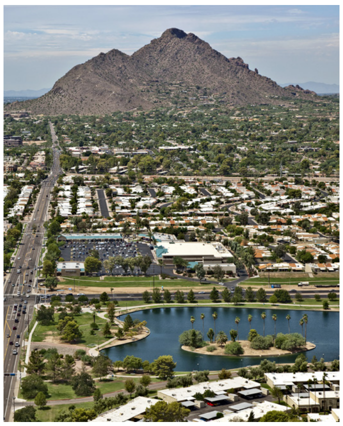

Water Reuse in Central Arizona

A Technical Report by Decision Center for a Desert City

ASU Global Institute of Sustainability, Arizona State University
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CH2MHILL WATER MATCH

Water Reuse in Central Arizona

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PREFACE

This report, *Water Reuse in Central Arizona*, is the result of collaboration between Arizona State University (ASU) and Intel Corporation and CH2M HILL's WaterMatch. The report was produced by the Decision Center for a Desert City, a unit of the Global Institute of Sustainability at ASU. The report aims to improve understanding of the issues surrounding wastewater use and management in Arizona with a special focus on the greater Sun Corridor – the central Arizona urban region that includes Phoenix and Tucson. Through expert interviews, literature reviews, qualitative analyses, and synthesis of existing research, this report summarizes the status of wastewater production and reuse in central Arizona and identifies challenges and opportunities for the future.

We believe this report makes a meaningful contribution to an ongoing and evolving dialogue about water sustainability in central Arizona. Specifically, the report seeks to develop a policy-relevant framework for discussing the future of wastewater management and reuse in light of current and anticipated challenges. These challenges include the potential increased competition for effluent as well as increased costs for treatment and infrastructure. Many recent reports and analyses have recommended increasing wastewater reuse as one important component of a comprehensive strategy to address anticipated water supply-demand imbalances in the region. Despite the excellent work being done in this area by a range of organizations, we still lack adequate knowledge about the dynamics of wastewater management and reuse, especially social, behavioral, and economic considerations. This limits our ability to anticipate the future and adapt to changing circumstances. We hope this report stimulates a robust and inclusive policy dialogue to evaluate the advantages and disadvantages of wastewater reuse for different beneficial purposes.

This report includes contributions and technical reviews from university researchers and representatives from industry, public agencies, and nonprofit organizations. The report represents the best efforts of Arizona State University, Intel Corporation, CH2M HILL, and all remaining participants to foster a productive conversation that advances the goal of water sustainability in the state of Arizona.

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DEFINITIONS OF KEY TERMS

Effluent	Wastewater treated by a treatment plant to a water quality level that meets regulations that allow it to be discharged to a water body or used for purposes that will not result in human contact.
Gray Water	Water that has been previously used for a purpose that lowers the quality of the water, but with quality still high enough that with minimal, or no treatment (such as filtering), the water can be reused for purposes other than as potable water.
Indirect Potable Reuse	The blending of effluent into a natural water source (groundwater basin or reservoir) that is in turn used as a source for drinking water.
Influent	Wastewater flowing into a treatment plant.
Non-Potable Water	Water not suitable for drinking.
Non-Potable Reuse	Includes all recycled or reclaimed water reuse applications except those related to drinking water.
Potable Water	Water at a quality level high enough to meet regulatory standards for purposes of human consumption.
Reclaimed Water	A subcategory of effluent that has been treated to a standard that allows its reuse for purposes that have limited human contact, such as watering a golf course.
Recycled Water	Multiple reuse of effluent or gray water before it is returned to the natural hydrologic (water) system for subsequent beneficial use.
Reuse	To use effluent or gray water for a beneficial purpose before it is returned to the natural hydrologic (water) system.
Safe Yield	The annual amount of water that can be taken from a source or supply over a time period without depleting that source beyond its ability to be replenished naturally.
Vadose Zone	The zone between the ground surface and the water table.
Wastewater	Water that has been previously used by a municipality, industry, or agriculture and has suffered a loss of quality as a result of use.

1 INTRODUCTION

There were times when society considered wastewater just what its name suggests — a waste product to be treated and disposed of while minimizing its impact on the environment. While that viewpoint still prevails in some places, communities across the United States are increasingly reclaiming wastewater and considering it a valuable resource. In these communities, the effluent from wastewater treatment plants can relieve the stress on overstretched water supplies by replacing other sources for non-potable, or sometimes even potable, uses.

This is particularly true in the arid Southwest, where droughts are a natural part of the climate cycle and water supply is inherently variable and limited. The projected impacts of climate change threaten future water supplies due to reduced precipitation, increased evaporation that follows higher temperatures, increased demand, and decreased water availability from surface water supplies such as the Colorado River. Arizona, for instance, has a long history of reusing water, reaching back to at least 1926 when reclaimed water was used for power generation at Grand Canyon Village.

Today, treated wastewater—or effluent—is being used in Arizona for a variety of beneficial purposes, including agricultural and landscape irrigation, industrial cooling, and groundwater recharge. While estimates of effluent reuse in the state vary, **Table 1** shows that reuse in the Phoenix Active Management Area (AMA) may be as high as 82 percent. Although effluent reuse satisfies only a tiny fraction of overall water demand, there is little excess effluent available. In fact, there is growing tension regarding how to best reuse wastewater to sustain central Arizona for the future. Tradeoffs between people, crops, industry, and recreation must be discussed and decisions must be made.

Table 1: 2010 Wastewater Effluent Utilization for Phoenix Active Management Area (AMA) Data source: ADWR annual water reports, ADWR assured water supply decrees, and/or water resource plans from 33 water utilities in the Phoenix AMA gathered as part of Decision Center for a Desert City WaterSim modeling project.

Effluent Use	Acre Feet per Year	Percentage of Available Effluent
Total Wastewater Produced	371,489	
Power	80,000	22%
Agriculture	81,657	22%
Recharge	79,374	21%
Environment (i.e., Tres Rios)	39,200	11%
Discharged (uncommitted)	67,893	18%
Total Effluent Reused	303,596	82%

In much of Arizona, sewer-flow volumes have been stable over the past decade. As a result of declining indoor water use, per capita flows have decreased, but population growth has offset this decrease, resulting in steady overall sewer-flow volumes. During the recent economic recession, sewer flows declined in some of the hardest-hit communities, but there are indications that these flows are returning to previous levels.

If the population in Arizona continues to grow at a rate that offsets any decline in per capita water use, it is expected that effluent production will remain close to today's levels, at least in the near to midterm future. Given the existing high level of effluent use, it is likely that as surface and groundwater supplies become strained from growth and drought, the competition for the highest and best use of effluent will increase.

In Arizona, the predominant use of reclaimed water is for landscape and crop irrigation with the remaining effluent going to industry, aquifer recharge, and a small amount for environmental amenities like urban lakes, fountains, and wetland restoration. Other potential uses exist, such as a direct or indirect supply for potable use. Drought and climate change may reduce the reliability of surface water supplies and increase the desire to use effluent as a potable water supply. This could create a more competitive environment for effluent between urban, agricultural, and environmental uses.

The cost of effluent could also be impacted by water-quality issues. Increasing salinity of wastewater could eventually require salt-removal methods in order to make it suitable for most current uses. The City of Scottsdale is already using reverse osmosis (RO) to deliver low-salinity effluent to golf courses in north Scottsdale. In the future, wastewater treatment might also have to deal with contaminants of emerging concern (CECs) and pharmaceuticals currently not regulated in effluent.

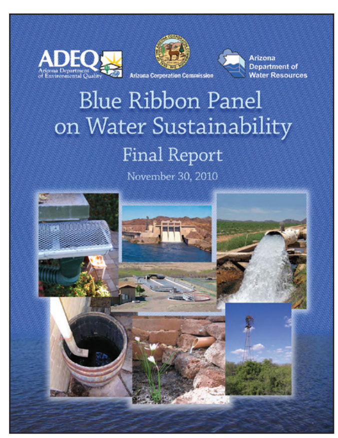
Lastly, the future use of effluent is affected by public attitudes towards the reuse of wastewater as a source of potable water. Negative public attitudes involving protests and hunger strikes over the use of treated effluent for artificial snow generation have already surfaced in northern Arizona[1]. This controversy is driven not only by environmental concerns, but also by cultural beliefs. How residents feel about wastewater as an indirect or direct source of potable water remains to be seen *(see Public Perception of Water Reuse)*.

These issues raise questions about the role effluent will play in the future of water resources in Arizona. This topic was addressed in detail by the Arizona Governor's *Blue Ribbon Panel on Water Sustainability*[2], but many key issues raised in that extensive report remain unresolved. This report presents case studies and policy briefs of wastewater use and management in Arizona with special focus on central Arizona and the greater Sun Corridor—the central Arizona urban region that includes Phoenix and Tucson. This report continues the conversation that was started by the Blue Ribbon Panel and the Morrison Institute's *Watering the Sun Corridor* report[3]. It provides an assessment of effluent reuse to inform public officials, water professionals, and the interested public about the water resource policy implications of effluent reuse.

Based on expert interviews, literature reviews, qualitative analyses, and synthesis of existing scientific research, this report summarizes the status of wastewater production and reuse in the Sun Corridor, and identifies potential constraints on wastewater reuse under the current and predicted future economic and regulatory systems.

The report is organized in the four following sections that address wastewater reuse issues and future implications for central Arizona:

- **Section 2** addresses the potential increase in competition for effluent based on a discussion of existing and potential future demands for reclaimed water.
- **Section 3** focuses on increased costs and their drivers, including salinity, percentage of solids, removal of pharmaceuticals, and infrastructure.
- **Section 4** discusses future implications and describes a new marketplace that may be created for the sale and allocation of effluent in the future; it briefly discusses future uncertainty and our current lack of knowledge about the dynamics of the cost drivers that limit our ability to anticipate the potential consequences of a new effluent marketplace.
- **Section 5** presents final thoughts on supporting a policy dialogue on water reuse in central Arizona and concludes with a suggestion of ten research priorities.



Public Perception of Water Reuse

Is it safe to drink? Public perceptions of reclaimed water are key for successful implementation of water reuse initiatives.

One of the major hurdles to water reuse initiatives is public perception and acceptance. Dr. Channah Rock, water quality specialist and assistant professor at the University of Arizona, says: "We can have all the science in the world telling us that something is right, but unless you get the public on board, it will be very difficult to get an initiative to move forward."

In general, there seems to be a lack of information that is available to the public about what reclaimed water is or what water reuse means. Dr. Rock's survey research found that only a very small subset of the population was actually able to define water reuse and had an understanding of the benefits versus costs of reused water.

"That's largely because of heightened media coverage and the sensationalization of different things that have happened in the past," Dr. Rock says. "The only information distributed is the negative information."

A big misconception among the general public is that reclaimed water comes straight from a waste facility to their homes as the phrase "from toilet to tap" suggests. The public has not been educated about the comprehensive treatment of reclaimed water, the testing, and how the quality of reclaimed water compares to the water that they are already receiving from surface water or groundwater sources. Especially in the state of Arizona, oftentimes the quality of reclaimed water is at or above drinking water standards.

Dr. Rock's research further showed that people were more comfortable with uses that did not involve direct contact with reclaimed water, such as irrigation of public lawns, fire protection, cooling towers, and environment use. People were more hesitant with uses that were increasingly personal, such as irrigating schoolyards. Increasing the general public's confidence in the current quality of reclaimed water might make them more accepting of it as an alternative water source.

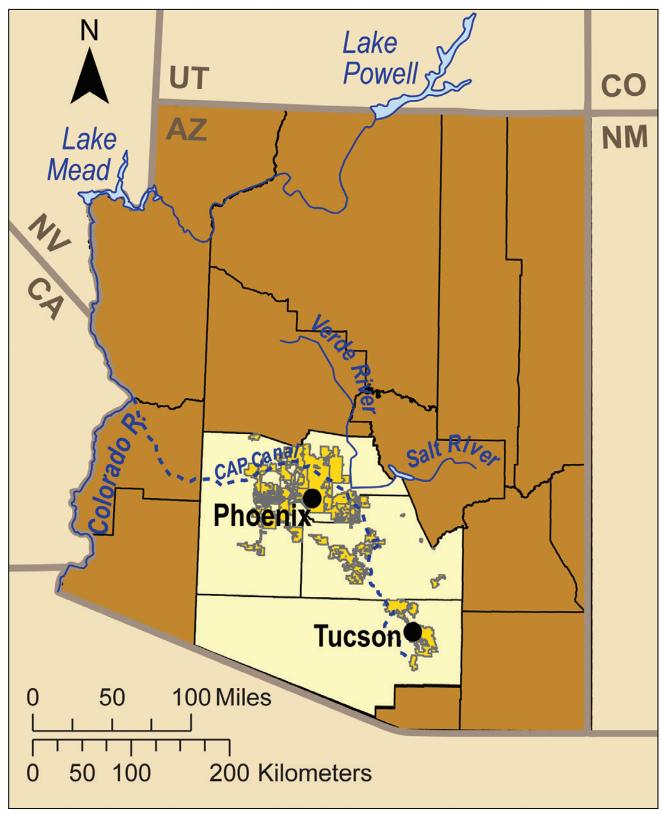
As University of Arizona Extension faculty, Dr. Rock promotes water reuse as a safe and practical resource for the Southwest. By educating the public through user-friendly messaging that uses appropriate terminology, she provides people with valuable information and helps them become comfortable enough to make their own decisions based on their cultural and religious perspectives. According to Dr. Rock, it is important to have the public be part of the conversation from the start.

"I think we are empowering people to make decisions about their lives and their community," Dr. Rock says. "It is rewarding, and education is really key for water reuse initiatives."

2 INCREASED COMPETITION

Before any policy changes can be made, existing effluent demands and supplies must be reviewed. In Arizona, effluent is largely consumed through irrigation of landscapes and agriculture. This section outlines both uses, as well as industrial uses. Due to efficient systems, wastewater sources in Arizona are declining, even while population continues to grow. However, there are still opportunities for sustainable water reuse, including potable water and environmental uses, which are also outlined in this section.

Figure 1: Arizona and the Arizona Sun Corridor (Decision Center for Desert City, Arizona State University)



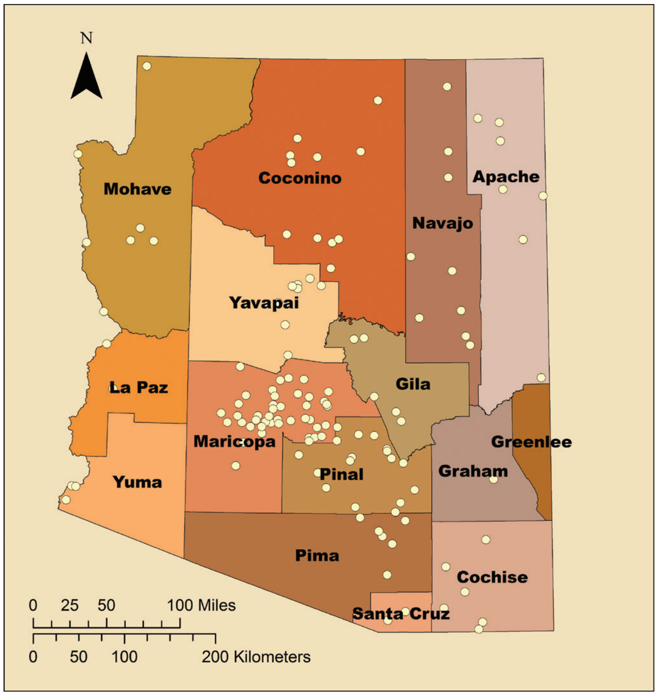
2.1 Existing Demand and Supply

Effluent is an important component of the water supply in central Arizona and helps to reduce the demand on freshwater resources. Generally, reuse can be classified into five categories:

1. urban irrigation
2. agricultural irrigation
3. industrial
4. environmental
5. indirect potable use

In Arizona, the largest use of effluent is primarily for irrigation purposes, either in an agricultural or municipal setting. Although there is some industrial use, indirect potable and environmental uses are minor. Infrastructure for treatment and delivery of wastewater has a significant impact on its ultimate use. The key point here is convenient, nearby infrastructure for both wastewater availability and demand.

Figure 2: Location of Wastewater Treatment Facilities in Arizona (WaterMatch, December 2012)[14]



Effluent from wastewater treatment plants can be treated to a number of different grades, or quality levels, each useful for different purposes. Most effluent is treated to a quality level that can be discharged into the state's streams, but not of sufficient quality for direct contact with people (e.g., swimmable or fishable). Effluent of this quality can be used for industrial purposes, such as power plant cooling, and the irrigation of crops not for human consumption, such as cotton.

Effluent can also be treated to a higher quality, often called reclaimed water, that can be used for irrigation within urban areas where there will be some human contact. This includes turf irrigation on golf courses, soccer fields, and parks.

Reclaimed water can be used to recharge aquifers by using large surface basins that allow the water to slowly percolate into underlying aquifers or through shallow wells that inject water into the upper vadose zone. In some cases, the salinity of reclaimed water may exceed plant tolerance and may not be appropriate for some irrigation purposes, such as for high-quality turf. In such cases, reverse osmosis is used to remove salts from the reclaimed water. In some states, but not yet in Arizona, reclaimed water can be treated to a higher standard and then recharged directly to the aquifer using direct injection wells for storage and recovery.

According to the Arizona Department of Water Resources (ADWR) Phoenix Active Management Area (AMA) Assessment Report[4], municipal water demand increased from 29 percent to 47 percent of total demand between 1985 and 2009. At the same time, largely due to urbanization, agricultural water use declined from 57 percent to 33 percent of total demand. Industrial use doubled during that 24-year period and accounted for 9 percent of total use in 2009. The total water demand in the Phoenix AMA has been relatively stable over the past two decades, averaging about 2.3 million acre-feet, or 750 billion gallons, per year *(Figure 3).*

On the supply side, the use of reclaimed water to meet demands has tripled from only 2 percent in 1985 to almost 6 percent in 2009[4]. Over this same time period, groundwater use has decreased significantly, from almost 50 percent to 27 percent, and surface water use dropped from 51 percent to 41 percent of the total demand. Colorado River water supply, which is delivered via the Central Arizona Project (CAP) canal established in 1986, met 21 percent of the 2009 total water demand in the Phoenix AMA. In-lieu groundwater, which is CAP or reclaimed water that was substituted for the use of groundwater, accounted for almost 6 percent of demand *(Figure 4).*

Figure 3: ADWR, Phoenix AMA Assessment Report, October 2010[4]

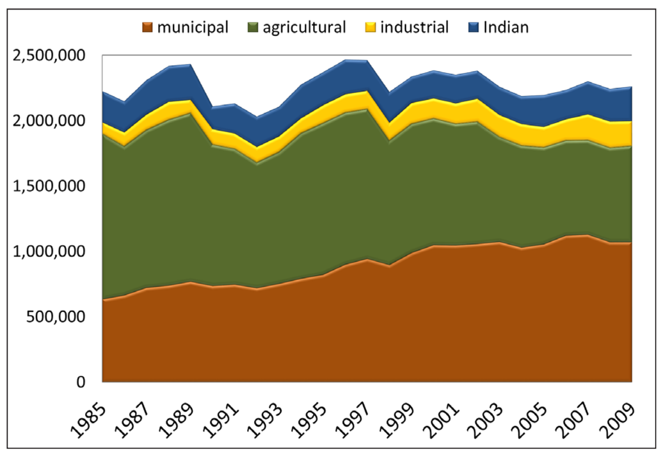
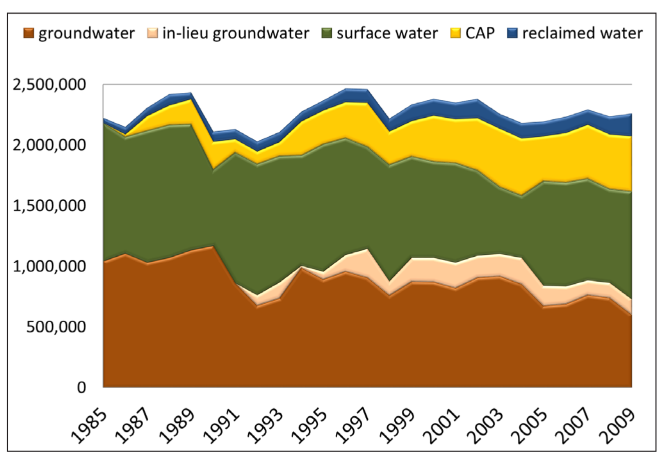


Figure 4: ADWR, Phoenix AMA Assessment Report, October 2010[4]



2.1.1 Demand: Urban Irrigation

Historically, the Phoenix area developed as an oasis in the desert. It was initially served directly by water from the Salt River, and beginning in the early 20th century, by the reservoirs of the Salt River Project. In the 1950s, a major source of water was from deep-well pumping. Finally, in the mid-1980s, the Central Arizona Project (CAP) began to deliver Colorado River water to central Arizona.

Compared to the surrounding desert, the Phoenix metropolitan area has a higher plant diversity and density, including both native and exotic species. Many local residences have swimming pools and mesic landscaping with lush lawns and non-native, medium-to-high water use plants.

The Phoenix metropolitan area encompasses almost 200 parks/public green spaces[5] and over 250 golf courses. In recent years, the City of Phoenix has delivered reclaimed water to all of the parks, golf courses, schools, and cemeteries north of the CAP canal. In Scottsdale, all of the golf courses located north of the CAP canal have been irrigated with reclaimed water for the last 20 years. Mesa and Chandler also deliver effluent to golf courses. Landscape irrigation has been, and will continue to be, a water demand that can be met through treated effluent.

2.1.2 Demand: Agricultural Irrigation

Agriculture has historically been important to Arizona's identity, culture, and economy. Although population growth and rapid urbanization have led to the conversion of agricultural lands into housing subdivisions in recent decades, farming still accounts for more than two-thirds of the state's water demand[6] and 20 percent of the national agricultural GDP[7]. In the Sun Corridor alone, about 1.8 million acre-feet of water are used annually for crop irrigation[3]. An acre-foot equals 325,851 gallons—enough water to supply two average Arizona households for a year. Many non-human consumptive agricultural crops in Arizona, such as cotton and corn, or fodder crops like alfalfa, are irrigated with effluent after secondary treatment and disinfection[8]. Approximately 20 percent of the Phoenix AMA's agricultural water demand is currently met by reclaimed effluent water supplies. A portion of the treated effluent from the two City of Phoenix wastewater treatment plants is used for crop irrigation. Phoenix also has an agreement with the Salt River Project and the Roosevelt Irrigation District to deliver effluent to farms in exchange for surface water. Agricultural water demand varies seasonally; therefore, reclaimed water is used to recharge groundwater when agricultural water demand is low[9].

2.1.3 Demand: Industrial

Effluent for industrial use in Arizona is dominated by cooling tower operations for power generation and manufacturing processes *(see Industry as Backbone for Stable Effluent Production).* The Arizona Public Service's (APS) Palo Verde Nuclear Generating Station located about 55 miles west of downtown Phoenix uses approximately 20 billion gallons of treated effluent per year for its cooling towers[10]. The main supplier of effluent to the Palo Verde plant is the 91st Avenue Wastewater Treatment Plant operated by the City of Phoenix.

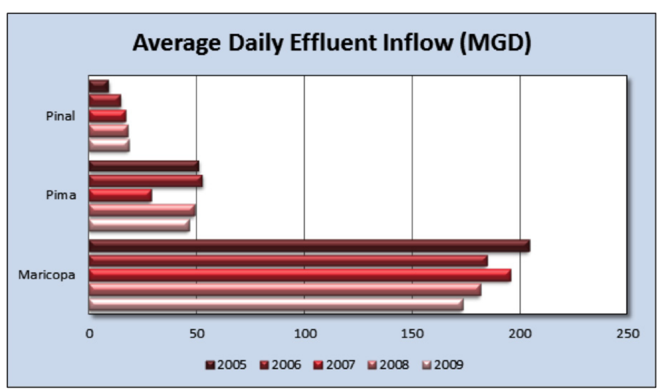
Intel's electronic chip manufacturing plant in Chandler uses a $20-million industrial water management system to treat wastewater from its manufacturing processes and internally reuse it for cooling processes[11]. A reverse osmosis facility treats approximately 1.25 million gallons of wastewater per day produced by Intel's chip manufacturing plants FAB 12 and FAB 22. Intel partnered with the City of Chandler to implement this progressive water management system, which has reduced Intel Arizona's daily water demand by up to 75 percent[12].

Overall, in 2009, industrial processes in Arizona met 43 percent of their water demand from reclaimed water supplies[3].

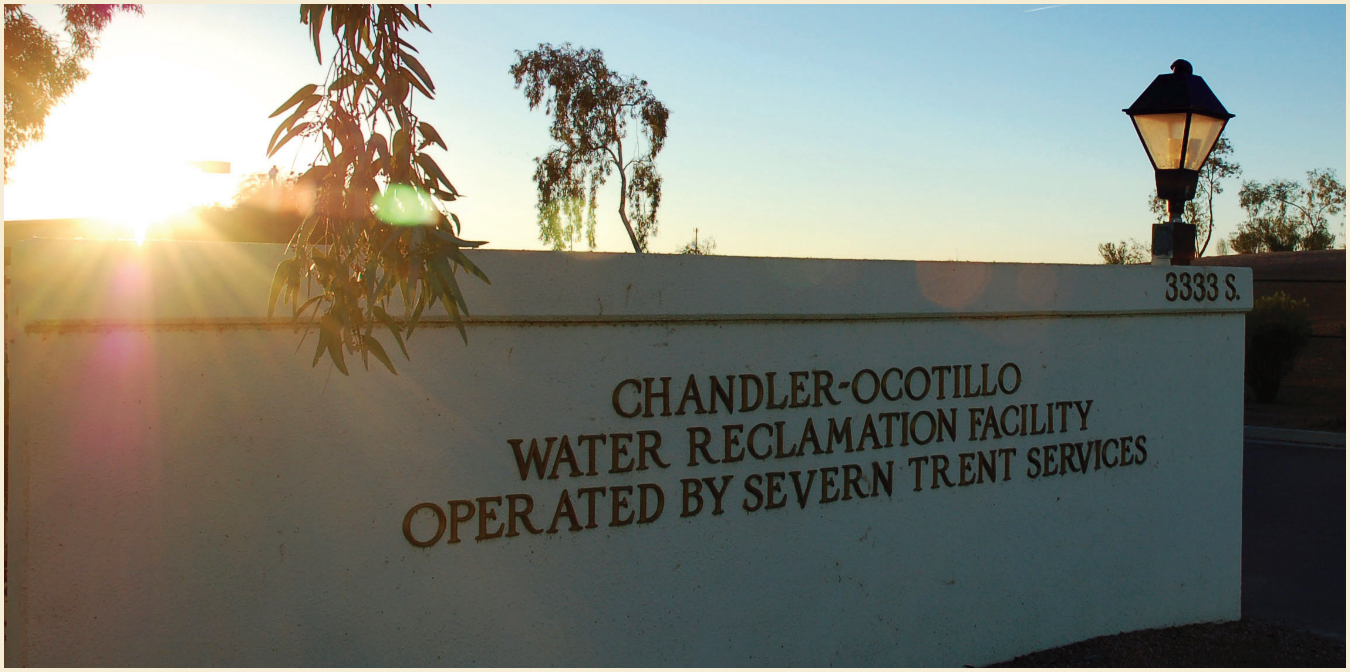
2.2 Future of Wastewater Supply

Despite the recent economic downturn, the Southwest is still one of the fastest-growing regions in the United States and home prices are again rising as growth rebounds with the recovering economy. Although a concurrent increase in wastewater production would be expected with population growth, sewer flows, however, have been essentially flat. In fact, some wastewater treatment facilities in Arizona have seen a slight decrease in influent volumes despite the increase in population that has occurred in their service area (Figure 5).

Figure 5: Average daily effluent inflow to wastewater treatment facilities in Pima, Pinal, and Maricopa counties during the years 2005 and 2009 in million gallons per day (mgd)[13].



Industry as Backbone for Stable Effluent Production



The City of Chandler's Ocotillo Water Reclamation Facility near Queen Creek Road and Dobson Road.

The Ocotillo Water Reclamation Facility (WRF) in Chandler is one of three wastewater treatment plants in the City. Operated and maintained by Severn Trent Services in partnership with the City of Chandler, the Ocotillo facility implemented an innovative water management system and was named the 2011 Wastewater Treatment Facility of the Year by the AZ Water Association. On average, the Ocotillo plant produces 10 million gallons of effluent per day (mgd), all of which is being reused.

"Whatever comes in the door right now, we have no problem finding a use for it," says Charles McDowell, project manager at Severn Trent Services.

Roughly half of the plant's treated effluent is delivered to Intel for use in the cooling towers of its three nearby chip fabrication facilities. The remaining reclaimed water is used for aquifer recharge, urban irrigation, and irrigation of agricultural fields near the Gila River Indian Community.

Unlike many other wastewater treatment plants, the Ocotillo WRF has not experienced a drop in effluent flow, and is even expecting an increase. The facility receives domestic sewage from the City of Chandler, but approximately half of their total incoming flow is Intel's industrial wastewater. Eventually, Intel will build a new fabrication plant, increasing their effluent production.

"There is an expectation, certainly in the City of Chandler, that wastewater flows are going to increase over the next few years," McDowell says. "Ocotillo will be looking at an expansion down the road."

Key to this reclamation effort's success is the strong public-private partnership between Intel and the City of Chandler. Since the water efficiency program was established, the Intel Ocotillo Campus has saved about five mgd of potable water supplies by using reclaimed water from the Ocotillo WRF for landscape irrigation and cooling tower operations. That equates to over 4.5 billion gallons of drinking water that have been saved for the City of Chandler.

For example, in the Fountain Hills Sanitary District, the average daily per capita sewer contribution has dropped from approximately 86 gallons to 78 gallons over the past 15 years. Only a few wastewater treatment plants have seen an increase in influent flow, normally in facilities that are supplied with industrial sewage or in cities that are experiencing population growth rates higher than the average regional growth rate.

Despite population growth, flat or slightly decreasing effluent volumes are likely due to declining domestic indoor water demand. Over the past decades, household plumbing fixtures have become more efficient. As new homes are built and as people retrofit older homes, more efficient faucets and low-flow showerheads and toilets conserve potable water supplies that would otherwise go into the sewer. Many cities in central Arizona have incentive programs that reimburse the homeowner for all or part of an in-home fixture replacement. Both the homeowner and the city get the long-term benefit of water savings.

The inverse relationship between indoor water conservation and wastewater production has led to a reduction of residential wastewater available for effluent production as well as a decrease in the per-capita amount of wastewater generated. Declining sewage flows have an impact on the sewer system, increasing the amount of solids in the wastewater and the "strength" of the water, which has implications for the wastewater treatment process. Ultimately, there is a reduction in the amount of treated effluent available and an increase in the per gallon cost to treat it.

Thus far, slightly decreasing flows have not affected the ability of most wastewater treatment facilities in Arizona to meet the needs of their reclaimed water customers or recharge goals. However, lower inflow volumes have forced some facilities to actively manage the flows at the plants, especially in the summer when water demand is high. Wastewater experts estimate that the downward trend of per-capita indoor water demand will continue and as a result, the quantity and quality of available effluent will go down. However, if continuing population growth balances this downward trend, the amount of wastewater available for reuse should remain stable *(see What if Growth Doesn't Occur).*

2.3 Potential Future Demand

2.3.1 Potable Water

Current regulations on the use of treated effluent do not allow for its direct use as potable water or as a supply for potable water. In Arizona, to use effluent as a source for potable water, an indirect method must be used. Effluent can either be recharged to an aquifer through surface recharge (vadose zone method), or it can be discharged to a water body which may later become a source of surface water supply.

However, most effluent-to-potable water use is accomplished using vadose aquifer recharge with recovery wells. Depending on the geology of the aquifer, vadose zone recharge can take 10 to 50 years for recharged water to reach a point in the aquifer where it is available for recovery.

From a technical standpoint, the release of highly treated wastewater directly into a potable water system is possible today. In California and Florida, municipalities already consider effluent as a viable source of water to replenish drinking water supplies and are blending their drinking water sources with highly treated effluent.

In Arizona, there is an understanding that wastewater should be reused because water is scarce in an arid desert environment. However, people will usually respond negatively if asked if they would drink reclaimed water citing the "yuck" factor. Public perception changes will likely play a crucial role in establishing future potable reuse in Arizona beyond recharge and recovery *(see Public Perception of Water Reuse).*

With increasing public education on drought and water conservation, people in Arizona are becoming more accepting of the beneficial use of reclaimed water. They feel more comfortable using reclaimed water for irrigation purposes; in fact, in many cases, they expect effluent to be used for irrigation, rather than potable water, which for many would be considered a waste of a natural resource[15]. Yet, the acceptance of reclaimed water as a potable water source is unclear. The objection to the use of effluent for other high contact uses, such as snow generation, seems driven by a lack of confidence in the treated wastewater quality, although cultural beliefs may also be a factor.

Public education and outreach are vital to effective reuse programs and will be instrumental in convincing the public that it is reasonable to reuse reclaimed water as drinking water. It will take time, money, regulation changes, and commitment. Eventually, direct potable reuse could emerge as a viable demand for effluent that will compete with the existing demands for effluent in central Arizona.

What if Growth Doesn't Occur?

Every hour from 9:00 a.m. to 9:00 p.m., the fountain in Fountain Hills rises 560 feet into the air. The landmark runs on 100 percent reclaimed water.

Located just east of Scottsdale, the town of Fountain Hills is well-known for being the site of one of the world's highest fountains, which attracts many visitors each year. What most people do not know is that this fountain, as well as the lake where it is located, is 100 percent reclaimed water.

Since its inception, the Sanitary District of Fountain Hills, a governmental entity handling the town's wastewater, has reused 100 percent of its effluent. Because the two downstream communities adjacent to Fountain Hills are American Indian reservations that will not allow reclaimed water to travel across their land, the District's wastewater treatment plant cannot discharge to natural waters. Therefore, the District constructed an aquifer storage and recovery (ASR) system. Designed as a "put-and-take" system, five wells store potable water when recovery demand is low in the winter for use later in the summer.

In 2008, the economic crisis forced many properties in Fountain Hills into foreclosure. As a result, the amount of flow volume into the District's wastewater treatment plant dropped by as much as 10 percent. Under continuing drought conditions, one of the Fountain Hills golf courses, Eagle Mountain, had an increase in the demand of reclaimed water for irrigation. The District faced a supply-side challenge: While the amount of sewage coming into the plant decreased, the demand for reclaimed water increased.

"We didn't think that we would be to the point that we were at this year, where we would run out of credits for stored water, but it happened," says Ron Huber, the Fountain Hills district manager.

Per contract, the District did not have to provide the golf courses with an alternate water source, but the only other water source available was the drinking water supply. The cost of potable water would have bankrupted at least one of the golf courses.

Ron Huber found a temporary solution to the supply and demand dilemma. He secured a two-year non-agricultural groundwater right lease with the Scottsdale Ranch Community Association in August 2012.

"Basically, we'll pump groundwater to the golf courses," Huber says.

The District can draw from the same aquifer where the ASR wells are already in place. Ultimately, the District is looking for something more permanent. One possibility would be purchasing CAP water, which would demand increased infrastructure and treatment costs.

2.3.2 Water for the Environment

The environment is usually the last beneficiary when it comes to water allocation. Some might not even consider discharging wastewater to a stream a "use" of water. Environmental reuse of reclaimed water includes restoring or enhancing natural wetlands and streams, and creating artificial wetlands. Wetlands are highly beneficial as wildlife habitat and refuge. They provide flood control and improve the overall water quality by serving as a natural water filter.

In Arizona, environmental reuse of reclaimed water is currently not regulated. In fact, only a few states in the U.S. have environmental flow standards that secure water for ecosystems. However, there are ongoing projects in Arizona to restore urban wildlife habitats.

In Tucson, the Sweetwater Wetlands[16] is a riparian corridor that is part of the City's Reclaimed Water System. It serves as a water treatment facility and recharges the local aquifer. In times of high water use, the reclaimed water is recovered for irrigation of public spaces. The Sweetwater Wetlands also serve as a public park, where visitors can experience wildlife in an urban environment and become better educated about ecosystems and water resources.

Using reclaimed water, the City of Phoenix restored 1,500 acres of dry river bed and its banks as a riparian area called the Tres Rios wetlands[17]. The wetlands were originally developed in 1994 as alternative wastewater treatment for advanced nitrogen removal. Today, the wetlands are a thriving, fully developed system and provide habitat to native flora and fauna. Tres Rios is supplied with highly treated effluent from the 91st Avenue Wastewater Treatment Plant. The wetlands serve many purposes besides nitrogen removal, such as flood control, groundwater recharge, and public outreach and education. The City is also working on a Safe Harbor Agreement with the U.S. Fish and Wildlife Service to support endangered species and to increase the sustainability of native wetlands.

Another successful site conversion is the Rio Salado Habitat Restoration Project[18] along the Salt River in the City of Phoenix. Supported by the Bureau of Reclamation, the Nina Mason Pulliam Charitable Trust, and the National Audubon Society, the Rio Salado project is operated and managed by the City of Phoenix Parks and Recreation Department. The project encompasses 595 acres of native wetlands with riparian and wildlife habitats and five miles of hiking trails for public access and recreational purposes. The wetlands and riparian areas are sustained with local non-potable groundwater as a substitute for the water that used to flow down the Salt River on a regular basis. Rights to this groundwater are obtained through the delivery of effluent to agricultural lands in the areas west of the Rio Salado site (see *Wet Water vs. Paper Water*). It is estimated that 50 percent of water used for irrigation at the wetlands is naturally filtered through the wetlands and recharged into the local aquifer.

3 INCREASED COST

The quality of the wastewater treatment plant inflow and the desired, or required, quality of effluent produced ultimately determine the treatment costs of wastewater. Higher-strength wastewater, which exhibits increased biochemical demand (BOD) and total suspended solids (TSS), will have higher treatment costs. Increased salinity levels also affect costs because brackish water requires advanced treatment and brine disposal. Other drivers of increased costs are pharmaceuticals removal and infrastructure requirements. This section discusses each of the drivers in detail.

3.1 Increasing Salinity

Salinity, the total amount of dissolved minerals in water, is measured in total dissolved solids (TDS). Groundwater in Phoenix is typically high in TDS through dissolution of natural minerals in rocks and soil. Additionally, dissolved salts enter the Salt River system through salt springs at the confluence of the Black and White Rivers, the "Red Wall" on the White Mountain Apache Indian Reservation, and CAP sources. Salinity of wastewater varies seasonally and is drought-dependent. Salinity is higher in drought years because water from the salt springs is less diluted and a greater percentage of groundwater with a higher natural salinity is mixed into the potable supply.

Besides these natural variations in TDS, many wastewater treatment facilities in central Arizona have seen an increase in the salinity of reclaimed water over the past decade, mainly due to human activities. In agriculture, the use of synthetic fertilizers increases soil salinity, which in turn enriches ground and surface water with salts. The application of detergents and water softeners in residences, particularly water softeners that are using sodium-based salts, affects reclaimed water salinity. Many industrial processes also increase the amount of dissolved constituents in water through cooling tower blow-down, a mechanism to reduce the TDS concentration in the water to improve cooling tower efficiency. Most wastewater treatment facilities do not remove influent salt, and the overall salinity of wastewater adversely affects the quality of the reclaimed flow.

Increased salinity is of great concern to golf courses that irrigate their landscape using reclaimed water. High TDS concentrations lower water uptake in plants. As a result, vegetation grows more slowly and more water is needed to sustain the landscaping, increasing operational costs. High concentrations of TDS also have toxic effects on salt-sensitive horticultural crops, such as lettuce. Salinity adversely impacts the flora and fauna of freshwater ecosystems, leading to environmental and riparian degradation. In industrial applications, high concentrations of TDS can disturb cooling processes. Salt buildup in cooling systems leads to high water use and can even cause serious damage to equipment, increasing production and operational costs for many industrial sectors.

Lastly, salinity impacts domestic water uses. High concentration of TDS causes mineral deposits to accumulate in pipes and fixtures, which may require them to be replaced. High salt content in drinking water may also have health impacts. There are no regulations on the amount of TDS in drinking water, and wastewater treatment facilities are not required to test for salinity; however, the U.S. Environmental Protection Agency (EPA) has defined non-mandatory water quality standards under the "National Secondary Drinking Water Regulations." According to federal standards, a TDS level of 500 mg/L is the upper limit beyond which taste, color, and odor are affected[19]. The World Health Organization (WHO) further established guidelines[20] for dietary salt intake, recommending that water at TDS levels greater than 1000 mg/L not be used for human consumption *(Table 2).*

Table 2: Total dissolved solids (TDS) in natural waters[21]

Water Source	Total Dissolved Solids
Precipitation	10 mg/L
Salt River	580 mg/L
Verde River	270 mg/L
Central Arizona Project (CAP)	650 mg/L
Groundwater	200 - 5,000 mg/L
Average Seawater	35,000 mg/L
Brines	> 50,000 mg/L
Reclaimed Water	Typically 300 - 500 mg/L higher than source water

Desalinating reclaimed water to increase water quality requires additional treatment. The most commonly applied technique is reverse osmosis (RO). In this treatment process, saline water is passed through a selective membrane under pressure, leaving behind a higher concentration of TDS on one side of the membrane and high-quality water on the other. RO is being successfully applied in many Arizona wastewater treatment plants including the Chandler RO Recharge Facility and the City of Scottsdale's Water Campus Advanced Water Treatment (AWT) plant.

However, there are two drawbacks of RO. First, the water needs to be pressurized to about 250 psi (equal to a column of water that is approximately 576-feet tall), and pressurization is a very energy-intensive process requiring expensive equipment. New technology currently allows for energy recovery of about 20 to 30 percent. Second, for every 10 million gallons of water that is processed through the membrane, only about 8 million gallons of clean water is produced; the remaining 20 percent is salty water, so-called "brine." Removing the waste salt from the system, either through evaporation ponds or through crystallization, is an expensive process. Oftentimes, the concentrated RO brine reject is discharged to a public sewer, which in turn decreases water quality at the receiving wastewater treatment plant and takes up hydraulic capacity.

Increased salinity in central Arizona has become an issue for plant and soil health, ecosystems, industrial processes, and potable uses. Overall, increased concentration of TDS leads to increased costs, but removing salt from the system is an energy-intensive and expensive proposition that involves brine disposal. Today, one of the key limitations to desalination of effluent or groundwater is the difficulty in managing the disposal of the brine stream *(see The Brine Side of Purified Water).* A partnership between the Bureau of Reclamation and several local utilities has been studying this issue for the last 10 years. Because of Arizona's location, the brine stream cannot be disposed of in the ocean, and deep well injection is not an option without threatening contamination of existing aquifers. Evaporation ponds are an effective method of concentration, but the lack of disposal options for this volume of brine concentrate make this a sustainable option only for those sites where the brine can be left in place. Land disposal is also complicated by the other contaminants that can be found in the concentrated brine stream.

Strategic alternatives need to be developed that are both cost-effective and feasible from an environmental standpoint, especially since central Arizona's wastewater treatment facilities will continue to experience an increase in influent TDS over the next few years.

3.2 Increasing Per Capita Solids in Sewage

Solid materials in wastewater include both organic and inorganic substances and organisms. Solids are classified according to their physical state: suspended, dissolved, settleable, and colloidal. Wastewater that contains a high concentration of organic solids is defined as "strong" *(Table 3).*

Flat or reduced effluent flow under population growth increases the solid load of a wastewater treatment facility. Because less water is coming into the plant, the density of solids increases and the wastewater becomes stronger. The constituents are still the same, but there is less dilution of the solids, impacting the flow through the sewer system and the required treatment method of the effluent.

Higher-strength wastewater has an increased biochemical oxygen demand (BOD). BOD is a measure of dissolved oxygen that is required by aerobic biological organisms to break down the organic material in wastewater. In central Arizona, domestic wastewater has the strength of about 250 mg/L BOD, which equals 99.75 percent water and 0.25 percent solids. Low-flow fixtures and

Table 3: Solids in wastewater[22]

Organic Solids	Solids that are subject to decay or decomposition (putrescible); generally combustible; in domestic wastewater, principle organic solids include proteins, carbohydrates, and fats.
Inorganic Solids	Solids that are inert and do not decay (exceptions are certain mineral compounds and salts); generally non-combustible.
Total Solids	Includes the total of all solid constituents; on average, domestic wastewater contains 50 percent organic and 50 percent inorganic solids.
Suspended Solids	Solids that are visible and in suspension in the water; can be removed physically or mechanically, for example, through sedimentation or filtration.
Total Dissolved Solids	Primarily minerals and salts, but can also include organic matter; pass through when wastewater is filtered.
Settleable Solids	Suspended solids that have sufficient size and weight to settle out from the rest of the effluent stream during preliminary treatment stages.
Colloidal Suspended Solids	Solids that do not dissolve, yet do not settle readily; difference between total suspended solids and settleable solids.
Biosolids	Nutrient-rich organic materials resulting from the treatment of sewage sludge; tested and determined to be safe for land application.

other water conservation measures can cause effluent strength to go up to 400 mg/L BOD or higher, increasing the amount of energy needed to treat the wastewater and, as a result, increasing treatment costs.

An emerging challenge for utilities will be the accumulation of biological solids and debris inside the sewer mains themselves where pipes are shallow in terms of slope. Sewers are constructed at a calculated angle to keep the wastewater flow rate above two feet per second in the sewer in order to prevent solids from settling. An increased solid load will slow down the effluent flow in sewer lines and stagnant water could potentially lead to sewer blockages, demanding costly repairs and cleaning procedures.

3.3 Pharmaceuticals

The presence of pharmaceuticals and personal care products (PPCP) in ground and surface water is a growing concern to the water management community. PPCP, also called contaminants of emerging concern (CECs), are a class of chemicals that includes drugs, cosmetics, and nutritional supplements. A small fraction of these chemicals pass through conventional wastewater treatment; that is, CECs are not completely removed from the wastewater and therefore persistent in the environment. These chemicals accumulate in biosolids, which are then applied on non-food agricultural crops.

PPCPs are currently unregulated, which means that wastewater treatment plants are not required to test for pharmaceuticals or personal-care products. Part of the problem is that there are so many chemical constituents in these products that it is difficult to determine which ones to test for; it is also expensive and testing can cost over $1,000 per sample. For testing purposes, surrogate or indicator compounds can be picked to represent entire groups of compounds, but it remains difficult to cover all possible constituents.

As analytical methods have become more sophisticated in the past decades, smaller concentrations of pharmaceutical compounds in the water cycle can be detected. Lower and lower concentrations of PPCPs can be found, ranging from parts per billion (ppb) up to even parts per trillion (ppt). Minute traces of pharmaceutical compounds have not only been detected in reclaimed water, but also in treated drinking water. The impact of those pervasive pollutants on human health and the environment are not yet fully understood. For a direct potable reuse program, micro-constituents of the water are going to have to be dealt with for real, or perceived, human and ecological risk. Eventually, there may be some regulations for PPCPs, either through the Arizona Department of Environmental Quality (ADEQ) or the U.S. Environmental Protection Agency (EPA). This will make wastewater treatment more complex because of the ability to connect low concentrations of PPCPs and new regulatory monitoring requirements. At the same time, pursuing higher levels of treatment to remove PPCPs will result in higher treatment and operating costs, including capital investments. Treating for PPCPs would almost double the costs of reclaimed water and the additional cost would most likely be paid for by the water

companies' customers.

Advances in wastewater treatment technologies can produce higher quality reclaimed water for different applications, but this comes at higher costs. Eventually, as water supplies become scarcer and the population continues to increase, the price of providing the extra treatment to have purified water might outweigh the cost of developing new water supplies, which may not even be available. Currently, pharmaceuticals and other CECs remain a challenge for the wastewater treatment industry.

3.4 Increasing Infrastructure Costs

One of the major drivers for increased wastewater costs is establishing infrastructure for wastewater treatment and transport. Infrastructure related costs can be split into three different types of expenses:

- facility expansion
- transport infrastructure to move water
- aging infrastructure maintenance or renewal

Expansion and transportation can be competing costs. For example, will it be cheaper to reroute sewage for treatment to an existing facility that is further away, or invest in an aquifer storage and recovery system on-site? Moving water from one place to another increases costs, especially if the water needs to be moved uphill. Sometimes, it may be cheaper to use other water sources that are closer to the end user than pumping the reclaimed water stream to the user.

Particularly for smaller end users, the cost of delivering reclaimed water poses a barrier to using reclaimed water. In other cases, geographical or cultural boundaries may increase transport infrastructure costs or even prevent reclaimed water from being transported. A facility expansion that initially seemed to be the most expensive option might turn out to be the most cost-effective solution compared to the capital and operational costs of transport infrastructure.

Residential customers are likely to represent the highest infrastructure and operational costs per delivered gallon of effluent because a new set of delivery pipes would have to be built adjacent to the current potable water system. In order for irrigation and internal plumbing to work properly, these systems will have to be under pressure. Every home would need to include a secondary system to deliver water to irrigation, toilets, and cooling.

Commercial and institutional irrigation users are likely to be the next highest per gallon costs. Again, a secondary delivery system would have to be constructed, though this system would not have to be as extensive as a residential system, and would only need the pressure necessary to deliver to a single site. Commercial and institutional irrigation systems can include reservoirs and pumps to bring the water up to the pressure needed for irrigation.

Industrial and agricultural uses would be the least expensive per gallon cost. Such deliveries would entail far fewer lines, and lines would be larger to convey higher volumes of water under low, if any, pressure. Delivery to customers via a gravity canal system would likely entail the lowest cost per gallon of effluent.

Wastewater treatment plants and collection systems age over time and infrastructure constantly needs to be repaired, replaced, and updated. Many municipalities in central Arizona have already had to raise rates to fund infrastructure additions and repairs. Increasing infrastructure costs poses a problem when specific funding must be obtained for a particular project. Some major projects have been scaled back and others have been canceled, especially as a result of the economic downturn.

4 FUTURE IMPLICATIONS

Contrary to many of the stories we read in the national press indicating that Arizona has a shortage of water, the state actually has an impressive portfolio of water supplies that has served it well for over 100 years and provides a good base for the future[3].

A small part of this portfolio is a result of central Arizona's relatively high percentage of effluent reuse, which as noted earlier, may be as high as 82 percent in the Phoenix AMA *(Table 1).* Within central Arizona, half of this reused effluent is traded for groundwater credits, offsetting the groundwater pumped for agriculture or for aquifer recharge. A quarter of the reused effluent is used for cooling at the Palo Verde Nuclear Power Plant, thus reducing groundwater withdrawal at the plant site. Less than 10 percent of the reused effluent results in an offset of potable water use, and just a little over 10 percent is used for environmental benefit, mostly for structured wetlands, though there is debate as to whether this is reuse for an environmental benefit or just part of the wastewater treatment process.

That effluent is dedicated to these specific uses is primarily a factor of today's economics of wastewater treatment, groundwater withdrawal, and effluent reuse regulation. In the future, the economics and regulation of effluent reuse will likely change as a result of a number of factors, including:

- the availability of surface water supplies;
- a better commitment to the sustainability of groundwater withdrawal;
- advances in the technology of wastewater treatment;
- increased knowledge about water containments;
- the cost of potable water;
- the cost of treating wastewater for reuse; and,
- the cost of infrastructure needed to deliver effluent for reuse.

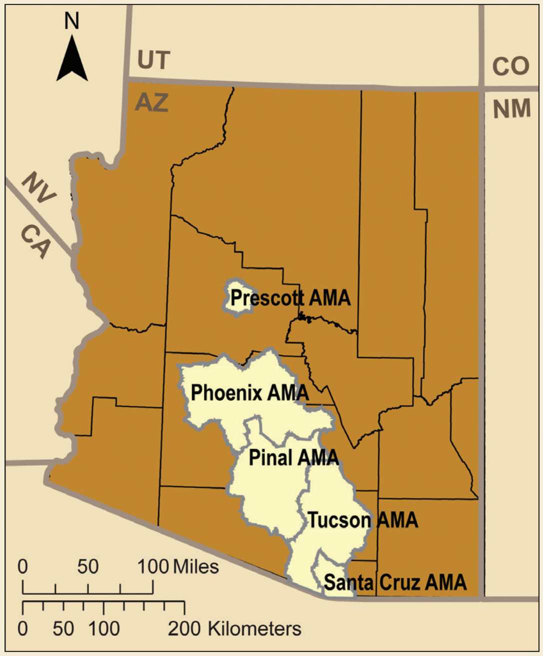
As the economics of effluent reuse change, the competition for effluent will likely increase, changing the future profile of effluent reuse. Such changes will have implications for the current and future users of effluent, including agriculture, power production, urban irrigation, and potable water consumption in general. The following discusses some of the changes and the impact they may have on the future marketplace for effluent reuse.

4.1 Regulations

Arizona has a rich history of managing and regulating water use and water quality. Changes to existing regulations or adaption of new regulations could change how effluent is reused in the future.

Arizona's groundwater pumping regulations in the AMAs are based on a regional paper accounting system that does not take into account the local dynamics of the underground aquifers where water is being pumped and recharged *(see Wet Water vs. Paper Water).* Under this system, it is possible to pump the local part of an aquifer dry while still showing adequate recharge for the aquifer as a whole. Although this has not occurred yet, the reality of the current system is that groundwater levels are continuing to decline in central

Wet Water vs. Paper Water



Arizona adopted the Groundwater Management Act of 1980 with the goal to reduce groundwater pumping statewide and help the urban regions of Tucson, Phoenix, and Prescott achieve safe yield, meaning withdrawals from the aquifers would be equal to or less than recharge to the aquifer.

Currently, Arizona has five Active Management Areas (AMAs) where groundwater is managed. The main indicator for safe yield is that the water table does not drop below 1,000 feet. The groundwater management regulations are based on a system of allocated "groundwater credits" that equal an amount of groundwater that can be withdrawn in each AMA to achieve safe yield.

In theory, if each entity does not pump more groundwater than their allocated credits, safe yield will be achieved. Entities can increase their groundwater credits, and can thereby pump more groundwater by actively recharging water to the aquifer, or by reducing the groundwater pumping of another entity.

However, currently, these added groundwater credits are a form of "paper accounting," and do not reflect the actual physical dynamics of the aquifers where water is recharged to or withdrawn from. Water managers now distinguish between "wet water" versus "paper water."

Such paper credits treat the groundwater system of the AMA as one large "bathtub" that balances itself as water is added or withdrawn. Under this paper system, for instance, water recharged in the far eastern end of the aquifer can provide credits for water that can be withdrawn at the far western end of the aquifer. Unfortunately, the aquifers in Arizona's AMAs are not like one big bathtub, and water recharged on one side of a system may not flow to replace water pumped out at the other side. Although recharge can balance an aquifer on paper, it cannot always balance the natural aquifer. Under this system, it is theoretically possible that a portion of the aquifer could drop below 1,000 feet even though credit levels remain balanced for the AMA as a whole.

Much of the current reuse of effluent is tied to this paper accounting system. For example, effluent delivered to farmers allows them to use less groundwater. The groundwater they do not use is converted to paper groundwater credits for the entity providing the effluent. Other effluent may be delivered to recharge basins, resulting in groundwater credits. These credits are then used to provide rights to pump groundwater at another location, and are frequently disconnected from the location in the aquifer where groundwater withdrawal was reduced or recharged.

Arizona. It is possible at some point that the state may change the groundwater rules to reflect how the aquifers actually function. Such regulations may require that credits be used to pump water from the location in the aquifer where effluent was recharged rather than a remote location in the aquifer. This would change the economics of effluent delivery to agriculture and recharge, as well as the recovery of recharged groundwater.

Currently, the EPA does not have a regulatory standard for introducing treated effluent into a potable water system or for using treated effluent as a raw water supply[24]. In order for such use of effluent to be safe, standards and regulations will have to be developed. The regulation of pharmaceuticals in potable water supplies will be a key part of such standards. Both the knowledge of the impact of pharmaceuticals on humans and the best methods for removing pharmaceuticals is currently not sufficient to support any public discussion about how they should be regulated. Therefore, standards and regulation for direct use of effluent probably will take several decades to resolve.

The EPA does have guidelines for blending effluent with source waters and recharge of treated effluent into an aquifer. Several states have adopted standards for such practice, but Arizona has not yet issued standards for such uses. Several pilot projects are underway in Arizona to assess the direct injection of effluent into aquifers and the time required to remove potentially harmful organics. However, the quality of effluent in central Arizona is not static. The regulation of pharmaceuticals, as well as increasing salinity levels, may complicate or limit the methods used for indirect potable reuse in the future.

Salinity of water supplies is not regulated in Arizona, but other states, such as California, Connecticut, Massachusetts, and Texas, regulate water softeners to limit or ban salt discharges to the public sewer system. Adopting such regulations for water softeners in Arizona could lead to a reduction of salt in the waste stream. Such an approach would shift some of the cost for salt removal from the public sector to the private sector and could change the economics of salt removal *(see The Brine Side of Purified Water).* In Arizona, most cities regulate salinity discharges from large commercial and industrial sources, but do not regulate residential sources such as water softeners; however, recently several cities in California have adopted water softener regulations more stringent than state regulations. Such a city-by-city approach in Arizona would be difficult to enforce, and thus to be effective, such regulations would likely require action by the state legislature and cooperation from the water softener industry in Arizona.

4.2 Treatment Costs

The cost of the production of effluent for reuse will be a function of the cost of the infrastructure needed to treat effluent, and the cost of operating treatment plants and distribution systems. The three major factors influencing the production cost in the future will most likely come from:

- basic treatment
- desalination
- pharmaceuticals treatment

Basic treatment of wastewater to meet federal and state standards for discharge or reuse requires significant investment in energy and supplies. In central Arizona, wastewater treatment is the largest user of all energy uses. Energy costs have been increasing over time, adding to the cost of operating these treatment plants. Though renewable sources of energy have been explored, such as digester gas generators or solar power, these sources to date have been more expensive than power from the grid. Other significant costs include chemicals, solid disposal, and capital.

In the short term, chemical costs have been very volatile, with some chemicals experiencing rapid price increases over a short period of time. In the long term, chemical costs have generally increased faster than inflation, and chemical costs in the future are highly uncertain. The cost and viability of solid disposal has been volatile and also subject to high uncertainty, but generally, cities try to find methods to reuse these solids.

Since wastewater treatment is hard on the equipment used, capital costs are high due to the necessity of frequent replacement of this equipment, adding to operation costs. However, one of the major drivers of capital cost is the steady increase in environmental standards for effluent quality. As these standards increase, new infrastructure is frequently needed, increasing treatment cost at a per unit basis.

Research is underway to improve the efficiency of desalination, particularly with regard to energy use. Today, if the full cost of desalination was passed on to users of effluent, the cost would likely exceed potable water costs. Therefore, how fast new technologies can improve the efficiency of this process could be a key factor in their use. Future trends in environmental standards are uncertain; however, pharmaceuticals may be the next frontier for such standards.

4.3 Valuation of Effluent

Ultimately, any partnership for effluent use will be based on the user's value of the water that the effluent

The Brine Side of Purified Water

Salt-based water softeners are often used to reduce water hardness and increase the performance of household detergents. They increase sewage salinity, which negatively affects wastewater and reclaimed water quality.

"The valley is a salt sink," says Graham Symmonds from Global Water. "All the dissolved solids come in, and they never leave."

Some aquifers in central Arizona hold high-salinity water, and dissolved salts travel the Salt and Colorado Rivers. The salinity of the system is further increased by human activities. Domestic water softeners and fertilizer runoff from agricultural fields and are just two examples of anthropogenic salinization.

Total Dissolved Solids (TDS) are highly mobile in the environment. Once flushed into the sewer, they will eventually reach a water reclamation plant. In a typical biological treatment plant, TDS are passed through, increasing the salinity in the reclaimed water and potentially limiting end uses. Additional treatment such as reverse osmosis (RO) is required to desalinate water. RO is an energy-intensive process and produces a concentrated waste stream as liquid residual, the brine, which must be properly disposed.

Conventional brine disposal strategies include discharge into a public sewer or surface water, and injection in brine disposal wells. These strategies will no longer be feasible with increasing TDS in central Arizona. An alternative disposal technique is zero liquid discharge (ZLD), a process that converts brine into a solid that can be disposed of in a landfill or beneficially reused. Capital cost and operational costs of ZLD systems are high due to the use of expensive evaporator and crystallizer thermal systems.

Another strategy to reduce liquid discharge is to distribute the brine into large salt ponds and let it evaporate naturally. However, many cities do not have space for such evaporation ponds. The Central Arizona Salinity Study[23] (CASS), a partnership of local utilities and the Bureau of Reclamation, estimates that the capital costs for an evaporation pond near Phoenix to dispose of five mgd of brine are about $125 million.

Although CASS has made progress in trying to identify viable solutions for brine disposal, no adequate solution has yet been found. Generally, the technologies for brine disposal are less complex than for desalination, and their viability may be more an issue of scale than technology. However, brine disposal has become one of the most challenging issues in wastewater treatment, and a viable solution will require a regional effort.

replaces and the practicality and cost of replacing this water with effluent.

Use of effluent for urban irrigation requires pipes that deliver water under pressure. Whether this occurs as part of new development or within existing developed areas, someone will ultimately pay the cost for such infrastructure. If these costs are transferred to developers via impact fees or user fees, these costs will be passed on to the home buyer. If people realize that these costs are increasing the cost of their housing, then both home builders and home buyers may exert political pressure to shift this burden back to the city (and thus all rate payers) or get rid of the reuse option.

Salinity could also play a factor. Residential and small commercial customers will be unfamiliar with the maintenance needs of higher saline irrigation. Recognition of such higher maintenance costs, or the loss of a lawn or landscaping from salt accumulation, could generate political opposition to such use.

The cost of using groundwater for agriculture irrigation is primarily the cost of the energy that is required to pump groundwater. Thus, the price of energy represents a key factor in the economics of agriculture. Currently, the cost to the farmer of using effluent for irrigation is less than the energy costs of pumping groundwater, providing an incentive for groundwater credit exchange. As energy costs rise in the future, the demand for agricultural reuse of effluent is likely to improve in the short term. However, in the long term, with an effluent marketplace where the demand, and thus value, for effluent is increasing faster than the cost of energy, agriculture may not be a successful competitor and the use of effluent for agricultural may decline. Either agriculture will rely on cheaper groundwater or farmers will have to move to new locations where the economics of water work.

4.4 Changing Dynamics of the Market

The future market for effluent reuse will not be that of a simple commodity market. In the most basic terms, for most commodities the key question is whether the cost of producing a commodity is less than the value of a commodity. However, the future market for effluent reuse will not be this simple.

Most reuse of effluent occurs because two parties, the provider and the user, realize benefit from the transfer of effluent to a particular use. Although the evaluation of these benefits drives such transactions, the factors affecting benefits can be quite complex and dynamic. To a great extent, such benefit is ultimately financial, though this financial benefit may be enabled or disabled by some regulation.

For example, in the case where effluent is transferred to agricultural use in exchange for groundwater credits, the benefit of such a transfer is financial. There are regulations restricting the crops that effluent can be used to irrigate, thus for the transfer to benefit the farmers, there must be a viable market for these restricted crops that financially justifies the exchange. A utility may benefit from cheaper groundwater than purchasing additional surface water rights. The system of credits for groundwater pumping enables the benefit to the city. Lastly, the infrastructure must be in place to allow such a transfer.

The cost of treating wastewater does play a role in valuing effluent, but deriving the cost of effluent production is not straightforward. Wastewater treatment for effluent reuse involves two separate but integrated activities, treating wastewater and producing effluent that can be reused.

Federal and state law requires that all wastewater must be treated to basic regulatory standards and disposed of in some permitted manner. The cost for this treatment is incurred even if the treated effluent is just discharged and not reused.

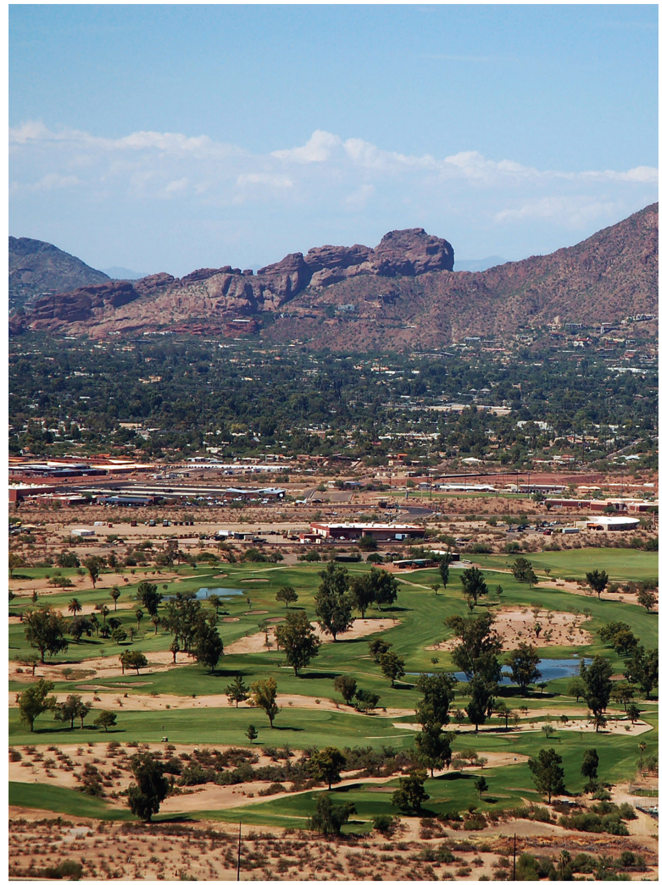
Effluent that is to be reused for some purposes such as turf irrigation requires further treatment, increasing the cost of treatment. How then should the cost of effluent for reuse be calculated? Should it include the cost of initial treatment, even though that cost would be incurred if the effluent is not reused? Perhaps the cost to produce effluent should be based on just the additional cost needed to make it suitable for reuse. This dual nature to producing wastewater effluent will always make calculating the costs of effluent complicated.

Given the constant changes in regulations for water quality of discharged effluent, the changing quality of wastewater entering the treatment plant, and the dynamics of chemical markets, the costs of treatment at both levels will be constantly in flux.

Decisions by the producer to market effluent will be based on the balance between the cost of production and the marketplace value of the effluent. In most cases, the value of effluent for reuse will be based on the cost of water the effluent replaces, such as groundwater or surface water. These costs in themselves can also be dynamic.

Groundwater is only available in areas where aquifers are accessible for pumping. The quality of groundwater varies from one part of the aquifer to another.

Probably the most important factor in valuing groundwater is the cost to pump. In areas where groundwater is shallow, the cost of pumping is much less than in areas where groundwater is deep. Surface water rights are required to access surface water, and all surface water rights are not the same. Some have higher priority for allocation under conditions of lower river flows. Some surface rights are geographically constrained either by the nature of the right or the available infrastructure to deliver water. Thus, effluent delivered to a field which has both groundwater and surface water rights would have a more complex value than that delivered to a field which had only rights for one or the other.



Economics are not the only factor affecting effluent value. In some cases, the delivery of reclaimed water for turf irrigation is driven more by the political desire to find alternative sources of water to replace water used for irrigation, freeing it to meet potable water needs. In Phoenix, turf facilities in the far northeast part of the City have been required to use reclaimed water for over 20 years. Developers in the area were required to pay a part of the costs of the reclaimed delivery system. In return, the City sells the water to the facilities for 80 percent of the cost of potable water.

Politics and cultural values can also be a constraint or an opportunity for effluent use. The City of Flagstaff's project that uses effluent to create artificial snow at the Arizona Snowbowl Ski Resort generated a large amount of opposition from American Indian tribes, environmental groups, and the general public. Lawsuits held up the project for years.

However, politics can also create value for effluent. For example, a community may decide that a riparian environment created with effluent has a high enough value that they are willing to pay market value for the water so it can be dedicated to environmental purposes. The Water Resources Research Center at the University of Arizona currently has a project to help communities develop such programs[25].

In summary, the marketplace where effluent reuse opportunities are negotiated is a blend of complex economic, regulatory, cultural, and political factors that will be in constant flux. As these change over time, it is likely that the manner in which effluent is reused will also change. The implications of such change are not clear, but could have secondary impacts on agricultural production, the cost of turf maintenance, and environmental features dependent on effluent discharge.

5 SUPPORTING POLICY DIALOGUE ON WATER REUSE IN CENTRAL ARIZONA

Treating wastewater and using the resulting effluent to meet a range of beneficial purposes is increasingly important, especially in water-scarce regions such as the desert Southwest. There is growing awareness that the future of water management in central Arizona will require difficult decisions and tradeoffs about how water is used — and reused — to satisfy municipal, industrial, agricultural, and environmental demands. Many analysts point to increased reuse of municipal wastewater as a key strategy to address potential shortfalls between supply and demand.

For example, the 2010 report of the Arizona *Blue Ribbon Panel on Water Sustainability* agreed that a primary goal of the commission was to make recommendations that, by 2020, would significantly "increase the volume of reclaimed water reused for beneficial purposes in place of raw or potable water." Similarly, the Bureau of Reclamation's recently released *Colorado River Basin Water Supply and Demand* study concluded that, "targeted investments in water conservation, reuse, and augmentation projects can improve the reliability and sustainability of the Colorado River system to meet current and future water needs." The *Watering the Sun Corridor* report by the Morrison Institute for Public Policy stated that the "reuse of urban water will be an important means of stretching water supplies in the future."

We agree with the broad goal of increasing reuse in central Arizona to be one component of a comprehensive state-wide water resource management policy. While some observers discuss effluent as a "new supply," it is more accurately described as a management strategy to use existing supplies more efficiently. As this report demonstrates, however, effluent reuse is certainly not a silver bullet to water sustainability. Many issues remain that must be addressed as we move forward. There are technical, economic, environmental, cultural, legal, and political dimensions.

As discussed in **Section 2** of this report, there is potential for increased competition for effluent among urban irrigation, agricultural irrigation, industrial,

Research Priorities

There is a large and growing body of research on water reuse currently being conducted by universities, federal, state and local governments, and nonprofit organizations.

Prior research has been integral to the development of existing management, technology, regulations, and policy. Each of the social, economic, and environmental issues that have been discussed in this report is subject to uncertainty and knowledge gaps. There is uncertainty about when and where changes will occur, exactly who will benefit, and who will bear the costs of future changes. Uncertainty and knowledge gaps need not be a barrier to discussing the future of effluent reuse and the policy implications of such futures.

Proceeding forward with discussions about such policy changes would benefit from a better understanding of the dynamics of current and future effluent reuse. A number of groups have identified key priorities for future research. For example, The National Academy of Science's Committee on the Assessment of Water Reuse as an Approach to Meeting Future Water Supply Needs summarized fourteen priorities related to a) health, social, and environmental issues, and b) treatment efficiency and quality assurance.

The WateReuse Research Foundation supports research on chemical contaminants, microbiological agents, treatment technologies, salinity management, public perception, economics, and marketing.

Based on our assessment for this report, we have concluded that scientists, managers, policymakers, and the public have inadequate knowledge on the following critical subjects. These are not prioritized here, but represent core areas for future research:

1. Identify cost-effective solutions and new technology for disposal of the brine stream.
2. Improve understanding of the health risks of contaminants of emerging concern in wastewater to inform regulatory processes.
3. Assess infrastructure needs to maximize beneficial regional reuse of wastewater.
4. Develop detailed understanding of public values and attitudes toward effluent reuse for different purposes, including agricultural irrigation, public landscape irrigation, industrial purposes, groundwater recharge, indirect potable reuse, and direct potable reuse.
5. Quantify the economic costs and benefits of effluent reuse for different beneficial purposes.
6. Quantify the ecosystem services produced by effluent reuse including support of effluent-dominated waterways.
7. Conduct institutional and public policy analysis to inform an integrated policy framework to support water reuse within the State of Arizona.
8. Anticipate the effects of drought, climate change, and other stressors on water supply and demand and the associated production of municipal wastewater and resulting effluent.
9. Assess the effectiveness of decentralized wastewater treatment systems for collection, treatment, and use of wastewater from individual homes.
10. Evaluate the effectiveness of effluent for regional groundwater recharge and aquifer storage and recovery.

environmental, and indirect potable uses. Moving forward, we must foster a more robust policy dialogue engaging all stakeholders to develop policy goals for prioritizing effluent use to achieve specific agreed-upon goals *(see Research Priorities).*

For instance, one reasonable objective would be to prioritize effluent to support industries that provide high-wage jobs and boost economic productivity for the region and the state.

Another laudable goal would be to incentivize the use of effluent for in-stream flows to restore urban riparian habitat, support biological diversity, and provide recreation opportunities.

These are just two examples of the many beneficial uses of effluent. It is up to us to decide how to appropriate this valuable resource. Regardless of the priority, we should make decisions deliberately, transparently, and based on a set of agreed-upon criteria and procedures.

Another set of challenges, discussed in **Section 3** of this report, relate to potential increased cost for effluent use associated with salinity, total dissolved solids, contaminants of emerging concern, and infrastructure. These potential increased costs come at a time where many municipal water services departments are increasingly challenged to generate adequate revenue to cover existing costs while water sales are flat or declining. We live in a new era of declining public investment in infrastructure and general lack of enthusiasm for government.

Addressing these challenges will require new thinking in fields such as toxicology, public health, and engineering. What commercial uses, for instance, can be found for brine? How can we turn this waste product into a commodity?

As noted in **Section 4,** we need to craft smart regulations and new economic approaches to valuing effluent in order to foster a dynamic marketplace that will allocate the resource efficiently.

At the most basic level, effluent reuse is a partnership between parties who are mutually benefiting from the delivery of an agreed-upon quantity of water at the appropriate quality and the right price. This implies that the opposite likely exists; that is, there are failed partnerships because the parties did not mutually benefit from effluent transfer. To understand what the future will bring, we must first understand the current situation including how social, economic, and environmental considerations enable or constrain effluent reuse. Once we have a better understanding of the dynamics of these partnerships, we can explore how various changes in technology, economics, regulations, and other factors might keep effluent reuse moving forward.

Finally, we must explore what such changes might mean in a broader scope of the region as a whole. Hopefully, this report advances the policy dialogue and contributes to a broad discussion among those who are concerned about central Arizona's water sustainability.

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The Decision Center for a Desert City (DCDC) at Arizona State University (ASU) was established in 2004 with support from the National Science Foundation (NSF) to advance scientific understanding of environmental decision-making under conditions of uncertainty. DCDC is an interdisciplinary research center advancing knowledge, education, and community outreach for water sustainability and urban climate adaptation.

DCDC aims to develop new understandings of how complex urban systems will function in a changing climate; to translate climate modeling and research into tools for managing complex urban systems in the face of climate change and other environmental risks; to build a boundary organization in which science is informed by and informs policy and decision-making; to develop and implement learning opportunities at the boundary of science and policy for students interested in urban climate adaptation; and to communicate the need for urban climate adaptation to decision-makers and larger public audiences.

To date, DCDC has produced a critical mass of basic research, including over 340 articles, books, and book chapters; WaterSim, a dynamic water-simulation model that serves as an important basis for stakeholder engagement and decision support, a point of articulation for interdisciplinary research, and an experimental setting to study decision-making under uncertainty; an extensive network of relationships with regional water managers and resource decision-makers; productive partnerships with research and education efforts affiliated with ASU's Global Institute for Sustainability (GIOS), including the Central Arizona–Phoenix Long-Term Ecological Research (CAP LTER) project, the Decision Theater, and the School of Sustainability; and a significant and growing set of comparative and collaborative partnerships linking our Phoenix-based case study to water sustainability and urban climate adaptation efforts nationally and internationally.

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