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Agricultural Use of Reclaimed Water in Florida: Food for Thought

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Abstract: Florida has successfully irrigated agricultural crops with reclaimed water (RW) for more than 50 years. Florida and California are the two largest producers and users of RW in the U.S. To allay early fears about RW, Florida regulatory agencies established rules in the 1980s that prohibited direct contact of RW with crops that are not processed but eaten raw. This means that RW cannot be used for direct contact irrigation or frost protection of crops such as strawberries or blueberries. Other states do not have such limitations on RW use. Reclaimed water has an excellent safety record, and no health problems have occurred from its use. The main edible crop that uses RW in Florida is citrus. Reclaimed water contains some macro- and micronutrients, but can provide only a small amount of nitrogen (N) to citrus. Some RW sources can provide adequate N to turf grass. Reclaimed water production has increased dramatically in the past 20 years, and much of the increased flow has gone to public access irrigation. While still important, agricultural use of RW as a percentage of total flow may continue to decrease, but the supply of RW continues to grow as Florida's population increases.

Keywords: *recycled water, water reuse, wastewater treatment facility, WWTF*

Which state in the U.S. is the largest producer and user of reclaimed water (RW) or recycled wastewater? A logical answer would be one of the arid western states such as Arizona or a state with a large population. Surprisingly, the answer is Florida. Even though Florida has an average annual rainfall of 54.5 inches (1385 mm) and ranks fifth in the nation in precipitation (Current Results 2017), it still leads the nation in RW production. Table 1 shows reported reuse and reuse per capita for several states (WateReuse National Water Reuse Database 2018) over the time period of 2009-2012. During this period, average RW daily use in Florida was an estimated 722.04 million gallons per day (mgd) (2733.2 thousand cubic meters per day or tm^3d), while daily RW use in California was an estimated 597.38 mgd (2261.3 tm^3d). The other states were noticeably lower. Even though Florida has about half the population of California, it still produces more reuse water, and reuse per person per day in Florida is more than twice that of California (Table 1). The purpose of this paper is to discuss RW use in Florida with emphasis on edible crops.

Florida Experience with Reclaimed Water

The reasons for Florida being a leader in recycling wastewater are varied, but many of the earlier RW projects were related to improving surface water quality. Initially, some projects were designed as ways to manage and dispose of wastewater. Later projects were set up to be sources of irrigation water (Parsons et al. 2010; Toor and Rainey 2017). To meet demand, arid western states have been able to use several water sources such as the Colorado River, along with dams and reservoirs, to capture snow melt from mountains. Recent western droughts, however, have forced them to reconsider RW as a potential water source. Florida has few dams and reservoirs

and essentially no snow melt. Much of Florida's drinking water comes from the Floridan aquifer, but droughts have also increased interest in RW as a supplementary water source.

The Florida Department of Environmental Protection (FDEP) defines RW as "water that has received at least secondary treatment and basic disinfection and is reused after flowing out of a domestic wastewater treatment facility." Reuse refers to "the deliberate application of reclaimed water for a beneficial purpose" (FDEP 2017c).

By state statute, Florida encourages water recycling. Florida Statute 373.250 encourages the "promotion of water conservation and reuse of reclaimed water" and indicates that these "are state objectives and considered to be in the public interest." It also states that RW produced by a permitted domestic wastewater treatment plant "is environmentally acceptable and not a threat to public health and safety" (Online Sunshine 2018).

Reuse flow in Florida has increased more than 3.6 times (from 206 to 760 mgd or 779.8 to 2876.9 tm^3d) between 1986 and 2016 (FDEP 2017a). Reuse flow from 1998 to 2016 is shown in Figure 1. In 1990, reuse flow was 322 mgd (1218.9 tm^3d). At 90 mgd (340.7 tm^3d), agricultural irrigation accounted for 28%, and public access systems at 99 mgd (374.8 tm^3d) accounted for 31% of the reuse flow. Since then, public access and landscape irrigation increased more than four-fold to 438.9 mgd (1661.4 tm^3d), while agricultural irrigation declined to 64.8 mgd (245.3 tm^3d). While total RW flow has increased, public access now accounts for 58% of the total flow, and agriculture accounts for only 8% of total flow (Figure 2) (FDEP 2017a).

There are currently 118 systems that irrigate agricultural crops, and 17 are those that irrigate edible crops (FDEP 2017a). One of the premier agricultural and public access projects is Water Conserv II, west of Orlando, FL (Water Conserv II 2018). The background of Conserv II is instructive because this project went through a history that other RW projects have often repeated. In the mid-1980s, the city of Orlando and Orange County were told that they could no longer dispose of their treated wastewater into Lake Toho, a good bass fishing lake, and would have to find an alternate disposal place. When city and county officials approached growers with the proposal of providing free RW that could be used to irrigate their citrus groves, the growers initially rejected the idea. Even though the city and county would provide the water free and nearly eliminate pumping costs, growers were wary of this "unknown" water. There were concerns about heavy metals, salinity, disease organisms, or flooding from excessive water (Parsons et al. 2001a). After much negotiation, nearly all of the grower demands were satisfied. Dr. Robert Koo of the University of Florida established water quality standards that met most drinking water standards. Parsons et al. (1981) had recently demonstrated that microsprinkler irrigation could

Table 1. Water reuse in different states estimated between 2009 and 2012. Reuse per Capita is based on 2010 population estimate.

State (year of report)	Population[1] (2010 est)	RW Daily Avg Use[2] (mgd)	Reuse per Capita (gal/person/day)	Rank (per Capita reuse)
Florida (2011)	18,846,461	722.04	38.31	1
California (2009)	37,327,690	597.38	16.00	2
Nevada (2011)	2,702,797	18.92	7.00	3
Texas (2010)	25,241,648	46.02	1.82	4
Arizona (2012)	6,407,002	10.04	1.57	5
Colorado (2011)	5,048,029	1.25	0.25	6

[1]Population estimate for July 1, 2010. (United States Census Bureau 2018)

[2]Reclaimed Water Daily Average Use from WateReuse Foundation National Water Reuse Database (2018). "Daily Reclaimed Water End Use Pattern (mgd)."

provide some frost protection, and the RW would provide additional water on freeze nights. The frost protection advantage convinced some growers to start using the water, and eventually, other growers accepted the water. Because there have been no major problems and the treatment facilities have consistently met water quality standards, most growers in the area now understand that this is a good quality resource for year-round use.

Growers in the Conserv II area requested that University of Florida scientists carry out research on this RW (Parsons et al. 2001a) to make sure it was not damaging their trees. Since the city and county were more concerned with wastewater disposal at the time, purposely-high irrigation rates of 100 in/yr (~2500 mm/yr) were applied. On these well-drained sandy soils, tree canopy growth and fruit production were greater at the high irrigation

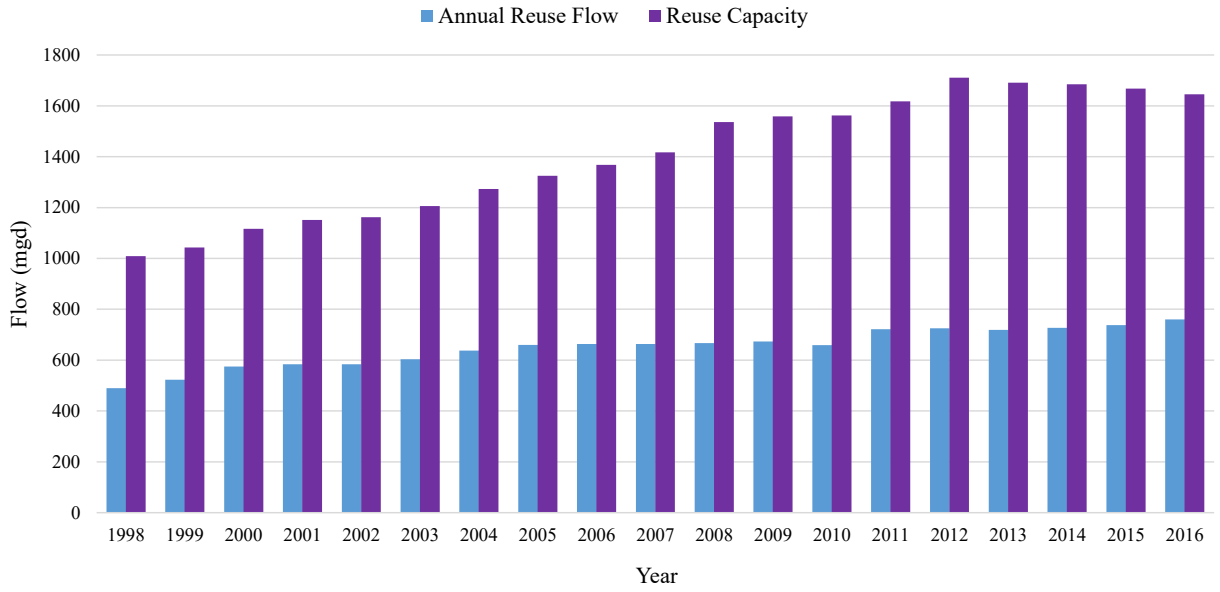

Figure 1. Growth of water reuse (Florida Department of Environmental Protection 2017b).

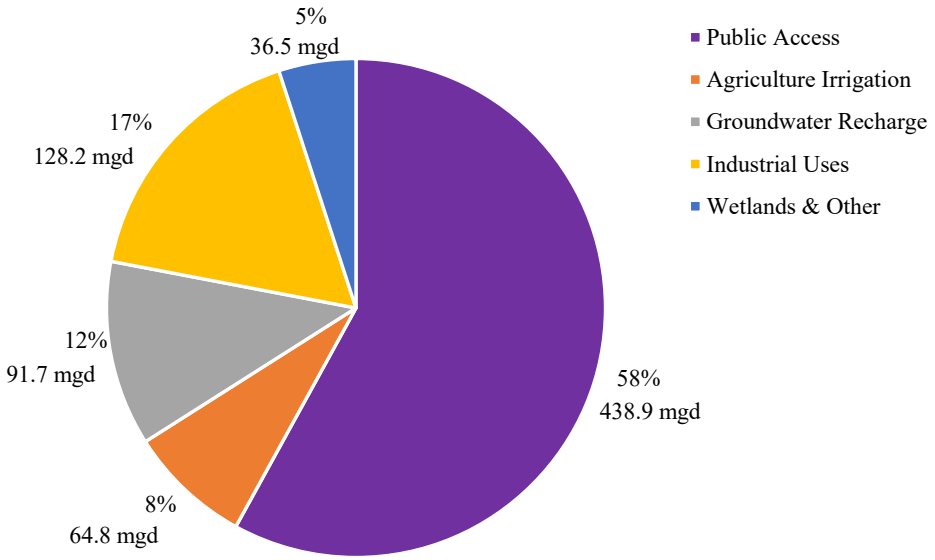

Figure 2. Reclaimed water utilization (Florida Department of Environmental Protection 2017b). Note: Agriculture irrigation includes edible crops (e.g., citrus) as well as feed and fodder crops (e.g., spray fields).

rate than at lower rates because the trees suffered essentially no water stress. The 100 in/yr rate reduced the concentration of juice soluble solids, but the greater fruit production significantly increased the total soluble solids per hectare (the basis on which growers are paid) (Parsons et al. 2001b). Disease was not a problem at the high rate. Now, most growers who were initially skeptical have become enthusiastic supporters of this water. Public acceptance has increased also because RW use has fewer pumping restrictions during droughts than potable water.

Nevertheless, the pattern of initial rejection of RW because of the perceived "yuck factor" is commonly repeated in other locations. In the 1980s, growers in Florida's east coast Indian River area rejected a proposal to bring RW to groves there. This area is noted for producing high quality grapefruit. Much of this Indian River grapefruit is marketed in Europe and Japan. Growers feared that, because of perception issues, marketers in these countries would not accept grapefruit that was irrigated with RW. However, recent work has shown that RW from treatment plants on the east coast can be lower in salinity and bicarbonates than existing well water (R. Adair, pers. comm. 2017). Thus, RW can be a better irrigation source than existing wells. Some growers in the region are now starting to get interested in irrigating with RW.

Approximately 79% of the agricultural reuse flow in Florida goes to irrigation of citrus. However, citrus production and acreage have declined in the past 20 years because of hurricanes, real estate development, and diseases. Two major bacterial diseases, citrus canker and greening, have caused major decreases in citrus acreage. Part of the reason for the decline in agricultural RW use is a disease called citrus greening that came into Florida in 2005. Greening, or huanglongbing, which is spread by an insect called a psyllid, causes trees to decline and eventually die, and is currently devastating the Florida citrus industry. The 2017-2018 production of Florida oranges was 44.95 million boxes, which is only ~18.4% of the 244 million-box production of the 1997-1998 season (USDA 1998, 2018). Because greening has caused major tree and production loss, some growers have abandoned their groves. In 2016, there were an estimated 130,684 acres of citrus groves abandoned (USDA 2016).

Safety of Reclaimed Water

Safety of RW has always been a major concern. Because RW comes from sewage or wastewater treatment facilities (WWTFs), public perception has often been an issue. The public outcry of "toilet to tap" has delayed or cancelled some RW projects. However, the safety record of RW is excellent. Florida has been using RW for more than 50 years, and there are no documented reports of people becoming sick from exposure to RW (SWFWMD 2017). Part of the reason for this excellent safety record is the water quality regulations established by governmental bodies. York et al. (2003) also stated "Reuse and the Absence of Disease. It must be noted that there is no evidence or documentation of any disease associated with water reuse systems in the United States or in other countries that have reasonable standards for reuse. This is true for protozoan, viral, helminthic, and bacterial pathogens."

Several organizations have established recommended microbiological quality guidelines for agricultural use of wastewater. One common way to determine water quality is to measure coliform or fecal coliform bacteria. Water quality standards and measurements are complicated and involved, and we will only discuss the main features of the water quality standards used.

The World Health Organization (WHO 1989) recommended that for "irrigation of crops likely to be eaten uncooked, sports fields, and public parks" the geometric mean number of fecal coliforms be less than or equal to 1000 per 100 ml. In Florida, the FDEP requires RW to have basic disinfection. "Basic disinfection" means that the arithmetic mean of the fecal coliform values shall not exceed 200 per 100 ml. For public access areas, FDEP requires high-level disinfection. This level of disinfection is the most stringent. It requires that over a monthly period, 75% of the fecal coliform values must be below the detection limits and "any one sample shall not exceed 25 fecal coliform values per 100 ml of sample" (Florida Department of State 2016. Rule: 62-600.440). Because 58% of reuse flow is for public access (Figure 2), this

means that at least 58% of Florida's RW receives high-level disinfection.

In an effort to encourage water reuse and reduce public perception of what has been called the "yuck" factor, Florida statutes were written that prohibited direct contact of RW with crops unless they were "peeled, skinned, cooked, or thermally processed before consumption" (Florida Department of State 1999. Rule: 62-610.475). This prohibition on direct contact of RW with crops eaten raw (e.g., salad crops) was done without scientific study, but remains in effect. This means that Florida has more severe restrictions on crop application than California. This is significant, because this Florida prohibition prevents the use of RW for frost protection using overhead irrigation on crops such as strawberries and blueberries. This is unfortunate because pumping of well water during some freezes to protect strawberries has caused sinkholes to develop due to water table drawdown.

California has allowed direct contact of RW on vegetable crops eaten raw for more than 30 years. A Monterey wastewater reclamation study for agriculture was carried out in the Salinas Valley of California (Engineering-Science 1987). This study showed that irrigation of vegetable crops (eaten raw) with RW was as safe as irrigation with well water. No virus was found on crops grown with RW. In addition, "levels of naturally-occurring bacteria on samples of effluent-irrigated crops were equivalent to those found on well-watered irrigated crop tissue samples." No health problems have occurred with California vegetables irrigated with RW.

Interestingly, in 2016, a variance to Rule 62-610.475 was granted to the City of Pompano Beach, FL to allow homeowners to irrigate their gardens with RW. The petition for the variance showed that the RW met all potable water standards except for chloride, sodium, and total dissolved solids. It also pointed out that a) water reuse was a state objective, b) other states allowed direct contact with crops eaten raw, and c) this would cause a substantial economic hardship. The final order found that "this economic hardship was unnecessary because the Petitioner could use reclaimed water to meet the demand for residential irrigation" (Florida Department of State 1999). It will be interesting to see if other Florida cities request a variance from the direct contact rule similar to the one granted to Pompano Beach.

Nutrients in Reclaimed Water

Reclaimed water contains several mineral elements, some of which are beneficial for plant nutrition. Elements of particular interest are nitrogen (N), phosphorus (P), and several micronutrients such as boron (B). While RW can provide some plant nutrition, the benefit depends on the level of treatment and the crop itself. Florida requires that all WWTFs producing RW for reuse must provide secondary treatment and disinfection. Treatment plants discharging into Tampa Bay and surface waters in the Southwest Florida Water Management District (SWFWMD) must meet the more rigorous N and P standards of advanced wastewater treatment (AWT). AWT standards are 5/5/3/1 (5 mg/L of $CBOD_5$, 5 mg/L of total suspended solids, 3 mg/L of total N, and 1 mg/L of total P).

Levels of N and P in RW are relatively low. Typical levels of total Kjeldahl N (which consists of organic N and ammonia N) are 13.9 ppm (mg/L) in secondary treated wastewater and 0.9 ppm in AWT water (Toor and Lusk 2017). Nitrate N levels are 1.4 ppm and 0.7 ppm, respectively. Jacangelo et al. (2012) reported that a "survey revealed that 40% of the sampled reuse facilities in Florida had total N concentrations less than 5 mg N/L, and 70% had total N concentrations less than 10 mg N/L. The higher total N levels were primarily from facilities with limited nitrification and, as such, they contained much higher levels of ammonium… Regarding total P concentrations, 40% of the 40 sampled facilities were below 1 mg P/L, and 90% had levels below 5 mg P/L."

In the Water Conserv II location near Orlando, FL, growers initially received the RW for free and used it at high rates to dispose of it. Trees grew well with the high irrigation rates and produced more fruit and total orange soluble solids than trees irrigated at lower rates (Parsons et al. 2001b). Zekri and Koo (1993) compared citrus trees irrigated with RW or well water and found higher levels of sodium (Na), chloride (Cl), and B in leaves of trees irrigated with RW. Because of the higher irrigation

rates, groves irrigated with RW also had a denser canopy, better leaf color, heavier fruit crop, and more weed growth. In a related later study, Morgan et al. (2008) found higher leaf B and magnesium (Mg) levels in trees irrigated with RW. As in previous studies, they also found that RW irrigation increased soil P and calcium (Ca) and reduced soil potassium (K). Hence, it may not be necessary to lime Florida soils irrigated with RW. Scholberg et al. (2002) carried out N studies on young citrus seedlings with emphasis on N concentration, application frequency, and residence time in the soil. They compared application frequencies of three 500-mL applications/week of 7 mg N/L (simulating RW) with one 150-mL application/week of 70 mg N/L. Increasing application frequency and residence times from two to eight hours increased nitrogen uptake efficiency (NUE). High irrigation application rates displaced RW below the main root zone and reduced NUE.

Both Zekri and Koo (1993) and Morgan et al. (2008) did not find increases in leaf N in trees irrigated with RW. This is probably because of limited N uptake, due to short residence time in the soil from high application rates, and low N concentration (typically < 7 mg/L). Maurer and Davies (1993) found that RW did not provide adequate nutrition for young trees and indicated that supplemental fertilization was necessary.

Reclaimed water may not play a large role in providing N for citrus trees. In a normal Florida rainfall year, citrus needs around 15 inches of irrigation water to supplement the rainfall. With RW of 7 mg N/L, 15 inches of RW would supply 23.8 lb/acre. Depending on tree size, tree age, planting density, and crop yield, the annual N fertilization rate for oranges should range from 140 to 250 lb/acre (Obreza et al. 2017). Hence, if the tree roots could extract all of the N out of the RW, the RW would supply only 9.5 to 17% of the total N requirement. If the RW met AWT standards of 3 mg N/L, 15 inches would supply only 10.2 lb of N, or less than 7.3% of the N needed.

Turf grass may respond better to RW. Pinellas County developed a map that shows that RW can supply N so that less fertilizer is needed in the landscape. Because WWTFs produce RW with different concentrations of N, the RW from some facilities can provide the entire N amount needed. For example, the St. Petersburg facility can provide sufficient N to meet the N requirement of several turf grass varieties (Pinellas County National Resources 2017). These varieties need no additional N fertilizer.

Conclusions

Reclaimed water use in Florida has increased greatly in the past 20 years, and much of the increase in RW flow has gone to public access irrigation. Because of diseases and real estate development, agriculture is changing in Florida. Nevertheless, agriculture is an important part of the Florida economy, and RW is a useful resource that helps keep agriculture productive. The common way to move RW from the WWTFs to the place of use is to pump the RW through a network of pipes (commonly colored purple). Instead of installing more purple pipelines, other methods of distribution, such as groundwater recharge and aquifer conveyance may be used in the future as a more economical way to bring RW from treatment plants to agricultural operations and other areas where it is used. With continued population growth in Florida, RW total flow will continue to increase.

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