. But Pinal County's hyper-growth of the last 10 years has transformed that notion into a matter of urgent importance.

Pinal has relied on agriculture to act as steward of its aquifers while both the Arizona State Land Department and the federal government manage much of its open spaces. The county contains three Active Management Areas—two with a goal of "safe yield," and one with a goal of "planned depletion." Agriculture still accounts for approximately 25% of the county's economy and nearly 90% of the Pinal AMA's water budget. However, the agricultural portion of this budget is diminishing as activity in the municipal and industrial sectors increases. Virtually all of the county's manufacturing is also located in the Pinal AMA.

But "planned depletion" does not mean "let agriculture de-water the AMA to a depth of 1,000 feet"—as many planners may have thought. The goal is actually: "to allow development of non-irrigation uses and to preserve existing agricultural economies in the AMA for as long as feasible, consistent with the necessity to preserve future water supplies for non-irrigation uses." The AMA's irrigation districts (excepting the San Carlos Irrigation District) have been using CAP water for the most part during the past 20 years. This has mitigated depletion of the AMA's aquifers while bolstering groundwater supplies.

The AMA's water budget includes additional supplies of renewable water from the conversion of non-Indian ag water rights to Municipal and Industrial ("M&I") purposes as well as significant naturally occurring renewable sources of water. However, the municipal and industrial sector has relatively small contract amounts of M&I priority CAP supplies (approximately 15,000 af) at present which, in turn, presents a significant challenge for Pinal AMA water resource planners. In addition to pondering the adequacy of water supplies, water resource and land use planners debate the merits of moving water to growth, or growth to water.

County officials have been responding to these challenges. County Supervisors and staff initiated a revision of their Comprehensive Land Use Plan in 2007, three years earlier than required. A Morrison Institute study cited Pinal County residents calling overwhelmingly for open spaces, green and sustainable communities, and balanced growth and development. As a result, the newly revised plan called for more serious consideration of water resources as development projects move through the zoning process. The rules concerning assured and adequate water supplies for the Pinal AMA were revised several years ago to promote the movement of growth to water (i.e., lands currently used for irrigated agriculture) as opposed to water moving to growth. And the Pinal County Water Augmentation Authority is assuming a larger role in the pursuit of additional renewable water supplies for M&I uses.

Tribal water settlements have been negotiated and finalized for two of Pinal County's four Native American communities: the Ak-Chin Indian Community and the Gila River Indian Community. Most of the claims asserted by the Tohono O'odham Nation have also been resolved. Discussions with the San Carlos Apache Tribe have been ongoing for some time and show no signs of conclusion. For the most part, these settlements have allocated significant supplies of Colorado River water to tribal control and ownership; water leases are rare, but exist as potential components to Pinal and Arizona short- and medium-term planning.

County leadership is also working with economic development organizations to market the county and to recruit manufacturing and transportation-related prospects. Pinal County is looking forward to the energy and synergy of the Sun Corridor. We are, however, determined to create a future that retains the county's unique identity. That future will include manufacturing, agriculture, green tourism and mining—together providing employment in a blended ratio of county-residents-to-jobs. In other words, residents who live in Pinal County will be able to work in Pinal County. That future will also enable residents to appreciate agriculture as a key part of the county's economy, its commitment to conservation and to the preservation of open space, and its respect for its cultural heritage.

Arizona has no official policy about preserving agriculture; except in the Pinal AMA where we seek to: "…preserve the agricultural economy for as long as feasible." Most Arizonans have assumed that agriculture in the Sun Corridor would be priced out of business as land is converted to subdivisions and water converted to urban uses. Because of our reliance on elaborate irrigation systems, Arizona farms have tended to be large, often corporate, and have generally focused on fiber rather than food. In recent years, agriculture has existed as a kind of holding zone—something to be done with land until it is urbanized. The common refrain has been that an acre of houses uses less water than an acre of crops—which is not entirely accurate as it depends on development density, landscaping and other amenities.

More significantly, there is a fundamental difference between agricultural and municipal water. Municipal water must be highly reliable. It must be always available, and cannot be easily reduced. Agricultural water, on the other hand, may be interrupted if there is a need or a higher value to which the water can be put. This is not true for long-term crops like citrus or pecan trees, but is a relatively widespread practice with cotton, alfalfa and other row crops. In the drought of the past decade, Phoenix metropolitan residents have not suffered mandatory cutbacks (unlike Las Vegas or other arid cities) because agricultural deliveries can be curtailed, preserving water for the cities.[67] As agriculture declines in the Sun Corridor, however, its availability as a buffer will diminish.[68]

In the late 1990s, under pressure from the federal government, the CAP, ADWR, SRP, and others sought to resolve the claims of central Arizona's tribes—principally the Gila River Indian Community—to Gila River water. The Salt and the Verde rivers are the main tributaries of the Gila, but their flows have been fully used by SRP's shareholders. The only significant unallocated water source available to satisfy the Gila community's claims, therefore, was the CAP. Some 653,500 acre feet of water from various sources, including CAP allocations, was dedicated to the tribe.[69] This water will flow to the 375,000-acre reservation lying in the middle of the Sun Corridor between Phoenix and Tucson.[70] This report includes this water in calculating the Sun Corridor supply, since the Gila River community's land is in the Sun Corridor and the water is dedicated to that use. Absent some new policy intervention, the Gila reservation may well be the only long-term significant agriculture to remain in the Sun Corridor. The water can potentially migrate either temporarily or permanently to urban uses.

Price and Conservation

Conservation is best thought of as *demand management*. Reducing per capita consumption stretches existing supplies and allows population to increase without finding new supply.[71] Three strategies have traditionally been pursued. The simplest is educating consumers to use more care in water use inside and outside the home. Phoenix, for example, has successfully educated existing customers and developers of new subdivisions about conservation techniques.

The second major conservation technique involves regulations on water use. Examples include requiring low-flow plumbing fixtures in new construction, limiting landscaping and restricting artificial lakes. The Groundwater Management Act has imposed some of these regulations in the Sun Corridor, such as restricting landscaping in public rights-of-way and limiting turf on golf courses. Cities have imposed regulations through their building codes and in individual zoning cases. Las Vegas has pursued an approach to the extent of paying residents to remove their lawns.

Sun Corridor cities also use pricing mechanisms—the third approach—to promote conservation. Water remains a relative bargain here, even compared to other parts of the U.S. Water is inevitably becoming more expensive throughout the U.S. But increasing its cost is politically difficult, and can raise tough questions of social equity. Municipal water prices are extremely complex, and include huge components for infrastructure costs, treatment costs, and maintenance and delivery. Often "water bills" also include other city services such as sewage and even garbage collection.

TYPICAL MONTHLY WATER BILLS: RANK AMONG 50 LARGEST U.S. CITIES. RANK FROM LOWEST (1) TO HIGHEST (50)

	3,750 Gallons	7,500 Gallons	15,000 Gallons
Phoenix	21	28	26
Tucson	22	14	49
Albuquerque	12	7	5
Atlanta	49	50	50
Chicago	2	2	2
Denver	5	4	10
Las Vegas	20	8	4
Los Angeles	29	40	40
Seattle	50	49	49

Source: Black and Veatch 2009/2010 50 Largest Cities Water/Wastewater Rate Survey.

Tucson has been a national leader in aggressive "block pricing." This makes a minimum block of water available at relatively low cost. A single family homeowner pays less than $2 per 1,000 gallons for the first 11,000 gallons of monthly use—an amount sufficient for use inside most homes. After that, however, the price nearly quadruples. Applying Tucson's four-level pricing structure to Phoenix would achieve dramatic reductions in use, while also causing dramatic changes in landscaping.[72]

This kind of price signal causes permanent behavioral changes, and reinforces conservation far more dramatically than regulation or education. Higher prices are undoubtedly a part of the Sun Corridor's future.

The comparisons of municipal water bills from U.S. cities reflect these complexities and a myriad of considerations having little to do with the actual price of developing water resources. Water is very expensive in Seattle, for example. But it is not needed there for landscaping, so per capita consumption is low. In most of the cities of the arid Southwest, water rates have been kept intentionally low to protect a lifestyle made possible only by subsidized water—first for agricultural settlement, and then for urbanization. When the City of Phoenix sought a 7% increase in January of 2011, it was met with a howl of protest from the citizenry.

The Natural Environment

In the development of the plumbing systems for the Sun Corridor, indeed for most of the Southwest, the place of free flowing streams and rivers has generally been treated as an afterthought. When we tote up how water is "used" whatever is left over for nature was historically regarded as the next source of supply. In the Sun Corridor, water flowing in a river bed is an unusual circumstance, and in an attitude inherited from the reclamation era, was long viewed as "wasted."

Water management decisions greatly impact natural environments throughout Arizona. Fresh surface water and groundwater are the foundation of social, cultural and economic well-being. Healthy freshwater ecosystems provide clean water, food, and fiber for humans, as well as energy and habitat for animals and plants. In the long term, sustainable uses of water resources must acknowledge that preserving and restoring hydrological systems and natural habitats accrue multiple economic benefits to local communities through tourism revenues, enhanced groundwater recharge, water quality protection, reliable water supplies, improved flood control and storm water management, increased air quality, moderated ambient temperatures, recreational benefits, and improved public health.

Surely some of the water supply of the Sun Corridor should be protected and dedicated to the environment. If such a provision is not made, conversion of the full supply to urban uses will seriously degrade the quality of life for all those who live here. How this balance should be struck is one of the central questions of the region's growth. But assigning a number of acre feet to preserve in-stream flows and protect the environment is beyond the scope of this report.[73]

Salt River

V

The Dilemma of the Sun Corridor: How Shall We Choose to Live?

Many of the national negative views of the Sun Corridor's water supply are based on simply analyzing rainfall vs. use and concluding there's a big imbalance. This is true of the TetraTech and Ceres reports cited in the introduction. Sustainlane.com criticizes urban Arizona's sustainability because water comes from far away. The Stockholm Environment Institute looks at all water use, including commercial agriculture, and concludes that it can't continue forever at current levels.

None of these critiques are on point. The population of central Arizona has outstripped rainfall since the time of the Hohokam. Arizona water policy is built around preferring imported, and therefore renewable, surface water. Agricultural use has been steadily, and largely intentionally, converting to urban use.

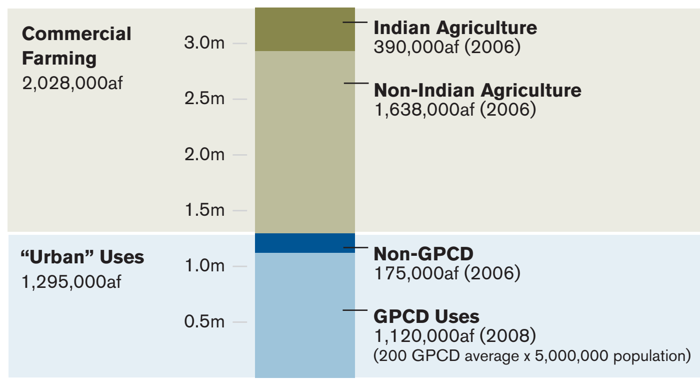
In fact, these critiques are so far off base that many Arizona water managers have never even bothered to respond. If any response is made, it's usually based on the assertion that we have enough water supply to serve a significantly greater population than currently lives here—up to 10 or 12 million people.

The simplistic assertion that there is plenty of water for the Sun Corridor's future is based on this sort of equation: *3 million acre feet x 5 persons/acre foot = 15 million people*. This is unrealistic. Even with our reservoirs, groundwater banking and other reliability mechanisms, we cannot assume that 3 million acre feet is a reliable number. Any allowance for climate change implies a further reduction in the reliability of existing systems. And the future presents an equation in which supply becomes more variable while demand becomes less variable.

It is also inappropriate to use the GPCD number as a proxy for the full urban economy of the Sun Corridor (meaning water uses except for commercial irrigated agriculture). Somewhere between 200-255,000 acre feet are currently being used outside of the GPCD statistic. If we add agriculture to the "urban" chart shown earlier, the total current water use picture looks something like the chart which follows.

This chart shows that the Sun Corridor currently uses about 3 million acre feet every year. The number is in excess of what we concluded was an "average" sustainable supply. Of course some years are above average, but consistent use at this level is the result of groundwater mining. This chart is also a useful graphic demonstration of the place of agriculture as a historical but declining sector of the Corridor's economy. As population increases, irrigated agriculture will continue to diminish. Agriculture is a rational "optional" use. The portion of the chart that shows Indian agriculture is likely to grow as a result of the CAP settlements. Non-Indian agriculture has been on a long decline as the result of both land and water being urbanized. Indian agriculture will likely not follow the same trajectory, since the land is not likely to urbanize with subdivisions.

CURRENT APPROXIMATE TOTAL WATER USE IN THE SUN CORRIDOR



Even if we supposed that all farming—even Indian farming—went away, the question of what population can be reasonably supported by existing water supply remains.

Let us take 2.4 million acre feet as the "supply" assumption, as suggested in part II, and freeze the non-GPCD urban uses at their 2006 level of 175,000 acre feet. That would essentially mean that things like mining, golf courses, and industrial uses will not increase in the future, unless they do so based on a municipal supply that is captured in the GPCD numbers. That may not be a completely realistic assumption, but these uses do not strictly track population growth, so some assumption is necessary. The remaining supply of 2.2 million acre feet becomes the "sustainable" base against which varying per capita use can be considered. This allows us to create a very simplistic matrix of the theoretically supportable population of the Sun Corridor:

Water Supply	**1,800,000af**	**2,000,000af**	**2,200,000af**
Per Capita Use	**Approximate Population**		
200 GPCD (.22 af/yr)	8,182,000	9,100,000	10,000,000
150 GPCD (.17 af/yr)	10,588,000	11,765,000	12,941,000

Running out of water is not imminent. Nor is it conceivable that residents of the Sun Corridor will turn on their taps and have nothing come out. The existing vast plumbing systems, storage mechanisms and redundant supplies are all designed to protect urban domestic use as the paramount water demand. But how we use water in the Sun Corridor is—and will remain—the defining characteristic of this place. The question ultimately becomes how much Sun Corridor residents should adjust their lifestyle and uses of water to accommodate more residents. Using less water per capita will change the way people live. But it will also mean that the water supply can be stretched further. This essential tension manifests itself in numerous policy choices.

- **AGRICULTURE.** The simplest explanation of the Sun Corridor's relatively comfortable water situation is that half of its water is used to grow crops. That huge amount can potentially be rededicated to urban populations and can, therefore, support long-term growth. The assumption has been that the growing megapolitan's future water supply will come from the gradual transfer of water from agriculture to urban uses. But agricultural water and urban water are often not the same commodity, and shifting from the former to the latter "hardens" the demand and erodes management flexibility. In other parts of the country, preserving local agricultural suppliers is an important issue of sustainability, healthy lifestyles, maintaining historic cultures, land use and open space preservation, and anti-globalization trends. All of those issues deserve greater discussion in the Sun Corridor, but the issue of water-management flexibility may well be far more important.

  Suppose, for example, that 500,000 acre feet of Indian water is permanently used for farming. This policy choice might be made by central Arizona's tribal communities. At an average use of 150 GPCD, that's 2.9 million fewer people to be accommodated.

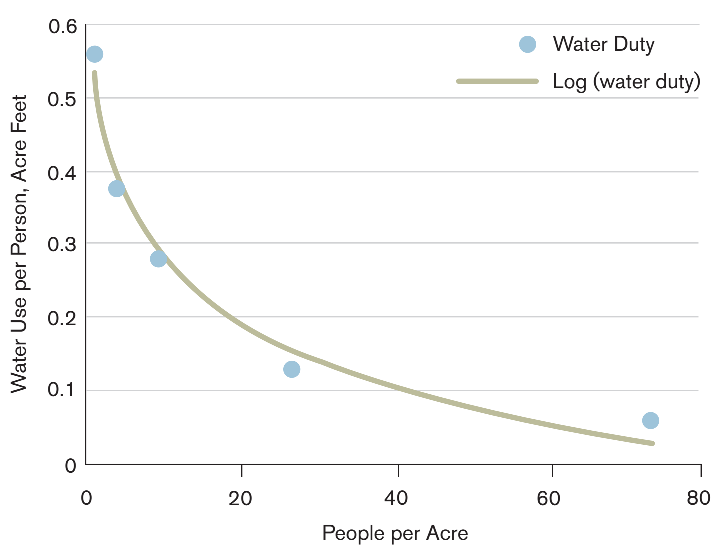
- **ECONOMIC DEVELOPMENT** What kind of an economy do we want to have? How does water use support or limit our economy? Electronics manufacturing, still a staple of the East Valley's economy, uses a lot of water, but does so efficiently and adds high economic value. Growing alfalfa uses a lot of water and has relatively low economic value. Golf courses are high water uses, but if coupled with resort hotels, are a mainstay of tourism, which "imports" dollars into the Sun Corridor. Solar power is a current piece of the state's economic development strategy, but some kinds of solar power generation are high water users. Expanded copper mining—it was, of course, a preeminent member of the "five C's"—uses a lot of water, often in ways that are not fully accounted for in GPCD projections.

  How water supports the economy we want to build must be more carefully integrated into economic development planning.

- **WHERE SHOULD WE GROW?** All parts of the Sun Corridor are not equal. The big cities of the Phoenix metro area, especially those parts within the boundaries of the Salt River Project, have the largest, most reliable and most flexible water supplies. But most recent growth has taken place in smaller municipalities on the west side, and in the high-growth mid-Corridor geography of Pinal County. Over the long term, this may not be a sustainable growth pattern. Either new (and potentially less reliable) water supplies will be needed to support urbanizing areas, or existing supplies will need to flow toward development, or development will need to migrate to areas with firmer supplies. This may well be manifest in a clash between market forces pushing homebuilding outward and legal and institutional protections of existing water rights pushing additional development into older neighborhoods.

- **URBAN FORM.** If development is to move where the most reliable supplies are, the existing built up areas of the Corridor must become more dense. The single-family detached home has been the essential building block of the Arizona lifestyle. But there is evidence that this may begin to change because of price and consumer preferences. Higher-density developments, ranging from patio homes with community swimming pools to multilevel condominiums, consume less water on a per capita basis.[74] Smaller lots present less landscaping area and have a higher percentage area covered by impervious surfaces like roofs and driveways. At significantly higher densities, in multifamily apartments or condominiums, landscaping per resident is even further reduced and may be subject to professional management. Work by Professor Patricia Gober at ASU suggests a dramatic decline in per capita water use at increasing density. But her colleague Ray Quay cautions that recent Phoenix data suggests a need to revisit this relationship. Density may not always be the critical variable; income can be as significant at higher densities as it is in single-family developments.

WATER USE IS RELATED TO RESIDENTIAL DENSITIES



Source: DCDC. Water duties from Salt River Project (2003) Canal Available Capacity Report, Table 2, 1995 Urban Water Duties in AF/Acre. Population densities based on land use classifications from Maricopa Association of Governments 1995 Land Use Classifications, http://www.mag.maricopa.gov/.

- **LANDSCAPING.** If Phoenix were to stop watering its existing Midwestern plant palette, the grass and trees would die and the area would become markedly more barren. Some of the trees that would die are 50 years old and more. Some are located on old golf courses, in historic neighborhoods with an agricultural heritage, in city parks or on the ASU campus. Should some of this landscape go? Phoenix will only reach Tucson's per capita consumption range through such drastic action. Doing so is at odds with Phoenix's history—and may exacerbate the "heat island" effect. But reducing our water use for landscaping remains the most effective way to stretch the water supply. Do we give up the "oasis" nature of the older parts of the city in order to accommodate even more residents?

- **THE LIFESTYLE OF AFFLUENCE.** Low-density single-family homes, lush landscaping , golf courses and multiple cars are all pieces of the lifestyle of affluent twentieth century Americans. In the hot desert of central Arizona there's another simple proxy for that lifestyle: nearly 30% of metropolitan Phoenix residents have private backyard pools,[75] one of the highest percentages in the world. Many of them consider their pools essential to a bearable summer. The average backyard pool holds about 16,000 gallons of water.[76] Evaporation uses nearly 10,000 gallons or more per pool each year.[77]

  Private swimming pools are an icon of a lifestyle of abundance that may be coming to a close for a variety of reasons related to average income, the price of housing, the end of cheap petroleum and a host of deep changes in the nature of society. This particular use of relatively cheap, apparently abundant water also crystallizes a sense of choices and priorities about living in the Sun Corridor. Will the day come when pool construction is limited to those serving larger numbers of people? Or is it more important to continue allowing individual pools? Is this an issue to be resolved through regulation or price or evolving social preferences? Are you willing to give up the right to a backyard pool so that we can have a more reliable supply, or maintain local agriculture, or support natural ecosystems, or allow more people to move into the Sun Corridor?

- **AESTHETICS AND URBAN ENVIRONMENT.** On July 20, 2010, the rubber dam that held back the Tempe Town Lake cracked and burst. Nearly a billion gallons of water moving at 15,000 cubic feet per second rushed down the Salt River channel.[78] Following the break, some people called for not refilling the lake because it was a "waste of water." Tempe, however, cites the lake as the second most-visited tourist attraction in Arizona (after the Grand Canyon). The city also views the lake as an engine of economic development because apartments, condominiums and other development have occurred along its shores. Perhaps most importantly, the lake has become a gathering place in an urban area that too often seems merely a seamless web of beige houses and big-box retail centers. If the Sun Corridor is to offer the kind of urban excitement and amenities other cities have, it will require punctuation marks throughout the urban fabric that concentrate populations and convene people for social and artistic reasons. Harbors, rivers and lakes have always been places where people congregate.

  Is this an appropriate use of Sun Corridor water? Similar uses exist in Scottsdale's Indian Bend Wash and Phoenix's riparian habitat, among others. All are examples of how water can be used to focus the celebration of human life. True, a less water-consumptive alternative to Tempe Town Lake might have been possible, but using water to celebrate life in an arid environment is a basic notion of shared civilization. We can and should integrate water into our urban environment in a way that is both efficient and also provides amenities and supports natural systems. Canals run throughout many urban areas and can serve as paths and trails. Historically, many canals were lined with trees that we cut down to save water—only to use that water to plant new trees in our backyards. Cutting off all celebration of water for its life-giving quality in the desert simply to support more residents is not a rational choice.

- **THE NATURAL ENVIRONMENT.** The most fundamental trade-off of all is the question of to what extent the natural environment of ephemeral desert washes, free-flowing streams and riparian habitats deserves to be protected. In the era of manifest

Generally, higher-density developments use less water per capita. But landscape choices still highly influence per capita water use.

> destiny and the settling of the West that question was clearly answered: uses for people, in farming and building settlements trumped all natural things. Dams, canals, pumping, irrigation and long-distance conveyance of water are all pieces of that decision. In the Sun Corridor there isn't much natural use of water left. But the pressures to continue building a huge urban area in the desert will increasingly require dewatering an ever larger area. It is often said that the era of dam and great canal building is over, partly because many of the best sites are already used, partly because of today's environmental demands, and partly because America's appetite for building great public works seems diminished. But to what extent will we try to protect, or even restore natural environmental benefits in the use of water in the future?

These questions represent the crux of a debate about water use in the Sun Corridor that must unfold over the next decade or more. The future involves complex societal choices which will necessarily be made through a combination of market forces, government regulation and behavioral attitudes. The better informed we are about water issues, the more likely that careful decisions will emerge.

Every bit as important as the potential "answers" to these questions is the process by which they are considered and debated. Arizona, and the Sun Corridor in particular, has long dealt with its water issues through complex, fragmented, overlapping institutions. Cities, counties, water agencies, public and private providers, special districts, the Arizona Department of Water Resources, the United States Bureau of Reclamation, tribal governments, nonprofit organizations and a host of associations have all played a role in the water decision-making process. This multiplicity of actors is sometimes inefficient and slow moving. But it has served us well. Having issues debated over and over, dissected, fragmented, and reexamined is beneficial when thinking about very long-term consequences and planning horizons. Making decisions in small increments is a good system for avoiding a big mistake. As challenges mount and increase in velocity, however, it may be time for some institutional change. A host of questions about decision making structure needs to be part of the debate. Should more "Sun Corridor wide" thinking be represented by new entities? Will the Department of Water Resources ever be rebuilt to its former capacity? Should municipalities more deliberately coordinate their regulatory and pricing policies for consistent goals and administration? What about the consistency of messages to the public?

Decisions about water are inherently political, but often require larger-scale and longer-term thinking than is typical of political bodies. Institutional evolution has occurred in Arizona's past: SRP, CAP and ADWR were all political creations within this challenging context. Dealing with the challenges of the Sun Corridor's future will spur further evolution.

As choices are made and decisions implemented based on projections like the ones in this report, then the projections themselves will change and new choices are possible. This feedback loop is what gives human society its endless adaptability and resilience. But there will also be unanticipated challenges and resource constraints to deal with, and novel institutions and solutions required to react. It is always important to predict and try to anticipate the future. But the only sure thing is that you will need to revisit every decision again and again.

Final Word

The watering systems of the Sun Corridor stand as a shining example of the power of previous generations of Arizonans to build civilization in a harsh and difficult environment. The challenges of little local rainfall and highly variable supply were met with dams, wells, canals and recharge basins. The challenge of competing demands was met with court decrees, legislation, treaties and compacts. All in all, it is a pretty remarkable story of human ingenuity. Water, among all things, has been what Arizona does really well.

The history and the existing reality of the watering systems of urban Arizona is apparently lost on a range of commentators from other parts of the country who look at this very dry place, and conclude it just cannot make sense for so many people to live here. Even more importantly, a large portion of the people who do live here do not understand where the water comes from or how much there is. Hopefully this report, and whatever larger dialogue occurs as a result, will at least help those who live in, and care about, the Sun Corridor, to better understand the nature of the issues.

Today there are a host of new challenges on the horizon—particularly the horizon after the mid-2020s. Competing in a global, and increasingly urban, economy will change the competitive position of the Sun Corridor. Climate change may further stress an already stretched water supply. Future variability may outstrip the storage systems built to manage the past. Agriculture may disappear. The return of rapid population growth will likely necessitate dramatic changes in lifestyle, particularly the lifestyle of desert dwellers at the high end of the socioeconomic ladder.

The Sun Corridor exists only because past Arizonans worked together tirelessly to build a vast, complex plumbing system. Using the power of government to do this represented the clearest consensus imaginable about serving the needs of society through collective action. The real question today is whether we still have that shared commitment to this place and its future, and whether we still trust in the power of collective action to meet these new challenges with the same faith and creativity.

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