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Introduction

A Research and Extension unit of the College of Agriculture and Life Sciences, the University of Arizona Water Resources Research Center (WRRC) has a mission to promote understanding of critical state and regional water management and policy issues through research, outreach, engagement and education. It accomplishes itsmission by assisting communities in water management and policy; educating teachers, students and the public about water; and conducting scientific research on state and regional water issues. The WRRC is known statewide as a hub for water resources research and information transfer in Arizona. It is the designated state water resources research institute established under the 1964 Federal Water Resources Research Act, and as such, the WRRC administers research grant programsand maintains a strong information transfer program that includes publications, presentations, conferences and other public events. In addition to these activities, the WRRC conducts programs of research on topics such asstatewide water planning, environmental water needs, conservation, water harvesting, transboundary aquifer management, and groundwater governance. Collaborations and cooperative arrangements are vital for accomplishment of the WRRC's active research, education and outreach goals. Among its key partners is the Water Sustainability Program, one of three programs making up the Water, Environmental and EnergySolutions (WEES) program, which is housed at the WRRC and funded from the UA's Technology andResearch Initiative Fund (TRIF). The WRRC also houses Arizona Project WET (Water Education forTeachers), which was initiated at the WRRC in 1991. Arizona Project WET is Arizona's premier water education program. In addition the WRRC is closely linked with Arizona Cooperative Extension.

Research Program Introduction

The University of Arizona (UA) WRRC provides support through the WRRA, Section 104(b) research grantprogram in the form of research grants to investigators at the three state universities in Arizona. The WRRC typically funds three or four research projects that investigate water issues judged to have statewide importance. A wide range of projects have been funded over the years, emphasizing mandated program goals of improving water supply reliability and quality, and exploring new ideas to address water problems and expanding understanding of water and water-related phenomena.

In the project year 2014-2015, the WRRCfunded two proposals that address these goals. Both projects were carried out by researchers at the University of Arizona WRRC and colleagues at UA.

The first project, "Improving Integrated Surface Water and Groundwater Management in the United States: Case Studies of Innovative Groundwater Governance Approaches" investigated groundwater governance practices of the U.S. states in order to (1) assess the performance of these practices and (2) examine how they contribute to integrated surface/groundwater management.

Groundwater is a critical component of the water supplies for agriculture, cities, industry, and ecosystems around the world. In the U.S., groundwater represents much of our potential future water supply. Water management is largely decentralized in the U.S., with each state maintaining significant authority and autonomy when addressing groundwater regulation and governance. As population growth, economic development, changing land-use patterns, and climate change stress existing water supplies, it is essential to identify ways to improve the ways we govern and manage groundwater.Yet despite the importance of groundwater for all of the water using sectors in the U.S., there is currently no comprehensive compendium of information on groundwater governance in the U.S., and, consequently, no assessment and analysis of these practices.

Building upon a pilot survey the project team completed in 2014, this project further analyzed and mapped its results. The project also looked in depth into the laws and practices of three case studies characterized by innovative groundwater governance strategies that contribute to integrated surface/groundwater management to enable identification of best practices. The case study analysis considered: groundwater governance practices, approaches, trends, and innovations; catalysts of and impediments to integration of groundwater and surface water management; outcomes associated with integrated surface/groundwater management; and obstacles and barriers to integration, as well as opportunities that could facilitate it.

Development of Antibiotic Resistance during Wastewater Treatment, the second research project, addressed an important water quality issue relating to water reuse.

As communities throughout the U.S. and the world move towards increased water reuse to augment surface and groundwater supplies, the potential for the release of antibiotic-resistant bacteria into the environment grows in concern. However, despite the potential for antibiotic resistance (AR) proliferation in wastewater treatment, few studies have attempted to identify processes or operational conditions contributing to the selection of resistant bacteria or those that are capable of reducing the level of resistance in wastewater. Such information is critical in quantifying the environmental burden of wastewater treatment plants with respect to antibiotic resistance and developing the most effective treatment strategies to mitigate any concerns.

The project quantified the impact of treatment optimization on the development of resistance in bacteria using bacterial cultivation methods. Bacterial isolates were exposed to four antibiotics to assess the level of resistance using laboratory methods developed by the PI. This work is part of a larger study (with cooperators from University of Nevada, Las Vegas) that is quantifying the presence of resistance genes and trace levels of

antibiotics in wastewater samples at several full-scale treatment plants. By characterizing the long-term impacts of AR in the environment, this study is providing knowledge and tools for treatment process optimization, resistance mitigation, and future risk communication efforts.

Improving Integrated Surface Water and Groundwater Management in the United States: Case Studies of Innovative Groundwater Governance Approaches

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IMPROVING INTEGRATED SURFACE WATER AND GROUNDWATER MANAGEMENT IN THE UNITED STATES

Three Case Studies of Innovative Groundwater Governance Approaches

December 14, 2015

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IMPROVING INTEGRATED SURFACE WATER AND GROUNDWATER MANAGEMENT IN THE UNITED STATES: THREE CASE STUDIES OF INNOVATIVE GROUNDWATER GOVERNANCE APPROACHES

Sharon B. Megdal, Andrea K. Gerlak, Robert M. Varady, and Ling-Yee Huang
December 2015

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Executive Summary

Groundwater plays an increasingly important role as a reliable source of freshwater when surface water sources become fully or even over allocated and less reliable due to climate variation and change. In the past few decades, scientists, managers, and decision makers have made great strides in understanding how surface water is governed and managed. Surface water benefits from being visible: When flows are low, reduced supplies are readily noticed. When river or lake water becomes contaminated and threatens human health, public attention and political action are swift.

In contrast, groundwater is largely invisible on a daily basis: Reduced supplies generally go unnoticed by most users, and contamination may be difficult to detect. Until recently, groundwater accounted for only a small part of the water supply in most United States communities. As a result, basic information about groundwater—such as how this resource is governed and used, whether its use is safe, and whether reliance on it is sustainable—is largely missing from the national dialogue on water management.

The purpose of this project was to begin understanding the diversity of groundwater governance approaches across the United States and to identify what, if any, lessons may apply from one region to another within a state or across the country. Three geographically diverse groundwater management regions were selected: the Prescott Active Management Area in north-central Arizona, the Orange County Water District in southern California, and the Central Florida Water Initiative in central Florida. These three regions have different surface water laws, groundwater allocation and management laws and regulations, demographics, economics, topographies, and climate. Yet they face similar pressures on groundwater because of increased and projected population growth and limited availability of surface water supplies. They provide an informative picture of how groundwater management institutions vary in strengths and development according to the age and nature of the institution.

Each case study examines the basic legal framework for groundwater management at the state level, provides basic water supply and demand information specific to the case study, and details groundwater management institutions and strategies specific to the case study. The analysis includes some of the catalysts of and impediments to groundwater management and outcomes of groundwater management.

Research for the case studies consisted primarily of peer-reviewed scientific and technical literature, law reviews and legal analyses, and other grey literature available online. The authors relied heavily on the University of Arizona (UA) search engines for the scientific and technical literature and on Westlaw for the statutory and regulatory citations and law review articles. UA search engines and databases such as ProQuest provided access to local and regional newspapers to fill in details not available in formal literature sources, such as the factors leading to certain developments or the extent and nature of public reaction to groundwater management strategies.

The authors also reached out by email and by telephone to individuals involved in groundwater management in each of the case study areas. These personal contacts again filled in

crucial details about the motivating factors and other behind-the-scenes information, not otherwise available online. The combination of online research of primary and secondary sources and the personal contacts with experts in each of the regions helped to provide a more robust and complete picture of groundwater governance in each of the case studies.

Principal Findings and Significance

The case studies uncovered unique regional approaches to groundwater management. Each case study tells a different story of groundwater management, although all three are driven by similar factors: litigation, or the potential for costly and lengthy litigation over water rights; a heavy but unsustainable reliance on groundwater; limited availability of surface water supplies; and to some extent local recognition of the need to manage groundwater, independent of state mandates.

1. The Prescott Active Management Area

The Prescott Active Management Area (PrAMA) was established in 1980 by Arizona's Groundwater Management Act. At the time, the Act was considered among the best groundwater management laws in the country, and it was passed to avoid potential conflict among groundwater users in the state. The Act established safe-yield by January 1, 2025, as the groundwater management goal for PrAMA. The Act also ties residential growth to demonstrating a 100-year water supply. In January 1999, the state officially declared that PrAMA was out of compliance with the safe-yield goal, concluding that the current and committed demand for groundwater exceeded the natural and artificial recharge capacity of the region's aquifers.

Although total population in PrAMA is relatively low, the population is growing and expected to continue growing. The PrAMA does not have ready or reliable access to surface water supplies. To facilitate growth and to demonstrate an assured water supply, the two largest municipalities in PrAMA, Prescott and Prescott Valley, embarked on a joint project to import groundwater from a nearby aquifer that is not subject to groundwater management provisions in the 1980 Act. While Prescott plans to use traditional financing mechanisms—namely charging ratepayers and issuing bonds—to pay for its portion of the project, Prescott Valley had an innovative solution. In 2007, it auctioned the rights to its treated effluent. Purchasing the effluent credits allows a buyer to demonstrate an assured water supply, and the proceeds from this auction will provide Prescott Valley with funding for its planned groundwater importation.

2. The Orange County Water District

The Orange County Water District (OCWD) was established in 1933 by a special act of the California legislature, in response to ongoing litigation among agricultural districts using the Santa Ana River to irrigate land. Today, the OCWD manages the groundwater basin beneath Orange County for the water providers and irrigation districts that provide water to more than 2.7 million people. In the 1950s, water managers at the OCWD recognized the need to replenish groundwater in order to provide robust, supply-side management for groundwater users in the OCWD service area. To fund replenishment projects—namely purchasing imported water and

injecting it into the groundwater basin—the OCWD implemented the replenishment assessment, a fee per volume of groundwater withdrawn that is assessed on all groundwater users.

To further manage groundwater use, the OCWD later implemented a basin production percentage, which is a mandated percentage of groundwater that each water provider can use to meet its needs, and a basin equity assessment, a fee per volume of water extracted above the basin production percentage. The equity assessment is roughly equivalent to the cost per volume of imported water and thus encourages water providers to turn to these water supplies, rather than groundwater, to fulfill the remainder of their needs. The OCWD also manages a state-of-the-art advanced wastewater treatment system, the Groundwater Replenishment System, which at full capacity will produce 130 million gallons of treated wastewater per day. This treated wastewater is injected into the aquifer to form barriers against saltwater intrusion and to augment groundwater supplies. The OCWD is nationally and internationally recognized for its groundwater management strategies, serving as a model for other regions in California that are now required to develop groundwater management plans as a result of the 2014 Sustainable Groundwater Management Act.

3. The Central Florida Water Initiative

The Central Florida Water Initiative (CFWI) was established in 2011, the second incarnation of a voluntary, coordinated, regional water planning effort in central Florida. In 1972, the Florida legislature passed the Water Resources Act and established five water management districts whose jurisdictions ran along surface water hydrological boundaries. In central Florida, the boundaries of three of these districts intersect. By the mid-2000s, conflicts had begun to emerge from the differences among each district's regulations and models and from permits issued in one district that affected groundwater resources in another district. In addition, the three districts concluded that there would be a significant gap between water supply and demand by 2035. Wanting to avoid potential water conflicts, the three districts embarked on a voluntary effort to manage water resources by harmonizing rules for granting water use permits and producing a common scientific and technical foundation.

In 2015, the CFWI published the Regional Water Supply Plan (RWSP), which identifies several alternative water supply projects and options for the region. However, the CFWI is a voluntary effort, so it is the responsibility for local governments to implement the projects identified in the Plan. Overall the CFWI is at the formative state and questions about governance and implementation remain.

Lessons Learned

These three case studies demonstrate not only a common and pressing need to address groundwater management, but also interesting variations on their institutions and management strategies. PrAMA, the OCWD, and the CFWI are at various stages of institutional age, illustrated by the strategies they have adopted or are considering. The OCWD is the oldest institution, authorized by statute in 1993. It has a long history of successful management using economic signals and prioritizing groundwater replenishment. PrAMA is the middle institution, authorized by statute in 1980. It is simultaneously looking forward with plans to import

groundwater and Prescott Valley's effluent action and looking backwards in continuing to rely on groundwater. The CFWI is the youngest institution and is voluntary in nature. It emerged from regional water conflicts, and how groundwater management will proceed in the future remains to be seen.

The role of the state water management or governance law in each case varies as well. The OCWD existed for more than eighty years before the enactment of a mandatory, statewide groundwater management law in California, and the new law sets minimum standards that the OCWD already exceeds. Similarly, PrAMA most likely would not exist without Arizona's 1980 Groundwater Management Act, and the regulations and programs stemming from the Act continue to shape and guide how groundwater management occurs in the region. In the CFWI, the 1972 Water Resources Act in Florida gave rise to the state's water management districts, but the CFWI emerged for water conflicts that arose much later and is entirely voluntary.

Case Study: Prescott Active Management Area

Introduction

Groundwater is a critical component of the water supply for cities, agriculture, industry, and ecosystems in Arizona. In 1980, the state passed the Groundwater Management Act to manage groundwater in certain areas. The Prescott Active Management Area (PrAMA) is among the five designated areas in Arizona where groundwater use is regulated. The cities and towns in PrAMA have been among the fastest growing communities in the state, and groundwater management in this region is an example of how growing communities with limited surface water supplies comply with groundwater use regulations. The purpose of this case study is to highlight distinct features of groundwater governance and management in PrAMA.

This case study will first provide a brief overview of PrAMA and the legal framework for surface water and groundwater in Arizona, discussing in some detail the 1980 Groundwater Management Act and how it applies to PrAMA. It will then discuss the strategy of two PrAMA municipalities, the City of Prescott and the Town of Prescott Valley, to secure reliable water for municipal use by transporting groundwater from outside the Active Management Area at some point in the future. Each municipality has pursued a different way to fund its share: Prescott through traditional financing and Prescott Valley through an auction of effluent credits. Next, this case study will examine impediments to and opportunities for integrated surface water and groundwater management, focusing on exempt wells as a significant impediment. Finally, the study will assess the outcomes of governance and management and draw lessons and conclusions that may apply to states facing similar challenges.

Groundwater Management in Arizona: The Legal and Administrative Context

The Arizona Department of Water Resources (ADWR) is the state agency that oversees the allocation of water across the state. In Arizona, the legal framework for water depends on whether the water is surface water, Colorado River water, groundwater, or effluent (ADWR 2010b). In the ADWR annual report for fiscal year 2015, the state water supply budget was 57.2 percent surface water (including Colorado River water), 39.5 percent groundwater, and 3.3 percent effluent (ADWR 2015). This section will give a brief overview of water laws in Arizona, focusing on groundwater pumping and management.

1. Surface Water and Colorado River Water

Surface waters in Arizona are subject to prior appropriation, whereby the first user in time is the first user by right. However, much of central and southern Arizona receives surface water from the Colorado River, which is a legally distinct source of water. Federal law allocates water among the states in the Colorado River Basin: Arizona, California, Colorado, New Mexico, Nevada, Utah, and Wyoming. In Arizona, a portion of the state's Colorado River water is delivered to central and southern Arizona communities through a 336-mile long conveyance system operated by the Central Arizona Project (CAP). The CAP subcontracts with municipalities, private water companies, irrigation districts, industrial users and Native American tribes to deliver this water, commonly referred to as "CAP water."

2. Effluent

Treated wastewater, or effluent, is another legally distinct source of water under Arizona state law. In 1989, the Arizona Supreme Court ruled that a city or other entity, such as a private sewer utility, that produces effluent can use it as it wishes, regardless of laws for surface water and groundwater (Arizona Pub. Serv. Co. v. Long, 773 P.2d 988 (Ariz. 1989)). Effluent remains a separate source until it is discharged as surface water or groundwater, after which it is subject to the laws governing surface water or groundwater. Effluent is not subject to the conservation requirements or transportation restrictions that apply to groundwater in the Active Management Areas (AMAs, discussed below). However, because effluent is water, it must be put to a beneficial use if it is not discharged into a stream. ADWR considers effluent a renewable source of water, and AMA management plans have many regulatory incentives to promote reuse of treated wastewater.

3. Groundwater & the 1980 Groundwater Management Act

Groundwater is a critical component of the water supply in Arizona, used to meet about 40 percent of the water demand in the state (ADWR 2014a). Withdrawal and use of groundwater in Arizona is generally governed by reasonable and beneficial use (ARS § 45-453). Early in the state's development, however, the Arizona Legislature recognized the ongoing and potential future conflicts among groundwater users, including agricultural users, cities, and mining companies (Connall 1982). On June 12, 1980, Governor Bruce Babbitt signed into law the Groundwater Management Act (GMA), hailed at the time as the most comprehensive groundwater code in the nation (Connall 1982). It represented a "historic, comprehensive legislation that established ambitious goals for water conservation and a complex regulatory scheme to achieve them" and "reflected a reasonable compromise on the part of many disparate groups" (Salt River Valley Water Users Ass'n v. Guenther 2009). The Arizona Department of Water Resources (ADWR) was established to implement the GMA (ADWR 2014a). The three main goals of the GMA are to control groundwater overdraft in designated parts of the state, to provide a process of allocating groundwater to meet demands, and to augment groundwater supplies by developing renewable water supplies. Groundwater management includes allocating and defining groundwater rights and permits, regulating wells, restricting development of agricultural land, and developing groundwater management plans.

The GMA established Active Management Areas (AMAs) in which groundwater pumping is regulated. Importantly, outside of an AMA, groundwater is neither regulated nor managed, except for in Irrigation Non-Expansion Areas (INAs), which face limitations on increasing irrigated acreage and requires reporting of groundwater pumping by non-exempt wells. Today there are five AMAs: Phoenix, Tucson, Prescott, Pinal, and Santa Cruz. 83 percent of the state's population lives within the boundary of an AMA (ADWR 2015). The GMA specifies a management goal for each AMA and requires the ADWR director to adopt a management plan for each AMA for certain periods through 2025. In the Phoenix, Tucson, and Prescott AMAs, the management goal is to achieve safe-yield by January 1, 2025. As established in the GMA, safe-yield means "a groundwater management goal which attempts to achieve and thereafter maintain a long-term balance between the annual amount of groundwater withdrawn in an active management area and the annual amount of natural and artificial groundwater recharge

in the active management area" (A.R.S § 45-561(12)). However, there are no consequences for an AMA if it fails to meet its management goal by the 2025 deadline (Glennon 1991; Maguire 2007).

The AMA Management Plans must include water conservation programs for agricultural, municipal, and industrial users; an augmentation plan to bolster existing water supplies; and a water management assistance program (ARS § 45-561 et seq.). The AMA planning period is in the fourth iteration. The Fourth Management Plan for PrAMA was adopted in July 2014 and covers the years 2017 until 2020 (ADWR 2014c; 2014b). A Groundwater Users Advisory Council (GUAC), a council of five members who are appointed by the governor and who serve staggered six-year terms, is tasked with advising the AMA area director, making recommendations based on groundwater management programs and policies, and commenting on the draft management plan (ARS § 45-421, 420).

The Assured and Adequate Water Supply (AWS) program is central to the GMA. The AWS rules link available water supplies to urban growth (Holway 2007). The rules require an applicant who proposes to subdivide land in an AMA into six or more parcels to demonstrate a 100-year assured water supply for that land (ARS § 45-576; AAC R12-15-701 et seq.). ADWR issues these determinations, as long as the applicant demonstrates that: the water supply for the land is physically, legally, and continuously available for 100 years; the quality of water is sufficient for the proposed use; any proposed groundwater use is consistent with the current management plan and the management goal of the AMA; and the applicant has the financial capability to construct any necessary water storage, treatment, and delivery systems (ARS § 45-576(J), AAC R12-15- 704, -710).

ADWR may issue a Designation of Assured Water Supply (DAWS), upon application, to a municipal water provider. An approved DAWS covers the water provider's entire current and committed demand, plus projected demand for a specified period of years for new subdivision approvals. An applicant who proposes a new development within the service area of a municipal water provider with a DAWS must get a letter of approval from that provider before construction. Where a proposed subdivision exists outside the service area of a designated municipal water provider, the applicant must apply directly to ADWR for a Certificate of Assured Water Supply (CAWS) (Holway 2007). Once a designation is issued, ADWR establishes a groundwater allowance account and allows for a limited amount of groundwater pumping. ADWR must review designations at least once every 15 years (AAC R12-15-711). The AWS rules are tailored to specific conditions in each AMA.

Overview: The Prescott Active Management Area

PrAMA is located in central Arizona, west of the Interstate 17, a highway that stretches from the Phoenix metropolitan valley to Flagstaff. PrAMA is 485 square miles, and the topography ranges from 4,400 feet to 7,800 feet in altitude. Precipitation varies across the AMA, with an annual average of more than 19 inches in Prescott to 12 inches in Chino Valley (ADWR 2010b). Natural recharge of aquifers is roughly 7,000 acre-feet per year (AFY), primarily from infiltration of runoff into stream channels and mountain front recharge (ADWR 2010b). PrAMA

is located within the Verde River Watershed, which contains Arizona's only section of federally designated river that is both wild and scenic (National Wild and Scenic Rivers Systems 2015).

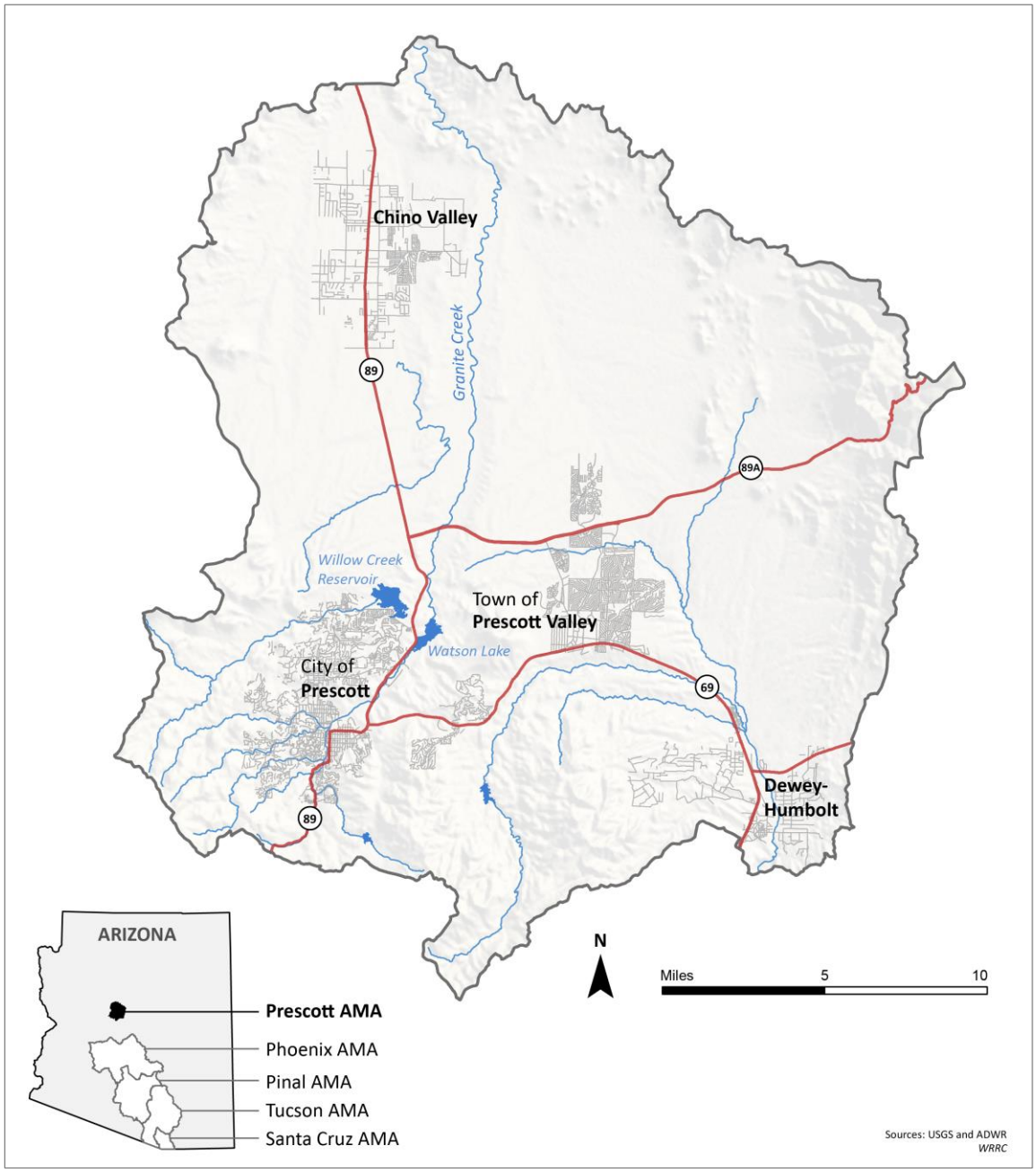

Figure 1. Map of Prescott Active Management Area (AMA) within Yavapai County.

The Verde River, located outside PrAMA boundaries to the north, is one of the last free-flowing desert rivers remaining in the western United States. It sustains a diverse regional wildlife population and riparian ecosystem and is home to eight native fish species, including three federally listed threatened or endangered species (Davis 2007).

1. Water Supplies

Use of surface water in PrAMA is limited because surface water supplies are unreliable and are affected by climate and weather. Surface water is also subject to the water rights of downstream users, as well as the pending Gila River General Stream Adjudication. Both Prescott and the Yavapai-Prescott Indian Tribe (YPIT) were allocated CAP water, but both communities relinquished those allocations to the City of Scottsdale as part of the negotiations for the 1994 YPIT Water Settlement Act. Transporting and storing the CAP water from central Arizona was not feasible for either the YPIT or Prescott (Pub. L. 103-434, 103d Congress 1994). The Settlement Act required proceeds from the sale of a CAP allocation to be used for investigating, acquiring, or developing alternative water sources, such as retiring agricultural land, developing groundwater outside of PrAMA, and artificially recharging groundwater (Pub. L. 103-434, 103d Congress 1994).

The City of Prescott received a total of $3.4 million, which it spent to acquire surface water rights from the Chino Valley Irrigation District (CVID) (OAH, 2009). In the early 1990s, Prescott was simultaneously negotiating an intergovernmental agreement with the CVID for surface water flows from Granite Creek and the storage reservoirs of Watson and Willow Lakes. Prescott sought to acquire the surface water flows from Granite Creek because the city believed it was one of the last opportunities to acquire surface water within PrAMA and use that water for demonstrating an assured water supply (OAH, 2009). Prescott also sought to preserve the two lakes for recreational purposes. The total cost of these water rights from CVID was approximately $21 million, of which $3.4 million came from the sale of Prescott's CAP allocation (OAH, 2009). As of 2015, the City's water system includes six wells in Chino Valley that supply a five million gallon reservoir at the Chino Production Facility, where pumps send the water to Prescott through high-pressure water mains (Prescott 2015a).

2. Water Demand

Since the first Management Plan for PrAMA was adopted in 1984, water demand in PrAMA peaked at 29,320 acre-feet (AF) in 1993, with 2012 demand at 20,210 AF (ADWR 2011, 2014c). Between 1985 and 2012, PrAMA agricultural demand fell from 80 percent to 13 percent of total demand, while municipal demand increased from 15 percent to 72 percent (ADWR 2014c). PrAMA depends heavily on groundwater because the annual availability of surface water is variable and limited. Since 2000, PrAMA has used surface water for storage and recovery. In 2012, groundwater constituted approximately 82 percent of the water supply, reclaimed water 16 percent, and surface water the remaining two percent (ADWR 2014c).

The population centers of PrAMA consist of Prescott, Prescott Valley, the town of Chino Valley, and the town of Dewey-Humboldt. The population of the entire PrAMA, calculated by the ADWR based on the 2010 Census, was 118,446 (ADWR 2014c). The City of Prescott and the Town of Prescott Valley are large municipal water providers, although only the City of Prescott has a DAWS. By definition, a large municipal water provider, including cities, towns, or private water companies, serves more than 250 AFY. Slightly more than eight percent (9,683) of the PrAMA population is served by small municipal water providers. These include the towns of Chino Valley and Dewey-Humboldt, as well as a number of other small private providers

(ADWR 2014c). Additionally, there are domestic wells within the AMA that are exempt from groundwater regulations because they pump less than 35 gallons per minute (GPM) for non-irrigation purposes (ARS § 45-454).

Agricultural water use for crop or feed production in PrAMA historically constituted a large portion of water use. However, it decreased significantly between 1985 and 2012 because of a decrease in the number of acres irrigated and the retirement of irrigation rights. As of February of 2014, there were a total of 162,284 AF of extinguishment credits within the Prescott AMA from the extinguishment of grandfathered rights. Of this total, 23,011 AF of credits are pledged to either the City of Prescott's DAWS or to CAWS within the AMA (ADWR 2014c). Credits pledged to a DAWS or CAWS assist in making groundwater use for new growth consistent with the management goal of safe-yield. The remaining credits are not pledged and may ultimately be utilized for Assured Water Supply purposes. During the early 2000s, there was a significant demand and market for extinguishment credits, but the demand has decreased with slower growth in the AMA.

Industrial water use in PrAMA is relatively low, around five percent of the total water use in 2012 (ADWR 2014c). Industrial water use is defined as non-irrigation use of water that is not supplied by a city, town, or private water company (ADWR 2014c). In PrAMA, the industrial sector includes turf-related facilities (e.g., golf courses and resorts), sand and gravel operations, and others, such as small landscape users, cooling uses, and construction. ADWR does not expect water use in the industrial sector to increase significantly in the future (ADWR 2014c).

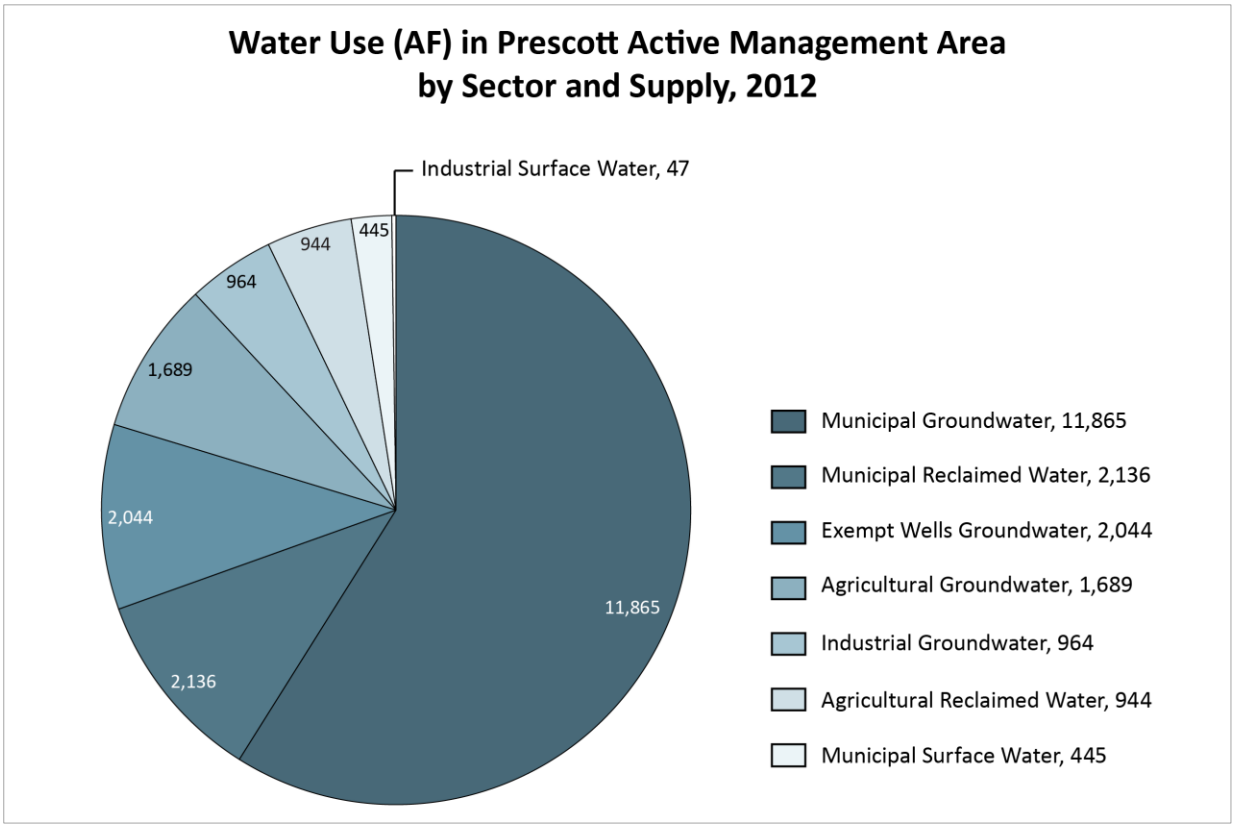

Figure 2. Water Usage by Sector in PrAMA (Source: ADWR).

PrAMA generates an estimated 6,000 AFY of reclaimed water from effluent (ADWR 2010c), much of which is used to irrigate turf (ADWR 2014c).

Groundwater Management in PrAMA: Achieving Safe-Yield

The groundwater management goal of PrAMA is to attain safe-yield by January 1, 2025 (ARS § 45-562(A)). The ability to meet this goal is shaped by two events in the late 1990s. First, in July 1998, ADWR approved the initial DAWS for Prescott, at the time the only large municipal water provider in PrAMA. It included a groundwater allowance for approximately 32,000 platted but unconstructed developments. Six months later in January 1999, ADWR officially declared that PrAMA was no longer at the safe-yield (1999). The agency cited short-term and long-term declines in water levels across PrAMA and noted that an additional 10,000 AFY was already committed to approved but unconstructed lots and subdivisions. ADWR's report concluded that "The sum of current and committed demand for groundwater *without question* exceeds the amount of natural and artificial recharge to the AMA's aquifers" (ADWR 1999, emphasis added).

As a result, provisions of the AWS rules limiting groundwater use apply to all developments proposed in PrAMA subsequent to this 1999 declaration, thus requiring proof of renewable water supplies. New developments are required to apply for a CAWS from ADWR or, if they are within the service area of a municipal water provider with a DAWS, official approval from that provider. Such developments are required to use renewable water supplies, but limited groundwater use is allowed to help municipal providers transition from groundwater to renewable supplies. However, the thousands of platted but unconstructed developments—filed prior to the 1999 declaration—are not subject to AWS rules limiting groundwater use (SYS 2006). If built, they are allowed to use groundwater even though that groundwater use would not be considered consistent with PrAMA's management goal for developments proposed after 1999 (ADWR 2014c).

In December 2005, the PrAMA GUAC established the Safe-Yield Subcommittee (SYS), which was tasked with assessing the impediments and opportunities for reaching the safe-yield management goal. The final report identified impediments such as the lack of enforcement strategy to meet safe-yield (SYS 2006). Importantly, the SYS emphasized that the consequences of failing to meet the safe-yield management goal could be severe in the long-term. PrAMA could face reduced groundwater storage capacity, less reliable future water supplies, increased costs for well drilling and pumping, diminished natural discharge, and increased land subsidence and fissuring (Maguire 2007; SYS 2006). Among the recommendations for attaining safe-yield, the SYS proposed common principles: all groundwater users, including exempt well users, are responsible for reaching safe-yield; all groundwater users should quantify their groundwater consumption; and alternative water supplies must be developed to meet the demands that exceed the safe-yield supply. The SYS concluded that the voluntary measures in the GMA to achieve safe-yield are inadequate and that ultimately "legislative changes and additional water management strategies will be required to obtain and maintain safe-yield" (SYS 2006).

Exempt wells represent a significant challenge to reaching safe-yield in PrAMA (SYS 2006). By 2012, exempt wells in PrAMA had increased to 11,671, up from 4,560 exempt wells

in 1985 (ADWR 2014c). In the Fourth Management Plan, ADWR reported that the PrAMA population supplied by exempt domestic wells was greater in 2012 than the population served by Small Municipal Providers (2014c). These wells are generally not subject to groundwater restrictions in PrAMA, and account for 14 percent of the total annual groundwater pumping (ADWR 2014c). One of the challenges of exempt wells in PrAMA and across the western United States is that monitoring their use is difficult and costly, to the extent that it is possible at all (Bracken 2010; Richardson 2012; ADWR 2014c). There are, however, a few regulations that apply to exempt wells in AMAs. For an exempt well drilled on or after April 28, 1983, total groundwater withdrawals are limited to 10 AFY for non-irrigation uses other than domestic purposes or stock watering (ARS § 45-454). As of January 2006, an exempt well is generally no longer allowed if it is located on land that is within 100 feet of a water distribution system of a municipal water provider with a DAWS (ARS § 45-454).

In 2010, ADWR closed the local PrAMA Office and relocated all AMA offices to ADWR headquarters in Phoenix (ADWR 2010a). ADWR attributed the closure to the state legislature's FY 2011 budget for ADWR of $9 million, which continued a series of decreases since FY 2009 when the budget was $16 million (Nellans 2010). In addressing the closure, the PrAMA office said that permitting activity and fees were insufficient to offset the funding gap from the severe budget reduction (ADWR 2010a).

Groundwater Management Strategies in PrAMA

In the Fourth Management Plan for PrAMA, one of the primary strategies to achieve safe-yield is to augment the AMA water supply with groundwater transported from the Big Chino Sub-basin. The transported groundwater will allow Prescott and Prescott Valley to meet the AWS requirements and to continue population and economic growth, despite otherwise limited water supplies. This section will discuss this strategy, including Prescott Valley's novel auction of effluent credits to fund its share of the pipeline.

1. Transporting Groundwater in Arizona and the Big Chino Water Ranch Pipeline

The GMA generally prohibits the withdrawal and transport of groundwater from areas outside of AMAs into AMAs (ARS §45-551(B)), a provision enacted as part of the 1991 Groundwater Transportation Act. The 1991 Act addressed the concerns of rural areas that cities within AMAs would mine their groundwater basins to serve urban populations, and effectively ended an earlier era of water farms (Gallogly 2009; Schaffer 2010). The Arizona legislature acknowledged that allowing a governmental entity to purchase land for water farms decreased the tax base of a county because, by ownership, the property would be removed from the county's tax roll.

However, the 1991 Act authorizes transporting groundwater from certain basins or sub-basins into an AMA, including among others the Big Chino Sub-basin of the Verde River Groundwater Basin, in part to accommodate the then ongoing negotiations for the YPIT water rights settlement (ARS § 45-555). The statute provided two separate provisions. The first provision, Section 45-555(A), authorizes a city or town that owns or leases historically irrigated acres in the Sub-basin to transport from that land to the Prescott AMA an annual average of 3

acre-feet of groundwater per acre. The second provision, Section 45-555(E), originally specified that the City of Prescott's right to withdraw and transport water was conditioned on either the "exchange, replacement or substitution" of CAP allocations, or for "directly or indirectly facilitating settlement of water rights claims of the Yavapai-Prescott Indian Tribe (YPIT) and the Camp Verde Yavapai-Apache Indian Community"(Arizona State Senate 2010). The 1991 Act accounted for the sale of CAP water to Scottsdale by allowing Prescott to transport up to 14,000 AF from the Big Chino Sub-basin. Thus, Section 45-555(E) allowed Prescott to have an alternative to its CAP water, and the proceeds of the sale were required to be used for investigating and acquiring alternative water supplies from CVID (Auer 2010).

In 2010, the state legislature expanded Section 45-555(E) to allow a city or town within PrAMA to withdraw and transport a maximum of 8,068 AFY of groundwater from the Big Chino Sub-basin, provided that it both relinquish its CAP allocation and be party to a federally approved Indian water rights settlement agreement with "an Indian tribe in the Prescott active management area"(ARS § 45-555(E)). Additionally, the amended statute provided an exception from the amount of 8,068 AFY if the city or town delivers more than 231 AFY to fulfill a water settlement agreement. If so, additional water in excess of the 231 AFY may be transported (ARS § 45-555(F)). Finally, Section 45-555(G) authorized the delivery and use of groundwater withdrawn and transported pursuant to Sections 45-555(E) and 45-555(F) by any city, town, or Indian tribe in PrAMA. The 2010 legislation also added a provision stating that groundwater transported pursuant to Section 45-555(E) is legally available under the AWS rules (ARS § 45-557(C)).

Although the language of the provision was broadened to refer to "a city or town" in PrAMA rather than explicit reference to the City of Prescott and specific tribes, only Prescott qualifies under the conditions because it is the only entity in the AMA able to take both of the required actions. The volume limit of 8,068 AFY is consistent with the amount authorized in the City of Prescott's AWS designation pursuant to ARS 45-555(E), which was calculated based on Prescott's relinquished CAP allocation, loss of potential extinguishment credits, and Yavapai-Prescott Indian Tribe (YPIT) water deliveries (ADWR 2009). Similarly, the specified quantity of 231 AFY in Section 45-555(F) reflects Prescott's projection of YPIT water demand in 2027 (ADWR 2009).

ADWR’s 1999 declaration that PrAMA was out of safe-yield prompted Prescott and Prescott Valley to consider options for alternative water supplies to accommodate continued population growth. Since Prescott Valley is not served by a municipal provider with a DAWS, the prohibition of local groundwater pumping applied directly to all new subdivisions within the town. These restrictions plus a lack of alternative water supplies in Prescott Valley would have caused new growth to stagnate (Wadsworth et al. 2009; Holt et al. 2006). However, the ability of the City of Prescott to withdraw and transport groundwater into PrAMA provided in Section 45-555(E) ultimately led Prescott and Prescott Valley to enter into a contract in 2004 to transport groundwater from the Big Chino Sub-basin. Prescott purchased land from JWK Ranch, located in the Big Chino Sub-basin, and renamed the land the Big Chino Water Ranch (BCWR). Prescott Valley then contributed funds to reimburse Prescott for a share of the expense (Prescott 2006). The acquisition consists of 4,852.1 acres of deeded lands and 1,948.6 acres of Arizona State Land and is located approximately 30 miles outside PrAMA. As proposed, a pipeline would

deliver groundwater pumped from the aquifer beneath BCWR to both Prescott and Prescott Valley. Both the cost of the pipeline and future water delivered are divided in a 54.1 to 45.9 percent split for Prescott and Prescott Valley, respectively, per a 2004 intergovernmental agreement (Barks 2012; Prescott 2004). Pursuant to the 2010 amendments to ARS 45-555, 8,068 AFY of groundwater may be withdrawn and transported from the Big Chino Sub-basin by the City of Prescott, and then shared with Prescott Valley.

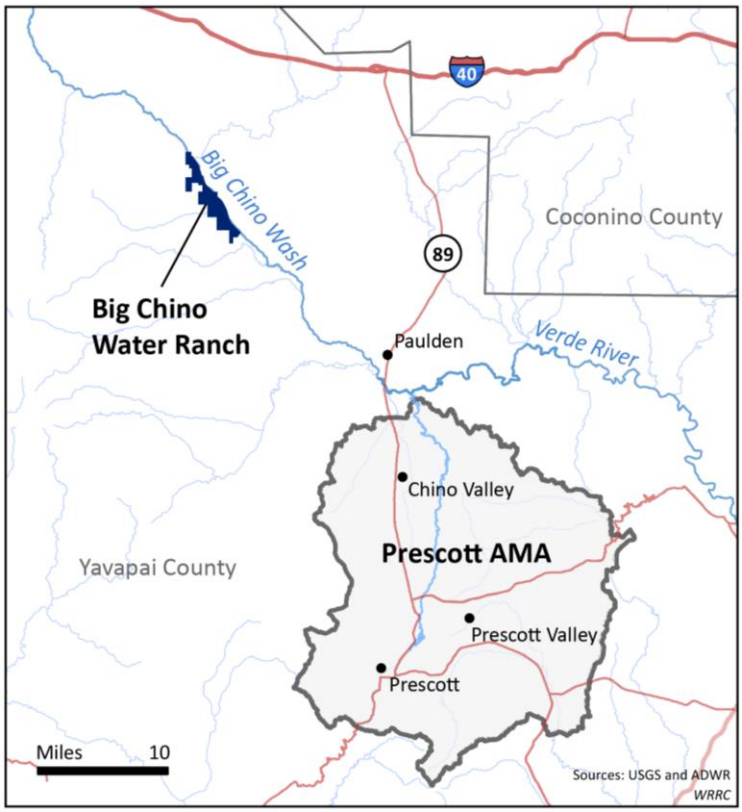

Figure 3. Location of Big Chino Water Ranch.

2. *Prescott's Modified Designation of Assured Water Supply*

On October 12, 2007, Prescott filed an application to modify its existing DAWS, seeking approval for additional 9,575.7 AFY of assured water supplies from transported water from the BCWR pipeline (ADWR 2009). Several parties—including the SRP, the Yavapai-Apache and Fort McDowell Yavapai Nations, and environmental groups—challenged the modification, and both administrative and judicial hearings were held. The key challenges related to the potential adverse impacts to downstream water rights outside of PrAMA, the demonstration of a 100-year AWS, and outstanding litigation of regional tribal water rights (Blackwood 2001). Environmental conservation groups, including The Nature Conservancy and the Center for Biological Diversity, expressed concern that pumping would significantly deplete the downstream Verde River and cause extensive ecological damage to the region (Marder 2009). The Maricopa Superior Court ruled that SRP, the Yavapai-Apache nation and the Fort McDowell Yavapai Nation did not have standing to object to Prescott's AWS application. The Superior

Courts decision was based upon ARS 45-578(B), which limits persons who can object to an AWS application to residents of the AMA. The Yavapai-Apache Nation appealed the Superior Court's decision, but it was affirmed by the Arizona Court of Appeals (Yavapai-Apache Nation v. Fabritz-Whitney, 260 P.3d 299 (Ariz. Ct. App. 2011)).

To preempt continuing and future litigation over the proposed pipeline, Prescott, Prescott Valley and SRP signed an Agreement in Principle (AIP) in February 2010. The AIP established the conceptual framework for future agreements and cooperation on modeling, monitoring, and possible mitigation associated with the BCWR and transporting groundwater to PrAMA. It also led to the withdrawal of all pending lawsuits against the pipeline project. This AIP was followed by the 2012 Comprehensive Agreement No. 1, which recognized the scientific and practical interests in better understanding the relationship between the Big Chino Sub-basin and the Upper Verde River. Under the Agreement, Prescott, Prescott Valley, and the SRP will implement an enhanced groundwater and surface water monitoring system to generate data for a new, more refined groundwater model to be developed. The Agreement also requires an annual written report of the monitoring data and data analysis. By July of 2014, eight of the nine monitoring sites included in the contract were installed and operational (Prescott 2014a).

3. Funding the Pipeline: City of Prescott

The cost of the pipeline, which the City of Prescott and Prescott Valley are splitting 54.1 and 45.9 percent respectively, was estimated to be $150 million in 2009. Prescott plans to take a traditional financing route, through the City's Water Enterprise Fund, which accounts for all necessary water service activities in the City and some parts of the County (Prescott 2015b). In 2005, work began on planning and design tasks, including property assessment, pipeline infrastructure design, and installation of groundwater monitoring wells, but these activities were later put on "indefinite hold" during the economic downturn of 2008 (Prescott 2014b). In 2009, James Holt, Senior Project Manager for the Big Chino Water Ranch, projected that the five-year Capital Improvement Plan (CIP) for FY 2010-2014 would include $142.6 million for constructing the pipeline infrastructure from the Big Chino Sub-basin to the Prescott AMA (OAH 2009). Prescott’s Water Enterprise CIP can issue up to $225 million in bonds, and Prescott may also issue other city bonds if needed (OAH 2009). In modifying Prescott’s DAWS, ADWR concluded that Prescott has the financial capability to construct, transport, and operate the pipeline because it adopted and submitted a five-year capital improvement plan that was certified by the city’s chief financial officer (ADWR 2009). Fundraising for pipeline construction was postponed during the adoption of Comprehensive Agreement No. 1, with project development now subject to the outcome of the 8-year monitoring and modeling study that commenced in late 2012. As of October, 2015, no bonds or funding have been issued, and there are no current construction activities or budget items related to pipeline infrastructure (L. Graser, personal communication, Oct 22, 2015).

4. Funding the Pipeline: Prescott Valley’s Effluent Auction

For Prescott Valley, the two immediate concerns were the cost of the pipeline and the need for water prior to completing the pipeline. To address these concerns, water managers in Prescott Valley identified two options: sell the rights to the transported water, or sell treated

effluent credits. Both options would provide funding for the pipeline. The first option, however, was rejected because the transported water was not available for AWS purposes: ADWR would not recognize the transported water as physically available until the pipeline was actually built. As a result, development in Prescott Valley would be stopped because no water was immediately available. Water managers thus turned to the second option, to establish wastewater effluent as a physically and legally available source that the ADWR could recognize as an assured water supply. Based on the town's current and projected demand for recharge activities, the ADWR recognized 3.36 million cubic meters (2,724 AF) of future effluent credits (Wadsworth et al. 2009).

The effluent credits offered a way to demonstrate availability when applying for a CAWS. Developers in possession of credits are allowed to recover the effluent from designated recovery wells in equal portion to the effluent volume the credits represent (Wadsworth et al. 2009). ADWR recognized 2,724 AF of effluent credits that may be used to support a CAWS application. Of that, 1,103 AF are available immediately and the remaining 1,621 AF are available for future use when Prescott Valley demonstrates its ability to consistently produce and recharge this volume of effluent (Prescott Valley 2014). The credits serve a dual role for the town as a strategy to address the water supply issue as well as a valuable source of assets for raising funds.

Prescott Valley decided that an auction would be the most "equitable" mechanism for obtaining the best value for the treated effluent credits, the proceeds of which would help fund its portion of the BCWR pipeline (Wadsworth et al. 2009). Prescott Valley held two auctions. In 2006, Prescott Valley partnered with Westwater Research LLC to hold the first auction, which failed because the only bid submitted did not meet the auction terms. Those terms required payment in full upon purchase of all currently available effluent credits with an option to purchase future available effluent credits at the bid price. In hindsight, these terms allocated all the risk to the purchaser and did not align with the risk tolerance and expectations of purchasers (Wadsworth et al. 2009).

In 2007, Prescott Valley held a successful second auction, this time partnering with Aqua Capital Management LP, the lone bidder in the 2006 auction. Prescott Valley and Aqua Capital established a guaranteed floor price for the water rights and a break-up penalty if a successful bid emerged. Applying the lessons from the first auction attempt, Prescott Valley restructured the terms for the second auction to reflect housing industry norms: The payment schedule was modified to a payment of 25 percent within 30 days of auction; 25 percent upon submitting the effluent credits to ADWR for a CAWS, and the final 50 percent on a prorated basis as building permits are submitted (Wadsworth et al. 2009). The winner could sell, assign, or pledge the effluent credits to one or more CAWS, or even for recreational and environmental uses, within the boundaries of Prescott Valley (Gelt 2008). Water Property Investors, LLC, a subsidiary of equity investor Water Asset Management, LLC, won the auction and paid $67 million—$24,650 per acre-foot—for the effluent credits (WAM 2015). Water Property Investors also retains the option to purchase more effluent credits as they become available.

Interesting lessons emerge from this auction of effluent credits, which was historic and internationally recognized (Dahms-Foster 2008; Scott 2012). The auction demonstrated that

recharged effluent credits represent a commodity with real market value for developers in AMAs for meeting AWS rules. However, effluent production and recharge must be sufficient for the availability of effluent credits to be recognized. Growth projections were scaled back after the economic downturn that began in 2008, but population and real estate development are expected to increase in PrAMA nevertheless, generating greater demand for water rights acquisition (CYMPO 2014). Partnering with the private sector was necessary to help Prescott Valley navigate water markets (Scott 2012). Terms that better reflected industry norms facilitated the auction success, namely the guaranteed price and contract structuring that gave all parties some security in proceeding with the auction

Catalysts and Impediments to Groundwater Governance

Groundwater management in PrAMA demonstrates the creativity of growing communities in Arizona to comply with groundwater limitations when available surface water and other water supplies are limited. PrAMA lacks access to reliable surface water supplies and CAP water, and faces the same population growth pressures as other regions in the state, creating the challenge of sustaining this growth while relying on alternative sources of water. Unlike larger AMAs, progress toward safe-yield has been significantly impeded in PrAMA by the proliferation of exempt wells (SYS 2006; ADWR 2014c). Prescott and Prescott Valley plan to address the challenge of attaining safe-yield by transporting water from outside PrAMA. In addition, the recognition of recharged effluent availability has made effluent recharge and recovery a viable strategy for meeting PrAMA management goals. Prescott Valley's successful auction pioneered a new effluent credit market in Arizona, and provided an innovative source of revenue for investment in groundwater transportation.

Timeline of Groundwater-Related Events

June 12, 1980	Groundwater Management Act signed into law
September 21, 1991	Groundwater Transportation Act becomes effective
October 31, 1994	YPIT Water Settlement Agreement approved by Congress
September 27, 1996	CAP subcontract for Scottsdale’s Prescott and YPIT entitlements executed
July 28, 1998	ADWR issues initial DAWS for Prescott, the only municipal water provider in PrAMA at the time
January 12, 1999	ADWR issues Declaration that PrAMA is not in compliance with the safe-yield management goal
December 7, 2004	Prescott and Prescott Valley sign agreement to secure groundwater from Big Chino Water Ranch

December 2004	Prescott and Prescott Valley purchase lands from JKW Ranch, rename lands Big Chino Water Ranch
September 2005	Prescott begins efforts to design improvements between BCWR and the Chino Valley Water Production Facility (Prescott 2011).
December 2005	PrAMA GUAC establishes the Safe-Yield Subcommittee
February 14, 2006	Prescott commits to permanently recharging the amount of effluent generated by a development in an annexed area (Resolution 3735).
November 1-3, 2006	Prescott Valley's first attempt to auction effluent credits fails
November 2006	GUAC Safe-Yield Subcommittee issues final report
July 17, 2006	ADWR issues Physical Availability Demonstration No. 20-402187.0000 for Prescott Valley's effluent credits
October 29-30, 2007	Prescott Valley's second auction attempt succeeds; Water Property Investors, LLC purchases rights to treated effluent credits
October 12, 2007	Prescott files application to modify DAWS
November 12, 2008	Parties file objections to ADWR's draft approval of Prescott's modified DAWS
April 8, 2009	Maricopa County Superior Court rules that SRP, the Yavapai -Apache Nation and the Fort McDowell Yavapai Nation, as non-PrAMA residents, did not have standing to object to Prescott's AWS application.
November 9, 2009	ADWR issues final modified DAWS for Prescott
April 2010	Groundwater transportation provisions amended
July 1, 2010	PrAMA Office and all other local AMA offices closed and moved to ADWR Headquarters in Phoenix
February 11, 2010	Prescott, Prescott Valley, the Salt River Project Agricultural Improvement and Power District, and the Salt River Valley Water Users' Association sign Agreement in Principle
October 5, 2012	Parties sign Comprehensive Agreement No. 1
July 28, 2014	ADWR adopts the PrAMA Fourth Management Plan

January 1, 2017	PrAMA Fourth Management Plan effective through 2020
January 31, 2025	GMA mandates compliance with PrAMA's management goal

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Case Study: The Orange County Water District

Introduction

Water is a critical resource in California, the most populous state in the country and the eighth largest economy in the world (CCSCE 2014). Water availability across the state is as varied as the diverse geographic terrain and demographics: The northern part of the state is characterized by abundant rainfall and runoff from snowpack and lower population density, while the southern part of the state has an arid to semi-arid climate but the highest population density. Dependence on groundwater tends to vary with annual precipitation, but groundwater use has increased significantly since the current drought started in 2012. Two years later, the California Legislature passed the Sustainable Groundwater Management Act (SGMA), the first comprehensive and mandatory statewide groundwater management law.

The Orange County Water District (OCWD) predates SGMA by nearly eighty years and is one of the oldest groundwater management districts in California, ensuring groundwater supplies for economic and municipal growth in the face of water scarcity. It is nationally and internationally recognized for its groundwater recharge and wastewater treatment programs and for successfully managing groundwater for the millions of people who live in the OCWD service area. This case study will first provide an overview of the legal framework for groundwater management in California leading up to the SGMA and provide a brief description of the law and its potential to change groundwater management in California. This case study will then examine the long history of the OCWD and the evolution of management strategies, namely using economic incentives to manage groundwater pumping. Finally, this case study will identify key lessons from the OCWD experience.

Overview: Groundwater Management in California

California is experiencing a historic and severe drought. In normal years, the winter snowpack provides approximately 30 percent of statewide water needs as it melts through the spring and early summer. At the end of January 2015, the California Department of Water Resources (DWR) announced that the statewide snow-water equivalent was four inches, or 75 percent lower than the historical average (DWR 2014b). In early April 2015, the Phillips snow course in the Sierra Nevada range measured zero snow, the first time in 75 years of early-April snow measurements (DWR 2015). To end the drought, the state climatologist declared that California would need 150 inches of rain by September 30, 2015 (DWR 2014b). On average, California receives 21.44 inches of rain per year (National Atlas 2005).

The drought is having a significant impact on groundwater resources across the state. Annual reliance on groundwater varies with precipitation: In wet years, groundwater accounts for roughly 40 percent of the state's water supply; in dry years it accounts for as much as 60 percent of the water supply (DWR 2014a). Since this current drought began in 2012, water users have drilled more than 650 new wells across the state, the majority located in populous and

agriculture-dominated southern California counties. Groundwater levels have decreased, and land subsidence is evident across the state (DWR 2014a).

California faces many groundwater management challenges in addition to the physical limits on water supplies. Although surface water has been managed since 1914, California did not have mandatory statewide groundwater management until 2014. Prior to SGMA, the state opted for local control over groundwater resources, resulting in a patchwork of groundwater management (Patashnik 2011). Groundwater governance, if any, occurred by adjudication or through local agencies, relying on authority in the California Water Code or other statutes. A special groundwater district,[1] created by a special act of the state legislature and prescribed specific powers, could implement groundwater management. A local government could also pass a groundwater ordinance or sign a joint-powers agreement related to exporting groundwater or defining groundwater well standards (Patashnik 2011).

As a result of these various governance mechanisms, surface water and groundwater management is highly fragmented across the state. Several state agencies are responsible for different aspects of groundwater management. The principal state-level agencies are the DWR and the State Water Resources Control Board (SWRCB). DWR was established in 1956 to plan and manage much of the state's water conveyance system and water use. The SWRCB, established in 1967, allocates surface water rights and protects water quality, including monitoring water quality and contamination and overseeing cleanup. Other agencies that have responsibilities for groundwater include the Public Utilities Commission, CalRecycle, the Department of Food and Agriculture, the Department of Pesticide Regulation, the Department of Toxic Substances Control, the Office of Environmental Health Hazard Assessment, and the Pollution Control Financing Authority (LAO 2014).

Another significant challenge is that, as in many states, California law does not acknowledge the connection between surface water and groundwater. California recognizes three categories of waters: surface water, subterranean streams, and percolating groundwater. Water rights—generally following the doctrine of prior appropriation—are required for using surface water and subterranean streams but not for groundwater, even though groundwater withdrawals affect surface water and vice versa. For groundwater, California follows the common law doctrine of correlative rights, meaning that a landowner can pump as much groundwater as he wants, without a permit, as long as the water is used for a beneficial purpose and the landowner does not interfere with his neighboring landowners' ability to pump the same.

Other challenges include prevalent groundwater contamination throughout the state; and significant information and data gaps about groundwater levels, conditions, and status (LAO 2014). For groundwater contamination, cleanup and treatment are expensive and may require closing off that water resource, even if no replacement is available. The lack of data on groundwater use and quality is a significant obstacle to groundwater management, and often the

[1] These districts fall into two categories: one type is authorized to limit groundwater export and extraction, upon showing of groundwater overdraft or threat of groundwater overdraft; the second type does not have authority to limit extraction, but users may be required to report extractions and the district can levy fees to fund groundwater management or supply replenishment.

data sources and information collected are not standardized and cannot be compared or tracked from year to year (LAO 2014).

The Sustainable Groundwater Management Act (SGMA)

On September 16, 2014, California Governor Jerry Brown signed into law the Sustainable Groundwater Management Act of 2014, a package of three groundwater management bills. SGMA marks the end of California's status as the only western state in the United States without some form of state oversight for groundwater management. California is experiencing an unprecedented, multi-year drought, which is exacerbating widespread groundwater overdraft across the state. The bill passed along clear lines: Supporters of the SGMA included many urban and coastal legislators, nearly all state Democrats, environmental groups, and water district managers; opponents included most Republicans, Democrats from agriculture-heavy districts, and agricultural interests (Mason 2014).

SGMA requires each groundwater basin to establish a local groundwater sustainability agency (GSA) that must assess groundwater conditions in the basin and adopt a locally-based groundwater sustainability plan (GSP).[2] The goal of the GSP is to achieve long-term groundwater sustainability within 20 years of the implementation date. In SGMA, "sustainable groundwater management" means using and managing groundwater in a way that can be maintained during the planning and implementation time period without causing undesirable results, such as chronically lowered groundwater or surface water levels, significant and unreasonable reductions of groundwater storage capacity and quality, and significant and unreasonable saltwater intrusion or land subsidence.

A GSP must include a physical description of the basin, including groundwater levels, groundwater quality, degree of subsidence, groundwater and surface water interactions, data on historical and projected water demand and supplies, and monitoring and management provisions. It must also include a description of how the plan will affect other city and county general plans. SGMA also grants GSAs authority to require registration of groundwater wells, to measure and manage groundwater withdrawals, to require groundwater use reports and assess groundwater withdrawal fees, and to request revisions of basin boundaries. Importantly, however, a GSA is not required to use these authorities.

Groundwater basins in California are prioritized as very low, low, medium, high, and very high, depending on groundwater reliance and other statutory criteria.[3] For high and medium priority basins, the GSA must adopt a plan within five to seven years of 2014, depending on the basin's status as in "critical overdraft." The DWR will review the GSP for adequacy. If the plan

[2] SGMA requires the Department of Water Resources to categorize groundwater basins as high, medium, low, or very low priority by January 31, 2015. DWR must also adopt a series of regulations: for basin boundary adjustments by January 1, 2016; for evaluating the groundwater sustainability plans and GSA coordination agreements by June 1, 2016; and for estimating water available for groundwater replenishment by December 31, 2016. DWR must also publish groundwater sustainability best management practices by January 1, 2017.

[3] Other criteria include the population overlying the basin, the current and projected population growth, the number of public supply wells in the basin, the total number of wells in the basin, the total irrigated acreage in the basin, and any negative impacts on groundwater in the basin.

is inadequate, the SWRCB may designate the basin as probationary. If the GSA fails to submit and adopt a compliant GSP within 180 days, the SWRCB can create an interim plan that will remain in effect until the local GSA complies with the GSP requirements. The plans are evaluated every five years.

SGMA is notable because it recognizes that surface water and groundwater are connected and long-term sustainability is necessary for the present and future generations (Frank 2014). However, critics from both sides point to potential problems and shortcomings. As the dominant groundwater users in the state, agricultural interests have long opposed statewide groundwater management (Laird 2013) and have argued that SGMA upends more than a century of water law, creates new layers of bureaucracy, and could exacerbate the economic impacts of the drought by restricting farmers' and landowners' ability to withdraw groundwater (White 2014). In contrast, environmental interests are concerned with the long timeline for implementing SGMA, the primacy of the local GSAs that may not use their full authority to require reporting, and the secondary role of state agencies such as DWR and the SWRCB, and the availability of resources for adequate oversight (Frank 2014).

A study pre-dating SGMA raises other potential concerns about the effectiveness of groundwater management plans (GMPs). In early 2014, the non-profit California Water Foundation (CWF) published its evaluation of existing GMPs, which at the time were not required by any law to achieve groundwater sustainability. CWF evaluated 120 groundwater management plans based on the required and voluntary components for GMPs in the California Water Code and the DWR Bulletin 118.[4] The evaluation found that GMPs cover approximately

[4] The mandatory groundwater management plan requirements (Cal. Water Code § 10750 et seq.) include:
(1) Documentation of public involvement
(2) Basin Management Objectives
(3) Monitoring and management of groundwater elevations, groundwater quality, inelastic land subsidence, and changes to surface water flows and quality that affect GW levels or quality
(4) Plan to involve other agencies in the GW basin
(5) Adoption of monitoring protocols
(6) Map of groundwater basin boundary and boundary of agencies subject to the GMP
(7) If not overlying GW basins, appropriate geologic and hydrogeologic principles used to prepare GMP.
(8) Map that identifies the recharge area for the GW basin

The voluntary and recommended requirements (Cal. Water Code and DWR Bulletin 118) include:
1) Control of saltwater intrusion
2) Identification and management strategies of well-protection and recharge areas
3) Regulation of migration of contaminated GW
4) Administration of well-abandonment and destruction program
5) Control and mitigation of GW overdraft
6) Replenishment of groundwater
7) Monitoring GW levels
8) Development and operation of conjunctive use projects
9) Identify well construction policies
10) Construction and operation of groundwater contamination cleanup, recharge, storage, conservation, water recycling, and extraction projects
11) Development of relationships with state and federal regulatory agencies
12) Review of land use plans and coordination with land use planning agencies to assess activities that create reasonable risk of GW contamination

38 percent of the state's groundwater basins, and areas with extensive groundwater use are generally covered by a plan. It found high variability in the quality of the GMPs: For example, some of the plans were more than 20 years old, and others were recently updated and tended to be better quality (CWF 2014). Some plans lacked very basic information and data, such as overall groundwater supply and demand estimates, as well as basic basin management objectives or an implementation strategy. Some plans also lacked information on outreach efforts and efforts to solicit public input as part of the plan development (CWF 2014).

Overview: The Orange County Water District

The Orange County Water District (OCWD) was established in 1933 to address conflicts with upstream water users (Laird 2013). Throughout its history, the OCWD has maintained a supply-side management strategy and has demonstrated flexibility and foresight when addressing concerns about both groundwater supply and groundwater quality. It actively manages the groundwater basin underlying central and northern Orange County by recharging groundwater and assessing fees on groundwater users. More than 20 different cities and water agencies pump from the vast groundwater basin, which underlies the OCWD service area and has varied geological features. The OCWD operates numerous groundwater recharge facilities and saltwater intrusion barriers throughout its service area and is widely recognized for its efforts using advanced treated wastewater to augment water supplies.

13) Management with guidance of advisory committee
14) Description of area managed under GMP
15) Links between BMOs and goals and actions of GMP
16) Description of GMP monitoring programs
17) Description of integrated water management planning efforts
18) Report of implementation of GMP
19) Periodic evaluation of GMP

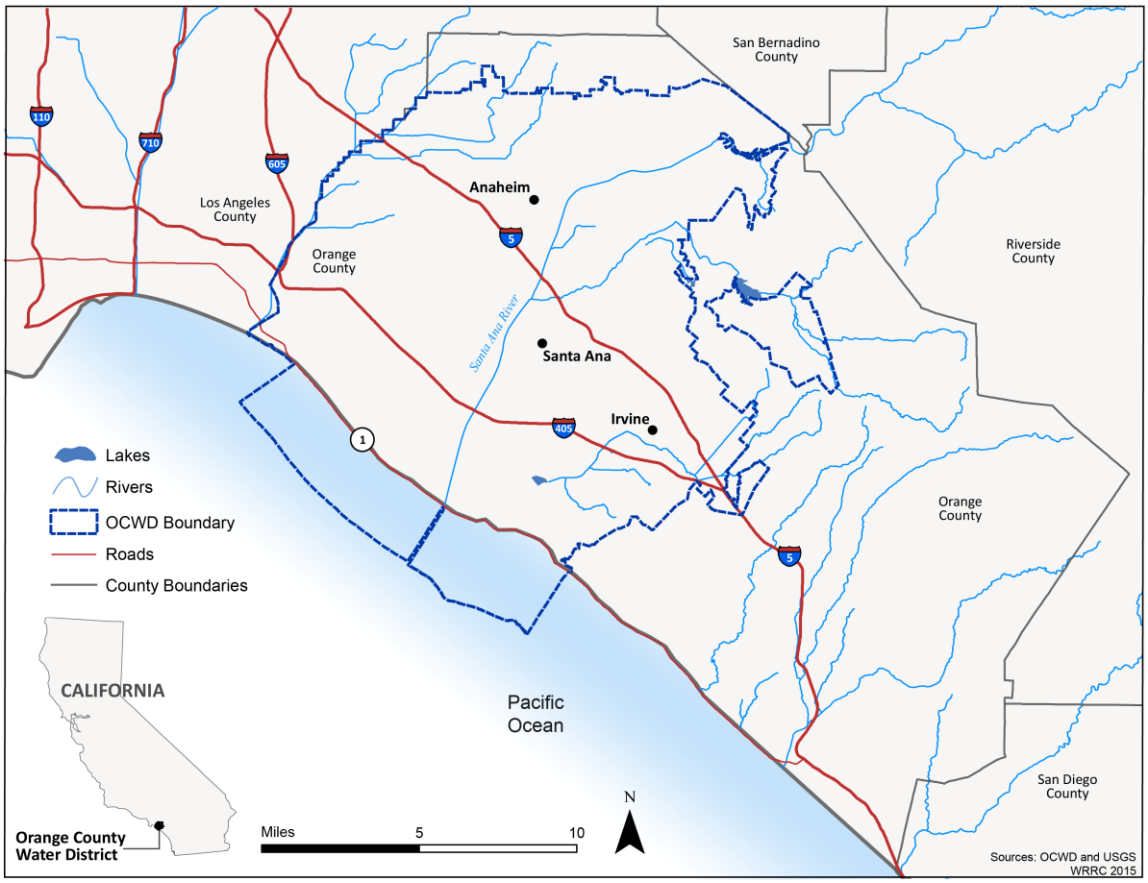

Figure 4. Location of Orange County Water District (OCWD) and Surrounding Counties.

The Orange County Water District Act authorizes the OCWD to provide for conjunctive use of surface water and groundwater, including storing, purchasing, and transporting water for beneficial use. SGMA also authorizes the OCWD to provide for the protection and enhancement of the environment related to water management. The OCWD is not authorized to regulate or restrict groundwater use (OCWD 2009a). In the early years of the OCWD, the water users were deeply opposed to adjudicating or restricting water rights. Instead they sought supply-side management strategies to provide water regardless of growth, drought, or other increases on water demand (Wong 1999; Hutchinson et al., n.d.).

1. Water Demand

The area and population served by the OCWD have increased demand for groundwater tremendously, from approximately 162,000 acres and 120,000 residents in 1933 to 229,000 acres and 2.5 million residents in 2009 (OCWD 2009a). Between July 1, 2012, and June 30, 2013, total water demand was 434,535 AF, excluding water used for groundwater replenishment and barrier maintenance. Groundwater production was 309,295 acre-feet (AF), or the volume of water that covers one acre to a depth of one foot (roughly 326,000 gallons), a ten percent increase from the prior year. Annual overdraft, or the decrease in basin storage without supplemental replenishment water, was 177,000 AF, compared to a five-year average annual

overdraft of 96,000 AF. The projected annual overdraft for the years 2013-2014 and 2014-2015 were 202,000 AF and 121,560 AF, respectively (OCWD 2014a).

By 2035, the projected population in the OCWD service area will increase to 2.7 million people, and annual water demand will increase to 525,000 AF. The OCWD plans to meet this increased demand by operating the existing Groundwater Replenishment System (GWRS, discussed below) and increasing its capacity, maximizing the Advanced Water Production Facility's capacity, capturing more Santa Ana River storm flows, purchasing imported water supplies whenever available, developing other recycled water supplies for replenishment, and expanding recharge facilities (OCWD 2014c).

2. Water Supply

Groundwater is the primary source of water in the OCWD service area, meeting the needs of 60 to 70 percent of the total water demands (OCWD 2009a). The most recent data for period between July 1, 2012, and June 30, 2013, show that precipitation in the OCWD area averaged 6.12 inches, or 46 percent below the long-term average of 13.4 inches per year. Groundwater is recharged by natural recharge, flows from the Santa Ana River and the Santiago Creek, reclaimed water, and water purchased and imported to the Basin. Most recharge occurs by flow from the Santa Ana River, although the capacity to recharge is diminishing with lower baseflow. During the 2012-2013 period, flows from the Santa Ana River were 102,830 AF, or 55 percent below the 30-year average (OCWD 2014a).

To ensure groundwater supplies are available regardless of pumping or climatic conditions, the OCWD operates more than 1,000 acres of recharge facilities and many recharge programs to augment and protect groundwater supplies. The focus on groundwater replenishment began in 1948, and today natural groundwater recharge from the Santa Ana River and Santiago Creek is supplemented by artificial recharge with treated wastewater and imported water. The OCWD is a leader in advanced wastewater reclamation, which it began using in 1975 to protect against seawater intrusion into fresh groundwater drinking supplies.

Historically, treated wastewater was used primarily as injection and percolation water for barriers and for irrigation and industrial uses (OCWD 2014c). Salinity in groundwater is a major basin management issue, resulting primarily from seawater intrusion and to a lesser degree from saline water trapped at the time of deposition and brines from past oil production. Saline water enters the groundwater basin through permeable overlying sediments and gaps in underlying geology, particularly near the Talbert and Alamitos Gaps. In 1975, OCWD constructed and began operating Water Factory 21, which produced treated wastewater until 2004. The water was then injected into the ground, forming the Talbert Barrier against seawater intrusion. In 2008, the GWRS replaced WF-21. It produces up to 72,000 acre-feet per year (AFY) and is operated jointly with the Orange County Sanitation District. The GWRS delivers wastewater that has been purified to drinking water standards and is directly injected into the Talbert seawater intrusion barrier. Some of this highly treated wastewater is sent via pipeline to spreading basins in Anaheim, where it percolates into the groundwater basin. OCWD conducts extensive monitoring for groundwater quality and groundwater levels to ensure treatment effectiveness (OCWD 2009a).

OCWD also purchases and receives imported water from the Metropolitan Water District, (when excess supplies are available); the State Water Project; the Colorado River; and flows from upstream of the Santa Ana River (OCWD 2009a).

3. Economic Incentives for Groundwater Management

To fund these groundwater replenishment strategies, OCWD initially relied on revenue from its ad valorem taxing authority to purchase water from the Metropolitan Water District. However, this revenue fell short: In the first two years, the OCWD was unable to purchase 72,000 AFY to compensate for the overdraft volume (Wong 1999). Faced with this revenue shortfall, the OCWD sought alternatives to raising the ad valorem tax. Although most groundwater users in the OCWD paid taxes and received the benefits of imported water purchases, some did not pay and nevertheless pumped groundwater and others paid taxes but did not pump or therefore benefit from the water purchases (OCWD 2009a). In the early 1950s, the OCWD determined that a fee linked to pumping would solve the fairness problem while maintaining a commitment to increasing supply rather than restricting demand (OCWD 2009a; Hutchinson et al. n.d.). This supply-side management also enabled continued urbanization and population growth (Endo 2014).

The replenishment assessment (RA), enacted and implemented in 1954, remains a key feature of OCWD's groundwater management strategy and is one of the most significant modifications to the original OCWD Act. The RA is assessed on each acre-foot of groundwater pumped but does not limit how much groundwater may be pumped. Revenues are used to purchase supplemental water for the groundwater basin. They are also used to operate and maintain water production and to acquire water rights and spreading facilities for replenishing and protecting groundwater supplies (OCWD 2009a). For the proposed budget in FY 2014-2015, the RA was $294 per AF, an increase from the previous year's RA of $276 (OCWD 2014b). In the most recent OCWD GMP, the funds generated from the RA amounted to more than 70 percent of operating revenues for the OCWD (OCWD 2014b).

The RA has two primary benefits: It generates the funding needed to purchase imported water supplies to replenish the groundwater basin in the OCWD, and it links the amount paid to the benefits received and thus more fairly spreads the cost of groundwater replenishment projects among groundwater users (OCWD 2009a). Within ten years enacting the RA, the combination of groundwater replenishment and decreased pumping restored average groundwater levels in the basin and eliminated the accumulated overdraft (Wong 1999). As importantly, implementing the RA required monitoring and reporting requirements that helped the OCWD accurately assess the fee and led to a long-term record of groundwater use in the basin. In 1954, the OCWD began requiring groundwater users to measure, record, and report water production for all wells in the Basin. In addition, the OCWD Engineer was required to submit an annual report on the Basin conditions and groundwater production. The RA also necessitated expanding OCWD boundaries to include the entire Basin, ensuring that the RA would be implemented fairly for all groundwater users pumping from the same Basin. The RA alone ultimately did not create an economic signal to conserve because it was not set high enough to affect water demand (Laird 2013; Palanca-Tam 2012).

In 1968, the OCWD Act was amended again to redesign the pumping fee. This amendment implemented two new strategies: the Basin Production Percentage (BPP) and the Basin Equity Assessment (BEA). The BPP is defined as the ratio of groundwater pumped from the Basin to all water—surface water, groundwater, and supplemental sources—produced by all water producers in the OCWD (OCWD 2014a). Historically, the BPP has ranged between 64 and 80 percent (MWDSC 2007). This ratio is set on a yearly basis by the OCWD Engineer and sets the target percentage of total groundwater reliance for every water user. Producers that use less than 25 AFY are exempt from the BPP. For FY 2014-2015, the BPP was set at 72 percent (OCWD 2014b).

Water users in the OCWD who exceed the BPP are subject to the BEA, which is established annually by the OCWD Board. It is defined as the differential cost between pumping groundwater and purchasing imported water. Effectively the BEA is roughly equivalent to the cost of purchasing alternative water supplies (MWDSC 2007) and is relative to the cost of pumping for each purchaser, which varies across the OCWD service area. Groundwater producers pay the BEA for each acre-foot of water that exceeds the BPP, and the proceeds of the BEA are used acquire water to replenish the groundwater supplies in the OCWD (Act, 2014). In FY 2009-2010, for example, the BEA ranged from $348.50 per AF for agricultural water use to $518 per AF for the City of Fountain Valley (OCWD 2009b). In FY 2014-2015, the revenue generated from the BEA was estimated to total $1,750,000 (OCWD 2014b). Overall, this economic approach to managing groundwater is effective because water producers prefer taking imported water, which allows them to rest their equipment and avoid paying the BEA (Personal correspondence with A. Hutchinson).

Combined, the goal of this strategy is to set the BPP "as high as possible to allow Producers to maximize pumping and reduce their overall water supply cost" (OCWD 2009a). However, there are certain exemptions to encourage pumping and treatment of groundwater that does not meet drinking water standards. Those producers are granted partial or total BEA exemptions to compensate for the cost of treating low-quality groundwater, such as groundwater contaminated by nitrates, total dissolved solids, volatile organic compounds, and other contaminants. These exemptions help OCWD manage where groundwater is pumped by, for example, shifting pumping to interior parts of the OCWD service area to relieve pressure on pumping near the seawater barrier (Personal correspondence with A. Hutchinson).

> Groundwater production in the OCWD is assessed as follows: If the volume of groundwater withdrawn is:
> - **Equal to or below** the BPP, the user is assessed the RA; or
> - **Greater than** the BPP, the user is assessed the RA and the BEA for each acre-foot that exceeds the BPP.

4. Relationship between the OCWD and SGMA

The 2014 SGMA specifically lists the OCWD among fourteen agencies created by statute as the exclusive local agencies within their boundaries to develop and meet the requirements of the SGMA. OCWD plans to continue its existing management strategy without adopting new powers that are authorized under SGMA (Personal correspondence with A. Hutchinson). To maintain the supply-side management strategy, OCWD will increase water recycling and groundwater recharge with stormwater and imported water. External factors, such as the

increasing cost of water in southern California and statewide water restrictions, are likely to reshape how cities and industries in the OCWD service area use water, particularly outdoor water use.

Lessons from the OCWD

The ongoing drought in California has forced surface water and groundwater management to the forefront of public awareness in the state and across the United States. Governor Jerry Brown issued statewide water restrictions on April 1, 2015, requiring the SWRCB to impose restrictions to cut water use by 25 percent across the state and ordering DWR to lead a statewide effort to replace 50 million square feet of ornamental lawns with drought-tolerant landscaping (Cal. Executive Order B-29-15).

The OCWD is an excellent model for water management, having successfully managed groundwater for more than 80 years. On its 75th anniversary in 2008, the U.S. House of Representatives lauded the OCWD's many accomplishments, including having one of the most sophisticated and efficient recharge systems in the country and having rigorous water quality monitoring and protection programs, among numerous other accomplishments (H. Res. 1199, 110th Cong. 2008). The OCWD originated from early critical groundwater problems and conflicts with upstream users. The recharge capacity of the OCWD has helped its southern California users weather two serious droughts in 1977 and between 1987 and 1992. The key and vital groundwater management strategy in the OCWD is the pumping fee, which provides funding for the replenishment program, equitably distributes the costs of the program among groundwater users who benefit from pumping, and establishes an economic signal to direct pumping and groundwater use (Wong 1999).

As the OCWD experience demonstrates, assessing fees or taxing groundwater withdrawals can be an important and effective tool for managing groundwater. Legal scholars point out that taxes must be sensitive to the economies of rural regions and implemented in phases to account for equity and history of groundwater use (Glennon 2004). Initially, the tax may not be high enough to affect demand, but gradual increases may help signal to users the need to maximize water use efficiency (Palanca-Tam 2012). Groundwater taxes can also be structured to affect particular uses. For example, groundwater withdrawals that have a significant impact on surface water levels or riparian habitats could be taxed at a higher rate, encouraging alternative sources of water.

Taxing can also generate revenues that can be used for many purposes, including watershed rehabilitation or aquifer replenishment. In the case of the OCWD, some have argued that pumping taxes are not high enough to promote conservation (Palanca-Tam 2012; Smith 1986). Nonetheless, implementing the pumping fee led to monitoring and reporting requirements, data that are necessary for sound policies, planning, and effective management (Wong 1999). Groundwater management in the OCWD has also benefitted from early and consistent recognition of the surface water-groundwater connection, as well as early efforts to use the supplies conjunctively. More importantly, the OCWD has shown flexibility in adopting different approaches when new problems arise, as well as a commitment to coordinating with water producers and state and local water agencies to manage groundwater.

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Case Study: The Central Florida Water Initiative

Introduction

Florida is a state defined by water, with thousands of miles of coastlines and rivers and millions of acres of lakes and wetlands. Water is plentiful from above and below: annual average precipitation in central Florida is between 50 and 54 inches, and the Floridan aquifer underlies nearly the entire state and parts of Georgia and Alabama. It is one of the most productive aquifers in the world. Florida nevertheless experiences water quality and quantity problems across the state. In central Florida, water withdrawals are approaching or have reached the sustainable limits for fresh groundwater, which is the traditional and least expensive water supply for most users in the state. Groundwater supplies about 90% of the potable water demands in the state. Much of Florida's water resources are necessary simply to support aquatic ecosystems and riparian habitats, but water availability for natural areas is decreasing as human population, agricultural irrigation, and industrial uses demand more water. (Salamone 2002).

Groundwater is the key focus of water management and governance in Florida, but limited supplies have forced the state and water users to consider alternative water supplies (AWS). In the mid-2000s, regional leaders recognized the intense pressure on groundwater supplies in central Florida, leading to a voluntary, regional effort to plan for future water supplies and to develop strategies to meet future demands. The present-day Central Florida Water Initiative (CFWI) builds on the strengths of Florida's 1972 Water Resources Act, a historic act that coupled groundwater and surface water and established regional water management districts divided primarily along hydrologic boundaries. This case study describes the legal framework for water governance in Florida and the ongoing effort to coordinate water governance in central Florida.

Groundwater Management in Florida: The Legal and Administrative Context

Similar to most states in the eastern United States, at statehood Florida adopted common law riparianism for water allocation. Under riparian law, landowners adjacent to a source of water can use that water in a reasonable manner for a useful or beneficial purpose on that land (Village of Tequesta 1979). At the time, the population in Florida was significantly smaller than today, and the abundance of water was largely viewed as a nuisance. Water had to be drained or diverted before land could be farmed or developed (FWRSC 1956). As the population grew, water quality and quantity problems did as well, such as water pollution, saltwater intrusion in coastal areas, and drought, prompting a review of the existing system of riparian water law (FWRSC 1956).

In 1954, the Florida Association of Soil Conservation District Supervisors asked the member districts to conduct an inventory of local water problems, leading to a compilation of more than 350 problems mostly related to agriculture. A year later, the Florida legislature created the Water Resources Study Commission to comprehensively study water issues across the state and across users and to study potential water legislation. This inventory allowed state leaders to identify statewide problems, ultimately leading to the Commission's recommendations that the state legislature adopt comprehensive water law. The Florida Water Resources Act of 1957 was

adopted, and it authorized the two existing governmental water agencies, then involved primarily in flood control, to also regulate water use (Fletcher 2002).

1. 1972 Water Resources Act

In 1972, the Florida legislature passed the Water Resources Act (WRA), which even today represents an innovative approach to integrated water resource management. The WRA replaced common law riparianism with regulated riparianism, a comprehensive approach to allocating and managing water by permits that do not distinguish between surface water and groundwater resources. It also established five regional water management districts, based on surface water hydrologic boundaries, and created the predecessors to today's Department of Environmental Protection (DEP). The WRA was based on the *Model Water Code*, written by law professors at the University of Florida (Maloney 1972). The Code recognized the importance of centralized, science-based planning by a state-level water board; the relationship between water pollution and water use; and the need to regulate consumptive use (Munson et al. 2005).

Among the more significant amendments, in 1997 the Florida Legislature revised the WRA to shift the focus from managing existing water resources to providing for future use and users and developing the water supply for the future (Munson et al. 2005). The primary purposes of the revision were to identify ways to increase the amount of water available, to identify shortfalls, and to develop additional supplies to avoid competition. The legislation required WMDs to quantify the water supply needs for "all existing and reasonably projected future uses" and set as the level-of-certainty the one-in-ten year drought event (Fla. Stat. § 373.036(2)).

Under the WRA, five water management districts (WMDs) provide statewide management of water that is divided along surface water hydrologic boundaries rather than political boundaries (Fla. Stat. § 373.069). DEP has general supervisory authority over the five districts, and each district has a nine-member governing board that is appointed by the Governor. Fla. Stat. §§ 373.026 & 373.083. DEP also serves as the state permitting authority for the federal water programs including Clean Water Act and the Safe Drinking Water Act. DEP issues permits under the National Pollution Discharge Elimination System (NPDES), sets water quality standards and total daily maximum loads (TMDLs), and administers other federal water programs.

The WRA originally laid out five primary functions for the WMDs: to construct and operate district works; to plan, manage, and permit consumptive uses of water; to supervise water well construction; to regulate systems that manage or store surface waters; and to evaluate water supplies and other resources within the district (Parker and Mann 1996). The Legislature has since delegated additional functions to the WMDs, such as developing groundwater availability inventories, administering the Environmental Resource Permit (ERP), managing the Surface Water Improvement and Management (SWIM) program, acquiring and managing certain lands, and restoring the Everglades and the Florida Bay. The WMDs are funded by legislative appropriations, permit application fees, bonds under certain conditions, the SWIM trust fund, the Water Management Lands Trust fund, and ad valorem taxes.

2. Consumptive Use Permits & Environmental Resource Permits

The hydrologic connection between groundwater and surface water is explicitly recognized in the WRA, which defines water to mean "any and all water on or beneath the surface of the ground or in the atmosphere…" and to include "natural or artificial water course, lakes, ponds, or diffused surface water and water percolating, standing, or flowing beneath the surface of the ground, as well as all coastal waters within the jurisdiction of the state" (Fla. Stat. § 373.019(22)). The WRA also integrates water quality and water quantity issues in part by having the WMDs issue both consumptive use permits (CUPs) and environmental resource permits (ERPs).

To obtain a CUP, an applicant must demonstrate that the proposed use meets three criteria: It must be a reasonable-beneficial use of water; it must not interfere with an existing legal use of water; and it must be consistent with the public interest (Fla. Stat. § 373.223). The term "reasonable-beneficial use" is defined as water used "in such quantity as is necessary for economic and efficient utilization for a purpose and in a manner which is both reasonable and consistent with the public interest" (Fla. Stat. § 373.019(16)). The term "public interest" is not defined.

A CUP has a maximum duration of 20 years, if there are sufficient data to provide reasonable assurance that the conditions for issuing the permit will be met for the entire permit duration. Municipalities, other governmental bodies, or public works or services corporations may be granted permits for up to 50 years if bonds are needed. A CUP may be modified and is not subject to competing claims, as long as the quantity of water requested does not increase and the source of water does not change (Fla. Stat. § 373.236).

The WMDs also issue Environmental Resource Permits (ERPs), a responsibility shared with DEP under certain circumstances. An ERP is required for land development that exceeds threshold sizes depending on the activity and location (Fla. Stat. § 373.413). This permit prohibits any activity that alters surface water flows by, for example, generating stormwater or dredging and filling wetlands. Each WMD develops criteria for issuing permits in its district. Recent efforts have made these as consistent as possible while accounting for variation in hydrologic and hydrogeologic conditions in each WMD. Prior to developing land, the applicant must provide reasonable assurances that the project will not cause adverse water quantity impacts, cause a violation of water quality standards, or adversely impact wildlife, among other criteria. Permit applicants must also meet public interest balancing criteria that consider the impact on recreational value, instream uses of water, and aquatic wildlife.

3. Water Reservations and Minimum Flows or Levels

To protect and provide water for aquatic ecosystems and the environment, the WRA authorizes both water reservations and minimum flows or levels (MFL). A reservation is a stringent classification for protecting water, which may be reserved from use in a specific location, quantity, and time for the protection of fish and wildlife or for the public health and safety (Fla. Admin. Code r. 62-40.474). However, existing legal uses of water remain protected "as long as such use is not contrary to the public interest" (Fla. Admin. Code r. 62-40.474). A

handful of reservations have been adopted, and more are expected for ecological restoration projects (FDEP 2014b).

A second statutory method of protecting water quantity for the environment is by setting a Minimum Flow or Level (MFL), which serves as a guideline for permitting consumptive uses of water (Fletcher 2002). MFLs represent an attempt to quantify environmental water needs and recreational instream water needs (Munson et al. 2005). A WMD is required to establish both (1) the minimum flow for all surface watercourses in the area, defined as "the limit at which further withdrawals would be significantly harmful to the water resources or ecology of the area" and (2) the minimum water level for the level of groundwater in an aquifer or for the level of surface water "at which further withdrawals would be significantly harmful to the water resources of the area." Calculating MFLs is based on the best information available, reflecting natural or seasonal fluctuations in water flows or levels, environmental values including wildlife uses, aesthetic and scenic values, and aquatic ecosystem services (Fla. Admin. Code r. 62-40.473). During a declaration of water shortage, these MFLs are protected except at the expense of public health or safety or if otherwise inconsistent with public interest (*see* Fla. Admin. Code r. 40E-8.441).

Although the MFLs program was part of the original 1972 Water Resources Act, the WMDs delayed setting them across the state (Klein et al. 2008). Prompted by litigation for this delay, the Florida Legislature updated the program requirements as part of the 1997 Water Act, which amended the WRA. Instead of requiring all waterbodies to have MFLs, the Legislature required WMDs to establish a list of priority waterbodies and exempted waterbodies less than 25 acres in size. The 1997 Act also noted the impracticality of establishing historical hydrological conditions, thus allowing the WMDs to use current conditions and structural alterations to set the MFLs (Leitman 2011; Mann 1997). This compromise struck a balance between protecting water resources and promoting economic growth by not requiring historical water levels, which may be impossible to achieve (Leitman 2011).

To achieve MFLs or prevent the existing flow or level from falling below an MFL, a WMD is required to develop a recovery or prevention strategy. The recovery strategy must achieve the MFL "as soon as practicable," and both strategies must include a timetable to allow existing and projected uses of water that meet the reasonable-beneficial use criteria to obtained sufficient water supplies to offset reduced withdrawals. If a waterbody is projected to fall below the MFL within 20 years or is below, the WMD must simultaneously approve of a recovery strategy.

4. Water Planning

The 1972 WRA requires different levels of water planning: a state-level plan, a plan by each WMD, and a regional water supply plan if "existing sources of water are not adequate to supply water for all existing and future reasonable-beneficial uses and to sustain the water resources and related natural systems" for 20-year planning periods (Fla. Stat. § 373.709). The state-level Florida Water Plan, must include DEP programs related to water supply, water quality, flood protection, floodplain management, and natural systems; the state water quality standards; the district water management plans; and strategies to develop and review programs as required by statutes or other directives (Fla. Stat. § 373.036(1)).

A district water management plan must include similar components and is based on a 20-year planning period and updated at least once every five years. The district plan must include scientific methodologies for establishing MFLs and all established MFLs, designated regional water supply regions, and a district-wide water supply assessment. The assessment must include identifying existing and reasonably anticipated uses, needs, sources of water, and conservation efforts and considering whether water supplies are adequate for demands and for sustaining the water resources and related natural systems (Fla. Stat. § 373.036(2)). The district plan must also incorporate any completed regional water supply plans.

A regional water supply plan must quantify water needs for existing and future reasonable-beneficial uses during the planning period, accounting for population growth and agricultural demands. The plan must also include a list of options for developing water supply projects that, for each project, details the amount of water produced; the timeframe for implementation; the costs for implementing, operating, and maintaining the project; an analysis of funding needs and potential sources of funding; and identification of the entity that should implement the project (Fla. Stat. § 373.709(2)(a)(3)). The plan must also identify any MFLs and related recovery or prevention strategies, along with any reservations of water by the WMD. In addition to intra-WMD planning, Florida has two inter-WMD Regional Water Supply Plans: the North Florida Regional Water Supply Partnership, which covers the northwestern portion of the state, and the Central Florida Water Initiative, discussed in detail below.

At each level of planning, identifying alternative water supply (AWS) projects is a priority. These projects will help water users transition from traditional groundwater resources to alternatives because, in some areas of the state, groundwater use is near or has reached or exceeded the sustainable limit (CFWI 2015). AWS include as brackish groundwater, surface water, saltwater and brackish surface water, and stormwater. AWS projects include developing, treating, or reusing reclaimed water, brackish groundwater, stormwater, surface water, saltwater, and surface water, as well as increasing conservation and reducing per capita consumption. As of 2013, Florida's Water Protection and Sustainability Program has provided funding for 389 AWS projects that, when completed, are expected to generate more than 700 MDG (FDEP 2014a). Other funding for AWS projects comes from the State Revolving Fund, a loan program.

Overview: Regional Water Planning in Central Florida

The metropolitan area of Orlando is home to 2.3 million people, and hosts millions of tourists each year at the nearby theme parks (Kunerth, 2015). These parks, as well as the agricultural sector and a growing industrial sector, are major economic contributors to the region, These pressures, along with water needs for the environment, drove the formation of the present-day Central Florida Water Initiative (CFWI), a voluntary and collaborative regional water planning effort by the three WMDs whose boundaries meet in this area. This section will review the water supply and demand profile in the region.

1. Water Demand

Average water demand in the CFWI planning area was 800 million gallons per day (MGD) in 2010. This demand is expected to increase to 1,100 MGD in 2035, as a result of a

growing population, increased agricultural acreage, and increased economic growth (CFWI 2015). The municipal sector has the highest water demand: The population in the CFWI planning area was around 2.7 million in 2010 and is expected to increase to 4.1 million by 2035. Orlando and the surrounding metropolitan area have more than 2.1 million residents. This growth corresponds to an increase in water demand from 436.03 MGD in 2010 to 654.34 MGD in 2035, or an increase of 50 percent above 2010 water demands. The domestic self-supply and small utility sector accounted for 20.36 MGD in 2010 and is projected to increase to 24.42 MGD in 2035, due to population growth. Domestic self-supply water users consist of individual private homes or businesses that rely on wells for water and are not required to have a CUP, and small utilities have permitted or annual average water use below 0.1 MGD. Overall, demand for potable water accounts for 70 percent of the increase in future water demands (CFWI 2015).

Agricultural use has the second highest water demand and is expected to increase from 53.75 MGD in 2010 to 100.83 MGD in 2035. All counties in the planning area are projected to decrease irrigated acreage, except for Osceola County. By 2035, an estimated 54,773 acres will be irrigated, up from 28,393 in 2010. The commercial, industrial, institutional sector and the mining and dewatering sector are expected to increase from 74.05 MGD in 2010 to 95.85 MGD in 2035 (CFWI 2015). These sectors include the service and tourism industries; manufacturing and chemical processing plants; hospitals, universities, and prisons; subsurface mining; and activities to remove or control water during excavation and construction (CFWI 2015).

The landscape, recreational, and aesthetic sector is also expected to increase in water demand, from 40.21 MGD in 2010 to 72.185 MGD in 2035, largely due to an increase in acreage from 8,404 acres in 2010 to 16,005 acres in 2035. Finally, the power generation sector, which includes water for steam generation, cooling waters, and replenishing cooling reservoirs, is also expected to increase from 17.2 MGD in 2010 to 22.41 MGD in 2035.

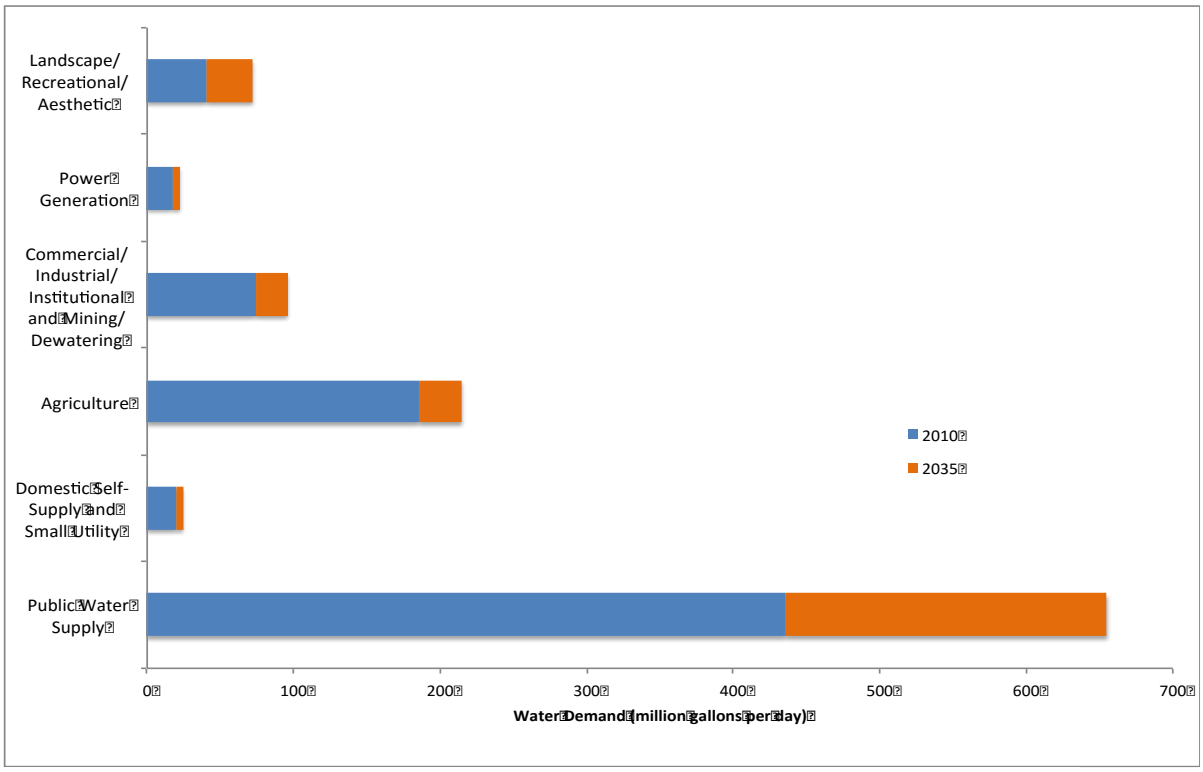

Figure 5. Water Demand in the CFWI Planning Area, 2010 and 2035.

2. *Water Supply*

The CFWI Planning Area has extensive water resources and aquatic ecosystems, despite the overwhelming reliance on groundwater for its water supply. The planning area contains the headwaters for seven river systems, as well as four distinct groundwater basins, 1,200 square miles of wetlands, and 475 square miles of open water bodies. The area also contains sixteen springs that are first (discharging more than 100 CFS), second (discharging between 10 and 100 CFS), or third order (discharging between one and ten CFS) (CFWI 2015; FGS 2003).

The primary water source for the CFWI Planning Area and most of Florida is groundwater, pumped from the surficial, intermediate, and Floridan aquifer system. The CFWI region gets most of its groundwater from the Floridan aquifer, which is one of the most productive aquifers in the world (O'Reilly et al. 2002). Alternative water supplies include reclaimed water, brackish groundwater, surface water, seawater, and stormwater. Within the planning area, more than 90 percent of reclaimed water—178 MGD of 193 MGD—is reused for recharge, agricultural irrigation, environmental flows, public access irrigation, and power plant cooling water.

A relatively small amount of water is withdrawn from surface water resources. Although central Florida has many rivers and springs and hundreds of lakes, these surface water bodies serve ecological resources, some of which are protected from harmful impacts of withdrawal. MFLs have been set for 46 waterbodies in the CFWI planning area, of which ten are already below the MFLs and another 15 are projected to fall below by 2035. All 46 waterbodies fall within the boundaries of the St. John's River Water Management District (SJRWMD) and the

Southwest Florida Water Management District (SWFWMD). Another 28 waterbodies are scheduled for development or reevaluation. The SWFWMD expects to reserve water for the Southern Water Use Caution Area and Lake Hancock. In addition, the future reliability of surface water as a water supply is uncertain because of changing climatic conditions.

Regional Coordination: The Central Florida Water Initiative

Despite plentiful water resources, water conflicts along geographic divisions and among users and uses are not uncommon in Florida. Beginning in the mid-2000s, increasing water demands and potential competition among water users led to the present-day Central Florida Water Initiative (CFWI), an inter-district, coordinated, and voluntary regional water planning effort among the SJRWMD, SWFWMD, and the South Florida Water Management District (SFWMD).

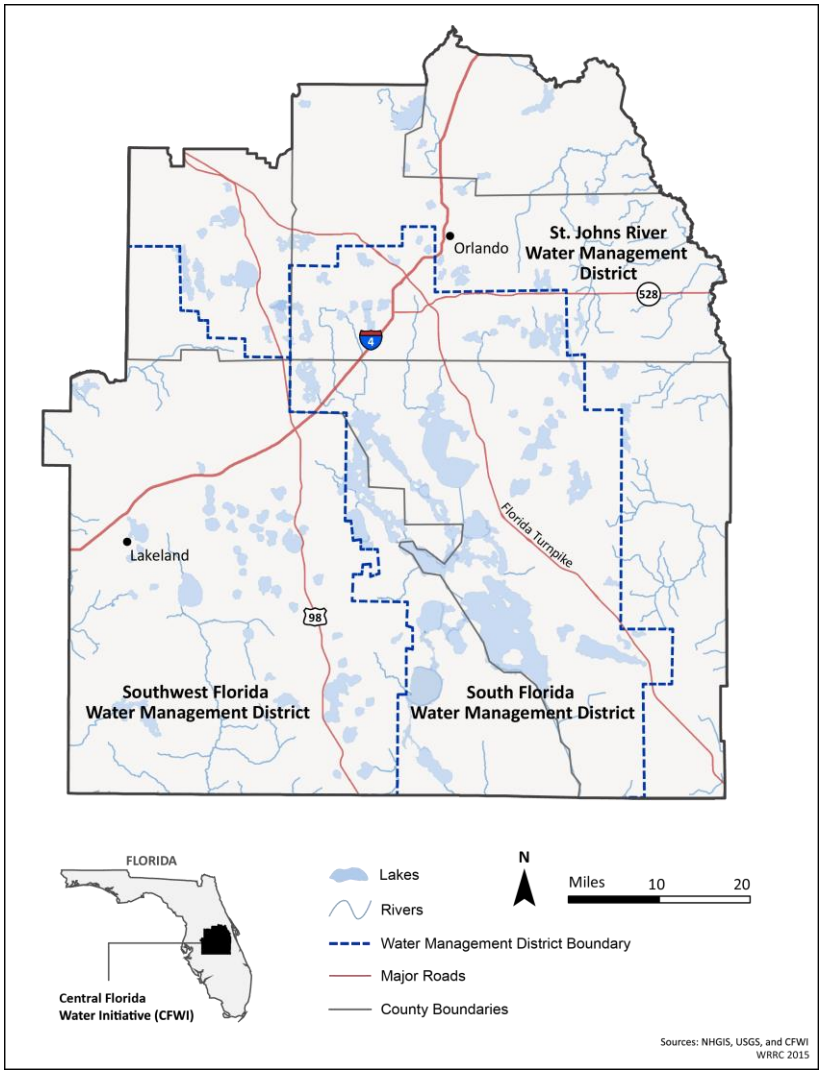

Figure 6. Central Florida Water Initiative Planning Area.

Prior to regional coordination efforts, the SJRWMD, the SFWMD, and the SWFWMD each conducted independent groundwater flow modeling and demand projections and established independent regional water supply plans. Each WMD also had different requirements for issuing CUPs, reflecting the different geographies, demographics, and water resources in each district. However, conflicts between these different requirements emerged in central Florida, where withdrawals in one WMD had the potential to affect other WMDs. Regional leaders also sought to avoid costly litigation over water rights, having watched protracted water litigation in the 1980s and 1990s in the Tampa Bay region that cost taxpayers hundreds of millions of dollars (Pittman 2007). For example, the potential for conflicts and time-consuming litigation prompted the Congress of Regional Leaders (CRL), an organization of sixteen elected officials in government and on school boards of Central Florida counties, to develop a strategic plan for water use in central Florida and identifying ways to avoid using public money to litigate over water (Minton 2014; Myregion.org 2010).

1. Initial Efforts: The Central Florida Coordination Area

The CFWI began in 2006 as the Central Florida Coordination Area (CFCA). The CFWI planning area includes all of Orange, Osceola, Seminole, and Polk counties, as well as southern Lake County. The SJRWMD, SWFWMD, and SFWMD recognized the benefits of cooperation in planning for water supplies in the region due to environmental constraints on groundwater supplies, the numerous water users with the potential for conflict, and overlapping jurisdiction of multiple regulatory agencies (CFCA 2008; King 2006; Grogan 2007a, 2007b). One of the main driving incidents was a highly contested groundwater permit application that affected the entire central Florida region. In 2003, Orange County applied simultaneously from both the SJRWMD and the SFWMD for a 65 percent increase in groundwater withdrawals, but later the county pursued the permit from SJRWMD first. The withdrawals within SJRWMD boundaries would have affected water resources in the SFWMD, as well as neighboring counties. Strong protests and opponents' hiring of lawyers in preparation to contest the application led the SJRWMD to delay the permitting decision (Pittman 2006; Palmer 2007).

In 2008, the three WMDs concluded that the growth in public water supplies from traditional groundwater sources was not sustainable and that the availability of sustainable groundwater quantities in central Florida was insufficient to meet future demands (CFCA 2008). They issued an interim water use rule in the CFCA to "avoid the adverse effects of competition as well as harm to the water resources" (Fla. Admin. Code r.40E-2.091 (2007)). Under this rule, public supply utilities and other applicants could be issued CUPs for 20 years. The rule also limited water withdrawals to 2013 levels, and an applicant was required to develop and use at least one AWS project to meet any demand above the 2013 limit (SWFWMD 2007). The interim rule was effectively a moratorium on future CUPs and thus affected the ability of the region to grow (Polk County 2009). However, this rule had limited application because parts of the region already had rules as strict if not stricter in place (CFWI 2015).

The CFCA adopted a two-phase approach to address the short- and long-term developments of water supplies in central Florida. The goal of Phase I was to address short-term water resource issues (CFCA 2010). The goal of Phase II was to establish new, permanent rules and to implement a long-term water planning approach in central Florida, both of which required

hydrologic models that needed to be developed. However, the CFCA members did not meet the deadline for the Phase II rules due to "the complexity of the water resources in the area, the need for additional data, and the desire for consensus among stakeholders" (CFWI 2015). This rule lapsed on December 31, 2012, and new rules have not been adopted (Spear 2013). In addition, the start of the 2008 recession decreased projected water demands and thus the imperative to identify and implement solutions quickly (CFWI 2015).

2. The Central Florida Water Initiative

In 2011, the CFCA transitioned into the Central Florida Water Initiative (CFWI). This new collaborative body expanded its membership to include local governments, agriculture, and commercial interests and to emphasize public input (CFWI 2015). The organizational structure (Appendix: Governance Structure of the CFWI) includes the Steering Committee at the highest level and then the Management and Technical Oversight Committees. Below these committees are topic-specific committees, which in turn are linked to the Solutions Planning Committee. The goals for the CFWI focus on collaboration and uniformity across the planning area: to develop a model used across the area for water supply planning; to standardize the definition of harm and reference conditions; to standardize the process for reviewing consumptive use permits and for establishing MFLs and reservations; to develop a coordinated Regional Water Supply Plan (CFWI 2015).

3. Groundwater Management Strategies in the CFWI

The primary benefit of the CFWI was to provide a common scientific and technical understanding of groundwater and a common groundwater management strategy. In November 2015, the CFWI published the Regional Water Supply Plan (RWSP) with a planning horizon that extends until 2035. The RWSP is based on a single model to predict water supplies and quantify the gap between supply and demand. It identifies programs and projects to "ensure that adequate and sustainable water supplies are available to meet future water supply needs while protecting the environment and water resources." The need for a RWSP was driven by the expected increase in water demands and previous regional planning efforts that concluded that the rate of groundwater withdrawal is either "rapidly approaching, or has surpassed the maximum rate that can be sustained without causing harm or adverse impacts" to regional water sources and aquatic ecosystems (CFWI 2015). Based on modeling tools developed by USGS, the deficit between supply and demand is estimated to be 250 MGD by 2035.

The RWSP is a collaborative product of government entities, the private sector, and citizen input. The government entities include the three WMDs, the Florida Department of Environmental Protection, the Florida Department of Agriculture and Consumer Services (FDACS). The private sector includes representatives from utilities, agriculture, and industry. The CFWI team hosted 122 public workshops, presentations, and meetings to disseminate information and to collect input from the public (CFWI 2015).

The draft RWSP identifies a variety of options for water conservation and for developing water supplies and sources. For example, the draft RWSP estimates that up to 42 MGD of the 250 MGD deficit could be conserved, 64 percent of which by the public supply utilities, 26

percent by agriculture, and 10 percent by other water users. The draft RWSP also identifies several potential alternative water supplies, such as reclaimed water and surface water. Many water utilities reclaim up to 90 percent of their wastewater, which is treated and then used for non-potable purposes. Potable use of reclaimed water is being investigated but is not currently used. The RWSP notes that legislative changes are encouraging the use of reclaimed water by directing the WMDs to establish rules for applying substitution credits or impact offsets (Fla. Stat. § 373.250). Another potential AWS is surface water, which has the potential to generate between 184 and 209 MGD. However, surface water flows are inconsistent over the course of a year and subject to climatic conditions over the long-term. Increased surface water withdrawal may have significant harmful impacts as well.

The RWSP also identified potential water supply development projects, which have the potential to provide up to 411 MGD. These projects include maximizing the use of reclaimed water, increasing water storage capacity, strategically using brackish and fresh groundwater, and using desalinated water. However, the RWSP recognizes that these development projects should be balanced against other options, along with cost considerations and environmental impacts.

Ultimately, the RWSP concludes that future water demands in the CFWI planning area can be met through 2035, while sustaining water resources and aquatic ecosystems" (CFWI 2015). Beyond this draft plan, the Solutions Planning Team will work on identifying alternatives to meeting water demands and on identifying areas where consistency in regulations and water resource protection strategies are needed across the three WMD jurisdictions. Importantly, although the RWSP describes the hydrologic and hydrogeologic conditions in the region and identifies potential solutions to close the gap between supply and demand, the CFWI does not have authority to implement any of the actions because because the effort is entirely voluntary. The question of implementing these AWS plans and conservation efforts remain entirely up to the local governments in the CFWI Planning Area.

Catalysts and Impediments to Groundwater Governance

In the early 2000s, local governmental and business leaders sought to maintain economic growth and development in light of limited available water supplies in central Florida. They were wary of different regulations in each WMD and of the potential for protracted and costly litigation over water, which would likely increase because of the 2008 conclusion of the WMDs that the limit of sustainable groundwater use was close to being met. Recognizing the same, the SJRWMD, SFMWD, and the SWFWMD embarked on a voluntary effort to coordinate regional planning efforts. The CFWI has produced the scientific and technical information needed for local governments and water providers to ensure water supplies for users and natural systems.

The CFWI nevertheless remains a voluntary and ongoing effort to strengthen and coordinate water governance in a fast-growing region of the state. The biggest hurdle is how to implement the actions identified in the RWSP without any mandatory obligation to do so, or potentially without additional funding. In the November 2014 elections, Florida voters passed a constitutional amendment to set aside revenues from the real estate tax to buy, conserve, and restore land and water resources in support of the Florida Forever conservation program. However, some lawmakers are trying to shift funding to other programs and projects, including

allocating money to long-underfunded state agencies (Alvarez 2015). There is some potential for part of these revenues to fund AWS and conservation projects in the CFWI, but no firm decisions have been made yet.

Although Florida has a strong legal framework for statewide water management, specific regional concerns drove the formation of a voluntary and coordinated water supply planning effort by the three WMDs who boundaries intersect in central Florida. In 1972, establishing the five WMDs represented a prescient and innovative need to govern water resources along hydrological boundaries. Nearly forty years later, the CFWI represents yet another evolution in organizing groundwater governance, one that accounts for connections beyond hydrological boundaries in its effort to coordinate water governance. Whether this voluntary institution succeeds, or transforms into a formal governance structure, remains to be seen.

Timeline

1957	Florida Water Resources Act of 1957 passed
1972	Water Resources Act passed
2006	Central Florida Coordination Area established
2008	SJRWMD, SFWMD, and SWFWMD pass interim rule on groundwater use
2011	CFWI established
December 31, 2012	Interim rule expired
April 2014	CWFI publishes draft Regional Water Supply Plan

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Appendix: Governance Structure of the CFWI

The figure above illustrates the organizational structure of the CFWI. Below is a brief explanation of each of these committees.

- The Steering Committee is the primary oversight committee and provides guidance and direction to the other teams and committees. Its members consist of high-level representatives from each of the WMDs, as well as representatives from FDEP and the Department of Agriculture and Consumer Services. Steering Committee meetings are open to the public and operate by unanimity.
- The Technical Oversight and Management Committees provide regular oversight to ensure a coordinated effort among all teams. The Technical Oversight Committee meets routinely, and the Management Committee meets as needed to address specific issues. They are limited to fact-finding and technical analysis. The members consist of representatives of the executive management teams from each of the WMDs, FDEP, and the public water supply utilities.
- The Hydrological Analysis Team is tasked with developing modeling tools and data analysis. Its members consist of representatives from the WMDs and from the public water supply utilities.
- The Environmental Measures Team is tasked with conducting environmental assessments of wetlands and surface water and the impact of groundwater pumping on these features. Its members consist of environmental scientists from the WMDs and representatives from the public water supply utilities.
- The Minimum Flows and Levels and Reservations Team is tasked with evaluating the status of existing MFLs and reservations and developing a standard, planning area-wide way to measure the effect of existing and proposed withdrawal scenarios on these programs (?).
- The Data Monitoring and Investigations Team is charged with developing a single reference source or database for regional monitoring data and standardizing that data, including aquifer levels, rainfall data, water quality data, flow data, and ecological investigations. Its members consist of representatives from the WMDs and technical representatives from the public water supply utilities.
- The Groundwater Availability Team is tasked with developing estimates of the groundwater availability for planning purposes. Its members consist of members of the Hydrologic Analysis, Environmental Measures, and MFLs and Reservations teams.
- The CFWI Regional Water Supply Plan Team is tasked with developing the regional water supply plan for the CFWI.
- The Solutions Planning Team is tasked with addressing future steps toward meeting the water supply needs of the CFWI planning area and developing alternatives to meet water demands.
- The Regulatory Team is tasked with identifying options for consistent regulations across the planning area and legislative changes, if any, to implement solutions generated by the planning process. Its members consist of representatives from the WMDs, DEP, and DACS, as well as representatives from public water supply utilities and environmental group representatives.

Development of Antibiotic Resistance during Wastewater Treatment

Basic Information

Title:	Development of Antibiotic Resistance during Wastewater Treatment
Project Number:	2014AZ530B
Start Date:	3/1/2014
End Date:	2/28/2015
Funding Source:	104B
Congressional District:	az003
Research Category:	Water Quality
Focus Category:	Wastewater, Water Quantity, None
Descriptors:	None
Principal Investigators:	Jean E.T. McLain

Publications

There are no publications.

Development of Antibiotic Resistance during Wastewater Treatment

Problem and Research Objectives

A 2000 World Health Organization (WHO) report identified antibiotic resistance (AR) as a critical human health challenge for the next century and heralded the need for "a global strategy to contain resistance" (WHO, 2000). According to the report, more than two million Americans are infected each year with antibiotic-resistant pathogens, and 14,000 die as a result. In a more general context, the prevalence of antimicrobial resistance may lead to higher human morbidity and mortality rates, an inability to control infectious disease, "a return to the pre-antibiotic era", increased health care costs, compromised medical procedures, and potentially damaged economies (WHO, 2012).

These grave societal concerns are particularly problematic for the wastewater industry because research has identified wastewater effluent as one of the "leading reservoirs" of antibiotic resistance in the environment (Novo and Manala, 2010). This is partially attributable to human use and subsequent release of antibiotics and metabolites into the wastewater system. It is estimated that 75% (Bockelmann et al., 2009) of antibiotics are excreted unaltered or as metabolites. AR may also develop among the intestinal flora of any person consuming antibiotics. As a result, raw wastewaters may contain antibiotic-resistant bacteria. Furthermore, exposure of pathogenic microorganisms to these reservoirs of AR could lead to horizontal gene transfer and the proliferation of antibiotic-resistant human pathogens subsequently released into the environment.

Although wastewater treatment plants (WWTPs) achieve significant trace organic compound removal, some of the treatment processes employed at these facilities provide optimal conditions for AR development, particularly during secondary treatment where there is considerable evolutionary pressure to induce such changes (Clara et al., 2005; Dhanapal and Morse, 2009). The conventional activated sludge (CAS) and membrane bioreactor (MBR) processes may be a significant source of AR due to their continuous exposure of bacteria in ideal growth conditions to relatively high concentrations of antibiotics. Despite the direct correlation between solids retention time (SRT) during secondary treatment, and reductions in antibiotic concentrations (Clara et al., 2005; Gerrity et al., 2012; Salveson et al., 2012), higher SRTs also provide prolonged exposure of bacterial populations to relatively high concentrations of antibiotics present in primary effluent. Some WWTPs will operate at SRTs on the order of 50 days, while CAS processes may be operated in the range of 1-20 days. Such extended retention times are more than sufficient to allow for bacterial adaptation given their high growth rates.

As communities throughout the U.S. and the world move towards increases in water reclamation to augment surface and groundwater supplies, the potential for AR bacterial release into the environment grows in concern. However, despite the potential for AR proliferation in WWTPs, few studies have attempted to identify processes or operational conditions contributing to the selection of AR bacteria or those that are capable of reducing the level of AR in wastewater. Such information is critical in quantifying the environmental burden of WWTPs with respect to AR and developing the most effective treatment strategies to mitigate any concerns.

Specific objectives of this work were:

1. To quantify the impact of SRT optimization on the presence of AR bacteria using bacterial cultivation methods.
2. As part of a larger study (with cooperators from University of Nevada, Las Vegas) that is quantifying the presence of AR genes and trace levels of antibiotics in wastewater samples, this work will contribute to a database that will allow the construction of AR mass balances at several full-scale WWTPs in order to quantify the relative contribution of raw sewage and WWTP operations to AR and identify the major source(s) of AR in the environment (i.e., biosolids application vs. irrigation with reclaimed water).
3. To provide additional knowledge and tools for treatment process optimization, AR mitigation, and future risk communication efforts.

Methodology

For comparing the effects of SRT, culture-based methods indicating the degree of resistance (i.e., minimum inhibitory concentration (MIC)) will help distinguish AR increases or decreases through the biological process.

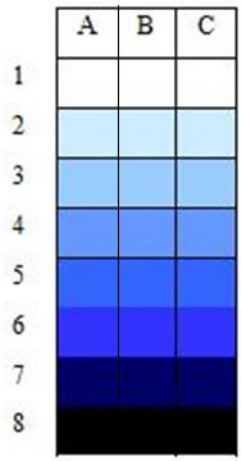
Table 1. Solids Retention Time of Wastewater Treatment Facilities included in This Study

WWTP Site	SRT (days)
Plant 3	3
Plant 4	9
Plant 7	19

This project made use of samples collected from WWTPs in Arizona, Nevada, and other locations throughout the United States. Samples were collected as part of a study funded by the Water Environment Research Foundation, based at the University of Nevada, Las Vegas. The WWTPs cooperating in that study cover a wide range of operational conditions, treatment trains, and discharge mechanisms. Because of the complexities inherent in the culturing of bacteria, only samples from three of the treatment plants, with a range in SRT from 3 days to 19 days (Table 1), were used for this project.

Following transport of the collected samples to the University of Arizona, AR bacteria and their degree of resistance were enumerated in the primary (raw wastewater) and secondary (samples from the retention basins) treatment waters. Isolates of Gram-positive and Gram-negative bacteria were extracted from the wastewater samples in accordance with standard methods. Each isolate was then tested for sensitivity to four or five (Table 2) antibiotics using a 96-well plating method for testing antibiotic sensitivity (Fig. 1) that was developed in the McLain laboratory and has been confirmed in several resistance studies. Individual wells on the 96-well microplates were loaded as in Fig. 1 and, following a 24 hr incubation at 37 ºC, growth in each well was quantified on a spectrophotometer plate reader (BioTek, Inc.) at a wavelength of 600 nm. This method, rather than being a "presence/absence" test for antibiotic resistance, allows resistance trends to be quantified; for example, a bacterium that initially showed high-level resistance to Nitrofurantoin at 128 µg mL^{-1} in the raw wastewater may be losing resistance if it is unable to grow beyond 64 µg mL^{-1} after a 20-day SRT.

Fig 1. Three columns of a 96-well plate. A single isolate in growth medium will be added to all cells in columns A and B. Column C will received medium only and will be used as negative growth control cells. Rows 2-8 will be pre-loaded with antibiotics. Row 1 = positive growth control wells; no antibiotic. Row 2 = lowest level of antibiotic; Row 3 = 2X antibiotic concentration of Row 2; Row 4 = 2X antibiotic concentration of Row 3…Row 8 = highest concentration.



Using guidelines put forth by the Clinical and Laboratory Standards Institute (CLSI, 2009), the minimum inhibitory concentration (MIC), or the lowest antibiotic concentration that inhibits visible growth, was recorded for each isolate. A single data point for each treatment (each SRT, each antibiotic, and Gram-positive or Gram-negative isolates; Table 2) was reported as an MIC_{50}, which is defined as the antibiotic concentration necessary to kill 50% of the isolates tested. The primary hypothesis of this work is that, since bacteria are exposed to high levels of antibiotics in secondary treatment basins, higher MIC_{50}'s will be associated with longer SRTs, thereby indicating that longer exposure to residual antibiotics leads to a higher degree of AR.

Principal Findings and Significance

The principal findings from this work are summarized in Table 2. Two hundred Gram-positive and two hundred Gram-negative isolates were analyzed, half from the primary influent and half from the secondary treatment. Isolates were divided equally between retention times, ranging from 3 to 19 days (Table 1). General trends emerged from this work: Gram-negative bacterial isolates cultured from secondary effluent displayed MIC_{50} at 8µg/mL of sulfamethoxazole with a SRT of 3 days; but, the MIC_{50} increased to 32 µg/mL as the SRT increased to 9 and 19 days. Gram-positive isolates exposed to sulfamethoxazole showed a similar trend, as the SRT increased from 3 to 19 days, so did the MIC_{50}. The MIC_{50} values of Gram-positive and Gram-negative isolates exposed to ampicillin displayed a comparable pattern to sulfamethoxazole. Conversely, the MIC_{50} of Gram-positive isolates grown in tetracycline decreased from 32 to 16 µg/mL; as the SRT increased from 3 to 19 days. Gram-positive isolates grown in vancomycin did not change the MIC_{50} at 16 µg/mL.

Of the 400 isolates screened for this study, more than 50% displayed complete resistance to one or more antibiotics, but it should be noted that the use of the selective enrichment culture media methods for isolation of Gram-negative and Gram-positive bacteria may have favored the isolation of AR bacteria. A study by Varela et al. (2013) indicated that the antibiotic supplemented culture media not only favored the isolation of AR bacteria to vancomycin, but the added antibiotics also favored the selection of AR bacteria to antibiotics other than those present in the culture medium, resulting in many of the isolates possessing a multidrug-resistance phenotype.

Current media coverage is linking water and wastewater to AR detection in the environment. For example, a recent study in Flagstaff, Arizona reported the presence of vancomycin-resistant

Table 2. Minimum inhibitory concentrations of antibiotic required to kill 50% of isolates tested (MIC_{50}) for Gram-negative and Gram-positive bacteria. All numbers reflect an antibiotic concentration in µg/mL.

	Gram-negative Isolates		**Gram-positive Isolates**	
	Primary Effluent	**Secondary Effluent**	**Primary Effluent**	**Secondary Effluent**
Sulfamethoxazole				
SRT 3 Days	32	8	512	64
SRT 9 Days	16	32	64	64
SRT 19 Days	16	32	512	512
Ampicillin				
SRT 3 Days	64	16	64	64
SRT 9 Days	64	64	32	32
SRT 19 Days	64	128	32	64
Trimethoprim				
SRT 3 Days	32	16	4	2
SRT 9 Days	64	64	8	8
SRT 19 Days	16	16	16	4
Vancomycin				
SRT 3 Days	N/A*	N/A	32	16
SRT 9 Days	N/A	N/A	4	16
SRT 19 Days	N/A	N/A	16	16
Tetracycline				
SRT 3 Days	16	4	32	32
SRT 9 Days	64	64	32	32
SRT 19 Days	64	32	32	16

*Vancomycin is effective against Gram-positive bacteria only

bacteria in reclaimed water distribution systems (Pruden et al., 2012). In response, officials noted that the study of AR in reclaimed water was "very early on in its research development" and that there was insufficient evidence to indicate that this posed a threat to human health (Cole, 2012). Therefore, it is time for the research community to address this issue with a more comprehensive approach: (1) determine the prevalence of AR in WWTP effluents using modern cultural and molecular methods, (2) determine the impact of treatment processes on the proliferation and/or reduction of AR, and (3) assess the relative risk of this discharge into the environment. These types of studies will provide the wastewater industry with the information that is currently lacking to address any public concerns.

No definitive conclusions can be made from the cultivation project, which (as stated above) was a small part of a larger, multi-institution project that is still ongoing. In order to reach conclusions on release of resistance into the environment through the wastewater treatment process, it is important to address all three components of AR (antibiotic compounds, antibiotic resistance genes, and AR bacteria) and the various discharge pathways for entry into the environment. In addition, studies must establish control sites, un-impacted by wastewater release, to assess background levels of these three components. As the adoption of recycled water becomes more widespread, and as the public comes into contact with recycled water at a higher frequency, there will be increased pressure for utilities and other water managers to better understand the dynamics of resistance development and destruction.

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Information Transfer Program Introduction

The University of Arizona WRRC maintains a robust Information Transfer program that includes three newsletters: a weekly email newsletter, a quarterly newsletter published in both email and hard copy form, and an annual publication, which each year covers a different single topic of concern to the water community in Arizona. The WRRC's Information Transfer program also features an annual conference and a series of Brown Bag seminars, along with other special events. In addition, the WRRC regularly updates its web site with news and events, builds and maintains WRRC program web pages, and provides many resources such as a directory of UA expertise in water. Outreach on social media is growing and keeps subscribers informed in a timely manner on various items of interest to the water community.

Information Transfer

Basic Information

Title:	Information Transfer
Project Number:	2014AZ531B
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Funding Source:	104B
Congressional District:	AZ003
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Focus Category:	None, None, None
Descriptors:	None
Principal Investigators:	Sharon B. Megdal, Susanna Eden

Publications

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University of Arizona Water Resources Research Center Information Transfer Program

During the reporting period, the WRRC's Information Transfer Program continued to produce its major component products. These include the *Arizona Water Resource* and *Arroyo* newsletters, the Annual Conference, Brown Bag seminars, and the website. Information on water harvesting in arid environments was shared through email, a web portal, and regular meeting of the Rainwater Stormwater Professionals Network under the umbrella of the Desert Water Harvesting Initiative hosted at the WRRC. In addition, the WRRC initiated a collaborative project to develop a public information campaign on Arizona's water challenges and choices using innovative Web and social media strategies as well as a feature length documentary to be released and distributed through the public media broadcasting system.

The highly regarded quarterly newsletter, *Arizona Water Resource* (*AWR*), is a keystone of the WRRC's Information Transfer program. With a new full-color design since Fall 2013, the AWR provides timely information on water resources news, including current research, law and policy developments, publications, and other items of interest to subscribers of both its print and email editions. Each year the *AWR* includes summaries of 104(b) research projects. Issues appear quarterly in January, April, July, and October.

The practice of including supplemental inserts by affiliated programs and external organizations also continued. The Winter 2014 issue contained an insert from the USGS, *The Desert Laboratory Repeat Photography Collection—An invaluable archive documenting Landscape Change*. The Spring issue featured an insert on the WRRC's history for its 50th Anniversary. Although long-term plans call for an on-line only newsletter, in 2014-15 a print edition continued to be sent to its approximately 2,200 subscribers. Several feature articles were contributed by graduate students, including "Arizona Irrigation District Tries Land Fallowing Water Transfer" and "Arizona Researchers Address Water Quality, Reuse and Management". Immediately after the WRRC's *Annual Conference, Closing the Gap between Water Supply and Demand*, the *AWR* contained articles on the conference and the following issue contained a feature article that summarized in their own words the remarks of conference panelists addressing "Closing the Gap: How can we do it?" Guest Views were provided by Jeff Tannler, Active Management Area Director, Arizona Department of Water Resources, and Chris Udall, Executive Director, Agribusiness & Water Council of Arizona, along with an interview with Raanan Adin, CEO, Adin Holding Ltd. The AWR also provided an opportunity to shine a spotlight on several of the students who work at the WRRC.

In 2014 the *Arroyo*, WRRC's annual newsletter on a single topic of timely interest to Arizona, was titled "What is the Value of Water—a complex question." Publication was delayed until July because multiple reviews were requested to ensure accuracy. Reviews were provided by Kathleen Ferris, Arizona Municipal Water Users Association; Patrick Graham, The Nature Conservancy; Kelly Mott Lacroix, University of Arizona; Tom McCann, Central Arizona Project; Amy McCoy, Ecosystem Economics; Leslie Meyers, Bureau of Reclamation - Lower Colorado Region; Cliff Neal, City of Phoenix; Bill Plummer, Agri-Business & Water Council of Arizona; Dave Roberts, Salt River Project; Ben Ruddell, Arizona State University; Ken Seasholes, Central Arizona Project and Margaret Wilder, University of Arizona. A summary of the *Arroyo* was published as an opinion piece in the *Capitol Times* and reprinted in *Reeves*

Journal, a magazine for pumbing, heating and cooling professionals.

Madeline Ryder, a senior with a dual degree in Natural Resources (B.S.) and Environmental Studies (B.A.), was selected from a highly talented pool as the Montgomery & Associates Summer Intern to work on the 2015 *Arroyo* on the water demand-supply gap, challenges and potential solutions. She produced a first draft over the summer, which underwent revisions and was sent out for review in February 2015.

The 2014 Conference, *Closing the Gap Between Water Supply and Demand*, was held on Tuesday, April 8, 2014 at the UA Student Union Memorial Center. This 2014 conference, which also celebrated the WRRC's 50 year anniversary, was organized in collaboration with the Arizona Department of Water Resources. The conference attracted 350 attendees from 43 Arizona communities and 6 Arizona Native American Nations, Tribes and Communities. A poster session, with 24 water-themed posters, included a competition for best student poster and a celebration of the WRRC's 50th anniversary. Two posters tied for first place, so Hwee Hawant (UA Department of Civil Engineering and Engineering Mechanic) and Aloa Pope (UA School of Natural Resources and the Environment) each received top prize honors. Todd McOmber (UA Department of Soil, Water and Environmental Science) took second place. Sponsors included the USGS, Arizona Department of Environmental Quality, Southern Arizona Water Users Association, Arizona Public Service, EPCOR Water, Salt River Project, Montgomery & Associates, BKW Farms, Farmers Investment Company, U.S. Bureau of Reclamation, Central Arizona Project, Pima Association of Governments, Arizona Water Company, Water Asset Management LLC, Carollo Engineers, Walton Family Foundation, WateReuse Arizona, UA Tribal Water Extension Program, and UA Water Sustainability Program. A number of media outlets attended and covered the conference, including Arizona Public Media's "Arizona Week," *The Arizona Daily Star*, the *Tucson Weekly* and the *Arizona Daily Wildcat*. Interviews with conference speakers were featured on Arizona Week a news magazine on KUAT, Channel 6 in Tucson (on-line at http://wrrc.arizona.edu/conference/recap).

The 2015 Annual Conference will address Tribal water issues. "Indigenous Perspectives on Sustainable Water Practices" will be held in June at the Wild Horse Pass Hotel and Casino in Chandler, Ariz. in partnership with the Gila River Indian Community. It will focus on what can be learned from the indigenous perspectives on water and how this knowledge can be used to improve water management.

Collaborations will continue with the Water Sustainability Program, now a part of the Water, Environmental and Energy Solutions Initiative, and with Arizona Project WET. Ongoing programs of research and outreach continued and were expanded. The Water Research and Planning Innovations for Dryland Systems (Water RAPIDS) focuses on new approaches to water resource management that integrate traditional planning for natural resources with land use planning at regional, state, watershed, and local scales. The goal is to help balance water demand for human uses with the water demands of ecosystems. In 2014, the Water RAPIDS program included four projects: 1) Conserve2Enhance (C2E), a trademarked program of the WRRC, which links water conservation to funding for local environmental enhancement projects; 2) Connecting Environmental Water Needs to Arizona Water Planning (EnWaP),

which builds collaborations with individuals and groups at the local, regional, and state levels to explore what it means to consider the environment in water management and planning; 3) Watershed Planning in the Upper Gila Watershed, which in 2014, used its baseline assessment of watershed resources to develop scenarios exploring possible futures for the watershed; and 4) development of a Water Resources Management Program with the Town of Clarkdale. Outreach is a major function of WRRC research projects, and although they are almost entirely funded from non-program sources, but their outreach receives some support from the Information Transfer Program.

The WRRC's Brown Bag seminar series continued to draw a range of speakers on water-related topics of interest to a wide spectrum of audiences. In 2014-15, the WRRC held 18 Brown Bag seminars featuring experts from Arizona and the Southwest, as well as other countries. Average attendance was 23 people (in person), approximately 45 percent from UA and 55 percent from the broader community. Access to the WRRC's Brown Bag series now routinely includes offsite listeners through live webcasts via Go-to-Webinar and in-house video coverage. Offsite attendance grew significantly; the WRRC had 149 participants avail themselves of remote observation. Past Go-To-Webinar recorded events at the WRRC can be viewed on the WRRC website. Brown Bag Seminars from the reporting period are listed below.

1. March 24, 2014: A Water Update From Down Under; Rosalind Bark, Resource Economist, Ecosystem Sciences Division, CSIRO [Commonwealth Scientific and Industrial Research Organisation].

2. March 25, 2014: An Insider's Look at WIFA and WIFA-funded Infrastructure Projects: The Most Needed, The Most Unique, The Most Sustainable; Susan Craig, Communications Director, Arizona Water Infrastructure Finance Authority (WIFA) & Melanie Ford, WIFA Technical Program Supervisor.

3. April 28, 2014: Tackling Water Quality Issues in Bolivia and Guatemala; Mark Taylor, PE, Principal, WestLand Resources, Inc.

4. May 2, 2014: Modeling Water Scarcity and Droughts to Analyze Climate Change Adaptation Policies in the Jucar Basin, Spain; Ariel Dinar, Professor of Environmental Economics and Policy, and Director of Water Science and Policy Center, University of California, Dept. of Environmental Sciences, Riverside, Calif.

5. July 10, 2014: Dusty Dry to Sopping Wet? Summer and Fall Climate Outlook for Southern Arizona; Mike Crimmins, Associate Professor and Extension Specialist - Climate Science, Dept. of Soil, Water & Environment Science, The University of Arizona.

6. September 3, 2014: Requiem for the Santa Cruz: An Environmental History of an Arizona River; Robert H. Webb, Adjunct Professor, Hydrology and Water Resources, the University of Arizona / Co-Author of *Requiem for the Santa Cruz: An Environmental History of an Arizona River*.

7. September 9, 2014: Grounding Water: An Exploration of the Unseen World Beneath Our Feet; Kerry Schwartz, Associate Specialist, Arizona Cooperative Extension, and Director of Arizona Project WET, the University of Arizona.

8. September 12, 2014: Natural Capital in the Colorado River Basin: Understanding the Economic Value of Ecosystems as Assets; James Pittman, Senior Consultant and Ecological Economist, Earth Economics.

9. September 19, 2014: Findings From a Health Impact Assessment of California Urban Water Conservation Alternatives; Sharona Sokolow, MPH, Doctoral Candidate, UCLA Fielding School of Public Health Sciences.

10. October 8, 2014: Ecosystem Valuation in Southwest Riparian Areas; Dave Goodrich, Research Hydraulic Engineer, USDA-Agricultural Research Service, Southwest Watershed Research Center/ Associate Adjunct Professor, Univ. of Arizona Dept. of Hydrology and Water Resources.

11. October 29, 2014: Claire Zugmeyer, Ecologist, Santa Cruz River Initiative; Tracking Wetland Conditions of an Effluent-Dependent River: The Lower Santa Cruz Living River Project.

12. November 12, 2014: Condensate Collection in Arizona? **(Webinar Format);** Diana D. Glawe, Ph.D., PE, LEED AP Associate Professor, Engineering Science Dept., Trinity University.

13. December 4, 2014: Surface Water/Groundwater Interactions in Arizona: Physical Realities and Experiences in the Real World; James Leenhouts, Director, USGS Arizona Water Science Center.

14. December 12, 2014: Hard to Swallow: Ensuring safe drinking water for our communities; Professor Brian Berkowitz, Head, Department of Earth & Planetary Sciences, Weizmann Institute of Science—Rehovot, Israel, Sam Zuckerberg Professorial Chair in Hydrology.

15. January 22, 2015: Shopping for Water: How the Market Can Mitigate Water Shortages in the American West; Robert Glennon, Regents' Professor and Morris K. Udall Professor of Law and Public Policy in the Rogers College of Law at the University of Arizona.

16. January 28, 2015: Colorado River Simulation System (CRSS) – Overview and Use in Planning and Operation of the Colorado River; Don Gross, Water Resources Engineer, Colorado River Management Section, Arizona Department of Water Resources.

17. February 19, 2015: Public Participation in the Implementation of the Water Framework Directive in Spain; Alba Ballester Ciuró, Researcher at University of Seville and University Autónoma of Barcelona.

18. February 26, 2015: Antibiotic Resistance in Agroecosystems; Alistair B. A. Boxall, Environment Department, University of York, Heslington, York, UK, and Eddie Cytryn, Researcher, Volcani Center Institute of Soil, Water and Environmental Sciences, Bet Dagan, Israel.

Other Outreach Events

The WRRC has sponsored, co-sponsored and hosted a number of events for a broad range of

interests.

On February 13, a brief program introduced the Beyond the Mirage project, a public information campaign on Arizona's water challenges and choices using innovative Web and social media strategies and a documentary, to assembled friends of the WRRC at the annual Chocolate Fest.

On April 22, a screening and panel discussion at a local movie theater featured the documentary, Watermark, for a public audience in a program cosponsored by the WRRC and the UA Institute of the Environment.

On June 8, the WRRC collaborated with Audubon Arizona and others on a workshop entitled "Protect Our Rivers," which discussed strategies and case studies in river preservation and restoration.

The WRRC was a co-sponsor of the Biennial Symposium on Managed Aquifer Recharge (BSMAR) held July 30-August 1 in Orange County, Calif. The symposium series, which originated in Arizona, had been in hiatus for some time and was revived this year as a cooperative venture shared between California and Arizona. As a follow up to our involvement in BSMAR, we are involved in the development of the International Symposium on MAR (ISMAR9) to be held in 2016 in Mexico City.

On October 26, the WRRC co-sponsored the Native Eyes Showcase, which consisted of multiple events including a resource fair and film screening at the Loft Cinema in Tucson.

On October 28, the WRRC hosted a memorial to honor the work of Marybeth Carlile, a major force influencing policy on water issues in Arizona. Among other achievements, she was instrumental in organizing the support needed to ensure the extension of the Central Arizona Project to Tucson.

The WRRC co-sponsored three Distinguished Speaker Series lectures with the Water Sustainability Program: 1) Aaron Wolf, Professor of Geography in the College of Earth, Ocean, and Atmospheric Sciences, Oregon State University spoke on "Shared Waters: Spirituality, Conflict and Cooperation, " on Mar. 27; 2) Mike Young, Research Chair in Water and Environmental Policy, University of Adelaide, Australia, spoke on "Water Scarcity: Missed Opportunity?" on April 11; and 3) Alice Aureli, Chief Groundwater Section International Hydrological Programme, UNESCO, spoke on "30 Years of Love for Groundwater; The Role of UNESCO in Striving for Water Security," on May 8, 2014.

A January 20, 2015 AZ Water Research workshop organized in collaboration with the WRRC brought together water researchers and research users for a series of presentations and panel discussions.

The 2014 WRRC Photo Contest promoted the theme "Catch the Rain". The winners were announced in the Weekly Wave and all 20 winning photographs (three top prizes and 17 honorable mentions) are displayed on the WRRC website. The three top prize winners were featured in the Winter 2015 AWR. Photo contest submissions are added to the WRRC photo archive, which is drawn upon for images as needed for posting and publications.

Website and electronic communication

Communications efforts at the WRRC continued to expand in the project year. Communications staff worked to improve the newly launched Weekly Wave e-news digest throughout the year, sending 31 editions of the Weekly Wave and seven editions of the bi-weekly Summer Wave. Each edition included updated WRRC and water community events, news, media appearances, announcements and social media interaction opportunities. Interest in the Weekly Wave grew steadily throughout the year; distribution lists grew by more than 300 recipients, resulting in increased website traffic, event attendance, and dissemination of WRRC news through other outlets. Communications staff regularly submitted WRRC news, events, and accolades to University channels – including the weekly newsletters, websites, and e-calendars of the College of Agriculture and Life Sciences and UA Cooperative Extension – as well as the UAnnounce e-memo distribution system. The UA Institute of the Environment newsletter and ASU's Sustainability Digest also regularly carried WRRC announcements. Externally, the WRRC was featured 22 times across a variety of news and media outlets.

Efforts continued throughout the year to expand the WRRC's social media visibility on Facebook, Twitter and YouTube, resulting in increased shares, views, retweets, follows and likes. Twitter followers of the WRRC nearly doubled from 2013 numbers, and the WRRC's Facebook page surpassed 200 likes. Video recordings of WRRC events previously available only on the WRRC YouTube page – namely select Brown Bag Seminars – were made more readily available directly through the WRRC website (wrrc.arizona.edu/video-gallery) via a searchable video gallery.

The WRRC furthered branding efforts in 2014 by creating several printed pieces, including banners, bookmarks, rack cards, printed quarterly and annual newsletters – all sharing a recognizable WRRC brand. A 2013 Annual Report was published and efforts are underway to produce a slightly modified Annual Report for 2014 that will be published on line.

The WRRC website also saw updates and changes this year. The Water Center expanded and enhanced its History, Press, Video and Personnel pages, and created a number of new and improved websites and program pages, including those for Conserve2Enhance (C2E), the Desert Water Harvesting Initiative (DWHI), and Arizona Project WET. The rotating three-story homepage feature was updated weekly to reflect the latest WRRC news and events, and homepage visibility for listserv signup pages, Annual Conference registration, and the WRRC's 50th Anniversary historical recap was heightened via visually appealing graphics. An archive of past editions of the Weekly Wave e-newsletter was also added to the website in 2014. Since summer 2014, the WRRC website also provides a link to 380 digitized archival copies of past WRRC publications, available through the University of Arizona Libraries' Campus Repository. Publications -- which date back to 1958 -- are searchable by title, author, date and subject, and include past editions of the Arizona Water Resource newsletter, the Arroyo, WRRC studies and much more.

During the project year, an innovative multimedia project has been developing through collaboration between the College of Agriculture and Life Sciences (CALS) video and web development teams, the Water Resources Research Center, and Arizona Public Media. The

project with up-to-date content and modern format is being created to provide maximum exposure and usability of water information for the public. The project, "Beyond the Mirage, Arizona's water reality," is expected to effectively reach a new and much broader audience than a print document, because of its innovative approach, high production values, and integration with popular social media platforms. "Beyond the Mirage" includes development of a feature length documentary through cooperation with Arizona Public Media, which will be designed to interest a regional and/or national audience.

Collaboration with the WRRC-based Arizona Project WET (Water Education for Teachers) has been mutually beneficial in expanding the reach and effectiveness of outreach and education projects, and this collaborative relationship continued through the project year. A comprehensive water education program with established relationships with school districts and communities throughout Arizona, Arizona Project WET reaches out to teachers and students across Arizona by providing programs, workshops, mentoring and partnership activities. The WRRC and Arizona Project WET continued to work toward increase program integration.

In addition to all of the above, WRRC personnel carried out various public service activities. They are called upon regularly to give lectures and make presentations to diverse audiences across Arizona. They often collaborate with local, state, regional, and federal agencies and organizations, as a resource for general information and as partners on specific projects. WRRC personnel participate on community and regional boards and commissions, serve on state and local task forces and study committees, and regularly attend important water resources meetings. In addition, the WRRC extends its research, outreach, and education role through its collaboration with the university-wide Water Sustainability Program, a component of the Water, Environmental and Energy Solutions (WEES) initiative. The WRRC Director serves as one of two co-Director of WEES. WRRC personnel also respond to inquiries from the public on issues of concern. The WRRC facility is open to the public and provides information on water related topics to the public and a space for water related meetings.

The following is a list of presentations for Information Transfer on 104b projects:

Project Number: 2014AZ529B

Title: Improving Integrated Surface Water and Groundwater Management in the United States: Case Studies of Innovative Groundwater Governance Approaches

Megdal, Sharon B., Andrea Gerlak, Robert Varady, and Ling-Yee Huang (presenter), Groundwater management and governance: A policy perspective. 2014 UCOWR/NIWR/CUAHSI Annual Conference: Water Systems, Science, and Society Under Global Change. Medford, Massachusetts (June 18-20, 2014).

Megdal, Sharon B., Groundwater Management and Governance: A Policy Perspective, National Ground Water. Association Annual Summit, Denver, CO, May 5, 2014.

Megdal, Sharon B., A Look at Arizona Groundwater Management and Governance through the Lens of World-wide Efforts to Identify Best Practices, AzWater Association Annual Conference, Glendale, AZ, May 7, 2014.

Project Number: 2013AZ530B

Title: Development of Antibiotic Resistance during Wastewater Treatment

McLain, J.E., Separating science from emotion in public health-related perceptions of recycled water using a One Health model. 5th Annual University of Arizona Food Safety Consortium Conference, Tucson, Arizona; October 10, 2014.

Gudvangen, E., K. Brown, S. Walston, C. Rock, and J.E. McLain, The critical challenge of antibiotic resistance: are wastewater treatment plants a concern? 5th Annual University of Arizona Food Safety Consortium Conference, Tucson, Arizona; October 10, 2014.

McLain, J.E., Separating science from emotion in public health-related perceptions of recycled water: the case of Flagstaff, Arizona. 18th Annual Water Reuse and Desalination Research Conference, Las Vegas, Nevada; May 19, 2014.

Presentations by WRRC personnel (chronological order)

March 3, 2014, Megdal, Sharon B., panelist, The Green Valley Water Forum on the Central Arizona Project (CAP) - Its future As A Sustainable Water Source for Green Valley/Sahuarita, Green Valley, Arizona https://dl.dropboxusercontent.com/u/258239/Megdal_GV_3March2014.pptxSeminar

March 4, 2014, Mott Lacroix, Kelly, Scenario Planning and How our Resources are Changing, Conserve to Enhance: an innovative program that links water efficiency with environmental enhancements, Scenario Planning for the Gila Watershed Workshop 1, Safford, Arizona

March 4, 2014, Rupprecht, Candice, Xiu, Brittany C., Community Enhancement Project Grant Workshop, Tucson C2E Grant Workshop, Tucson, Arizona

March 5, 2014, Rupprecht, Candice, Xiu, Brittany C., Conserve To Enhance (C2E): An Innovative Program That Links Water Efficiency with Environmental Enhancements, U.S. Bureau of Reclamation, Phoenix Area Projects Office, Phoenix, Arizona

March 7, 2014, Mott Lacroix, Kelly and Brittany C. Xiu, Perspectives on Water for Natural Areas, Workshop on the Future of Water for Natural Areas, Tucson, Arizona

March 11, 2014, Megdal, Sharon B., Technology and Cooperation, Israeli and Palestinian Waterways Conference, University of California, Berkeley, Institute for Jewish Law and Israel Studies, Berkeley, CA

March 14, 2014, Megdal, Sharon B., How Full is Our Water Glass?, Alumni Council, John and Doris Norton School of Family and Consumer Science, University of Arizona, Tucson, Arizona

March 26, 2014, Xiu, Brittany C., C2E for Panda Express Regional Managers, Casa Grande, Arizona

March 27-28, 2014, McLain, Jean E. and Todd McOmber, Is Treated Wastewater Effluent Improving the Water Quality of the Upper Santa Cruz River? Sonoran Institute at the Joel D. Valdez Downtown Library, Tucson, Arizona

March 31, 2014, McLain, Jean E., Rainwater Harvesting from Tucson Rooftops: Can We Promote Water Conservation and Protect Public Health? Pima Association of Governments Seminar Series, Tucson, Arizona

March 31, 2014, McLain, Jean E., Antibiotic Resistance and Recycled Municipal Wastewater, Pima Association of Governments Seminar Series, Tucson, Arizona

April 1, 2014, Rupprecht, Candice and Brittany C. Xiu, The Conserve to Enhance Water Use Dashboard: A Free Tool for Tracking Water Use and Funding Community Water Priorities, American Water Works Association Sustainable Water Management Conference, Denver, Colorado

April 8, 2014, Mott Lacroix, Kelly, The Forgotten Sector: Water for Natural Areas, WRRC 2014 Annual Conference, Closing the Gap Between Water Supply and Demand, Tucson, Arizona

April 10, 2014, McLain, Jean E., Building A Water Tech Cluster Building Water Technology Proficiency and Instrumentation in Pima County, Pima Association of Governments, Tucson, Arizona

April 11, 2014, McLain, Jean E., A Demonstration of Water Quality Testing to Promote UA Water Quality Extension, Wildcat Water Lab, Expo of Excellence University of Arizona, Tucson, Arizona

April 12, 2014, Rupprecht, Candice, C2E – Table Display, 20th Annual Reid Park Earth Day Festival, Tucson, Arizona

April 16, 2014, Mott Lacroix, Kelly, Water Challenges in the Cienega Watershed, Academy Village Presentation, Vail, Arizona

April 17, 2014, Mott Lacroix, Kelly and Brittany C. Xiu,, Perspectives on Water for Natural Areas, EnWaP Roundtable, Workshop on the Future of Water for Natural Areas, Phoenix, Arizona

April 18, 2014, Rupprecht, Candice and Brittany C. Xiu, C2E – Table Display, UAMC University Campus 4th Annual Earth Day Festival, Tucson, Arizona

April 19, 2014, McLain, Jean E., A Long and Winding Road: Lessons Learned Along the Way, Women in Science and Engineering 8th Annual Excellence in Science and Engineering Banquet, Tucson, Arizona

April 22, 2014, Mott Lacroix, Kelly, panelist, Watermark Documentary Panel, Loft Cinema, Tucson, Arizona

April 22, 2014, McLain, Jean E., moderator, Watermark Documentary Panel, Loft Cinema, Tucson, Arizona

April 23, 2014, Xiu, Brittany C., Good to the last drop: Water Challenges in the Colorado River Basin, Ventana Medical Systems, Oro Valley, Arizona

April 26, 2014, Schwartz, Kerry, Watershed Education for Teachers & Students, using Arizona Project WET, Patagonia Festival Speaker Series, Patagonia Town Council chambers, Patagonia, Arizona

May 5, 2014, Megdal, Sharon B., Groundwater Management and Governance: A Policy Perspective, National Ground Water Association Annual Summit, Denver, Colrado

May 7, 2014, Megdal, Sharon B., A Look at Arizona Groundwater Management and Governance through the Lens of World-wide Efforts to Identify Best Practices, AZ Water Annual Conference, Glendale, Arizona

May 8, 2014, Eden, Susanna, Engaging Stakeholders with Models for Water Resource Planning, AZ Water Association Annual Conference, Glendale, Arizona

May 8, 2014, Rupprecht, Candice and Brittany C. Xiu, C2E- Tabling, Cooperative Extension 100th Anniversary Celebration, Tucson, Arizona

May 9, 2014, Rupprecht, Candice and Brittany C. Xiu, convenors, Atturbury Wash Dedication Event, Tucson, Arizona

May 12, 2014, Megdal, Sharon B., The Context for Research on Water Management Conflicts and Cooperation in Arizona and the Colorado River Basin, BLUEGRASS project kickoff meeting, Interdisciplinary and Global Environmental Studies, CNRS, The University of Arizona, Tucson, Arizona

May 15, 2014, Rupprecht, Candice, Connecting the C2E Drops: Tracing Water Use from the Tap to the Landscape, Rainwater-Stormwater Professionals Network (RSPN) Semi-Annual Meeting, Tucson, Arizona

May 16, 2014, Mott Lacroix, Kelly and Brittany C. Xiu, EnWaP, Perspectives on Water for Natural Areas, Workshop on the Future of Water for Natural Areas, Flagstaff, Arizona

May 17, 2014, Xiu, Brittany C., Good to the last drop: Water Challenges in the Colorado River Basin, WRAN Training Workshop, Flagstaff, Arizona

May 18-20, 2014, McLain, Jean E., Separating Science from Emotion in Public Health-Related Perceptions of Recycled Water: A Case Study of Flagstaff, Arizona, a Summarizing Initial Results from the Flagstaff City Manager's Expert Panel on Emerging Contaminants, 18th Annual Water Reuse and Desalination Research Conference, Las Vegas, Nevada

May 21, 2014, Mott Lacroix, Kelly and Brittany C. Xiu, Perspectives on Water for Natural Areas, Workshop on the Future of Water for Natural Areas, Yuma, Arizona

May 21, 2014, Rupprecht, Candice, Conserve to Enhance Water Use Dashboard, C2E Webinar for the Western Rivers Action Network

June 2, 2014, Rupprecht, Candice, C2E Wateruse Dashboard, Where Does My Conserved Water Go? Ensuring Tucson's Water Conservation Efforts Benefit Our Community, River Rally 2014, Pittsburgh, Pennsylvania

June 2, 2014, Rupprecht, Candice, Where Does My Conserved Water Go? Ensuring Tucson's Water Conservation Efforts Benefit Our Community, Women Impacting Tucson, Tucson, Arizona

June 6, 2014, Rupprecht, Candice, Conserve to Enhance Water Use Dashboard, Ventana Medical Systems Green Team, Tucson, Arizona

June 11, 2014, Mott Lacroix, Kelly and Ashley Hullinger, Scenario Planning Update, Gila

Watershed Planning Meeting and Steering Committee Meeting, Safford, Arizona

June 14, 2014, Mott Lacroix, Kelly, and Brittany C. Xiu, Perspectives on Water for Natural Areas, EnWaP Webinar for the Western Rivers Action Network, AMWUA, Phoenix, Arizona

June 18, 2014, Mott Lacroix, Kelly, Stakeholder Engagement in Water Resource Management, UCOWR Boston, Massachusetts

June 19, 2014, Megdal, Sharon B., Water Management Innovations in Water-Scarce Regions, United Nations NGO Briefing, Every Drop of Water Makes a Difference, New York City, New York

June 18, 2014, Megdal, Sharon B., Decentralized use of grey water and treated wastewater for agriculture in the Middle East, UCOWR-NIWR-CUASHI 2014 Annual Conference, USDA Track, Boston, Massachusetts

June 26, 2014, Mott Lacroix, Kelly, Rupprecht, Candice, Fullerton, Christopher, conveners, Forum on Water Management for Small Towns, Clarkdale, Arizona

July 1, 2014, Megdal, Sharon B., What is the Potential for IWRM in the Practice of Water Management in Arizona? American Water Resources Association Summer Specialty Conference on Integrated Water Resources Management, Reno, Nevada

July 14, 2014, Rupprecht, Candice and Brittany C. Xiu, Conserve to Enhance Water Use Dashboard, Prescott Tri-NGO C2E Presentation, Prescott, Arizona

July 16, 2014, Rupprecht, Candice, Connecting Conservation and Community Action: The Conserve to Enhance Water Use Dashboard, Advanced Water Education Workshop: Using Technology to Better Understand (and contribute to) our World, Tempe, Arizona

July 18, 2014, Rupprecht, Candice and Brittany C. Xiu, Conserve to Enhance Water Use Dashboard, Statewide Water Conservation Info Share, Flagstaff, Arizona

August 5-8, 2014, McLain, Jean B., Antibiotic Resistance in Agroecosystems: State of the Science, Biosphere 2, Tucson, Arizona

August 13, 2014, Megdal, Sharon B., Colorado River and Tucson Water Issues, Green Chamber, Tucson, Arizona

August 26, 2014, Mott Lacroix, Kelly, Participatory Watershed Assessment Poster, Desert Landscape Conservation Cooperative CMQ1, Sante Fe, New Mexico

August 26, 2014, Mott Lacroix, Kelly, Environmental Water Demands Database Poster, Desert Landscape Conservation Cooperative CMQ1, Sante Fe, New Mexico

August 26, 2014, Schwartz, Kerry, Stormwater Education with Arizona Project WET, STORM Meeting, Maricopa Flood Control District, Phoenix, Arizona.

August, 29, 2014, Mott Lacroix, Kelly, Stakeholder Engagement, ARLS Annual Meeting, Tucson, AZ

September 4, 2014, Xiu, Brittany C., Conserve to Enhance Water Use Dashboard & Toolkit, Colorado WRAN/Audubon, Webinar

September 10, 2014, Megdal, Sharon B., JNF Tree of Life Award Dinner, Pittsburgh, PA, Keynote Address: Water Management Innovations in Water-Scarce Regions

September 10, Mott Lacroix, Kelly, Considering Water for the Environment in Arizona through Understanding Science, Policy & Water User Perspectives. International Boundary and Water Commission Citizen Forum Meeting, Yuma, Arizona

September, 10, Xiu, Brittany C., Water RAPIDS: Research and Stakeholder Engagement, Department of Soils, Water and Environmental Science Careers Class guest lecture , Tucson, AZ

September 18, 2014, Eden, S., International Boundary and Water Commission, Southeast Arizona Citizens Forum, Groundwater, Climate and Stakeholder Engagement (GCASE) Update

September 18, 2014, Megdal, Sharon B., Women's Salon Series, Tucson, AZ, How Full is Our Water Glass?

September 20, 2014, Megdal, Sharon B., Flinn-Brown Civic Leadership Academy, Tucson, AZ, Water Dialogue: Questions and Conversation

September 27, 2014, Mott Lacroix, Kelly and Brittany C. Xiu, Roadmap for Considering Water for Arizona's Natural Areas, WRRC Webinar

October 2, 2014, Mott Lacroix, Kelly, On the Ground: Collaboration for Riparian Protection and Restoration, Arizona Riparian Council Annual Meeting, Tucson, AZ

October 3, 2014, Mott Lacroix, Kelly, Roadmap for Water for Arizona's Natural Areas Poster, Arizona Riparian Council Annual Meeting, Tucson, AZ

October 6, 2014, Megdal, Sharon B., American Society of Animal Science and American Meat Science Association Innovate 2014: Global Food Security, Brainerd, MN, Water Supply and Demand Imbalances and the Competition for Water Resources

October 6, 2014, Xiu, Brittany C., Tucson Village Farms Water Partnership Dedication, Tucson Village Farms, Tucson, AZ

October 10, 2014, McLain, J.E., 5th Annual University of Arizona Food Safety Consortium Conference, Tucson, Arizona, Separating science from emotion in public health-related perceptions of recycled water using a One Health Model.

October 10, 2014, Xiu, Brittany, WaterSmart Innovations 2014 in Las Vegas, NV, The C2E Water Use Dashboard: http://prezi.com/lxhehcrbqbi5/?utm_campaign=share&utm_medium=copy&rc=ex0share

October 15, 2014, Megdal, Sharon B., Panel on new Book, Des Moines, Iowa

October 17, 2014, Xiu, Brittany C., Conserve2Enhance program and C2E Dashboard, Flagstaff Open Space Symposium, Flagstaff, AZ

October 21, 2014, Megdal, Sharon B. Symposium on Arid Lands Agriculture, Panel on Technologies and the Politics of Water, Tucson, AZ. Water Management Challenges and Solutions in Water-Scarce Regions: Focus on Agriculture

October 21, 2014. Megdal, Sharon B., International Conference on the Rehabilitation of the

Lower Jordan River (Phase A) and the Development of the Border Region Between the State of Israel and the Hashemite Kingdom of Jordan along the Jordan River, Keynote Lecture, Thirsty Rivers in Water-Scarce Regions: Experiences from the Colorado River, Kibbutz Nir David, Jordan Valley, Israel

October 25, 2014, McLain, Jean E., Expanding Your Horizons Conference, Sponsored by Women in Science and Engineering, Tucson, AZ, Keynote Address

October 25, 2014, Xiu, Brittany C., C2E, Harvest Home Tours Table, Tucson, AZ

October 25, 2014, Xiu, Brittany C., C2E, Haunted Harvest Hootnany Table, Tucson, AZ

October 27, 2014, Mott Lacroix, Kelly, Water RAPIDS and the Roadmap, Arizona Department of Water Resources, Phoenix, Arizona

November 1, 2014. Megdal, Sharon B., Water Management Challenges of Water-Scarce Regions: Focus on Israel and Jordan, Center for Middle Eastern Studies teachers' program, Environmental Issues in Latin America and the Middle East, Biosphere II, Tucson, Arizona.

November 3-6, 2014. Megdal, Sharon B., B. Haggard, and E. Greene, Poster Presentation, USGS and NIWR – A Model Partnership, American Water Resources Association Annual Conference, Tyson's Corner, Virginia.

November 4, 2014, Megdal, Sharon B., Stakeholder Engagement Practices of the Arizona Water Resources Research Center, Special Session on the 50th Anniversary of the Water Resources Research Act, American Water Resources Association Annual Conference, Tyson's Corner, Virginia.

November 4, 2014, Megdal, Sharon B., An Overview of the Water Resources Research Act and the National Institutes for Water Resources (NIWR), Special Session on the 50th Anniversary of the Water Resources Research Act, American Water Resources Association Annual Conference, Tyson's Corner, Virginia

November 7, 2014, Megdal, Sharon B., Panelist, Agriculture, Water and Families, CALS and the Norton Legacy, The Norton School of Family and Consumer Science Council of Alumni and Friends Annual Homecoming Luncheon and Awards, The University of Arizona, Tucson, Arizona

November 7, 2014, Schwartz, Kerry and Mary Ann Stoll, Give Up Control. Embrace Freedom! ASTA Conference, NAU Phoenix Campus, Phoenix, Arizona.

November 7, 2014, Wilkening, Betsy, Google Tools, Improving Geo-Literacy and Critical Thinking Skills, sponsored by Tucson Water, ASTA Conference, NAU Phoenix Campus, Phoenix, Arizona

November 10, 2014, Megdal, Sharon B., Contributing to a Transatlantic Dialogue on Water: Solutions Development and Implementation, 5th SWAN Progress Meeting-Workshop, Towards a Framework for a Transatlantic Dialogue on Water: What Role for The University of Arizona, Tucson, Arizona

November 14, 2014, Megdal, Sharon B., Arizona's Water Future, Morrison Institute for Public Policy State of Our State Conference, Phoenix, Arizona

November 17, 2014. Megdal, Sharon B., and E. Shamir, Connecting Climate Change and

Surface Water Flows to Aquifer Recharge and Groundwater Management, Drylands, Deserts and Desertification Conference, Ben Gurion University of the Negev, Israel

November 20, 2014. Megdal, Sharon B., Transboundary Aquifer Assessment at the United States-Mexico Border, Drylands, Deserts and Desertification Conference, Ben Gurion University of the Negev, Israel

November, 24, 2014. Megdal, Sharon B., Stakeholder Engagement and Improving Governance and Management of Water Resources, 4th Meeting of the OECD Water Governance Initiative, Paris, France

December 7, 2014. Megdal, Sharon B., Water Management Innovations in Water Scarce Regions Hadassah Southern Arizona luncheon, Tucson, Arizona

December 8, 2014, Megdal, Sharon B., Water Management Challenges and Solutions in Water-Scarce Regions: Focus on Agriculture, Women in Agriculture visitors from Pakistan, Tucson, Arizona

January 14, 2015, Mott Lacroix, Kelly, Public Information Sharing, Arizona Water Association Research Conference, Phoenix, Arizona.

January 14, 2015, Mott Lacroix, Kelly, Roadmap for Considering Water for Arizona's Natural Areas, Arizona Water Association Research Conference, Phoenix, Arizona.

January 21, 2015, Xiu, Brittany C., Arizona Water Challenges and Opportunities, Prescott College Prescott, Arizona

January 30, 2015, Xui, Brittany C., WRRC Programs, UA Department of Soil, Water and Environmental Science, Careers Class guest lecture, Tucson, Arizona

February 3, 2015, Mott Lacroix, Kelly, Explore, Synthesize, and Repeat: Process Design for Effective Stakeholder Engagement in Water Management, Tucson, Arizona and SWAN webinar (Europe)

February 4, 2015, S. B. Megdal, Bridging waters: Good water stewardship in Arizona, Israel and beyond, Congregation Anshei Israel Education Program, Tucson, Arizona

February 6, 2015, Megdal, Sharon B., Challenged but unbroken: Water management in Arizona, the Colorado River Basin and beyond, Yale Club, at Arizona Inn, Tucson, Arizona

February 9-11, 2015, Megdal, Sharon B., Presiding Officer (President), National Institutes for Water Resources Annual Meeting, Panelist and Moderator, Various sessions, Washington, DC.

February 20, 2015, Megdal, Sharon B. commentary, Water Resource Management Challenges in a Time of Changing Climate, Institute on Science for Global Policy, Climate Change Arctic Program: Living with Less Water, Tucson, Arizona.

February 22, 2015, Mott Lacroix, Kelly, Water for the Environment in a Changing Climate, Splendido Water Series, Oro Valley, Arizona.

USGS Summer Intern Program

None.

Student Support					
Category	**Section 104 Base Grant**	**Section 104 NCGP Award**	**NIWR-USGS Internship**	**Supplemental Awards**	**Total**
Undergraduate	3	0	0	0	3
Masters	4	0	0	0	4
Ph.D.	0	0	0	0	0
Post-Doc.	0	0	0	0	0
Total	7	0	0	0	7

Notable Awards and Achievements

The publication Megdal et al. 2014 in Groundwater, "Groundwater governance in the United States: Common priorities and challenges," a work related to the project 2014AZ529B, has been featured in highly read blogs, including Water Wired, a blog maintained by water expert Michael Campana. The post is located at http://aquadoc.typepad.com/waterwired/2015/03/gw-governance.html. Comments by Dr. Megdal and a link to the paper generated a lively discussion among water professionals. This work on groundwater governance has led to Dr. Megdal's inclusion in the planning committee for a workshop by the American Water Resources Association and the National Groundwater Association in April 2016, which will feature issues related to groundwater governance.

As a result of work implementing the antibiotic resistance research methodology of project 2014AZ530B in a body of related research, Dr. Jean McLain has been appointed Expert Panelist to City Manager's Compounds of Emerging Concern Technical Advisory Panel, City of Flagstaff, Arizona; the Technical Advisory Committee for Identification and management of critical control points in the spread of antibiotic resistance from animal manure to raw produce, USDA-Agriculture and Food Research Initiative project based at Virginia Tech University; the Technical Advisory Committee for WateReuse Research Foundation Project WRRF-14-02: Establishing Pathogen Log Reduction Credits for Wastewater Treatment Plants; and Technical Expert for New and emerging challenges and opportunities in wastewater reuse, European Cooperation in the Field of Scientific and Technical Research, COST Action oc-2013-2-16816. It also resulted in her participation in Pruden, A., M. Edwards, D. Engelthaler, and J. McLain,Relative abundance and diversity of antibiotic resistance genes and pathogens in reclaimed versus potable water distribution systems a proposal funded by the National Science Foundation Chemical, Bioengineering, Environmental, and Engineering Systems ($315,000).

Publications from Prior Years

1. 2012AZ492B ("Toxicity of Emerging Contaminants in an Effluent Dependent Stream: the Role of Suspended Solids and Sediments") - Articles in Refereed Scientific Journals - Dong, B., A. Kahl, C. Long, H. Vo, S. Ruehl, T. Zhang, S. Snyder, E. Saez, D. Quanrud, and R. Arnold, 2015, Fate of trace organics in a wastewater effluent dependent stream, Science of the Total Environment, 518-519, 479-490.
2. 2013AZ516B ("Sequential advanced oxidation and soil-aquifer treatment for management of trace organics in treated wastewater") - Conference Proceedings - Quanrud, D., R. Arnold, K. Lansey, and E. Saez,"Role of natural attenuation processes in water reuse systems," in Conference Proceeding, U.S. Iran Symposium on Resilient Cities, Irvine, CA, June 15-18, 2014.
3. 2013AZ516B ("Sequential advanced oxidation and soil-aquifer treatment for management of trace organics in treated wastewater") - Dissertations - Dong, Bingfeng, 2014, Application of Water/Wastewater Treatment in Trace Organic Compounds Removal and Other Industry Sectors, PhD Dissertation, Department of Chemical and Environmental Engineering, University of Arizona, Tucson, Arizona. http://arizona.openrepository.com/arizona/handle/10150/333205#
4. 2007AZ219B ("Geospatial Analysis of Urban Thermal Gradients: Application to Tucson Arizona s Projected Water Demand") - Articles in Refereed Scientific Journals - Halper, E., S. Dall'erba, R. Bark, C.A. Scott, S. Yool, 2015, Effects of irrigated parks on outdoor residential water use in a semi-arid city, Landscape and Urban Planning 134, 210–220, doi: 10.1016/j.landurbplan.2014.09.005.