Aquifer Storage and Recovery Case Study

Site: Tucson, Arizona

Highlights

"*Arizona has an innovative groundwater storage program, made possible by the abundance of large sand and gravel aquifers thousands of feet deep that provide storage space for millions of acre-feet of water. What began as a means of saving unused water…has expanded into a multipurpose tool that simultaneously addresses a number of water supply issues"*

-Noah Silber-Coats and Susanna Eden (Arroyo, 2017)

- Development of irrigated agriculture in Arizona in the first half of the 20th century led to significant overdrafting of groundwater leading to hundreds of feet in decline of the water table in certain areas.
- Tucson Water initiated their full-scale Central Arizona Project (CAP) storage and recovery operations in May 2001. Almost immediately after beginning recharge, water levels in the aquifer near the percolation basins began to rise and have continued to rise since then.
- Much of the water that is stored underground is diverted from the Colorado River through an extensive aqueduct system called the Central Arizona Project (CAP). Arizona receives an allotment of 2.8 million acre-feet/year from the CAP. Many large municipalities, including the city of Tucson, rely heavily on this CAP allotment as an alternative to pumping groundwater.
- The city of Tucson recharges their aquifers with CAP water and recovers a blend of recharged and native groundwater. Since initiating this process, the Tucson/Avra Valley Aquifer has recovered from years of overdrafting, with the water level rising almost 200 feet in some locations.
- The state of Arizona is the primary regulator for the recharge and recovery of water stored in underground geological formations. Two crucial pieces of legislation were passed in order to make underground storage in Arizona a reality. These consisted of the Underground Water Storage and Recovery Act in 1986 and the Underground Water Storage and Replenishment Act in 1994.

Summary

The invention of the high-speed centrifugal turbine pump in 1937, along with several other factors, fueled an explosion of irrigated agriculture in Arizona and throughout the arid western United States. Groundwater use increased threefold between 1940 and 1953, and from then until 1980, as much as 60-70% of the water withdrawn in Arizona was from groundwater. Much of this increase in use was also attributed to an increase in population that resulted from t irrigated agriculture being viable in the state. From 1940 to 1998, the City of Tucson's population grew from 36,800 to 612,800 and the water table beneath the City fell 100-200 feet(Figure 1). It is estimated that this decrease resulted in nearly a foot of ground subsidence in north-central Tucson from 1940 to the early 1990s.

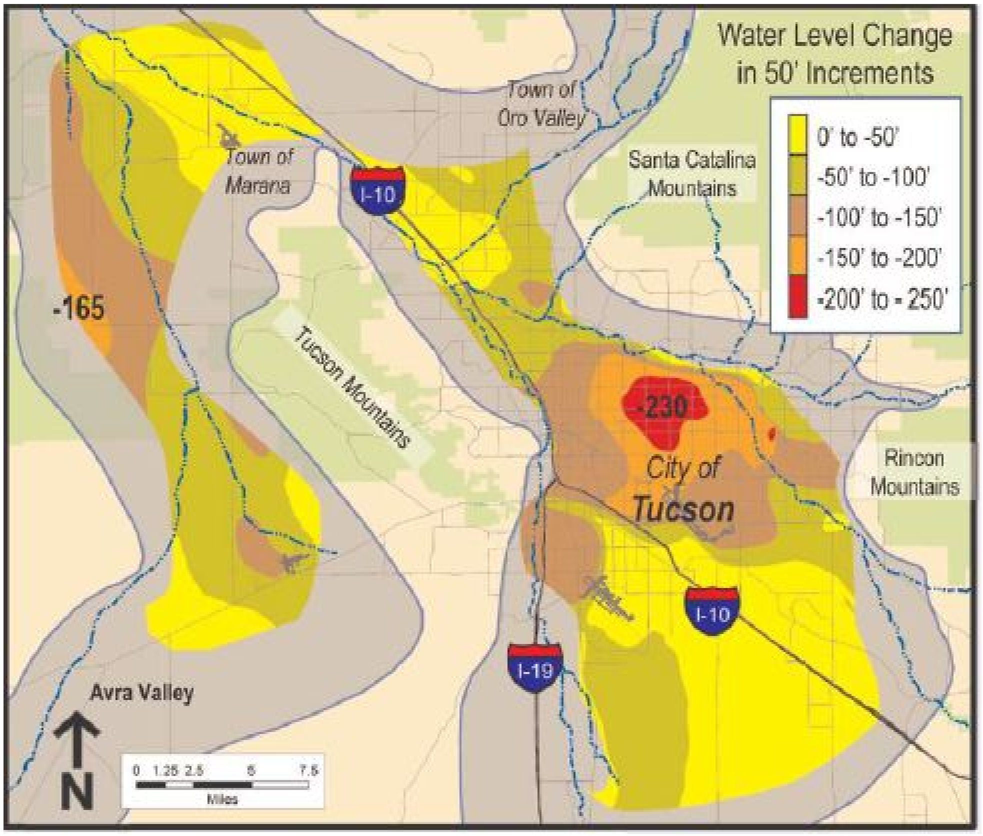

Figure 1: Water table decline in and around the city of Tucson from 1940 to 1998 (Source: [1])

The need for alternative sources of clean water in Arizona was noted since the 1940s, when significant overdraft was first observed. Finally, in 1968, President Lyndon B. Johnson signed the Colorado River Basin Project Act, which gave the green light for the construction of the Central Arizona Project (CAP), a 336-mile aqueduct system that would bring water from the Colorado River to central and southern Arizona, and eventually serve 80% of the state's population. Construction began in 1973 and was completed 20 years later, costing more than $4 billion. However, CAP faced a number of obstacles during its construction. Futile efforts to curb overdraft led to an ultimatum from the U.S. Secretary of the Interior in 1979, threating to cut off funding for CAP if the state did not put forward a plan to curb their groundwater use.

In response to this ultimatum, the Arizona Groundwater Management Act (GMA) was passed by the state legislature in 1980. The GMA divided the state into three zones, each classified based on the extent of overdraft that areas were experiencing. The parts of the state witnessing the worst overdraft were classified as Active Management Areas (AMAs), which required a groundwater management plan to be established and prohibited the development of new irrigated agricultural land inside the AMA. In addition, new housing developments within the AMAs were required to prove that they had access to an "Assured Water Supply" for 100 years. The second tier of overdrafted zones were termed as Irrigation Non-Expansion Areas (INAs). While INAs do not require an active management plan to be authored, development of new irrigated agricultural land is also prohibited inside the zone boundaries. The third and final tier is everywhere else in the state that is not encompassed by an AMA or INA. These regions are not regulated or restricted in any unique way, beyond the overarching laws of the state and the country (Figure 2).

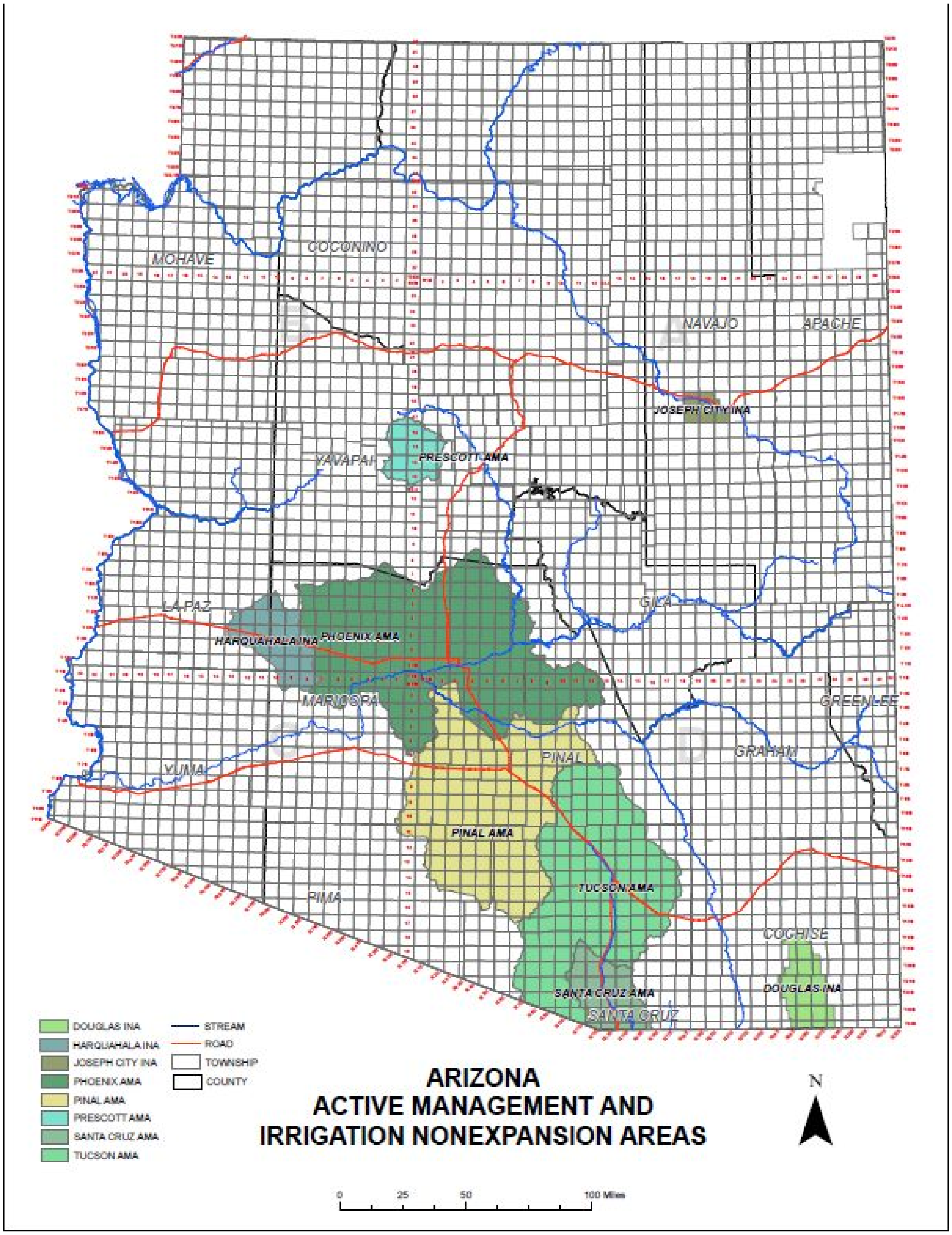

Figure 2: AMAs and INAs in Arizona (Source: [2])

There are five AMAs in the state of Arizona, in aggregate containing 80% of the state's population. The broad goal of the AMAs is to achieve "safe yield" in the designated areas by

2025. Safe yield is defined as a long-term balance between groundwater withdrawal and recharge within the AMA. The city of Tucson has a metropolitan area of over 1 million people and is the center of one AMA.

When Colorado River water began being delivered through CAP in the late 1980s, a significant portion of Arizona's 2.8 million acre-feet/year allotment was unused. To use their full allotment, Arizona proposed that the excess water from CAP be stored underground for future use and to support the state's groundwater management goals, including achieving safe yield in the AMAs. Two crucial pieces of legislation were passed in order to make underground storage in Arizona a reality. These consisted of the Underground Water Storage and Recovery Act in 1986 and the Underground Water Storage and Replenishment Act in 1994. Use of other water sources for groundwater replenishment, including treated wastewater effluent, was also allowed by this legislation.

A key component of the 1986 and 1994 underground storage legislation was delineation of ownership over the stored water. The legislation stipulated that entities that store water have the right to recover that water within the same calendar year (Annual Storage and Recovery) or may receive long term storage credits (LTSCs). Possession of LTSCs entitles the holder to recover the same amount of water that was replenished, at a later date anywhere within the same AMA, except if the local groundwater table is experiencing an average annual rate of decline greater or equal to four feet. These LTSCs can be transferred freely among entities within the same AMA. When water is recovered pursuant to an LTSC, it retains the same legal characteristics as the water that was stored. Additionally, recovered volumes are always (except for special cases) less than the recharged volume, due to an allotment subtracted for evaporation, and a 5% reduction in order to promote long-term recovery of aquifer water levels. There is a stipulation in the legislation around LTSCs that says the 5% cut to the aquifer that must be left in the ground does not apply to effluent sent to Groundwater Savings Facilities (GSFs) or Underground Storage Facilities (USFs) to encourage storage of treated wastewater effluent that may otherwise be discharged to a surface water feature.

The state of Arizona is the primary regulator for the recharge and recovery of water stored in underground geological formations. There are a few different types of permits pertaining to underground water storage, savings, and replenishment. An Underground Storage Facility (USF) permit is required for any project that is performing managed aquifer recharge (MAR) or aquifer storage and recovery (ASR). This USF permit allows for the holder to operate a facility that stores water underground in an aquifer. These facilities can range from percolation or infiltration basins, to vadose zone or aquifer injection wells (Figure 3).

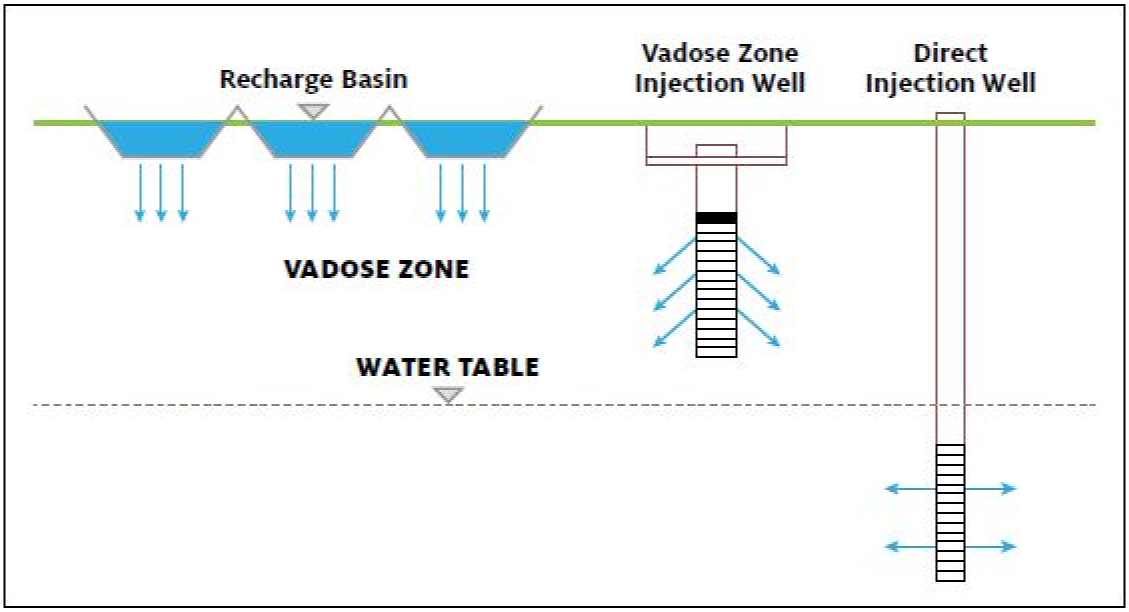

Figure 3: Methods of groundwater replenishment to an unconfined aquifer (Source: [3])

Water can also be recharged by way of a naturally water-transmissive area such as a streambed which facilitates percolation into the aquifer without the need for a constructed device. Use of this method requires a special permit called a Managed Underground Storage Facility Permit. In addition, water infiltrated using this method is subjected to a 50% cut to the aquifer instead of the typical 5% cut. If an entity is withdrawing and using groundwater, savings can be accrued through a Groundwater Savings Facility (GSF) Permit, which allows the holder to deliver a renewable water supply to a groundwater user. Every gallon of renewable water that the recipient accepts will offset a gallon of groundwater, thereby accruing savings. These facilities are commonly an agricultural operation or an industrial entity that typically draws groundwater for use in their operations.

While a USF or GSF permit allows for the operation of facilities that store and preserve groundwater, to actually perform the storage or delivery of renewable water, the permit holder must have a Water Storage (WS) permit. A WS permit requires the applicant to prove that they have the right to use the water that will be stored-at or delivered-to a USF or GSF. Finally, in order to perform either Annual Storage and Recovery or exercise LTSCs, an entity must obtain a Recovery Well (RW) Permit. This permit carries with it the stipulation that the recovery of the stored water must not damage other land or water users. Under certain circumstances, an impact analysis is required before the permit is issued.

Tucson Water is the utility responsible for water management in the Tucson metropolitan area(Figure 4)

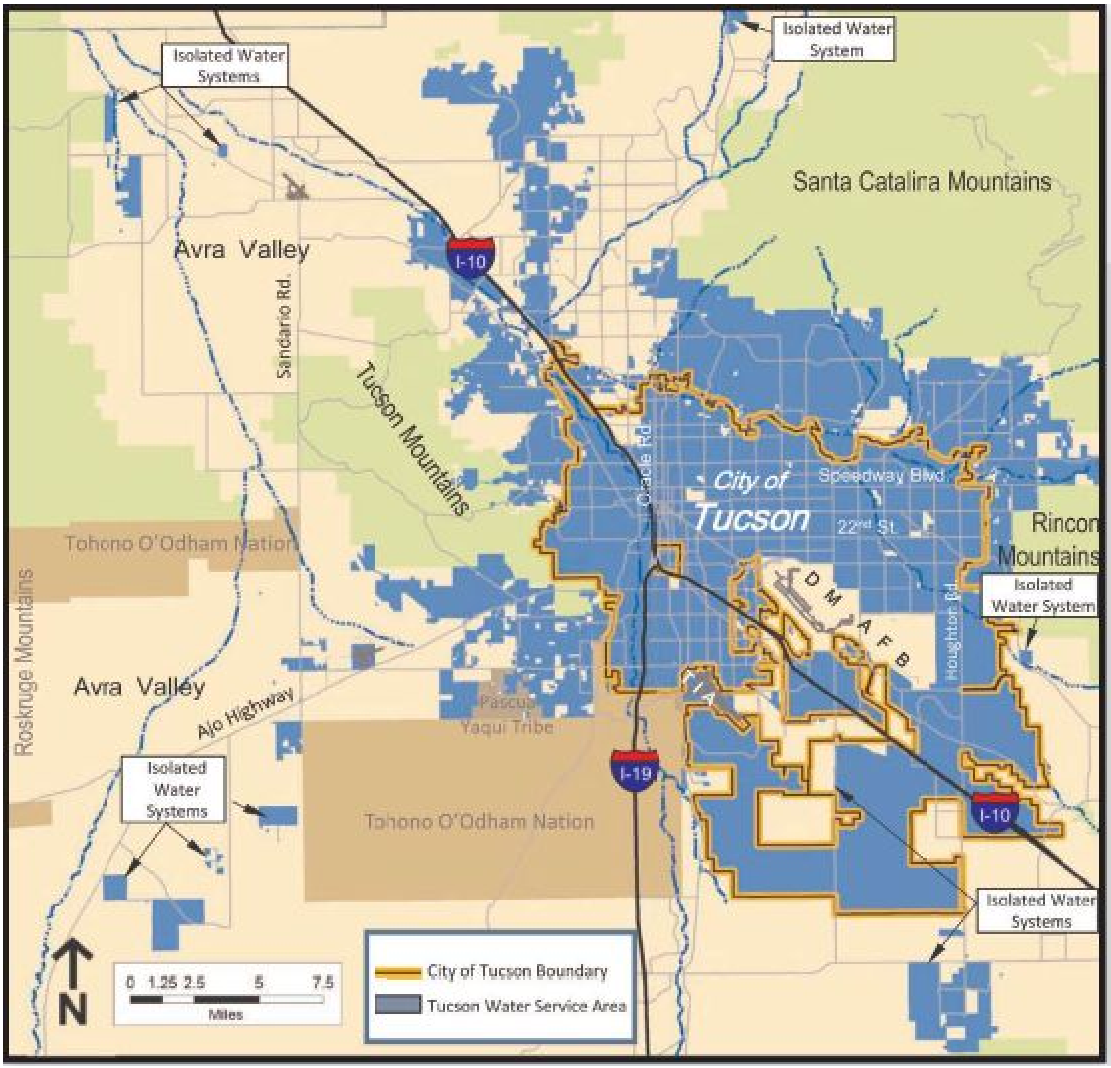

Figure 4: Tucson Water service area (Source: [1])

The majority of water production for the Tucson Water service area is from CAP delivery. Remediated water (formerly contaminated groundwater), recycled water (reclaimed wastewater effluent), and a small amount of captured rain and stormwater, however, have been used as alternative water sources for many years (Figure 5). Tucson Water has effectively ceased to pump groundwater; they do have a number of production wells, but these do not draw more than the recharge from CAP provides to the aquifer.

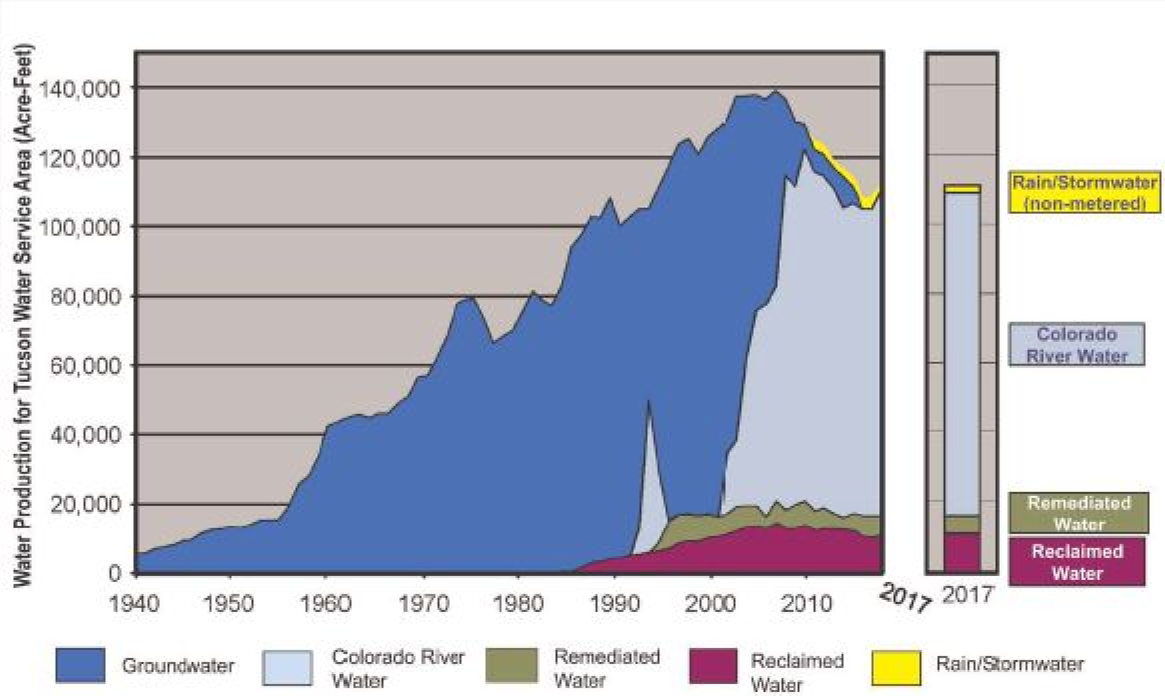

Figure 5: Source of water production for Tucson Water from 1940-2017 (Source: [1]).

Tucson Water is required to use a USF to store its CAP supply as it is delivered, based on a 1995 voter initiative that prohibited the direct distribution of CAP water to end users. They use Annual Storage and Recovery and utilize three percolation basins to recharge CAP water, which percolates down into the alluvial Tucson/Avra Valley Aquifer (Figure 6) Recharge consistently outpaces recovery, and both are continuous processes, only interrupted for maintenance.

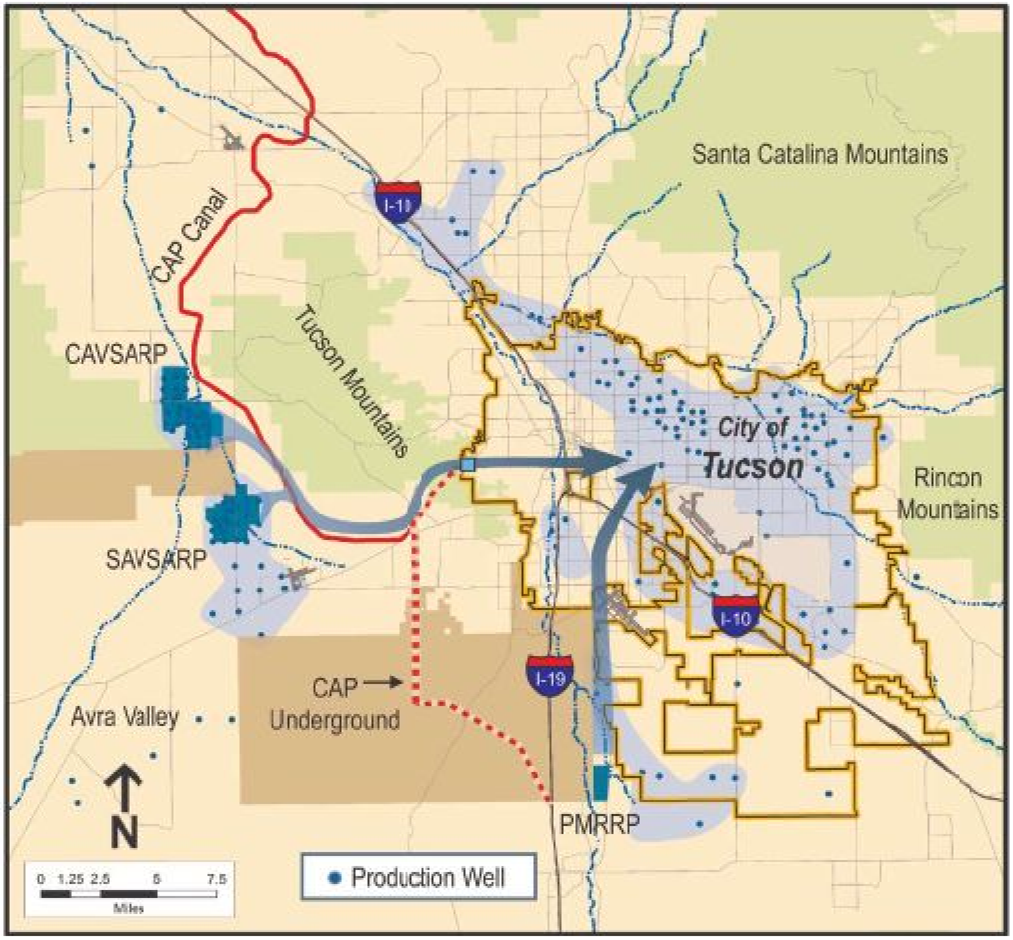

Figure 6: Location of three percolation basins and dominant suspected flowpaths of recharge water to production wells (Source: [1]).

Tucson Water initiated their full-scale CAP storage and recovery operations in May 2001. Almost immediately after beginning recharge, water levels in the aquifer near the percolation basins began to rise. Aquifer water levels have continued to rise since then (Figure 7) below. Compare Figure 7 to Figure 1 for a clear visual depiction of the benefit imparted by ASR activities on the aquifer.

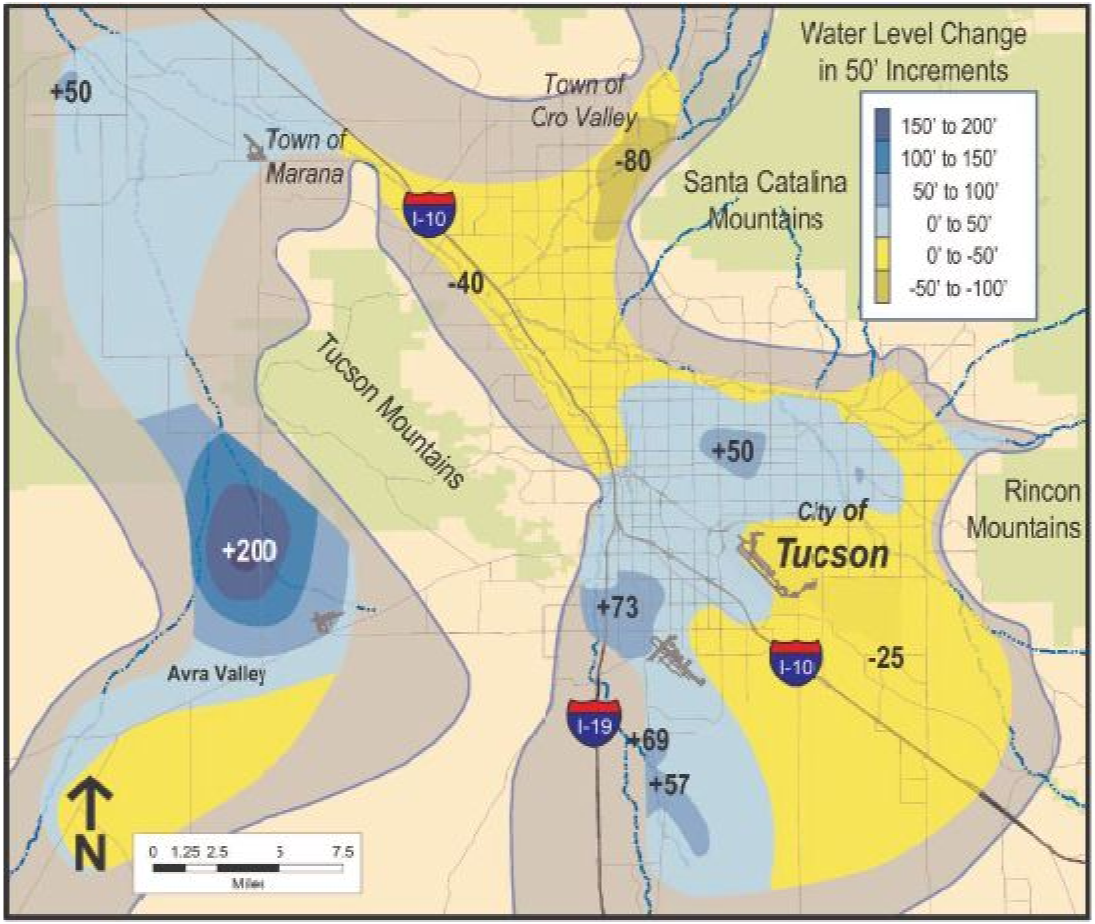

Figure 7: Water level change in the Tucson/Avra Valley Aquifer between 2000 and 2016 (Source: [1]).

Remediated water comes from the formerly contaminated groundwater under the Superfund site near the Tucson International Airport. The Tucson Airport Remediation Project/Advanced Oxidation Project (TARP/AOP) removes trichloroethylene and 1,4-dioxane from the groundwater before it is blended with other water in the distribution system and delivered to customers. In 2017, TARP provided about 5% of Tucson Water's drinking water supply.

Reclaimed water consists of wastewater that has undergone tertiary treatment at Pima County's wastewater treatment plants. It then is transferred to the city's Reclaimed Water Treatment Plant, where it is subjected to disinfection and blending. The reclaimed water is not added to the main drinking water distribution system. Instead it is primarily used for irrigation purposes and has recently started to be delivered to a number of additional locations via a new separate reclaimed water distribution system.

A blend of native groundwater and recharged Colorado River water is drawn from the aquifer and placed into the Tucson Water's distribution system. It is delivered to customers for drinking and other municipal uses. The water that is withdrawn from the aquifer does not require additional treatment before distribution. Recovery wells are spread out around the city of Tucson, and many are concentrated in well fields (Figure 8).

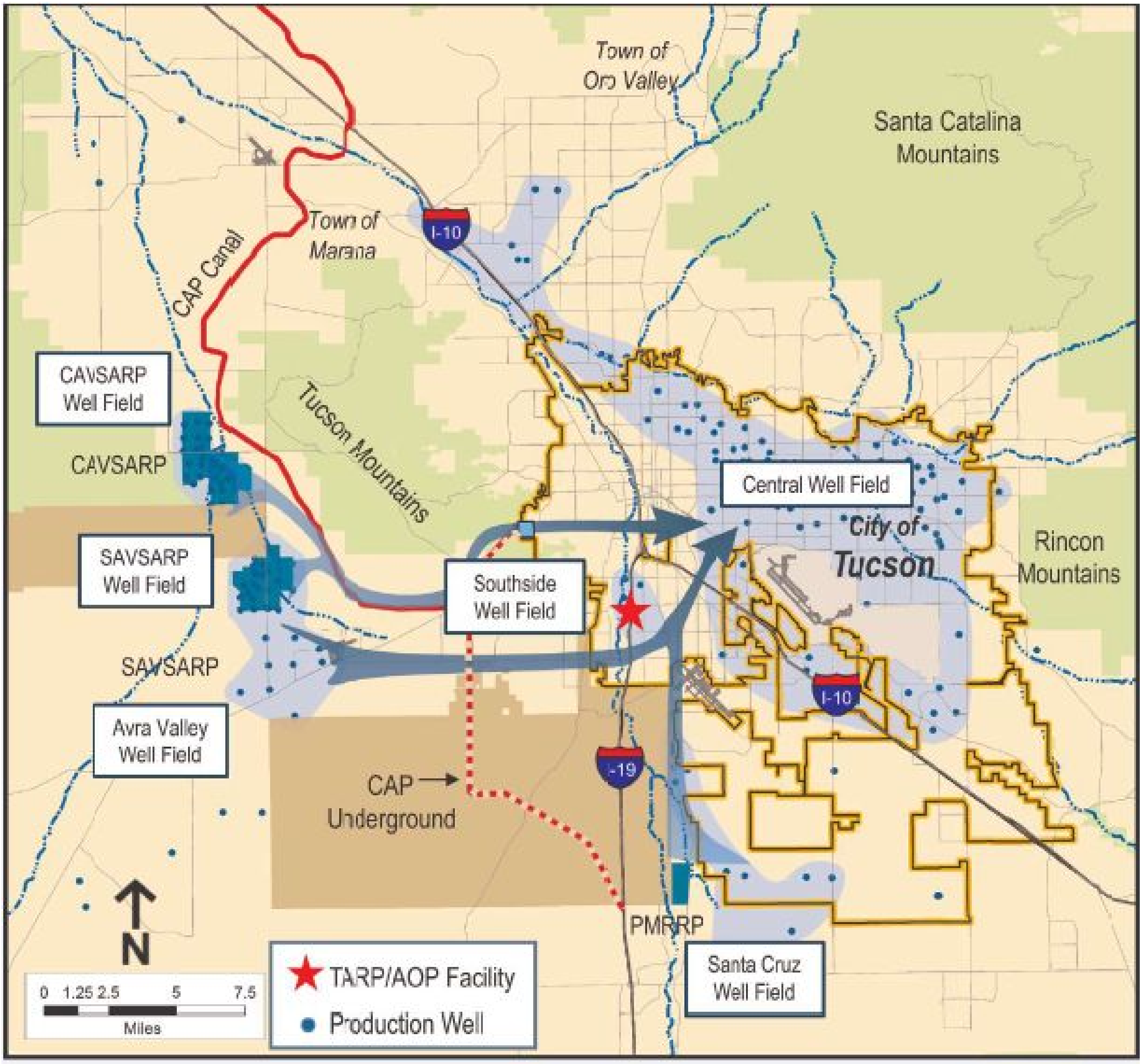

Figure 8: Location of production well fields around Tucson (Source: [1]).

Policy Connections

Arizona has a very robust system for groundwater management, inspired primarily due to the unsustainable use of groundwater in the 20th century, which led to an increase in population in arid regions. Once it was realized that this resource was running out and the detrimental effects of its depletion were identified, the state was forced to adapt. That adaptation was primarily through acquisition of massive amounts of freshwater by way of diversion of a portion of the Colorado River. There is no guarantee that the Colorado River will always flow as abundantly as it does now. Tucson and many other cities in Arizona continue to grow in population, and while water conservation strategies are helpful, they do not curb demand enough to answer the looming question: what will happen if there are consistent shortages in Colorado River flow? Arizona is not the only state that draws from the Colorado River. California, Colorado, Nevada, New

Mexico, Utah, and Wyoming share 15 million acre-feet of water/year, while Mexico receives another 1.5 million acre-feet/year. The legal situation becomes complicated when water rights of cities, states, and Native American tribes clash. For a more extensive evaluation and summary of the regulations behind distribution of Colorado River water between numerous parties, see cited sources, namely the Arroyo publication from 2017.

Economic Considerations

It is difficult to quantify the economic benefit of ceasing groundwater overdraft for the city of Tucson. Certainly, there would be some disruption of infrastructure as significant ground subsidence occurred, but the extent of this damage is speculative at best. The transferability of LTSCs has created an insulated market economy, where high water-use facilities can buy the right to withdraw water from other entities that recharge, either using CAP or other water that they have rights over. Between 2008 and 2014, close to 400,000 acre-feet of storage credits changed hands. One major seller of LTSCs is the Gila River Indian Community (GRIC), who receives more water than they use, based on settlement agreements.

Future Projections

Operation of ASR in the Tucson area has led to substantial rebound of the water level in the underlying aquifer. It has also allowed for the development of a resource that can be exhausted in a time of crisis or great water shortage. If there were interruptions to the delivery of CAP water to Tucson, the city would be able to pump groundwater from the Central Well Field. Overall, this ASR project is quite substantial, and it has provided a great deal of water security to the residents of the Tucson metropolitan area. Tucson Water also continues to diversify their source water portfolio, with expansion of recycled water and rain and stormwater harvesting infrastructure.

References

1. Tucson Water, 2018, *2018: Status and Quality of the Aquifer*.
2. “Arizona Department of Water Resources.” *AMA and INA Map | Arizona Department of Water Resources*, new.azwater.gov/permitting-wells/ama-and-ina-map.
3. Silber-Coats, N. and S. Eden, 2017, “Water Banking, Recharge, and Recovery in Arizona,” Arroyo, University of Arizona Water Resources Research Center, Tucson, AZ.
4. Brand, Cortney C. (2008). An ASR Primer. Southwest Hydrology, 7(3), 16–17.
5. “Arizona Department of Water Resources.” Types of Recharge Permits | Arizona Department of Water Resources, new.azwater.gov/recharge/type.
6. “Background & History.” Central Arizona Project, 2016, www.cap-az.com/about-us/background.