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Agricultural Use of Recycled Water for Crop Production in Arizona

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Introduction

We have all heard the saying "food grows where water flows," but in the Western United States, agriculture's share of freshwater supplies have been under pressure. This has been especially true in parts of Arizona, where the majority of the state was classified as suffering moderate to severe drought conditions in June 2014 (ADWR, 2014a). Lack of precipitation, combined with widespread urbanization of farmland has stimulated the transfer of water rights away from agriculture. But in turn, urbanization has also accelerated an increase in a completely new source of irrigation water: recycled municipal wastewater, defined by the Arizona Legislature as "water that has been treated or processed by a wastewater treatment plant or an on-site wastewater treatment facility" (AZLEG, 2014).

Recycled water is unique in the arid Southwest, as it is the only water source that is currently increasing. According to Arizona Department of Water Resources (ADWR), though water recycling was virtually unheard of less than 30 years ago, recycled water now accounts for roughly 4% of the water used annually in Arizona, about 260,000 acre-feet (AF; ADWR, 2014b). Recycled water in Arizona can be used for landscape irrigation, industrial cooling, golf course irrigation, agricultural irrigation, constructed wetlands and permitted groundwater recharge. Groundwater recharge is unique to arid areas, and is a means of storing excess water supplies so that they may be used in the future. Storing water underground to ensure an adequate supply for the purpose of satisfying current and future needs is both practical and cost-effective in our desert environment. More information on recharge methods and permits in Arizona can be found at: http://www.azwater.gov/AzDWR/Watermanagement/Recharge/default.htm

Agriculture is by far the largest water-demanding sector in Arizona, accounting for 70% of water demand (ADWR, 2009). Arizona's agriculture industry is extremely diversified, producing many crops that can legally be irrigated with recycled water, including cotton, alfalfa, wheat, citrus, and vegetables. Throughout the State, farming communities are taking advantage of increasing supplies of recycled water. In many cases, this is a money-saving measure, as agricultural water transported over great distances (e.g., from the Colorado River) can require tremendous amounts of energy. While recycling water is also energetically intensive, performing wastewater recycling on site or nearby an agricultural field reduces the energy needed to move water longer distances or pump water from deep within an aquifer. In fact, the use of recycled water for agricultural irrigation is often limited by the distance of agricultural districts from large urban centers where water reclamation facilities are located.

Regulations Concerning the Use of Recycled Water for Agricultural Irrigation

While no federal regulations exist pertaining to recycled water use for agricultural irrigation, there are recommendations set forth by the U.S government. Originally drafted in 1980, the United States Environmental Protection Agency (USEPA) Guidelines for Water Reuse established minimum standards and criteria recommended for the use of recycled water for agricultural irrigation. The USEPA guidelines, which were updated in 2004 (USEPA, 2004) and again in 2012 (USEPA, 2012) to conform to advances in water treatment technologies, provide states with criteria to establish their own regulations on the use of recycled water.

TABLE 1. Arizona Recycled Water Standards. Source: Arizona Administrative Code, Title 18, Chapter 11, Article 3 (http://apps.azsos.gov/public_services/Title_18/18-11.pdf)

Water Class	Water Quality Criteria
A+	• 24-hour average turbidity ≤ 2 NTU; • No detectable fecal coliform bacteria in four of the last seven daily water samples taken, and • The maximum concentration of fecal coliform bacteria in a single water sample < 23 per 100 mL; • Total nitrogen < 10 mg per L.
A	• 24-hour average turbidity ≤ 2 NTU; • No detectable fecal coliform bacteria in four of the last seven daily water samples taken, and • The maximum concentration of fecal coliform bacteria in a single water sample < 23 per 100 mL;
B+	• The concentration of fecal coliform bacteria in four of the last seven daily water samples taken < 200 per 100 mL; • The maximum concentration of fecal coliform bacteria in a single water sample is < 800 per 100 mL; • Total nitrogen < 10 mg per L.
B	• The concentration of fecal coliform bacteria in four of the last seven daily water samples taken < 200 per 100 mL; • The maximum concentration of fecal coliform bacteria in a single water sample is < 800 per 100 mL.
C	• The concentration of fecal coliform bacteria in four of the last seven daily water samples taken < 1000 per 100 mL; • The maximum concentration of fecal coliform bacteria in a single water sample is < 4000 per 100 mL.

Using the USEPA guidelines as a model, the State of Arizona has established regulations on the use of recycled water for agricultural irrigation. Arizona's recycled water standards establish five classes of recycled water, each requiring a specific minimum treatment in order to meet a limited set of numeric water quality criteria (TABLE 1). Agricultural irrigation standards for recycled water are based on crop type (e.g., food crop, animal forage) and whether food crops will be consumed raw, or will be processed. For irrigation of food crops, the required minimum quality of recycled water is Class A, while for surface irrigation of an orchard or vineyard the required minimum quality of recycled water is Class B (TABLE 2). Forage, fiber, and seed crops require even less stringent water quality (Class C).

The agricultural use of recycled water in Arizona is monitored through a permitting program administered by the Arizona Department of Environmental Quality (ADEQ).

TABLE 2. Permitted Agriculture Direct Irrigation by Recycled Water Class, State of Arizona. Source: http://www.azwater.gov/azdwr/WaterManagement/documents/ARTICLE3ReclaimedWaterQualityStandards.pdf

Irrigation Target	Minimum Class Recycled Water
Irrigation of food crops	A
Spray irrigation of an orchard or vineyard	A
Surface irrigation of an orchard or vineyard	B
Pasture for milking animals	B
Pasture for non-dairy animals	C
Silviculture	C
Irrigation of sod farms	C
Irrigation of fiber, seed, forage, and similar crops	C

There are various permit types available through ADEQ that facilitate agricultural use (TABLE 3), and each permit requires a Notice of Intent (NOI) and is valid for five years. Generally, the NOI must include to the volume, source and class of recycled water being directly used as well as information on the description, acreage, and vegetation type receiving irrigation. Water reuse for agricultural irrigation can also occur through Individual Type Reuse Permits, typically held by industrial facilities that generate wastewater as part of the manufacturing process (TABLE 3).

Not all recycled water used for agricultural irrigation in Arizona takes place through a permitting system. Instead, growers may use recycled water incidentally in a variety of ways. For example, wastewater treatment plants (WWTP) can legally dispose of recycled water directly into Arizona agricultural irrigation canals, rivers, and streams, and the surface water can in turn be used for irrigation purposes. Some industrial facilities can also discharge treated industrial wastewater into streams or rivers. Such discharges are permitted by the U.S. government (USEPA) and the State of Arizona (ADEQ) through a system established by the Clean Water Act in 2002. Through this act, a WWTP or industrial facility can apply for a National Pollution Discharge Elimination System (NPDES) Permit (administered by USEPA) or an Arizona Pollution Discharge Elimination System (AZPDES) Permit (administered by ADEQ). Permit holders are allowed to discharge treated effluent into any "water of the United States," including irrigation canals. In the State of Arizona, waterways directly receiving recycled water discharge include canals in the Roosevelt Irrigation

TABLE 3. Types of Reuse Permits Administered by the Arizona Department of Environmental Quality (ADEQ) for Irrigation Water used in Arizona Agriculture. Source: http://www.azdeq.gov/environ/water/permits/reclaimed.html

Type 2 Recycled Water Permits	General Provisions
General Permit for Direct Reuse of Class A+ Recycled Water, for applications where there is a relatively high risk of human exposure to potential pathogens in the recycled water	Allows for direct reuse application provided that the recycled water meets the quality criteria for Class A+ (TABLE 1.).
General Permit for Direct Reuse of Class A Recycled Water, for applications where there is a relatively high risk of human exposure to potential pathogens in the recycled water	Allows for direct reuse application provided that the recycled water meets the quality criteria for Class A (TABLE 1). Includes requirements for nitrogen management and lining of impoundments.
General Permit for Direct Reuse of Class B+ Recycled Water	Allows for direct reuse application provided that the recycled water meets the quality criteria for Class B+ (TABLE 1).
General Permit for Direct Reuse of Class B Recycled Water	Allows for direct reuse application provided that the recycled water meets the quality criteria for Class B (TABLE 1). Includes requirements for nitrogen management and lining of impoundments.
General Permit for Direct Reuse of Class C Recycled Water	Allows for direct reuse application provided that the recycled water meets the quality criteria for Class C (TABLE 1). Includes requirements for nitrogen management and lining of impoundments.
Type 3 Recycled Water Permits	**General Provisions**
General Permit for a Recycled Water Blending Facility, the facility receives recycled water of a certain class and improves the quality by blending it with water from one or more additional sources.	Blending recycled water with industrial wastewater is not authorized. The applicant must receive a written Verification of General Permit Conformance from the ADEQ before use of blended water can be initiated.
General Permit for a Recycled Water Agent, the agent distributes recycled water to more than one end user. The agent, rather than the end-users, is responsible for meeting the appropriate Type 2 permit conditions of the water sent to end users and thus, end users can receive recycled water from an Agent for appropriate applications without having to notify ADEQ to obtain permit coverage.	Each Agent is required to maintain contractual agreements with end users that stipulate end user responsibilities and report annually the amount of recycled water delivered to end users. The applicant must
Individual Permits	**General Provisions**
Individual Type Reuse Permits	Reuse of industrial wastewater that contains a component of sewage or is used in processing any crop or substance that may be used as human or animal food

District, the Buckeye Irrigation District, and the Arlington Canal. These canals deliver irrigation water directly to farms located in and around Buckeye, Arizona, thus growers that irrigate with water from these canals are incidentally using recycled water.

Non-permitted incidental reuse of treated recycled water or industrial wastewater through surface water diversions also occurs in Arizona. A "surface water diversion" is defined as removal of surface water from the natural hydrologic cycle. In the 1989 case of Arizona Public Service Company v. Long, the Supreme Court of Arizona ruled that "municipal sewage effluent is neither surface water nor groundwater; it is water that loses its original character as surface water or groundwater, does not reestablish its legal character until it is returned to the ground as either surface water or groundwater...The Cities' expenditure of tens if not hundreds of millions of dollars for sewer lines, purification plants and equipment does not transform the water and change it back into groundwater or surface water. It remains effluent" (APS v. Long, 1989). Once discharged into a river or stream for the purpose of disposal, treated recycled water legally becomes surface water that may be used by surface water appropriators. Thus, individual growers or irrigation districts may use surface water that contains treated recycled water or industrial wastewater for agricultural irrigation without an ADEQ reuse permit.

On-Farm Issues with Recycled Water Use

Growers can face several challenges with recycled water use. One problem that can occur is the fluctuation in continuous supply of water needed for crop irrigation in Arizona. Often, recycled water is only readily available when irrigation demand for crops is low, such as in the winter months. Increased demand for irrigation water for parks and other municipal green spaces decreases the availability of recycled water for agricultural irrigation in summer.

Growers may be reluctant to increase dependence on recycled water due to instability in long-term supply. In many cases, newly constructed WWTPs provide growers with recycled water only temporarily until supplies are diverted to other forms of beneficial use. For example, if urban development occurs near a WWTP, recycled water can be transferred away from agricultural use or AZPDES disposal to irrigate urban landscapes.

Even when recycled water is readily available, growers may be reluctant to utilize it for crop irrigation. One issue, perhaps the most difficult to overcome, is the negative public perceptions that may remain regarding the use to recycled water for food crops. A 2008 survey of Arizona residents found

that, while 58% of them supported the use of recycled water for irrigation of non-edible crops, far fewer (28%) found this policy acceptable for edible crops (Rock et al., 2012).Thus, it would be likely that growers with a range of water supply options may not choose to irrigate with recycled water.

Another issue associated with recycled water use is salinity. Recycled water typically contains a concentration of total dissolved solids (TDS; a surrogate measurement for salt ions) that ranges from 800 to 1400 parts per million (PPM), and can be higher in some cases (SalinityManagement.org, 2008), compared to Colorado River. In 2013, water delivered through Central Arizona Project canals averaged about 600 PPM TDS (CAP, 2013). However, the high salt concentration of recycled water can be managed properly for its use in agriculture by periodically applying an "excess leaching fraction," or a sufficient amount of excess irrigation water to flush salts below the root zone. Put simply, a grower can maintain the root zone salt balance by applying enough excess water to carry the same amount of salt out of the soil as the water itself brings in (Grismer, 1990). If recycled water is readily available in adequate supplies, the cost savings to growers (compared to the cost of CAP deliveries, or even electricity costs for pumping groundwater) may be worth the cost of having to apply excess irrigation water to leach salts. It is also important to note that many crops irrigated in Arizona with recycled water have a fairly high tolerance to salinity; these include barley, wheat, Sudan grasses, date palms, and cotton.

Soil quality related to salinity is often monitored using the sodium adsorption ratio (SAR), which is equal to the ratio of sodium to magnesium plus calcium. As stated above, growers who irrigate with recycled water need to carefully monitor the buildup of exchangeable sodium in the soil. Typically, irrigation water with an SAR > 9.0 will be troublesome, particularly on fine-textured clay soils (Wu et. al., 2009). High exchangeable sodium coupled with low salinity causes soil particle dispersion, which leads to poor soil structure, reduced water infiltration, increased soil pH, and nutrient imbalances, resulting in poor plant growth (Davis et. al., 2012). If high sodium becomes problematic, growers can attempt to exchange the sodium with calcium or magnesium, followed by leaching; this can be facilitated with the use of gypsum, or acid in calcareous soils (Walworth, 2012).

In addition to salinity issues, growers must also be aware of the nitrogen content in recycled water used for irrigation. Depending on target final quality of the treated recycled water, treatment may or may not include denitrification prior to release to the environment (TABLE 1) and thus, fertilizer application to crops may have to consider pre-existing levels of nitrogen in irrigation waters. Pre-existing nitrogen in irrigation water can be highly beneficial, both from a crop standpoint (because nitrogen is an essential plant nutrient) and from an economic standpoint (because chemical fertilizers are expensive and increasing in cost; USDA-ERS, 2013). At the same time, application of excess nitrogen to crops can have highly detrimental effects, including enhanced nitrogen runoff and eutrophication of nearby waterways. For this reason, nitrogen applications must be carefully considered in using recycled water.

Estimating Agricultural Use of Recycled Water Statewide in Arizona

Quantifying the volume of statewide recycled water use for agricultural irrigation presents many challenges. Quite simply, accurate data is not available for a variety of reasons, including limited monitoring by budget-strapped state agencies and little reporting from growers. These, combined with some confusion about how much incidental (non-permitted) recycled water use occurs, have undoubtedly led to an underestimation of agricultural use of recycled water. A 2012 research study conducted at the University of Arizona Water Resources Research Center (WRRC) included the examination of current ADEQ reuse permits (existing in April 2012), a comprehensive literature review of current documentation, and correspondence with irrigation district managers and local growers, all to gain information on current agricultural use. The results strongly suggest that more recycled water is being used for agricultural irrigation in Arizona than has previously been reported.

Results of the WRRC research study described above revealed that recycled water use for agricultural irrigation is concentrated near metropolitan areas, where there is greater

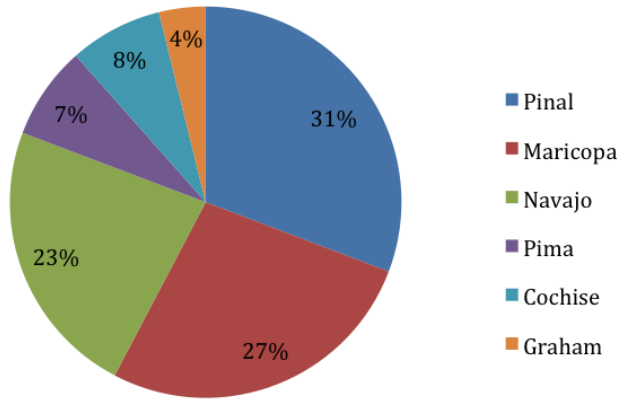

FIGURE 1. Percentage of Recycled Water Irrigation Permits Issued by County, 2012 (Source: records maintained by Arizona Department of Environmental Quality)

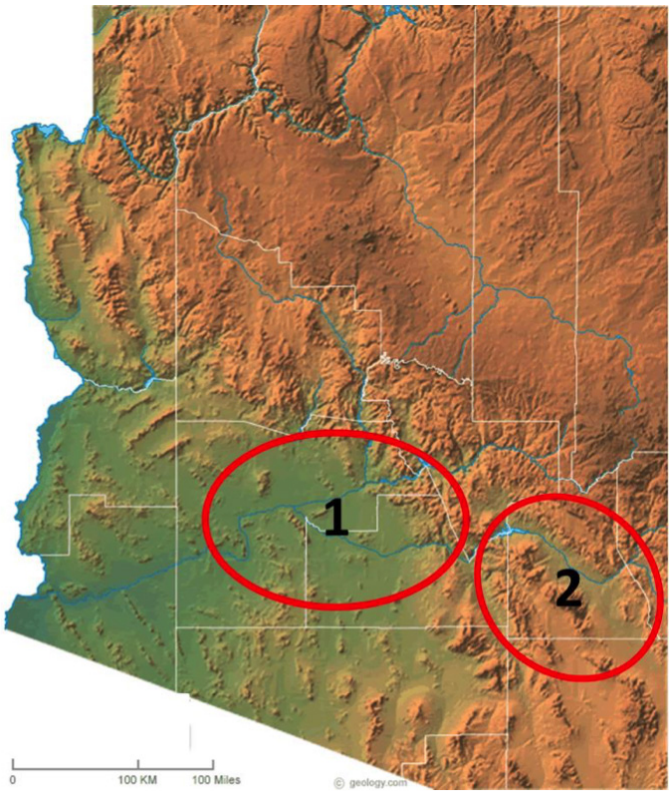

FIGURE 2. Map showing primary areas where recycled water is used for agricultural irrigation in Arizona, showing: 1) Central Arizona, approximately 160,000 acre feet per year, and 2) Eastern Arizona, approximately 40,000 acre feet per year.

availability of recycled water. As of April 2012, ADEQ had issued 28 reuse permits in Arizona that included agricultural irrigation. Permits were issued in seven counties (FIGURE 1), but more than half of the permits were in Maricopa and Pinal counties alone, where 66.3% of Arizona residents live (USCB, 2014). The 28 reuse permits issued in 2012 amounted to a permitted volume of recycled water of roughly 60,000 AF per year. However, the actual use of treated recycled water for agricultural irrigation is undoubtedly far higher, as this estimate does not include non-permitted incidental reuse. Many of Arizona's largest rivers, including the Verde, Salt, San Pedro, and Gila Rivers, are dependent on recycled water for maintenance of at least a portion of their flow. All of these rivers are also a source of agricultural irrigation waters, making hard-to-measure incidental reuse not only possible, but highly probable. The 60,000 AF estimate also does not include any recycled water use on agricultural lands of the Indian Nations, which are not subject to Arizona's recycled water regulations. Accounting for all types of reuse, it is estimated that agricultural practices use about 200,000 AF of recycled water each year in the State of Arizona.

Agricultural Use of Recycled Water in Central Arizona

In Central Arizona, recycled water is used for crop production via reuse permits and incidental reuse in Maricopa, Pinal, and Pima counties (FIGURE 2). The largest volume of permitted use of recycled water occurs just outside the Phoenix metropolitan area. Both the Buckeye and Roosevelt Irrigation Districts have contractual agreements with the City of Phoenix for recycled water delivery via the Gila River, and these two irrigation districts use a combined total of over 80,000 AF of recycled water to irrigate approximately 41,000 acres of farmland each year. In addition to permitted use, incidental reuse from the Lower Gila River is undoubtedly common, as many stretches of the Lower Gila are classified as effluent-dependent, with treated recycled water discharged from Phoenix area WWTPs into the normally dry riverbed. Approximately 50 miles southwest of Phoenix, downstream irrigators in the Gila Bend area also use Gila River treated effluent, as well as agricultural tail water and groundwater discharge from upstream irrigation districts that drain into the Gila River. The Gillespie Dam, located on the Gila River between Buckeye and Gila Bend captures water to be made available for irrigating croplands in the Lower Gila Bend area and from there, water is diverted to farms south through the Gila Bend Canal and Enterprise Canal.

In addition to the large-volume users of recycled water for irrigation listed above, there are several other areas in Central Arizona where smaller volumes of water are delivered under permits to individual growers and businesses. A total of 15 reuse permits have been issued to various Central Arizona sites, totaling about 20,000 AF for irrigation of over 6,500 acres. Some of the largest permitted users include Frito Lay Inc. (based in Casa Grande, Arizona) and Miedema Produce Inc. (Surprise, Arizona). Another large user of recycled water is the Gila River Indian Community (GRIC), which covers more than 370,000 acres in northwest Pinal County. The GRIC manages 15,000 acres of community farms that support a variety of crops such as cotton, wheat, millet, alfalfa, barley, melons, pistachios, olives, citrus, and vegetables, and they receive up to 40,000 AF of treated recycled water per year from the cities of Mesa and Chandler as part of a three-way exchange of water supplies. Because the Indian Nations are exempt from State rule, this reuse does not require a permit from ADEQ. A survey of incidental use and non-permitted reuse in Central Arizona results in a rough approximation only, but it is estimated that the total volume of recycled water utilized for agricultural irrigation in this area is approximately 160,000 AF per year.

Agricultural Use of Recycled Water in Eastern Arizona

In Eastern Arizona, 13 recycled water permits have been issued that include agricultural irrigation in Graham, Cochise, and Navajo counties (FIGURE 2) and amount to about 40,000 AF of permitted reuse. Many growers receive recycled water directly from industrial facilities or WWTP's. Eastern Arizona is largely undeveloped, leading to reduced opportunity for urban reuse (for irrigation of golf courses and parklands), and allowing growers to benefit from increasing recycled water supplies. Some of the larger users of recycled water in Eastern Arizona include the Catalyst Paper Mill (Snowflake, Arizona; out of business since 2012), Fiesta Canning Company (McNeal, Arizona) and Double R Cattle Company (St. Johns, Arizona). All permitted reuse in Eastern Arizona is utilized for irrigation of forage.

Agricultural Use of Recycled Water in Yuma County, Arizona

No use of treated recycled water or industrial wastewater for agricultural irrigation occurs in the Yuma area. Current food safety regulations permit the use of recycled water for irrigation of food crops, including vegetables that are eaten raw, but this requires a very high level of treatment to produce water of sufficient quality to meet standards. In Yuma County, an abundant and extremely low-cost supply of Colorado River water precludes the development of a wastewater industry for production of recycled water.

Conclusions

As Arizona's population grows and demand for fresh water supplies escalate, the agriculture industry will most probably become increasingly dependent on recycled water. Many agricultural regions throughout the state are already taking advantage of increasing supplies of high quality recycled wastewater. Current guidelines permit the direct use of recycled water for agricultural production, and such water can also be used incidentally though AZDPES disposal into agricultural irrigation canals. Most agricultural use occurs near metropolitan areas, where high demand for freshwater sources exists, and where water does not have to be moved great distances from WWTPs to agricultural fields. The majority of crops being irrigated with recycled water are those that require Class C water, non-edible crops such as alfalfa, grain, feed corn, cotton and grasses.

Agricultural production is a vital part of the economy of Arizona. The industry contributes over 10 billion dollars to the State's economy. As Arizona grows, recycled water supplies will grow and will be available to meet more of the State's water demand. With the growing availability of recycled water as a clean and safe product, it is important to both monitor agricultural irrigation using recycled water and to provide growers with a full accounting of the benefits and concerns regarding its use.

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