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How a Drought-Resilient Water Delivery System Rose Out of the Desert: The Case of Tucson Water

TUCSON (ARIZ.) WATER'S COMPLEX JURISDICTIONAL EXPERIENCES HAVE DEMONSTRATED THE IMPORTANCE OF AN OPEN AND CONSULTATIVE DECISION-MAKING PROCESS—AND DEMONSTRATED THE BENEFITS OF COLLABORATION WITH OTHER UTILITIES AND JURISDICTIONS AND THE VALUE OF SHARING LESSONS LEARNED.

The City of Tucson (Ariz.) operates Tucson Water as a city department. Tucson is the largest city in southern Arizona, with a population of 524,000 people as of 2012. It is located within Pima County, which had a 2012 population of 990,000. The boundaries of Tucson Water's service area are not coterminous with the city borders; most but not all Tucson residents are served by Tucson Water, and about one-third of Tucson Water's customers live outside the city limits. Tucson has an incorporated area of 587 km^2, with Tucson Water having a service area of 906.5 km^2. The number of people served by Tucson Water in 2012 was estimated at 709,000. Approximately 56% of Tucson Water's deliveries are to single-family homes and 19% to multifamily homes, with the remaining 25% going to commercial and industrial water users. Figure 1 depicts the city's boundaries and the service area of Tucson Water.

TUCSON'S INTRICATE WATER AUTHORITIES

There is a complex jurisdictional interweaving of water responsibilities in Tucson. Other water providers, both publicly and privately owned and operated, serve parts of the Tucson metropolitan region. Tucson Water does not collect and treat wastewater from its customers; instead, Pima County provides wastewater collection and treatment services to most Tucson Water customers. Through an intergovernmental agreement, in 2012 Tucson Water had control over about 41% of the 76×10^6 m^3 of treated wastewater produced by

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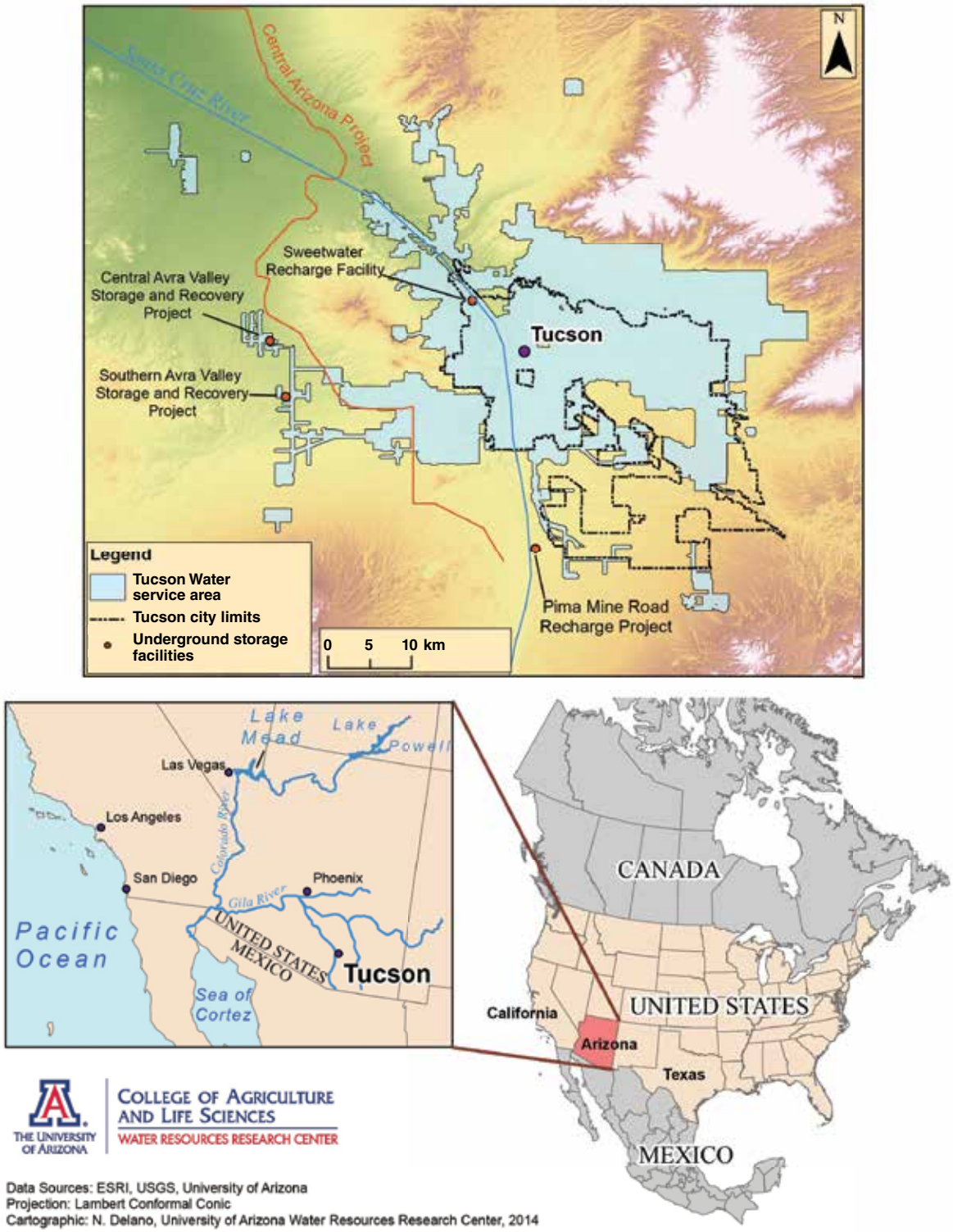
FIGURE 1 Locator map and Tucson Water service area



USGS—US Geological Survey

Key landmarks include the boundaries of the city of Tucson; Tucson Water's service areas; and Central Arizona Project's Pima Mine Road Recharge Project, Southern Avra Valley Storage and Recovery Project, and Central Avra Valley Storage and Recover Project.

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Sweetwater Wetlands is part of the City of Tucson's reclaimed water system, which provides nonpotable water used primarily for turf irrigation. The area is a highly visited urban wildlife habitat and riparian zone.

Pima County's metropolitan wastewater reclamation facilities. The reuse of water figures prominently in Tucson Water planning, as will be discussed later.

Tucson Water's water resources planning and management must meet state groundwater regulations and national water quality standards for drinking water. The US Environmental Protection Agency establishes drinking water standards, with compliance enforced by the Arizona Department of Environmental Quality. The Arizona Department of Water Resources (ADWR) is the state agency responsible for implementing and enforcing Arizona's Groundwater Management Act. Enacted in 1980, the complex Groundwater Management Act was designed to curtail overdraft of aquifers that was occurring in several of the more-populated portions of the state, including Tucson. The act and its accompanying regulations require a demonstration that new residential growth will be served by a 100-year assured water supply (AWS). To satisfy AWS rules promulgated in 1995 and enforced by ADWR, Tucson Water has had to demonstrate legally, physically, and continuously available water for 100 years. Tucson Water has also had to show that the water supply plan is consistent with the statutory management goal for the region, which is safe-yield. Safe-yield is defined by statute as "a groundwater management goal which attempts to achieve and thereafter maintain a long-term balance between the amount of groundwater withdrawn in an active management area and the annual amount of natural and artificial recharge in the active management area" (ARS 2015). The "consistency with the management goal" provision of the AWS rules has had far-reaching implications for Tucson Water.

THE WATER SUPPLY CHALLENGE: REDUCING GROUNDWATER MINING

Years of effort went into securing the federal funding necessary to build the Central Arizona Project (CAP), the southern-most portion of which is shown in Figure 1. The CAP is a 540-km-long lined and open canal. Water from the Colorado River is pumped from near sea level to a maximum elevation near Tucson of about 730 m. Built to transport approximately 1,850 × 10^6 m^3 of water annually, the CAP is the largest consumer of electricity in Arizona. The canal project was funded by the federal government and built by the US Bureau of Reclamation, with operations and repayment responsibilities falling to the Central Arizona Water Conservation District, an elected body established legislatively by Arizona. Deliveries of CAP water (i.e., Colorado River water delivered through the CAP canal) to the Tucson area began in the early 1990s.

The anticipated delivery of CAP water to Tucson was significant. Delivery of this renewable water supply provided Tucson Water with a much-needed alternative to groundwater and a way to show consistency with the safe-yield management goal for the region. In fact, Tucson was granted the largest municipal allocation (approximately 178 × 10^6 m^3/year) within the CAP system. Because Tucson has been historically reliant on the region's good-quality groundwater, which did not require much treatment before delivery to customers, integration of this new surface water source through direct delivery required the construction of a large, centralized treatment plant in order to meet drinking water standards. The Hayden-Udall Water Treatment Plant was built using a combination of rate-payer charges collected in advance of operation and revenue bond financing. In 1992, Tucson Water delivered treated CAP water, the first real infusion of surface water into the Tucson Water system, for half of its service area. This bold move by Tucson Water was in anticipation of the need to move away from groundwater overdraft (mining). However, the effort was fraught with difficulties related to the introduction of water with a different chemistry from that of groundwater traveling in a different direction through old water mains. Issues with water corrosivity and damages associated with burst pipes—coupled with utility hesitancy to acknowledge the problems—led to a lack of confidence and customer activism to restrict the manner in which this new water source could be used. In 1995, city voters approved the Water Consumer Protection Act, which effectively

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prohibited the use of the Hayden-Udall Water Treatment Plant and forced Tucson Water to go to a storage and recovery (S&R) approach to use CAP water.

In addition to the challenges associated with this turbulent introduction of CAP water to the Tucson community, Tucson is a desert city. Historical average rainfall has been about 300 mm annually. Downscaled climate models project the region to get hotter and possibly drier (Shamir et al. 2015, 2014). Even if total precipitation does not diminish, precipitation patterns may change. It is significant that tree-ring studies have shown the Colorado River to be overallocated among seven US states and Mexico, and the Colorado River basin has experienced drought for more than 15 years. The US Secretary of Interior, who, through the US Bureau of Reclamation is responsible for Colorado River operations, had not yet declared a shortage on the Colorado River. Although in May 2015 the US Bureau of Reclamation estimated the probability of shortage declaration for 2016 to be more than 50% (CAP 2015), an unusually wet May has reduced to almost zero probability of shortage in 2016, giving the region at least a short-term reprieve. A declaration of shortage has significant implications for CAP in that deliveries to its customers are among the first to be cut. This junior water-right-priority challenge is one that has been addressed in part by the Arizona water community. Tucson Water's "plan B" for using CAP, now fully implemented, also addresses its preparation for possible Colorado River shortage conditions.

TUCSON WATER'S RESPONSE

The adverse experience associated with the introduction of a new water source into Tucson Water's water supply portfolio led to a different, more drought-resilient system for CAP water use. To comply with the 1995 Water Consumer Protection Act and the AWS rules, Tucson Water took an indirect approach to using CAP water. Rather than treating the water in a large treatment facility and then directly delivering the water to its customers, Tucson Water deployed an S&R approach. Arizona state law has authorized the use of aquifers for water storage and groundwater replenishment. A system of permits and accounting administered by ADWR governs the construction and use of water storage facilities, water storage, and recovery of stored water. This legislatively authorized underground S&R program is an important component of Arizona's water management toolbox. It is used by entities throughout Arizona, whereby soil aquifer treatment is used to accomplish one or more of the following goals: (1) avoid the costs of centralized treatment plants, (2) store water underground for future use, (3) replenish groundwater already pumped, and (4) address water management objectives.

> The Groundwater Management Act was designed to curtail overdraft of aquifers that was occurring in several of the more-populated portions of the state, including Tucson.

Therefore, Tucson Water's S&R approach allows it to use CAP water by first storing it underground, mostly through large, shallow spreading basins—where, after infiltration, it mixes in the aquifer with groundwater—and then by recovering it for delivery through its vast distribution system. Through 2013, Tucson Water had invested $134 million in the facilities required for its S&R system, with approximately another $180 million planned. Annual investment is approximately $38.6 million. Figure 1 shows the location of the three major CAP storage facilities: the Pima Mine Road Recharge Project, the Southern Avra Valley Storage and Recovery Project, and the Central Avra Valley Storage and Recovery Project. The final recharge site is the Sweetwater Recharge Facility. There, basins recharge wastewater effluent that is treated to secondary levels as well as secondary effluent that has passed through adjacent wetlands. The recharged water is then recovered into Tucson Water's purple-pipe reclaimed water system, which is totally segregated from the potable water delivery system. Tucson Water also delivers reclaimed water that goes through its filtration plant without being recharged first. The Sweetwater S&R system provides seasonal storage so that Tucson Water can meet summertime peak demands. The Sweetwater Wetlands has birding, walking, and education activities, with many school groups visiting it. The photograph on page 48 shows Tucson Water's Sweetwater Wetlands facilities; the photograph on page 50 is of the Southern Avra Valley Storage and Recovery Project.

The S&R system is a carefully designed and engineered system. It enables Tucson Water to use its surface water without large-scale and expensive treatment systems, and it accommodates storage of water for future use. This last feature is extremely important to Tucson Water's ability to withstand Colorado River shortage declarations. Tucson Water is not currently delivering its full allocation of CAP water to its customers, but it is taking delivery of the full allocation. Water over and above that needed to supply current demands is being stored underground for future use. In addition, the state of Arizona had the foresight to establish the Arizona Water Banking Authority (AWBA) in anticipation of a Colorado River shortage declaration. The AWBA has been storing CAP water underground since 1997 to firm up

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The Southern Avra Valley Storage and Recovery Project is constructed on former agricultural land that was purchased in the 1970s. Its nine recharge basins total 226 acres, seven monitor wells, and 11 production wells. *Photo courtesy of Tucson Water.*

CAP deliveries to municipal customers. Though cutbacks to municipal users of CAP water are not envisioned in the next dozen or more years, even if there were, the water stored by the AWBA would offset some or all of the cutbacks. The AWBA has been storing water in Tucson Water's storage facilities, meaning that Tucson Water has developed an essentially drought-proof system. Should there be future curtailment of CAP water deliveries, Tucson Water can rely on its own storage as well as that of AWBA. In addition, Tucson Water can increase its use of groundwater when needed, according to the complex rules and regulations governing its use.

Tucson Water has also approached planning differently, relying on scenario analysis rather than action paths that rely on deterministic, single-point projections. It has updated its 2000–2050 Water Plan multiple times since its 2004 release, most recently in 2012. Tucson Water has also to a great extent incorporated stakeholder engagement in its planning efforts. An excellent example of this is Tucson Water's December 2013 *Recycled Water Master Plan* (Tucson Water 2013).

Because Tucson is a growing community, Tucson Water must plan for the future, which is ever-changing. The economic slowdown of 2008 significantly affected the growth rate of Tucson and the surrounding region. Reductions in community water use expressed on a per-capita basis have been larger than that which can be accounted for by the economic slowdown or increasing rates, likely because of Tucson Water's active conservation program and the community's strong water ethic. Total potable water use in 2013 was at the same level as that in 1989. Recycled or reclaimed water—wastewater effluent that has been treated to sufficiently high standards to allow reuse—is an important component of Tucson Water's water resources. Historically, recycled water has been used primarily for turf irrigation. Among the goals of Tucson Water's *Recycled Water Master Plan* are the following:

- Fully use the city's recycled water entitlements for the benefit of Tucson Water customers.
- Collaborate with the city's mayor and council, Tucson Water customers, and other stakeholders on recycled water issues and investment decisions.

All stakeholders are expected to be included in the process, including representatives of Pima County, which treats the wastewater for the metropolitan area, other jurisdictions, and, most importantly, the customers. Recommendations for implementing the *Recycled Water Master Plan* include continuous coordination with city leaders, Tucson Water customers, and the community, with periodic reviews to reflect industry trends and changing conditions. A water customer survey was completed in December 2013; it revealed that customers recognize the importance of using recycled water and that about 50% are comfortable or neutral about the possibility of it being part of future drinking water supplies. Two-thirds of the sample indicated interest in touring a facility to see how advanced technology is used to produce purified water. This effort demonstrates recognition that there must be public support for actions taken regarding future use of recycled water. It also underscores the importance of water quality in meeting Tucson Water's future water demands. Water-scarce regions tend to focus their efforts on ensuring there is sufficient water quantity to meet demands, but water quality also figures into planning at all stages of the process.

Another key element to balancing supply and demand is demand-side reductions through water conservation. The Tucson region has long had a strong water conservation ethic. Tucson was the first city in the United States to enact an ordinance requiring harvested rainwater use for meeting 50% of the outdoor water needs of new commercial construction. It also requires that new houses include a stub-out that would allow on-property reuse of household graywater instead of sending that water to the regional wastewater treatment system. Rainwater harvesting and using graywater reduce demands on the potable water system. Both have been encouraged by Tucson Water rebates. Tucson Water has also participated with local

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partners to implement the first Conserve2Enhance™ program, which involves customers connecting their water savings to local environmental enhancement projects, thereby providing an additional motivation to conserve.

OVERCOMING BARRIERS AND FORMING NEW PARTNERSHIPS

Tucson Water worked hard to overcome the loss in confidence associated with the failed introduction of CAP water to the Tucson community. This required enhanced communication with its customer base and external stakeholders. Tucson Water recognizes the need to continue to consult and communicate with its stakeholders and, as explicitly noted in the Master Plan, regularly inform and engage its governing body, the Tucson mayor, and the city council. Tucson Water's director is appointed by the Tucson city manager, who reports directly to Tucson's mayor and council, who in turn are responsible for approving Tucson Water's budget and rates. The Citizens' Water Advisory Committee, whose members are appointed by the mayor, council, and city manager, serves as an external review committee for budgetary and policy matters. The capital investment plan undergoes rigorous review. Bonding is done through revenue bonds, which through 2005 were submitted to City of Tucson voters for approval. After the disappointing community experience associated with introducing CAP water, Tucson voters approved sizable bond issues to fund replacement of large transmission pipelines and other capital needs. The voters understood that replacing old infrastructure was necessary and supported the higher rates associated with $380 million in bonding between 1994 and 2005.

As has been discussed, Tucson Water operates according to groundwater use regulations established by the state and water quality standards set by the US government. It also depends on Pima County to treat the wastewater to at least US standards; that wastewater is then further treated.

At one time, Tucson Water was expected to be the regional provider of treated CAP water to other water systems. In fact, Tucson Water's CAP allocation was based on population projections for some areas outside of its service area. The failed introduction of CAP water, coupled with political and other considerations of surrounding communities, resulted in the unraveling of joint planning. Some of Tucson Water's CAP allocation was later designated for the other water systems, and Tucson Water entered into agreements that changed ownership of some amounts of treated wastewater. Relationships among the Tucson area water entities have sometimes been tense, but over time, voluntary agreements that are beneficial to all have been developed. Tucson Water now has reclaimed water passing through its transmission infrastructure to the nearby Oro Valley utility for use on golf courses and to another utility. Tucson Water has recently entered into an agreement with a private water company to deliver CAP water held by a privately owned utility to an area that has relied on local groundwater to meet its water demands. In addition, Tucson Water has collaborated with the US Bureau of Reclamation, Pima County, and several other local water utilities on a project involving instream recharge of effluent that is discharged into the Santa Cruz River channel after secondary treatment.

Tucson Water is the largest municipal customer for CAP water and must therefore interact with CAP's staff and governing body. Water is of paramount importance for Arizona and the Colorado River basin, and Tucson Water's service area and well fields share borders with lands owned by Native American nations, which have sovereignty over water management. The Tucson region's largest municipal water utility is engaged in water matters at these multiple jurisdictional levels.

The Tucson region is home to some agricultural activity, mostly to the northwest and south. Tucson Water partnered with a local farming entity at the early stages of implementing its S&R program. The agricultural partner helped construct some of the water conveyance infrastructure that was used to deliver CAP water to farmlands and to recharge basins. Tucson Water accrued water storage credits pursuant to state law and ADWR permitting associated with the use of CAP water on agricultural fields in lieu of groundwater. The state's Groundwater Savings storage program, which is incorporated in the statutory framework discussed previously, is yet another example of a mutually beneficial and voluntary partnership.

There is an additional and significant agricultural connection to Tucson Water's current S&R program. In the 1960s and 1970s, Tucson purchased agricultural land in the Avra Valley northwest of the city with the expectation that the water rights associated with this land would be used to meet Tucson Water's future demands. The 1980 Groundwater Management Act quantified the amount of groundwater that Tucson Water can count toward its AWS rules beginning in about a decade. What was not envisioned at the time of land purchase was that the land would become the site of the large storage facilities that are the backbone of Tucson Water's S&R system for using CAP water. The ownership of these lands enabled Tucson Water to avoid land acquisition costs when constructing the Central Avra Valley and Southern Avra Valley Storage and Recovery Projects.

LESSONS LEARNED: ADAPTATION AND FLEXIBILITY

A key takeaway from Tucson Water's experiences of the past two-plus decades is the importance of flexibility. Although strict federal drinking water quality regulations prevail at all times, state groundwater regulations, including the AWS rules, allow utilities flexibility in

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their approach to using renewable surface water supplies. In other words, a one-size-fits-all approach was not imposed by the state regulatory framework. Tucson Water was able to adapt from direct delivery to an S&R system. In the process of responding to customer preferences articulated through a voter initiative, Tucson Water made significant investments in constructing storage facilities and recovery wells and repurposing its existing land holdings in the Avra Valley by developing a more drought-resilient system.

Tucson Water serves a growing desert community. Arizona took action in 1980 to require use of renewable water supplies to restrict groundwater overdraft. The construction of CAP enabled importation of new water supplies to the region. Though cities will not be affected in the short term by the shortage conditions on the Colorado River, the potential for some curtailed surface water deliveries, though unlikely to happen for many years (in large part because of the establishment of AWBA), has underscored the importance of a diversified water resources portfolio. Tucson Water is also looking within its boundaries as it looks to meet future demands. Demand management and water reuse are significant elements of this diversified portfolio. The regular development and updating of plans, based on consideration of alternative future scenarios, include opportunity for stakeholder and customer feedback. Whatever the particular challenge, Tucson Water's experiences have demonstrated the importance of an open and consultative decision-making process. Thise experiences have also demonstrated the benefits of collaboration with other utilities and jurisdictions, along with the value of sharing lessons learned.

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