



ARROYO

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Closing the Water Demand-Supply Gap in Arizona

There is an acknowledged gap between future water demand and supply available in Arizona. In some parts of Arizona, the gap exists today, where water users have been living on groundwater for a while, often depleting what can be thought of as their water savings account. In other places, active water storage programs are adding to water savings accounts. The picture is complicated by variability in the major factors affecting sources and uses of water resources. Water supply depends on the volume that nature provides, the location and condition of these sources, and the amount of reservoir storage available. Demand for water reflects population growth, the type of use, efficiency of use, and the location of that use. In a relatively short time frame, from 1980 to 2009, Arizona's population grew from 2.7 million people with a \$30-billion economy to nearly 6.6 million people with a \$260-billion economy. Although it slowed since 2007, growth is expected to continue. Growth also varies by location, so projections of water demand for different areas varies from sufficiency to shortage. Legal and political factors, as well as economic and financial factors, play a part in the availability, distribution, and uses

of water. As a result, there is no one-size-fits-all solution to closing the water demand-supply gap.

Introduction

Many information sources were used to develop this issue of the *Arroyo*, which summarizes Arizona's current water situation, future challenges, and options for closing the looming water demand-supply gap. Three major documents, however, provide its foundation. All three conclude that there is likely to be a widening gap between supply and demand by mid-century unless mitigating actions are taken.

The first document is the Colorado River Basin Water Supply and Demand Study (<http://www.usbr.gov/lc/region/programs/crbstudy.html>), a massive report released by the U.S. Bureau of Reclamation (Reclamation) in December 2012. It was compiled with input from the seven Colorado River Basin States (Arizona, California, Colorado, Nevada, New Mexico, Utah, and Wyoming) and other partners and stakeholders. The report projected a median imbalance

of 3.2 million acre-feet (MAF) of water by the year 2060 for the Colorado River Basin and adjacent areas that use Colorado River water. It acknowledged that water demand had already surpassed the average annual Colorado River supply and that continued drought and climate change are likely to have additional impacts on the Colorado River supply. With the release of the report, three follow-up workgroups were formed to carry out what was named the Moving Forward process. One focused on agricultural conservation, productivity, and water transfers; a second on municipal and industrial conservation and reuse; and a third on environmental and recreational flows (including hydropower). The workgroups were tasked with evaluating and quantifying current trends and potential future programs and identifying actions that address projected supply and demand imbalances. Composed of a diversity of stakeholders, these collaborative efforts resulted in the *Moving Forward Phase 1 Report* released by Reclamation in the spring of 2015. The report presents an extensive list of recommendations, highlighting the varied options that exist.

For the Arizona picture, the second document relied upon is the final report completed by the Water Resource Development Commission (WRDC) (http://www.azwater.gov/AzDWR/WaterManagement/WRDC_HB2661/Meetings_Schedule.htm). The development of this report, released in 2010, was a major undertaking for Arizona with input from multiple committees. The Commission was formed by the Arizona Legislature to study issues related to water sustainability. The Commission found that developed water supplies in Arizona were estimated at 6.5 to 6.8 MAF per year in 2009. Developed supplies include groundwater, surface water, and reclaimed water for which infrastructure for production and delivery is in place. Undeveloped groundwater and reclaimed water supplies, for which infrastructure is needed were considered additional water sources. From a demand perspective, the WRDC reported total statewide demand projections in 2035 between 8.1 MAF and 8.6 MAF. Total demand projected for 2060 by the WRDC ranged from 8.6 MAF to 9.1 MAF. Unless additional supplies are developed and more stringent conservation measures are implemented, this demand could result in a statewide projected demand-supply gap somewhere between 1.8 MAF and 2.6 MAF in 2060.

The third foundational document, which was prepared by the Arizona Department of Water Resources (ADWR) and released in early 2014, is *Arizona's Next Century: A Strategic Vision for Water Supply Sustainability* (Strategic Vision) (http://www.azwater.gov/AzDWR/Arizonas_Strategic_Vision/). The Strategic Vision drew on the Reclamation and WRDC reports in addition to ADWR's internal informational resources. It concluded that over the next 20 to 100 years, Arizona will need to identify and develop an additional 0.9 to 3.2 MAF of water supplies to meet its projected demands. The somewhat different gap projections reflect different time scales and supply definitions. ADWR reported that

there are 7.7 MAF per year of water supplies currently developed or readily available in Arizona. These supplies include already developed groundwater, diversions from in-state rivers, reclaimed water, and Colorado River water from the main stem, either directly or from the Central Arizona Project (CAP). The Strategic Vision adopted the WRDC's population growth and water demand projections.

The Strategic Vision pointed out that many rural Arizona cities and even some larger metropolitan cities may not be able to finance needed water supply projects through the traditional funding or financing mechanisms. As noted in the WRDC report, needed regional water supply projects identified in Arizona are estimated to cost, collectively, many billions of dollars.

Water Sources and Their Challenges

Renewable water supplies are the foundation of water sustainability. Each year the natural water cycle provides fresh supplies to replace the water used in the previous year. Renewable supplies are deposits in the state's water checking account. The Colorado River supplies roughly 65 percent of Arizona's renewable water supplies, according to ADWR. While the Colorado River is Arizona's largest renewable supply, other renewable supplies include in-state rivers, natural recharge into groundwater aquifers, and treated wastewater.

The Colorado River

The Colorado River supports approximately 40 million people and 5.5 million acres of irrigated cropland. Seven states in the United States, and two states in Mexico, Sonora and Baja California, share the River's water. When the U.S. portion of the Colorado River Basin was apportioned in 1922 by the Colorado River Compact, the Upper Basin (Colorado, New Mexico, Utah, and Wyoming) and Lower Basin (Arizona, California, and Nevada) were each allocated 7.5 MAF of water. In 1944, the United



The "bathtub ring" showing decline in water elevations at Lake Mead.
Source: National Aeronautics and Space Administration

States and Mexico through a treaty, apportioned 1.5 MAF of Colorado River water for delivery and use in Mexico, bringing the total amount of water apportioned in the Colorado River Basin to 16.5 MAF. The 1922 Compact used data from a very wet period in the Basin, from about 1900 to the early 1920s, when average flows were approximately 17 MAF. Recent research has shown that long-term average flows are more likely between 13 and 15 MAF per year. As a result, the full use of entitlements leads to long-term shortages, even with normal water supplies conditions on the river. Since 2003, Lower Basin states have used all of their apportionment, while Upper Basin states have yet to fully utilize their apportionment. Although less than full utilization by the Upper Basin states has masked the impacts of over-apportionment, the continuing regional drought is reducing river supplies.

Lower Basin water supplies are released from upstream reservoirs, notably Lake Powell, and stored for release in Lake Mead, the largest reservoir on the Colorado River system. Reclamation, which acts as watermaster under the authority of the Secretary of the Interior in the Lower Colorado River Basin, operates the reservoirs.

Lake Mead, which can store 28 MAF, is filled largely by upstream releases from Lake Powell. Although the 2007 “Colorado River Interim Guidelines for Lower Basin Shortages and Coordinated Operations for Lake Powell and Lake Mead” (Interim Guidelines) specify a possible range of releases from Lake Powell, the “minimum objective release” is 8.23 MAF. The minimum objective release represents the normal release from Lake Powell to Lake Mead.

A 8.23 MAF release plus tributary inflows between Lee Ferry and Lake Mead total 9 MAF per year. Water use in the Lower Basin totals 10.2 MAF, which includes reservoir evaporation, riparian vegetation use, and other operational losses. Thus, under normal operating conditions, there is an annual deficit between available supplies and water consumption of 1.2 MAF. This deficit results in a decline of about twelve feet per year in Lake Mead in normal water supply years.

The CAP’s report on the State of the Colorado River in 2014 noted that annual releases from Lake Powell would have to exceed 9.5 MAF to raise Lake Mead’s elevation to a level sufficient to avoid shortages in the near term. Given the current state of Lake Powell, that would require inflows of historic proportion, nearly 16 MAF. This is roughly the same inflow as recorded in 2011, which was the 14th highest flow to Lake Powell observed in the 105 year inflow record.

As part of the 2007 Interim Guidelines, the Lower Basin states agreed to a schedule for reducing water use. In a separate agreement in effect through 2017, Mexico agreed to accept voluntary reductions to its 1.5 MAF allocation in shortage years. According to these agreements, Arizona, Nevada and Mexico will reduce their water diversions by specified amounts, when water levels fall to specified trigger elevations. The first shortage trigger level is at

elevation 1075 feet. Reclamation will declare a first level shortage when its August 24-month Study projection for the following January 1st is at or below elevation 1075 feet.

Arizona’s annual apportionment of Colorado River water is 2.8 MAF, with approximately 1.2 MAF for irrigated agriculture, population centers, and Native American communities adjacent to the river. The remaining 1.6 MAF is delivered by the CAP to population centers, wildlife refuges, irrigated agriculture, and Native American communities in Maricopa, Pinal, and Pima Counties. Completion of the CAP provided a much needed supply of renewable water to these areas. However, to gain necessary financial support for the project from Congress, Arizona agreed that the CAP would have junior water right status relative to California. Accordingly, should a severe shortage occur, Arizona’s CAP water allocation could be reduced to zero before California is required to cut its use.

ADWR and CAP have emphasized that Central Arizona and its water users are prepared for potential near-term shortages on the Colorado River. With a shortage declaration, CAP water supplies to the Arizona Water Banking Authority and a portion of the CAP water supply for groundwater replenishment would be eliminated. Agricultural users in central Arizona would also see impacts, and CAP water rates would increase. Any near-term shortage is unlikely to affect water supplies to Arizona’s cities, towns, industries, tribes, and mines. Water suppliers and users have been proactively building

Lake Mead Elevation	Arizona Reduction	Nevada Reduction	Mexico Reduction
1075’	320,000	13,000	50,000
1050’	400,000	17,000	70,000
1025’	480,000	20,000	125,000

Colorado River shortage reductions in acre feet.
Source: Central Arizona Project

resilience through underground storage, conservation, and water recycling, and ADWR and CAP are taking steps to address the risk of Colorado River shortages and improve the health of the river system by working in collaboration with the Colorado River Basin States, federal government, Mexico, and local and regional partners in water resource management.

Groundwater

Renewable groundwater sources are rainfall and snowmelt that infiltrate into the earth and recharge aquifers. They also include incidental recharge, which is the return of water to the aquifer incidental to its use. In the areas where it has active groundwater management responsibilities, ADWR estimates that roughly one MAF of groundwater are annually recharged, naturally or incidentally. Most groundwater used in Arizona, however, is nonrenewable. That is, it has been accumulating

underground for hundreds to thousands of years and is replenished extremely slowly. Geologic conditions for groundwater vary across Arizona, but a region reaching from the northwest corner through the southeast third of the state—the basin and range province—contains vast quantities of this “fossil” groundwater. Although it is nonrenewable, it is often viewed as a long-lasting water supply. Like a savings account, continued withdrawal will eventually lead to depletion. Locally, where municipal and agricultural demands have consistently been met by groundwater, these aquifers have seen significant declines, limiting their value to water sustainability.

The Groundwater Management Act of 1980 and subsequent legislation created a regulatory structure for reducing and eliminating groundwater depletion in those areas of the state where it was deemed to be severe. Five groundwater basins are designated Active Management Areas (AMAs) in the state. As of 2006, just over 82 percent of Arizona’s population lived in the five AMAs, which include the Phoenix and Tucson metropolitan areas and many smaller cities and towns.

In-State Surface Water

Renewable supplies in addition to water from the Colorado River are provided by in-state river systems, which supply an average 1.2 MAF annually. The major reservoir storage systems used to manage these supplies are located on the Salt, Verde, Gila, and Agua Fria rivers. The dams operated by the Salt River Project store and regulate the Salt and Verde Rivers for its member lands in the metropolitan Phoenix area.

Legal factors affect use of Arizona’s in-state river systems. Two on-going legal proceedings, the Gila River and the Little Colorado River General Stream Adjudications, aim to determine “the nature, extent and relative priority of the rights of all persons to use water” in the Gila and Little Colorado River systems. These adjudications will resolve all claims and rights established throughout Arizona’s changing water management history. Both adjudications have been in progress for decades—the Gila River Adjudication began in 1974 and the Little Colorado River Adjudication began in 1978—and resolution is not

foreseen in the near future given the complexity of the proceedings.

The watersheds in these two adjudications make up more than half of the land in Arizona, including some of its most populous urban centers, such as Phoenix, Tucson, Flagstaff, and Prescott. Together these adjudications encompass over 71,000 square miles and include almost 98,000 claims. The parties comprise both private and public interests, including tribes, national parks, military installations, mining corporations, municipalities, agriculture, and electric utility companies. The uncertainty represented by these unresolved claims creates additional challenge in planning to meet the water demands of the future.

Most surface water supplies in Arizona come from precipitation in the form of snow and rain.

Snowpack constitutes the biggest reservoir in the West, holding water from winter storms until thaws release flows in the spring through early summer.

The seasonal timing of snowpack and rainfall have been changing since the 1950s in the western United States. Winter snowpack is melting earlier in the year; some snow storms are replaced by rain; and April snowpack frequently contains less water. Earlier snowmelt decreases the amount of water available for agriculture during the growing season, increasing evaporation from reservoirs, and diminishing river flow. Changes in the timing and volume of snowmelt also affect the ecological conditions of watersheds, which in turn can have long-term impacts on environmental river functions, like river fisheries, and on the health of forests.

Current and Future Water Demand

According to the Strategic Vision, water demands, driven by future economic development, are anticipated to outstrip existing supplies despite Arizona’s strong water management foundation. The greatest emerging influence on water demand in the state comes from extraordinary population growth. Between 2000 and 2009, Arizona’s population increased 30.3 percent by adding 1.6 million people. A majority of this growth occurred in communities bordering Arizona’s large cities, and along the Sun Corridor spanning Phoenix and Tucson. Growth is projected to continue in these locations as the state recovers from the national economic downturn, which stalled population growth in most of the state.

Since 1980, despite dramatic population and economic growth, each decade state-wide water use has either declined or remained constant at approximately 7 MAF. On a statewide scale, reduced water demand has resulted from retiring agricultural lands, the increasing use of reclaimed water, and widespread conservation efforts of farmers and municipalities. For example, the number of people living in Metro Phoenix (Phoenix and its surrounding cities) increased by 157 percent between 1980 and 2010.



Melting snowpack in the Colorado Rocky Mountains.
Source: Cody Sheehy

Deposits into Arizona's Water Savings Accounts

From 1996, when first established, to 2014, the Arizona Water Banking Authority (AWBA) saved more than 3.3 MAF of unused Colorado River water at a cost of nearly \$219 million. The stored water is to be used in times of shortage to secure water supplies for Colorado River and CAP municipal and industrial water users. Recovery planning is underway.

These water supplies also fulfill the state's water management objectives to store water for use as part of water rights settlement agreements with Arizona Native American communities. Additionally, the ABWA assisted Nevada through interstate water banking by storing over 600,000 acre-feet, including both Arizona and Nevada's unused Colorado River apportionment, at a cost to Nevada of \$109 million.

Phoenix, Tucson, and other cities have been recharging CAP and reclaimed water to store water for future need. The member cities of the Arizona Municipal Water Users Association, an organization made up of ten cities in the larger Phoenix metropolitan area, have invested \$400 million to store nearly 1.7 MAF underground—enough to meet their collective needs for over two years. The opposite of groundwater mining, this activity adds to Arizona's water savings account. Unlike reservoir storage, water stored underground has negligible evaporative losses. A total of 9 million acre-feet of water has been stored underground in Arizona, including ABWA storage.

However, water use increased by just 87 percent. In Phoenix alone, where population grew 83 percent, the per-capita demand for water decreased. Much of Arizona's reduced demand is attributed to conservation efforts and water management initiatives. These include the Groundwater Management Act's mandatory conservation requirements for agricultural, municipal, and industrial water users within the AMAs and the adoption of plumbing codes mandating low water use fixtures.

Municipal and Industrial Demand

Even with remarkable demand reduction efforts, growing populations and their water demands will exceed existing supplies. Because of population growth, the WRDC projected statewide water demand will increase to between 8.1 and 8.6 MAF by 2035 and to between 8.6 and 9.1 MAF in 2060. These projections were made before the economic downturn, during which growth slowed; therefore, these projections reflect high growth scenarios. In addition, it was assumed that per capita water demand would remain the same, although it actually has declined in recent years.

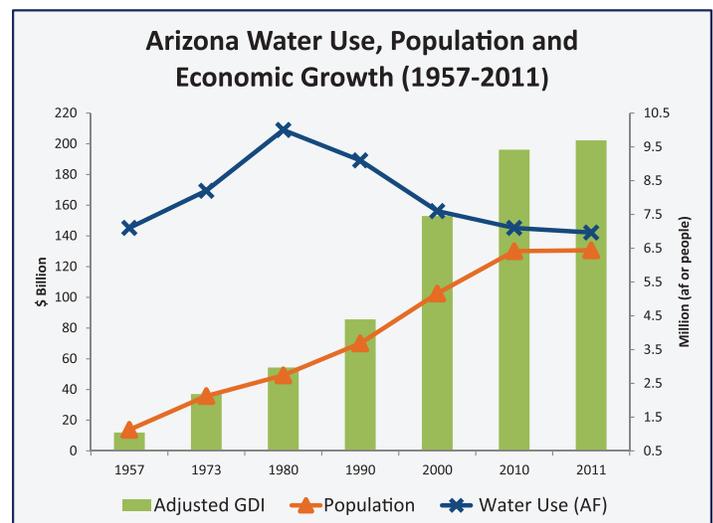
Even so, providing water for people will become an increasingly urgent need for Arizona by the middle of the 21st Century. Municipal water demand makes up the second largest sector of water demand in the state. Measured at 1.6 MAF, or 25 percent of all state water demand in 2006, the WRDC projected municipal demand to increase to roughly 2.7 MAF by 2035 and 3.4 MAF by 2060.

Many companies, from small businesses to corporations, rely on substantial amounts of water. Industry uses about 6 percent of Arizona's water supply or about 400,000 acre-

feet per year. Of this, mining and thermoelectric energy production accounts for roughly 200,000 acre-feet per year and golf course irrigation uses much of the rest. Sources include groundwater, surface water, and recycled water.

Aside from mining, thermoelectric generation and golf courses, industrial withdrawals provide water for purposes such as fabricating, processing, washing, diluting, cooling, or transporting a product; incorporating water into a product; or for sanitation needs within a manufacturing facility. In Arizona, industries include aerospace and defense, technology, innovation and venture capital, bioscience and health care, optics and photonics, and advanced marketing and business solutions. Intel's \$300 million research and development facility in Chandler, and GM's new Innovation Center dedicated to automotive software improvement (driverless cars) are examples of a growing industrial sector in Arizona. The U.S. Geological Survey's (USGS) 2010 report, *Estimated Use of Water in the United States*, stated that 12.9 million gallons per day (mgd) (14,400 acre-feet per year) were withdrawn for self-supplied industrial demand in Arizona. Water volumes supplied by water providers were not included in this estimate.

Plentiful supplies of water are critical for mining operations. About 65 percent of the nation's copper is mined in Arizona, as well as gold, silver, molybdenum, and lead. Arizona also produces non-metallic minerals including sand and gravel, crushed stone, clay, gypsum, lime, perlite, pumice, and salt. In 2005, there were 72 mining companies operating 126 mines in Arizona. In addition, 70 sand and gravel quarries operated throughout the state. Mining companies have been instrumental in creating water infrastructure in some areas. Freeport-McMoRan Copper & Gold Inc., a major mining company in Arizona (formerly Phelps Dodge Corporation) developed extensive systems, constructing large dams, reservoirs, pumping plants, and pipelines to support their facilities in six Arizona counties in cooperation with federal, state, and



Arizona Water use, population and economic growth 1957-2011. Source: Arizona Department of Water Resources

local agencies. According to USGS estimates, self-supplied water used by mining was 86.6 mgd of groundwater (96,200 acre-feet per year) in Arizona. Water supplied by water providers was not included in this total.

Steam-driven turbine generators use water to generate thermoelectric power. The water intensity of this use depends upon the type of cooling system. Traditional coal-fired generating plants in Arizona use an average of 548 gallons per megawatt hour (gal/MWh) and natural gas plants use 300 gal/MWh. In 2010, Arizona withdrew 86,700 mgd (97,100 acre-feet per year) to meet the demand of the thermoelectric-power sector. Groundwater supplied 74 percent of withdrawals and surface water supplied 26 percent. Reclaimed water use was 67.6 mgd (75,700 acre-feet per year), used mainly by the Palo Verde Nuclear Generating Facility.

Some renewable energy sources demand less water. For example, the Agua Caliente Solar Project, located near Yuma, Arizona, one of the largest operating photovoltaic power plants in the world, has an essentially zero water footprint for electricity production. Not all renewables can boast such stringent water use, however. Wet concentrated solar power, biomass, and wet geothermal sources all use over 500 gal/MWh, putting them in the same range as traditional sources.

Agricultural Demand

Agriculture has long been the largest water demand sector in the state. Since 1980, agriculture has demanded between two-thirds and three-quarters of all water used in Arizona. As calculated by ADWR, agricultural water demand refers to surface water diversions and groundwater pumped for agricultural uses. A portion of this water is consumed in agricultural production and a portion drains back into the surface and groundwater system.

Agricultural demand is declining in terms of both water and land use. The retirement of agricultural lands for surrounding urban and suburban expansion has been a major reason for this decline. Average agricultural water demand at the turn of the 21st century was roughly 5.6

MAF, but WRDC projections for 2035 and 2060 show this demand declining to 4.8 and 4.4 MAF, respectively.

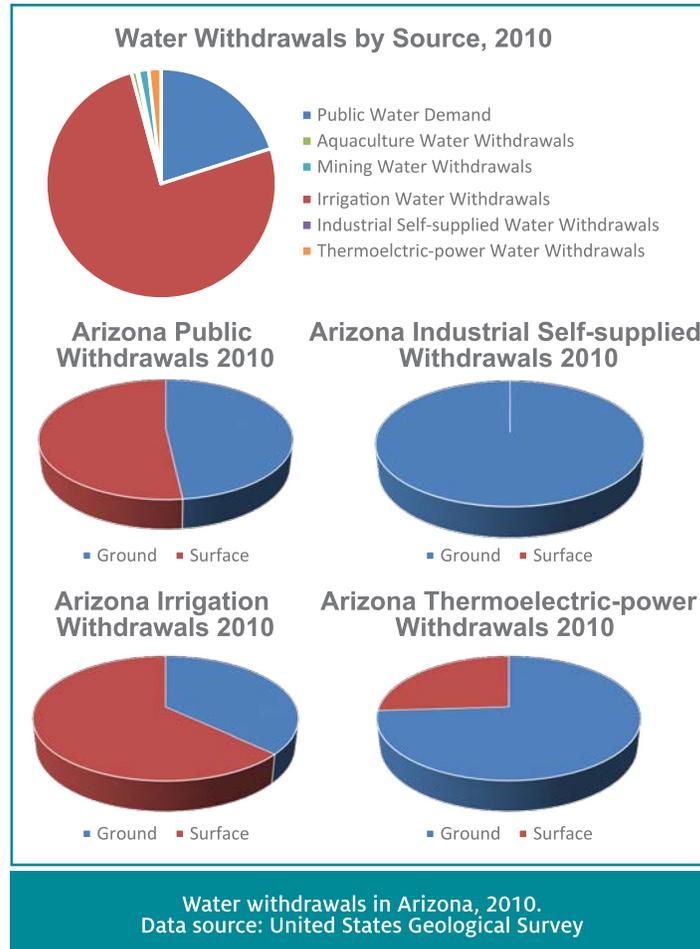
Most agricultural demand is for irrigation. According to the U.S. Department of Agriculture, there were 993,000 acres of irrigated land in Arizona in 2010. Types of irrigation systems include sprinklers, surface water irrigation, in which water flows across the surface of the land by gravity, and newer systems like micro-irrigation, in which water is applied to plant root zone at low volume and under low pressure.

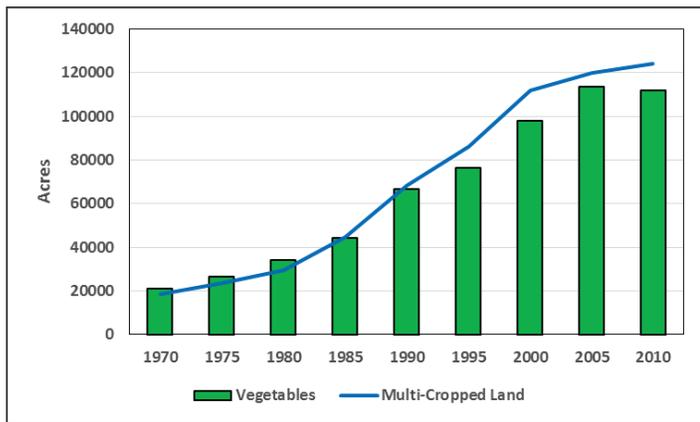
Surface water is the source for the majority of the irrigation in Arizona. Surface water contributed 3.2 MAF to irrigation in 2010. Groundwater contributed 1.9 MAF. The average application rate of water to crops in Arizona was 5.16 acre-feet of water per acre. Aquaculture used 53,000 acre-feet of water, supplied primarily by groundwater, and livestock operations accounted for 30,000 acre-feet, all from groundwater.

The Yuma region is a highly productive agricultural area because of its long, nearly frost-free growing season, fertile soils, and a dependable supply of irrigation water. Agricultural water use efficiency improved over time as production shifted from perennial and summer-centric crops, such as alfalfa,

citrus, and cotton, to winter-centric, multi-crop systems that produce vegetable crops. In addition, most Yuma growers now use highly efficient level furrow or level basin surface irrigation systems, which have average application efficiencies from 80 to 85 percent. In 2006, almost 30 percent of the water diverted from surface water or pumped from groundwater for agriculture in Arizona was used in Yuma and the Lower Gila sub-regions, as defined in the Arizona Water Atlas.

Pinal and Maricopa Counties have two of the largest agricultural areas in Arizona, although Yuma County has more production and water use. Agricultural water use in 2006 in these two counties together was estimated at almost 36 percent of diverted surface water and pumped groundwater. Crops grown in Maricopa County and Pinal counties include alfalfa, cotton, wheat, other grains, and some vegetables. A decrease in agricultural demand with the growth of population centers was evident in 2006,





Irrigable acres planted in vegetable and multi-crop production systems in Yuma County, 1970-2010. Source: Yuma County Agriculture Water Coalition

when more than 130,000 acres of agricultural land had been urbanized since 1984, mostly in Maricopa County.

Other areas of agricultural production include the Lower Colorado River above Yuma, the Gila Bend region, and southeastern Arizona in the Upper Gila watershed. Agricultural water use by sovereign Native American tribes and communities should also be considered in accounting for total water demand in Arizona. The Colorado River Indian Tribes, the Ak Chin, Tohono O’odham, Gila River, Salt River Pima Maricopa, and Ft. McDowell Indian Communities, among others, have agricultural operations.

New to Arizona, wine production has been growing. While in most areas the number of acres in irrigated agriculture is stable or declining, between 2004 and 2011 the number of wineries expanded from fewer than 10 to more than 50. There are three established grape growing regions in Arizona – Sonoita/Elgin in Santa Cruz County, the Greater Willcox region in Cochise County, and the Verde Valley in Yavapai County, and vineyards can be found in Pima, Graham, Mohave, and Gila counties. A relatively low water use and high value crop, wine grape production is beginning to show local impacts on water use.

Environmental Demand

Most of the value from water for natural areas is derived from instream flow and associated shallow groundwater that support riparian and aquatic ecosystems. It is difficult to include allocations of water for natural areas in new water plans because there are few legal requirements to do so and scientific data on water needs for riparian and aquatic species and related habitats are either not available or are site specific and complex. An analysis of 121 studies by Mott Lacroix and colleagues, published in *River Research and Applications*, reveals that only approximately 22 percent of perennial or intermittent river-miles in Arizona have been studied for some aspect of the water needs of riparian and aquatic species and ecosystems; there are only limited generalizable data for aquatic species; and only 11 percent of 135 species have been studied more than once.

There are few instream water rights for natural areas in Arizona and the West because they are the newest form

of water rights. In Arizona, individuals and organizations can obtain a certificated instream flow water right from ADWR. This right protects non-consumptive uses such as wildlife habitat or recreation. As of June 2015, there were 43 certificated rights, two permits (pending certification), and 90 applications for in-stream use.

In the past, acquiring a water right required diversion of water from the stream, so surface water was largely allocated before there was a process for acquiring instream flow rights. In addition, the legal separation between groundwater and surface water in Arizona makes protection of instream flows more difficult because, even where instream flow rights do exist, the impacts of groundwater pumping that diminishes stream flow and depletes shallow aquifers is not necessarily recognized. The long-term result is that water in streams has diminished as surface water and groundwater demands by other water using sectors have increased.

Most attempts to have natural areas included in water planning efforts have been focused on cooperation among different water interests. The WRDC’s Environmental Working Group is an example of a recent effort to bring water needs of natural areas into planning. Through many meetings and discussions, the WRDC Environmental Working Group created an inventory of Arizona’s water-dependent natural resources and estimated flows currently supporting riparian and aquatic species in 11 Arizona streams. The inventory created by the WRDC was used in the Reclamation’s Central Yavapai Highlands Water Resource Management study to include natural areas in planning for the region.

Evidence exists that retaining water in natural areas has some public support. Environmental organizations such as The Nature Conservancy and Arizona Land and Water Trust are using conservation easements to protect land and stream flows that support natural ecosystems. Communities are engaging in dialogues that place water dependent ecosystems on the water planning agenda. Sierra Vista in Cochise County is actively implementing near-stream recharge specifically to support flow in the river and buffer it from up-gradient groundwater pumping. Programs such as Conserve2Enhance in Tucson, which connects municipal water conservation with ecological restoration efforts, are demonstrating that people value water in the environment enough to make direct contributions to support wetland and riparian restoration, in-stream flows, and green infrastructure.

Environmental regulation, such as the Endangered Species Act, can also affect water allocations. The presence of endangered species can trigger requirements for meeting the water needs of specific water-dependent ecosystems. On the Lower Colorado River, implementation of a multi-species conservation program includes water needs for riparian and aquatic species. The program utilizes land and water resources dedicated to the National Wildlife Refuges located along the Lower Colorado River to mitigate

impacts from operations of the water control structures on the river.

Supply and Demand Management Solutions

One of the primary goals of Reclamation’s Colorado River Basin Supply and Demand Study (Colorado River Basin Study) was to analyze potential water management options to help “sustain the environment, people, and economy of this region.” That study and the Strategic Vision both highlight potential solutions to decrease demand, increase supplies, adjust operations, and modify governance. Regardless of the potential of any one solution, there is a general consensus that diverse solution portfolios are needed to prepare for the projected imbalance, continued drought, and changing climate.

Further analysis of potential solutions by the Moving Forward workgroups resulted in a long list of recommendations. These included steps to enhance conservation and water efficiency, as well as protect environmental and recreational flows. The focus of the recommendations was on planning, outreach, partnerships, coordination, incentives, sustained funding, and infrastructure improvements. This focus highlights the challenges and complexities of meeting future water needs.

Conservation

Conservation is generally considered the “no regrets” option for water management. It is applicable to any water use, relatively inexpensive, and quick to implement compared to acquiring new supplies. Conservation reduces withdrawals from the water bank account, leaving water for the future. It comes in a variety of actions from individual behavioral changes to infrastructure efficiency upgrades and water management practices. Conservation in the municipal, industrial, and agricultural sectors is expected to yield additional water savings in the future, but other actions will be needed to fill the growing gap between supply and demand.

Municipal Conservation

Many local governments, water providers, and individuals carry out mandatory and voluntary conservation practices. Water managers are developing far-reaching, diverse, and relatively low-cost conservation measures to prepare for future water supply stresses. Several city water utilities, including Prescott, Tucson, Flagstaff, and Scottsdale, provide incentives and rebates for residential and commercial users to remove turf and

install water-efficient household fixtures. Water providers in these and other areas offer educational programs for rainwater harvesting, water smart landscaping, and indoor conservation practices.

Free and low-cost audit programs are also offered by many Arizona water utilities to detect leaks and test meter accuracy to reduce system losses. Repairing, retrofitting, and replacing existing infrastructure can aid in efficiency. In 2008, system losses ranged from 2.5 to 11.9 percent for 17 of the largest utilities around the state. The City of Chandler surveyed and repaired over 400 miles of its distribution system and saved an estimated 8.8 million gallons (27 acre-feet) of water in 2008.

Progressive or conservation tiered rate structures (increasing block rates) have been implemented by many water providers to keep water prices low for modest daily needs and provide disincentives for high-water use. In 2008, Prescott, Tucson, Buckeye, and Payson had the four steepest tiered water rate structures in the state.

Large and medium-sized municipal water providers located within AMAs (those that deliver more than 250 acre-feet per year for non-irrigation use) are required to participate in a conservation program, and many have chosen the Modified Non-Per Capita Conservation Program. Public education is a key component of the program. Water providers must also implement one to ten Best Management Practices (BMPs) depending on their size. BMP categories are public awareness, education and training, outreach services, incentives, ordinances/conditions of service, and physical system improvements. The BMPs that are designed to serve residential customers include, among a long list of options, conservation training; physical systems evaluation; incentives for water audits; and rebates on low-use appliances. BMPs are also tailored to commercial customers in the AMAs.

Arizona’s rapid growth in the 1990’s brought attention to sprawl and negative effects of unregulated development. In 1998, then-Governor Jane Hull signed the Growing Smarter Act, followed by the Growing Smarter Plus Act in 2000. In terms of water supplies and management, smart growth can help to decrease overall demand. A study conducted by the Colorado Water Conservation Board in 2010 found that, starting from a 50/50 indoor and outdoor water use scenario, a 20 percent increase in density led to a 10 percent decrease in per-capita water demand. A smaller lot size generally reduces the amount of

landscaped outdoor area. The rate of decrease diminishes as density increases. The City of Avondale instituted Commercial and Residential Infill Incentive Plans in 2004 to strongly encourage and incentivize infilling through

Usage Charges	
Customer Class/ Charge Categories	Charge per Ccf
Residential Block Rates	
Single Family	
1-10 Ccf	\$1.38
11-15 Ccf	\$3.00
16-30 Ccf	\$7.00
Over 30 Ccf	\$11.25
Duplex-Triplex	
1-15 Ccf	\$1.38
16-20 Ccf	\$3.00
21-35 Ccf	\$7.00
Over 35 Ccf	\$11.25

Tucson Water residential tiered rates, 2015.
Source: Tucson Water

fee waivers, relaxed design standards, and streamlined reviews.

Industrial Conservation

Although industry uses a relatively small proportion of Arizona's water, industrial conservation can save substantial amounts of fresh water locally. For example, Intel in Chandler recycles up to 75 percent of its water with a program that recovers, treats, and returns a portion of its rinse waters to the aquifer, and uses reclaimed water for mechanical systems (i.e., scrubbers, cooling towers), landscape watering, and farm irrigation. In 2012, PepsiCo Frito-Lay was awarded a U.S. Water Prize for its Casa Grande snack food manufacturing facility. An innovative process water reuse system allows the facility to run almost entirely on recycled water and produces nearly zero waste. The 650,000-gallon-per-day process water recovery treatment system recycles up to 75 percent of the facility's process water; the facility reduced its annual water use by 100 million gallons.

The Palo Verde Nuclear Generating Station is one of the primary examples of in-state, water-efficient projects because it uses 100 percent reclaimed wastewater to cool its nuclear reactor cores. In fact, it is the only nuclear power plant in the world to use reclaimed wastewater for its cooling water supply. The facility receives nearly 20 billion gallons of reclaimed wastewater each year from five Phoenix area cities and recycles the reclaimed water through condensers and cooling towers an average of 25 times before the blowdown is discharged to evaporation ponds for final disposal.

Energy-water conservation can go even further with the use of dry or hybrid cooling instead of wet cooling technology for power generation. A study in 2007 by the Arizona Water Institute found that conversion to such cooling methods could save an average of over 75 percent of water used by power generation plants. Dry cooling, however can be substantially more expensive than wet cooling given the relatively low price of water. By one estimate, the price of a water right would have to exceed \$17,000 per acre-foot for the cost of dry cooling to be equal to wet cooling. Renewable energy sources also provide an avenue for dramatic water use reductions. Photovoltaic solar, dry concentrated solar power, and wind average only 30 to 85 gal/MWh, which can make them extremely competitive in situations of restricted water availability.

Many Arizona energy utilities have stated explicit goals to reduce energy water use. For example, Palo Verde's parent company Arizona Public Service has a goal of reducing water use per kilowatt hour 24 percent by 2029, and Tucson Electric Power plans on reducing water consumption 16 percent from 2012 levels by 2020.

Agricultural Conservation

Agricultural conservation is another potential source of long-term water savings. Within AMAs, BMPs employed in the two most recent management periods include

converting to more efficient irrigation systems, such as drip and sprinkler irrigation, which can reduce water use up to 50 percent. BMPs require about 70 percent efficiency, and recent studies show that Pinal AMA irrigation districts have achieved 85 percent efficiency by using laser leveled



Lined irrigation ditches installed at Morning Star Farms in Florence, Arizona, to improve irrigation efficiency. Source: National Resources Conservation Service

fields, sprinklers, and drip. Other conservation BMPs include employing irrigation scheduling, crop rotation, land fallowing, and increasing organic matter in soils. State tax credits are also given to farmers for up to 75 percent of the cost of purchasing or installing water conservation systems.

Agricultural water efficiencies have increased in most areas of the state as technology helps farmers apply the optimal amount of water for the crops being raised. Optimizing inputs, such as water, lowers the cost of production, increases yields, and has led many farmers to adopt more water efficient practices. In the Yuma area, irrigation water diverted to farms decreased 15 percent since 1990 and nearly 18 percent since 1975. Factors contributing to this reduction include a reduction in irrigable acres, expanded use of multi-crop production systems that require less water, and significant improvements in crop and irrigation management and infrastructure.

Although the Colorado River Basin Study lists agricultural conservation measures among the least costly options available, they are not necessarily inexpensive for individual farming operations. Some irrigation districts in the Pinal AMA have invested \$3,700 per acre on lined systems and efficient irrigation. For farmers, the market prices of crops and their ability to pay the up-front costs of conservation measures can often have greater influence over whether they employ such practices than the potential water savings. In addition, state surface water law requiring farmers to use their water rights or lose them

can be a strong disincentive for farmers to invest in water conserving infrastructure. Legal and institutional changes that provide new conservation incentives could motivate additional agricultural water savings, but practical considerations present barriers to such changes.

Reuse

Treated wastewater (“reclaimed water”) is playing an increasing role in supplying water demands and many planners in Arizona are looking to reuse treated wastewater to augment freshwater supplies. The reclaimed water supply increases as population grows. Often, its



Tucson’s Reclaimed Water

Since 1984, Tucson Water has maintained one of the most extensive reclaimed water programs in the state, with delivery to nearly 1,000 diverse sites including golf courses, parks, schools, and more than 700 single family homes. Enough potable water is diverted from non-potable purposes each year to supply over 60,000 families. The utility encourages the use of reclaimed water through subsidized rates lower than rates for potable water. The lower rate, \$797 per acre-foot, is not enough to cover total costs of the operation.

Photo Source: Marie-Blanche Roudaut, WRRC

major users, such as riparian ecosystems and irrigators downstream of water reclamation plant discharges, are uncounted in official calculations of water reuse. Thus, although the Arizona Department of Environmental Quality (ADEQ) reported in 2011 that 65 percent of all wastewater treatment plants in the state already distribute water for reuse, reclaimed water use makes up only 3 percent of the state’s total use according to ADWR. A study done for the CAP shows, however, that 95 percent of the reclaimed water generated in the Phoenix, Pinal, and Tucson AMAs is used for beneficial purposes. These purposes include agriculture, underground storage, power generation, industrial uses, turf irrigation, and riparian habitats. Flagstaff’s second largest water user, SCA Tissue,

has been using reclaimed water for years to manufacture recycled paper products.

Water may also be recycled through residential and commercial graywater systems. Graywater, which is water from washing machines and bathroom sinks, showers, and tubs, excludes water from toilets and kitchen sinks. It is typically used as a source of water for irrigating landscaping. ADEQ streamlined the permitting process for graywater, substituting informative guidelines for regulatory hurdles.

Where reclaimed water is concerned, the WRDC report conservatively estimated that 0.75 MAF of treated wastewater would be generated in 2035, and with continued population growth, the quantity will continue to grow to just under 1.3 MAF in 2110. The Strategic Vision reported that greater use of this water source could reduce Arizona’s projected water imbalance by 50 percent through 2110. This would require a significant increase in developed capacity for reuse.

Although use is increasing, many municipalities in Arizona do not use all their reclaimed water supplies. Development of reclaimed sources is often limited by a lack of available infrastructure, and many municipal planners are looking at ways to expand their distribution systems. State water quality laws mandate a set of pipes for reclaimed water separate from potable water pipes. In general, managers across the state try to direct reclaimed water towards non-potable uses, to reserve potable supplies for human consumption.

Public support of water reuse is essential to its growth as a water supply. As public awareness of water scarcity challenges grows, acceptance of non-potable reuse has increased. The idea of potable use of reclaimed water, however continues to generate negative reactions from many members of the public. Increasing water quality standards for reuse may be able to change negative public perceptions, and the Strategic Vision suggests mounting a campaign to address this issue.

In San Diego, the San Diego Public Utilities hopes to begin treating 83 mgd by 2035 for potable reuse, blending the produced water with other potable water sources. San Diego differs from many other desert cities in that it lacks an underground aquifer to store the produced water for later potable use.

Letting reclaimed water seep into an aquifer before pumping it out for later use takes advantage of the natural water treatment capabilities of soil aquifer treatment (SAT) and avoids the stigma of the “toilet-to-tap” epithet sometimes associated with potable reuse. Arizona has an extensive aquifer system and many utilities can choose to recharge aquifers instead of placing the highly treated wastewater directly into the potable water system. SAT is a relatively inexpensive option for treating water for reuse, which makes it even more attractive for Arizona water planners. The Town of Gilbert uses recharge basins costing \$1.3 million to recharge reclaimed water that is eventually

pumped and blended with water in the potable water system.

The City of Tucson is moving ahead with plans to develop a reuse system that will take reclaimed water from its upgraded wastewater treatment facilities to recharge the aquifer, pump it back out, treat it to drinking water standards, and blend it with other potable supplies for distribution. Many water planners are looking ahead to the greater efficiency of reusing produced water directly in the potable water system.

Transactions

Both the Colorado River Basin Study and the Strategic Vision urge water planners to investigate the option of water transactions as a method for closing the demand-supply gap. The Western Governors' Association and Western States Water Council also urged a close look at transfer options in a report titled "Water Transfers in the West, Projects, Trends, and Leading Practices in Voluntary Water Trading". Transfers can involve water from various sources and can be temporary or permanent. From 1988 to 2009, Arizona saw 217 transactions—including sales and leases—totaling 8.4 million acre-feet, according to this report.

There are established laws, policies, and procedures for transfers of groundwater, Colorado River water, and intrastate surface water. They are designed to protect local area of origin interests and other water users and water right holders in the system. As a result, water transfers can be cumbersome to implement, making it difficult to assess their potential. With few exceptions, the transportation of groundwater from one groundwater basin to another is prohibited under state law. Stakeholder input is sought when transfers of Lower Colorado River water are contemplated. A person who holds a vested or existing water right that may be affected by a surface water transfer within Arizona can file an official objection with ADWR. These processes are intended to prevent negative impacts from occurring when the water is moved. If a comprehensive study that satisfies stakeholders were to be carried out on how to assess impacts, the transfer process might be streamlined.

Surface water law permits sales through "sever and transfer" of surface water rights, if criteria are met. Because current Arizona law reserves water not used by an appropriator for other appropriators (the so-called "use it or lose" provision), a farmer cannot sever and transfer a right to surface water saved through conservation.

In order to transfer a right to conserved water, a change in law would be required. Such a change would be difficult to make, but a 2015 study by Culp, Glennon, and Libecap suggests that with the right balance of free market and government oversight, water conserved through greater efficiency could be permanently transferred to municipal or industrial use without damaging local economies. Opportunities provided by such a market could motivate irrigators to implement greater agricultural water efficiency. While any complete survey of potential resources to fill the water demand-supply gap should include changes in law and institutions, they would require greater consensus than currently exist.

Transactions in surface water through various lease arrangements also occur in Arizona. Native American Tribes have leased CAP water to non-Indian water users where such arrangements have been enabled by water settlements entered into by the tribes as sovereign entities. In 2015, these leases made up roughly 8 percent of CAP deliveries. Appropriators can lease their water rights without forfeiting them through "use it or lose it", provided the water is beneficially used for five or more consecutive years. In a 2006 article by Colby, Smith, and Pittenger, the authors found that by fallowing only a small percentage of agricultural land irrigated with Lower Colorado River water, substantial amounts of water could be saved. Forbearance contracts, in which irrigators forbear to divert water to fallowed fields for a season, could make this water available to other users on a short-term basis.

In Arizona, an experiment in fallowing for water saving is ongoing. For this pilot project, the Yuma Mesa Irrigation and Drainage District (YMIDD) is fallowing up to 1,500 acres (10 percent of the district's irrigated acreage) per year for a base rate of \$750 per acre. The replenishment arm of CAP, termed the Central Arizona Groundwater

2014 Intern Sees Holistic Solutions to Multi-faceted Challenges



Madeline Ryder, the Montgomery & Associates Summer Writing Intern at the WRRC was a senior with a dual degree in Natural Resources (B.S.) and Environmental Studies (B.A.). She graduated in December

2014. Interning at the WRRC guided her in understanding Arizona's complex relationship with water. Her goal for the future is to further understand her place in the world, through her interactions with other people and the environment. She has always been sensitive to environmental issues and learns more and more each day about respecting

and caring about the lives of other human beings as well. Many times, environmental and social injustices go hand-in-hand, and working towards a solution for one can often only work long-term if it addresses both. After graduating, Madeline hopes to do work that brings attention to the many degraded ecosystems and disadvantaged people in this world by highlighting our common values and ways to support each other.



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Replenishment District (CAGR), has contracted with the YMIDD and is leaving the saved water in Lake Mead. The CAGR contemplates larger transactions to eventually provide water to replenish groundwater pumping in Central Arizona. Larger scale following operations are already underway in California, where the Palo Verde Irrigation District (PVID) has an arrangement with the Metropolitan Water District of Southern California for a 35-year program to transfer up to 118,000 acre-feet annually through following up to 28,000 acres per year in the PVID. A similar and even larger arrangement exists between the Imperial Irrigation District and the San Diego County Water Authority.

California also has a water bank to facilitate short-term transfers of water. A mechanism such as this, which brokers certain types of water transfers between parties, such as short-term leasing arrangements, could operate in Arizona if such an institution were created.

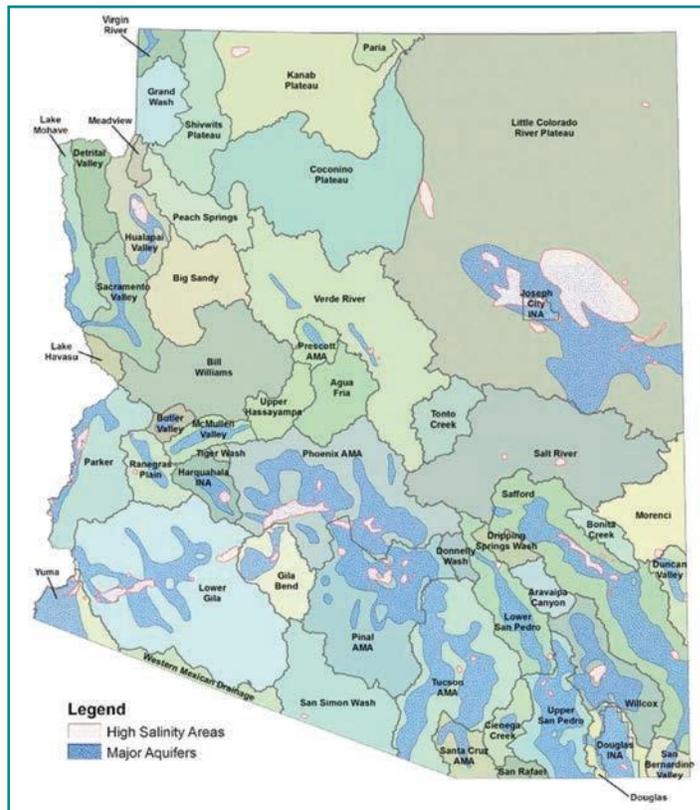
Even if laws and institutions were modified to facilitate water transactions, the issue of physical transportation infrastructure remains. The Strategic Vision surveyed the transportation issues, which include obtaining permits for rights-of-way over federal land in addition to engineering and financing issues.

Arizona has a system that allows underground storage of water and development of long-term storage credits (water stored for more than one year) that may be purchased. The water retains the legal character of the water stored—CAP, reclaimed water, or, in limited cases, other surface water. This system allows the renewable water banked in one area to be legally withdrawn in another, but only within the same AMA or groundwater basin. This mobility, however, has raised concerns about local groundwater depletions, when water is pumped from sub-basins distant from the recharge. An active market in long-term storage credits exists because of the advantages of recovering renewable water and the ease with which these transactions can take place.

Groundwater Reserves

The available data and estimates (from the USGS, ADWR, and other entities) indicate that there is a large amount of groundwater within the state: approximately 1.2 billion acre-feet in storage down to 1,000 to 1,200 feet below land surface. If this amount of groundwater were used, there would be about 12.5 million acre-feet available annually for the next 100 years. Some portion of the large amount of groundwater in aquifer storage within the state could potentially be developed to supply projected future unmet demands.

There are several barriers to using this supply. Groundwater is extremely variable as to its location, quality, and ease and cost of development. Large relatively untapped supplies are likely to be long distances from potential users. Large-scale withdrawals could have negative consequences, including subsidence and environmental impacts. Inter-basin transportation of



Major aquifers in Arizona. Source: Arizona Water Map, WRRC

groundwater was prohibited except in specified cases by the 1991 Groundwater Transportation Act, preventing AMAs from acquiring rural groundwater supplies. Potential impacts on rural communities were a major concern when the law was enacted.

Even if transportation of groundwater from one basin to another were permitted, the difficulties of moving the water from its basin of origin to its place of use raise significant barriers in cost and permitting. Long-distance transportation of groundwater pumped in one area of the state to another area would be prohibitively expensive for most water uses. Realistically, any groundwater developed and transported long distances may only be practically affordable to some municipal and industrial water users.

Even within an AMA or groundwater basin, the available groundwater may be located distant from areas with highest projected demands. In addition, the depletion of this groundwater sets up risks for future water security. Sustainable use of groundwater generally means that no more groundwater is withdrawn than is recharged on a long-term basis, however, the data is lacking to define long-term maintenance of groundwater aquifers for most of Arizona. Regional studies are needed to determine what groundwater usage is sustainable or optimal from a public policy perspective.

Brackish Groundwater

Areas of brackish groundwater are found across Arizona and represent a source of additional supply. Reducing the high salt concentration in brackish groundwater could

make it suitable for potable use. A study by Montgomery & Associates, a water resources consulting firm, identified an estimated 600 MAF of brackish groundwater obtainable in Arizona down to 1,200 feet. Some of this is associated with salt in sedimentary formations, but other contributors include agricultural runoff and wastewater recycling.

Desalination of brackish water is less expensive than seawater because of the much lower salt concentration of the brackish water. In addition, distances from water source to users are generally shorter. In the Buckeye area, irrigation drainage water has contributed to an area of shallow brackish groundwater that could be a source for desalination. A desalination plant operated in the area for over two decades beginning in 1962. A newer facility was later closed when it was considered uneconomical. Other municipal and private facilities in the state desalinate brackish water, including a prison and a bottling plant.

In landlocked Arizona, disposal of brine is an issue. Aquifers in Arizona are considered drinking water aquifers and therefore protected from degradation through discharge of brine by injection or basin spreading. The method of brine disposal used most often in Arizona is evaporation ponds, which can become costly as the volume of brine and need for more land increases. Designing desalination facilities for higher efficiency has the additional benefit of minimizing the brine stream, but these facilities may be more costly to build and operate.

Texas serves as an example of the potential for brackish water desalination plants to augment water supply. The state has 34 operating plants with a collective capacity of 73 mgd (roughly 490 acre-feet per year) at an average cost of \$1.50 per 1,000 gallons. In El Paso, the site of the world's largest inland desalination plant, brine is disposed of through deep well injection.

Augmentation

Augmentation refers to acquiring new water through any of several methods. The Strategic Vision and Colorado River Basin Study both indicate that some kind of augmentation will likely be part of the portfolio of future water supply strategies, as efforts to stretch existing supplies are unlikely to be sufficient to balance future supply and demand. Large-scale augmentation is a high priority for study now, considering the long lead time needed from concept to implementation. Smaller scale augmentation can also provide new supplies that may be cumulatively significant.

Importation

Importation of significant freshwater supplies has been suggested. It is the least likely option to be developed, considering the needs of the already-established communities along the Mississippi, Missouri, Green, Snake, and Columbia Rivers from which the supplies would come. The costs would be relatively high as well, and significant controversy is associated with these options on environmental, political, financial, and regulatory

levels. State water planners take into account long-term, changing water scenarios, and the potentially more drastic water gap in the future may keep these options from being completely dismissed.

Seawater Desalination

Seawater desalination is a very attractive option for many because of its potential for supplying substantial quantities of new water. Any efforts to establish



The Yuma Desalter

Operating the Yuma Desalting Plant could produce approximately 78,000 acre-feet of desalinated water to augment Colorado River supplies. The facility was constructed in 1992 to treat saline agricultural return flows from the Wellton-Mohawk Irrigation and Drainage District that were raising salinity in the Colorado River above levels acceptable to Mexico. While the plant was in construction, the drainage water was channeled away from the river, which helped resolve Mexico's concerns. The plant operated briefly in 1993. Following closure for repairs, it was not operated again due to normal and surplus conditions on the lower Colorado River, along with budget constraints. Prolonged drought in the basin brought attention back to plant operation. In 2012, it was operated at 1/3 capacity, for a pilot run, which resulted in over 30,000 acre-feet of conserved water. The pilot revealed that several upgrades should be considered if the plant were to operate at capacity. While the pilot operation cost about \$300 per acre-foot, the Colorado River Basin Study, estimated the cost would be \$600 per acre-foot (\$1.84/1,000 gals) for sustained operation, assuming five years of permitting and five years of implementation. Objections raised against operating the plant include: finding an environmentally safe means of brine byproduct disposal and ensuring a source of water for the wetland formed from the diversion of Wellton-Mohawk drainage, the Cienega de Santa Clara, which has become an environmental asset in Mexico.

Photo Source: U.S. Bureau of Reclamation

desalination facilities, and arrangements for bringing the new water to Arizona, will take a great deal of lead time as they involve multiparty negotiations, regulatory hurdles, and large financial commitments. Generally, options for acquiring and delivering desalinated sea water require substantial investment in treatment and transportation infrastructure. There are also issues regarding access to the water and the availability of electric power. Potential sources for sea water desalination for Arizona would be California or Mexico. Exchanging desalinated sea water

for some of California's Colorado River apportionment could be an option. Securing a supply from Mexico through an international agreement would involve the State Department in negotiations. Nevertheless, Mexican options exist. A recent study analyzed the potential for a desalination plant located on the Sea of Cortez, near Puerto Peñasco. In one scenario, desalinated water would be pumped to Imperial Dam north of Yuma. That water would flow into Mexico, while the same amount of Colorado River water could be diverted from the river upstream by users in the United States. A second option would be to import desalinated water from the Sea of Cortez into Arizona. Transporting water into Arizona would add substantially to costs. The United States and Mexico have agreed to further study of desalination projects that would benefit both nations. Two concepts are under study: one on the Pacific coast near San Diego and a Sea of Cortez concept in Sonora, Mexico.

California has already begun a seawater desalination project that many state officials are treating as the deciding case study for 15 other proposed desalination projects along its Pacific shoreline. The plant is situated in Carlsbad in San Diego County and is expected to begin operations in 2016. If successful, the project will be the largest desalination operation in the Western Hemisphere. Construction costs total \$1 billion and the plant will use a reverse osmosis treatment to produce 50 mgd. A 54-inch transmission line will carry the water 10 miles to the nearest existing transmission facilities. Annual operating costs are estimated at approximately \$50 million and about 50 percent of that cost would be for energy needed to operate the facility. The water will cost San Diego \$2,014 to \$2,257 per acre-foot, almost twice the cost of traditional sources.

Watershed Management

There are several proposed methods of watershed management that could increase runoff by decreasing vegetative water consumption. Some plans would also



Tamarisk and Russian olive, non-native species in Glen Canyon Dam National Recreation Area. Source: U.S. National Park Service

work in tandem with other natural resource goals, such as habitat restoration and fire risk reduction.

Removal of tamarisk (or salt cedar) from riparian corridors can provide multiple benefits, including restoration of native habitat. Tamarisk is an invasive, high-water-use species that was introduced in the 1930s to control soil erosion and quickly out-competed native species in riparian areas. It alters flow regimes for streams and rivers, increases fire frequency, and often develops into monoculture stands. Tamarisk has been found to be habitat for endangered birds, however, and removal can require the creation of replacement habitat. One commonly cited tamarisk removal study took place at a dried lake bed in 1989 in Artesia, New Mexico. The lake had dried after a tamarisk invasion in the 1960s. Application of an aerial herbicide resulted in 95 percent control of tamarisk. After application, the water table around the lake rose by 6 to 12 inches per month, and since 1996 there has been continuous water present.

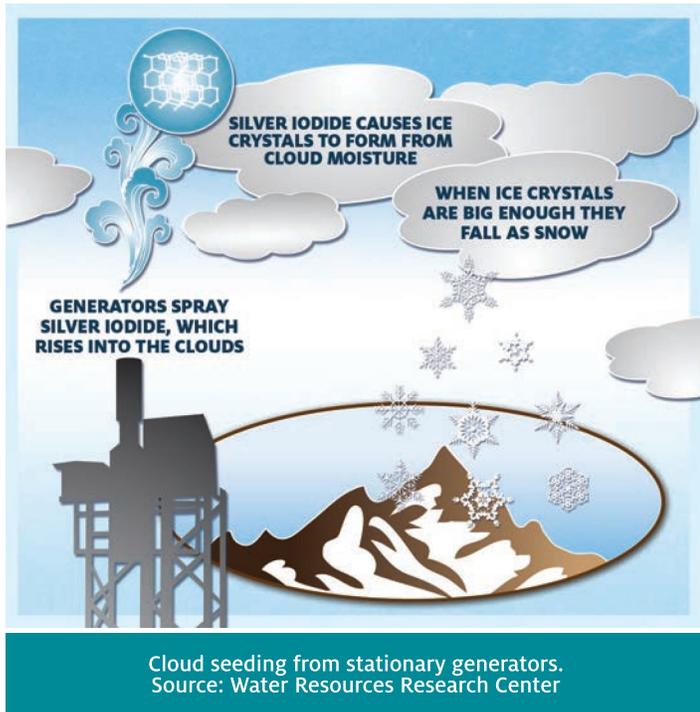
Forest management is another proposed watershed management option. Thinning of unnaturally dense forests can increase runoff through reducing vegetative consumptive use and allowing more snow and snowmelt to reach the forest floor. While it may increase runoff, increased yield is not a given. In addition, if it is determined to increase yield, it does so in a stream system that is fully appropriated in the context of the general stream adjudication. On the other hand, watershed management does increase the landscape resiliency to insect and other human pressures in the face of drought and climate change.

Forest management can also reduce the potential for unnaturally intense and large-scale fires. Such fires leave watersheds vulnerable to flooding and erosion producing heavy sediment loads in streams and rivers and accumulation of silt in reservoirs. These post-fire impacts can reduce storage capacity in reservoirs and result in both short- and long-term infrastructure impacts. There are also increasing costs to treat post-fire runoff water supplies. In November 2012, Flagstaff voters approved a \$10M bond to support a partnership effort between Arizona, Flagstaff, and Coconino National Forest for treatments, such as thinning of trees and prescribed fire, to help reduce the risk of devastating wildfire and post-fire flooding in the Rio de Flag and Lake Mary watersheds.

Large-scale removal of vegetation is a suggestion for directly increasing runoff; however, multiple uncertain or negative consequences for forest health, water quality, infiltration, and flow regime, including flood potential, are closely associated with such an approach. The Strategic Vision suggests that other natural resource efforts such as the Four Forest Restoration Initiative, a forest management program being implemented in northern Arizona, can provide more holistic benefits.

Weather Modification

Weather modification often refers to the practice of cloud seeding, using technological means to increase



precipitation, either as snow or rain. In order for precipitation to occur, water droplets in clouds need particles around which ice crystals can form. In cloud seeding, silver iodide compounds are the most commonly introduced particles, either via aircraft or ground-based generators. Ground-based generators are frequently cited as the least cost method, with operating costs in the \$25 to \$50 per acre-foot range. In 1974, Reclamation released a study on weather modification for the southwest region that indicated 300,000 acre-feet of potential additional supplies could be created in the Lower Basin states. A majority of that amount could come from Arizona, with the greatest possible output being along the White Mountains and Mogollon Rim.

Questions about the potential negative impacts of large scale weather modification programs have largely been addressed through the sustained operation and regulatory experiences in states such as North Dakota, California, Colorado, Idaho, Utah, and Wyoming. State permitting processes protect against liability for environmental consequences, such as increased flooding risk, increased snow removal, and avalanche hazard, by requiring that cloud seeding operations be suspended if snowpack is higher than a specified threshold. In all states, no ownership of seeded snow or resulting runoff is credited to the seeding entity; it becomes system water distributed by normal allocation processes.

The effectiveness of weather modification has yet to be quantified. In 2003, the National Research Council concluded that there is “no convincing scientific proof of the efficacy of intentional weather modification efforts.” Individual projects, however, have touted the practice’s efficacy. Idaho Power has employed cloud seeding projects since 2003 and has reported that precipitation increases of 7 to 9 percent have occurred in targeted areas. Utah water

providers have also reported between 8 and 20 percent increases during year-long projects in 2000 and 2001, though the data shows no distinct correlation between the number of generators or prior seeding projects and precipitation increases.

The Wyoming Weather Modification Pilot Project has conducted cloud seeding activities every winter season since 2007 in three Wyoming mountain ranges. The project report, released in December 2014 by the Wyoming Water Development Commission, concluded that seeding could increase snowfall between 5 and 15 percent. Hydrological models indicated the resulting increase in stream flow was between 0.4 and 3.7 percent. Although the study had some technical problems, based on its results and the low relative cost, the United States, Arizona, California, Nevada, Utah, Colorado, and Wyoming are funding cloud-seeding pilot programs in mountains that feed the Colorado River watershed.

Rainwater Harvesting

A simple definition of rainwater harvesting is the capture and storage or use of precipitation runoff. The water can be used for non-potable purposes, such as landscaping and infiltration into the aquifer without treatment. It has also been used indoors to flush toilets. As practiced in Arizona, rainwater harvesting is usually employed on a small scale for single houses, commercial properties, industrial lots, or parks. As long as the price of water is relatively low, the payback period for investing in water harvesting at these scales can be very long. No permitting is necessary for residential water harvesting in Arizona. A 2005 study conducted at the University of Arizona found that city-wide on-site rainwater harvesting and use for landscaping could reduce residential water use by 30 to 40 percent. Evidence, however, is lacking regarding water savings from existing water harvesting installations.

Larger-scale techniques for the capture of rainwater or storm-water can be used for residential subdivisions, commercial developments, industrial sites, parking lots, roads, and highways. Large-scale rainwater harvesting and storm-water capture can have benefits beyond augmenting non-potable water supplies, such as controlling storm-water runoff volume, peak flooding, and pollutant loading from urban areas. The potential for storm-water capture to replenish local aquifers can be another significant benefit. Collectively, these benefits can contribute to better overall urban watershed management.

Cities that implement water harvesting projects may not see overall reductions in water use because the harvested water is often used to irrigate new landscaping. Other benefits provided by water harvesting, such as supporting vegetation that provides shading to reduce energy demand for cooling and combat the effects of the urban heat island, may be stronger motivators than offset in potable demand.

There are concerns from some water rights holders that capturing rainwater reduces flows that otherwise would enter the surface water system. Until recently, rainwater



Water Resources Research Center
College of Agriculture and Life Sciences
The University of Arizona
 P.O. Box 210437
 Tucson, AZ 85721-0437

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harvesting was illegal in Colorado because it was believed that collecting rainwater would reduce regional watershed replenishment by precipitation. In 2009, however, Colorado began allowing permitted well owners to collect rainwater after a pivotal study found that 97 percent of all precipitation either evaporates or is taken up by plants before ever reaching the State’s river systems. According to this study, collecting rainwater would save precipitation that would otherwise evaporate before use. In Arizona, a Joint Legislative Committee on Macro-Harvested Water was formed in 2012 to evaluate large-scale rainwater harvesting and its potential impact on water supplies as well as other issues that are associated with harvesting water on a large scale. However, that Committee has never met.

Conclusion

By acknowledging and assessing the growing gap between sustainable water supplies and water demands, Arizona advances the process of statewide water planning for a secure water future. Although there will always be pressure to meet increasing needs, Arizonans have worked together to produce solutions, such as the Groundwater Management Act, CAP, and the SRP system, all of which create added certainty for water users. Next steps, however, present major challenges. As discussed

above, many options exist, but to assemble a balanced portfolio of options, Arizona will need to engage in broadly based dialogue and harness the will of its citizens and elected officials and the cooperation of its neighbors. Arizonans consider water to be one of the primary issues in need of policy attention and are looking for ways to contribute to timely solutions through individual and community actions. Arizona water planners have found opportunities to work within the state to expand supplies and with our state neighbors to develop solutions, such as water exchanges and cost-sharing agreements, but additional efforts are needed. Large water projects take a tremendous amount of time for public acceptance, funding, permitting, and construction, and yet timely action is needed to forestall potential negative impacts to the state’s economy and environment. Large water projects alone, however, will not close the demand-supply gap, so thought must be given to options at all levels. There will be costs for any solutions and they must be considered along with the tradeoffs that are a part of all choices. Attention to environmental water needs can contribute to building a functionally resilient plan when water using sectors come together to find solutions. Research and education are essential to clarify choices and increase understanding of costs and consequences. Responsive and well-informed leaders must point out the most promising pathways and inspire action.

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