RESPONSE OF INFILTRATION RATE TO EFFLUENT WATER QUALITY IMPROVEMENT AT THE SWEETWATER RECHARGE FACILITY AND SANTA CRUZ RIVER

By

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A Thesis Submitted to The Honors College

In Partial Fulfillment of the Bachelors degree
With Honors in

Environmental Hydrology and Water Resources

UNIVERSITY OF ARIZONA

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Response of Infiltration Rate to Effluent Water Quality Improvement at the Sweetwater Recharge Facility and Santa Cruz River

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1 Abstract

The Reclaimed Water System allows drinking water to be conserved by reducing the amount of potable water applied to large water-use sites like golf courses and parks. Advancements in effluent infiltration can amplify this conservation by making more reclaimed water available. This study, conducted in Tucson, Arizona, assesses the practicality of nitrogen and phosphorus removal as a method of enhancing effluent infiltration. Infiltration rates in recharge basins RB-001 to RB-008 at the Sweetwater Recharge Facility, as well as reach length and recharge in the effluent dominated Lower Santa Cruz River, were studied before and after the removal of nearly 90 percent of nitrogen and 50 percent of phosphorus species in March, 2014. In general, basin infiltration increased between 30 to 70 percent, the wet reach of the Santa Cruz River decreased dramatically and river recharge increased after the water quality improvement, indicating that water quality improvement does improve effluent infiltration.

2 Introduction

Water scarcity is a pressing issue in the Southwestern United States. Due to its arid environment and lack of large surface water sources, residents of the southwest rely on the region's groundwater as their primary drinking water supply. Unfortunately, this water takes time to naturally replenish, and urbanization and large water demands cause this groundwater to be extracted faster than it recharges. The Reclaimed Water System is one method many cities use to manage their water resources, since it uses recycled instead of potable water to meet the large demands of sites like golf courses, parks and schools. In Tucson, Arizona, the Sweetwater Recharge Facility (SRF) is an integral component of the Reclaimed Water System; the recharge basins at the SRF use soil aquifer treatment (SAT) to treat and store water that the Reclaimed Water System can later draw from in times of high demand or treatment plant maintenance.

Soil aquifer treatment has been well studied by many hydrologists, including Bouwer, who proposed SAT as a method of renovating secondary-sewage effluent (1974). In his study, Bouwer found SAT to be an effective method of removing nitrogen and phosphate, as well as the biochemical oxygen demand (BOD), total suspended solids (TSS) and fecal matter in secondary effluent. Later studies found this to be true, but determined that this nutrient removal was limited by infiltration reduction, caused by a thin clogging layer of organic material immediately below the soil surface, referred to by Ellis as "schmutzdecke" (Siegrist, 1987; Ellis, 1987). Before Siegrist and Ellis' works, this clogging layer has been observed previously by a number of other studies (Jones and Taylor, 1965; Thomas et al., 1966; Kristiansen, 1981). Through comparison of domestic septic tank effluent, greywater septic tank effluent and tap water, Siegrist found that soil clogging was highly dependent on the amount of TSS and BOD in the water, and determined that ponding caused by soil clogging was greatly reduced in higher quality waters. Despite this observation, the waters studied by Siegrist were largely different in quality, making it difficult to draw conclusions about the effect finite water quality improvements may have on infiltration rate. This problem is of interest to Tucson Water, Tucson's municipal water provider, since their basins have recently begun receiving higher quality water from a new wastewater treatment plant. Whereas historically, the basins have received Class B water from the Roger Road Wastewater Treatment Plant (RRWTP), they are now sent Class A water from the Agua Nueva Wastewater Treatment Plant (ANWTP), which removes nearly 90 percent of the nitrogen and 50 percent of the phosphorus species from the water before delivery. This water is also treated and discharged into the Santa Cruz River (SCR) when the recharge basins have been filled to capacity.

In 2004, Rodgers et al. found that the development of the clogging layer is largely controlled by a biomass buildup consisting of Nitrogen, total Phosphate and total Sulfur. Since the effluent water quality improvement in the recharge basins at the SRF is dominated by the removal of nitrogen and phosphorus, this would imply that the recharge basins at the SRF should see reduced clogging and improved infiltration rates, which would allow more water to be stored and available for the Reclaimed Water System. According to Treese et al., nutrient removal may also cause reach shortening in the Santa Cruz River, since the clogging layer observed in the basins is also present in effluent dominated streams (2009), and the removal of the clogging layer in a stream would allow the water to travel vertically into the profile instead of skating horizontally downstream on the river bed.

The combination of historic data from the RRWTP water and incoming new data from the ANWTP provides a unique opportunity to study changes in infiltration rates of the same research site under different water quality conditions, reducing mineralogical and climatological errors. Therefore, this study will utilize historical and current data from recharge basins and the Santa Cruz River to examine the effect of nitrogen and phosphorus removal on infiltration rate, and will draw conclusions on whether quality improvement is a valid method of improving the Reclaimed Water System.

3 Site Description

3.1 The Sweetwater Recharge Facility

The Sweetwater Recharge Facility is an underground storage and recovery facility (USF), owned by Tucson Water and located in Tucson, Arizona. With a permitted storage volume of 13,000 acre-feet/year, the Sweetwater Recharge facility is the largest constructed USF to recharge effluent water in Tucson, and the second largest in the state of Arizona (ADWR). It consists of 11 recharge basins, located on the east and west sides of the Lower Santa Cruz River (Fig. 1, 2a).

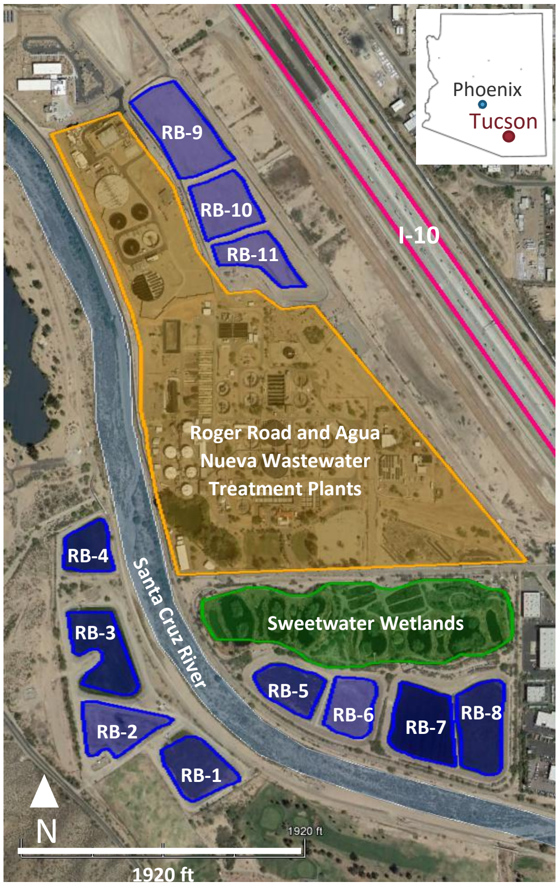

Figure 1. Map of the Sweetwater Recharge Facilities

Basins RB-001 through RB-004 are located on the west side of the river, while basins RB-005 through RB-011 are located just east of the river. Together, all 11 basins occupy about 40 acre-feet of land, and can be filled to about 3 feet.

The development of recharge basins RB-001, RB-002, RB-003 and RB-004 began in 1989 and finished in 1991. To increase the permitted recharge capacity of the site from about 3,200 to 6,500 acre-feet per year, RB-005 through RB-008 were created and implemented in 1997. To meet the requirements mandated by the Arizona Department of Environmental Quality (ADEQ) and the Clean Water Act, the RRWTP ceased operation in December, 2013 and was replaced by the Agua Nueva Wastewater Treatment Facility on March 12, 2014. Rather than Class B secondary effluent the RRWTP produced, the ANWTP delivered Class A tertiary effluent to RB-001 through RB-008 as a result of a near-90 percent reduction in nitrogen and 50 percent reduction in phosphorus. In July 2014, the Sweetwater recharge facility expanded again to include new recharge basins RB-009, RB-010 and RB-011. Because these basins became operational after the closure of the RRWTP, they have only received Class A water from the ANWTP.

From the ANWTP, water is either chlorinated and released into the Lower Santa Cruz River or directed to the Tertiary Effluent Pumping Station, "TEPS" (formerly known as SEPS when wastewater was a lower grade of effluent). From TEPS, water is either sent directly into the Reclaimed Water System after carbon-sand filtration and chlorination treatment, or delivered to the recharge basins at the Sweetwater Recharge Facility for soil aquifer treatment and storage. The ANWTP produces 25 MG/day, but can only filter 10 MG/day directly into the Reclaimed Water System; the additional 15 MG, plus any water not directly needed in the Reclaimed Water System at low demand times is used to fill the basins at the SRF before the excess water is chlorinated and sent down the Santa Cruz River (Fig. 2b).

According to Wilson et al. (1995) and Quanrad et al. (2003), localized clay lenses are present below the entire facility, but at greater depths below the northern-most basins. Otherwise, the basins are composed of mostly gravel and sand (Wilson et al., 1995). The basins are operated in wet-dry cycles to remove algae buildup in ponded water. However, despite this wetting and drying cycle, Tucson Water has had difficulty maintaining the basins in the past, which has caused organic

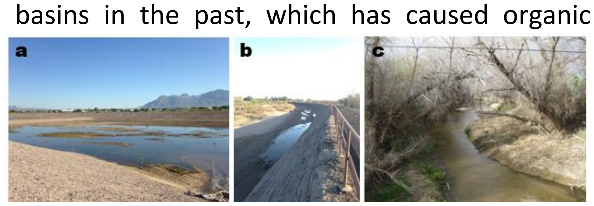

Figure 2a. Sweetwater Recharge Facility recharge basin
Figure 2b. Santa Cruz River at the SRF
Figure 2c. Santa Cruz River at Trico Road

material to build up and limit infiltration rates. Because of this, Tucson Water is in the process of excavating the basins replacing the sediment with new sand and gravel. Unfortunately, the documentation of these sediment removal events is not public, so the exact dates and locations of sediment removal are not known at this time. However, it is known at the time of this paper, all basins besides RB-007 and RB-009 through RB-011 have had this maintenance done to them.

3.2 The Lower Santa Cruz River

The Lower Santa Cruz River is an effluent dominated stream that receives the majority of its flow from the ANWTP and the Tres Rios Wastewater Treatment Plant (Fig 3). The river receives a minimum or 3 MG/day from the ANWTP, but can receive more if the recharge basins at the SRF are full or drying. Besides effluent flow, the Santa Cruz River is generally dry, but can experience seasonal flows after rains, and occasionally experiences extreme flood events after monsoon storms during the summer. Tucson Water receives recharge credits for any Santa Cruz River water that infiltrates before leaving Tucson's boundaries at Trico Road. The river bed is mainly composed of fine sand and gravel eroded from surrounding mountains (Dong et al., 2015). Discharge is documented in the river at the SRF, the TRWTP, and at US Geological Survey (USGS) stream gaging stations at Cortaro and Trico Road .

Figure 1. Map of the Lower Santa Cruz River (credit: Sonoran Institute, A Living River, 2013 Water Year)

At a latitude of about 32°N and longitude of 111°W, Tucson experiences a semi-arid climate with average temperatures ranging from 40°F in the winter to 100°F in the summer, and an average rainfall of nearly 12 inches per year (NOAA).

4 Methods

4.1 The Sweetwater Recharge Facility

Infiltration rates for the recharge basins at the Sweetwater Recharge Facility were determined using falling head analysis. Real time head values for the 11 recharge basins were electronically collected every hour using a Supervisory Control and Data Acquisition (SCADA) data monitoring and collection system. The basins were repeatedly filled, the pumps were turned off and the basins were allowed to drain through infiltration (Fig. 4). Occasionally, the basins are scraped or dried to remove the buildup of organic material. The change in water level over time of each drain was considered to be the infiltration rate.

$$Infiltration\ Rate = \frac{\Delta h}{\Delta t} \qquad \text{[Eq. 1]}$$

Median infiltration rates before and after the improvement in water quality were used to draw conclusions about the effect of water quality on infiltration rate. Because recharge basins RB-009 through RB-011 never received water from the RRWTP, they will be excluded from the analysis. Data was analyzed from March, 2013 to March, 2015, one year before and after the

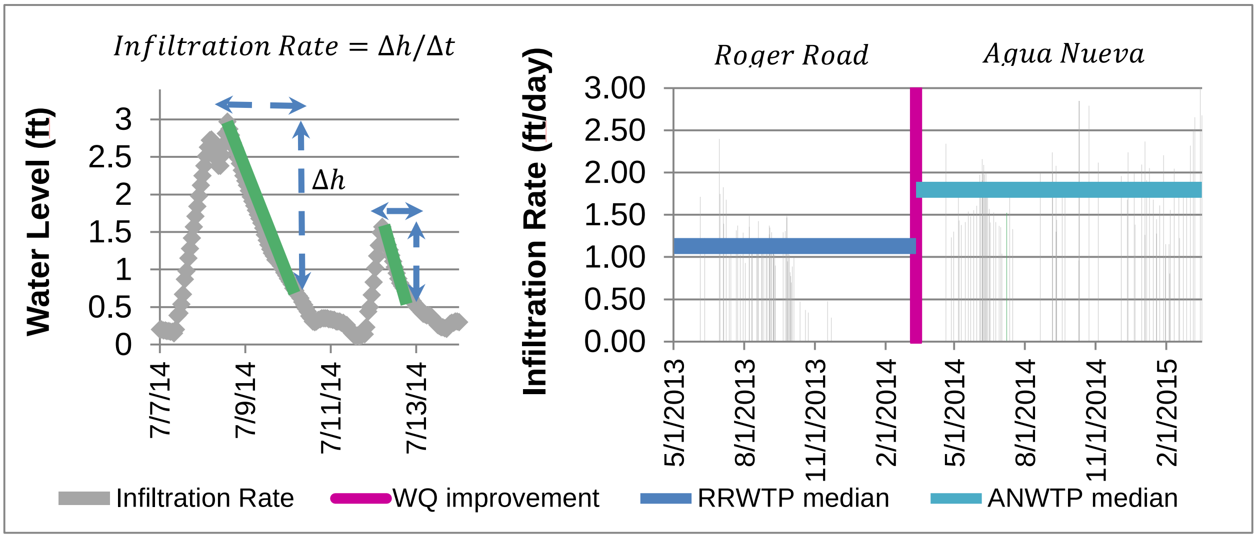

Figure 2. Sample infiltration calculations from SRF basin RB-005, Including falling water levels collected by temporally by SCADA collected water levels (left), and repeated many times to collect the median infiltration rate of the RRWTP (dark blue) vs ANWTP teal) water

improvement in effluent water quality.

4.2 THE LOWER SANTA CRUZ R IVER

Tucson Water uses a water balance (Eq. 2) to estimate the volume of water recharged into the Santa Cruz River based on evaporative losses, volume released from the SRF, volume released from the downstream Tres Rios Wastewater Treatment Plant and volume passing by the USGS stream gaging station at Trico Road, the border between Tucson and the city of Marana.

$$Recharge = V_{ANWTP} + V_{Tres\ Rios\ WTP} - Evaporation - V_{Trico} \qquad \text{[Eq. 2]}$$

High recharge is an indicator that water is infiltrating faster, since more water is being transmitted underground in the same duration of time. Like with the infiltration basins, the recharge was analyzed before and after the improvement in water quality. Since the addition of new recharge basins RB-009 through RB-011 increased the basin capacity at the SRF, the volume of water sent to the river, normally what the basins cannot use, decreased upon new basin operation. Since the water balance used to find recharge is volume dependent, infiltration changes were analyzed before the addition of the new basins.

Like Treese et al., the reach, or length that water travelled along the river before the river dried up was initially considered as another point of analysis. However, because the ANWTP is spending more time cleaning the water, it is not able to produce the magnitude of effluent the RRWTP could. After RB-009, RB-010 and RB-011

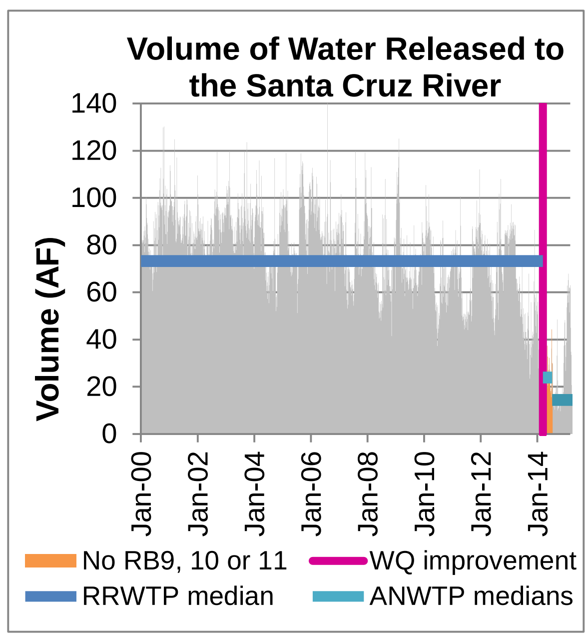

Figure 5. Volume of water released by the RRWTP (left of pink line) and the ANWTP (right of the pink line)

became operational in July, 2014, the discharge sent down the river decreased more, since Tucson Water is electing to fill the basins before sending any water into the river. it was determined that the changes in volume released to the river after the improvement of water quality and again after the addition of RB-009 through RB-011 (Fig. 5) were too drastic to draw conclusions about the effect of higher quality water on the reach length of the Santa Cruz River, as opposed to the effect of decreasing discharge alone.

5 Results & Discussion

5.1 The Sweetwater Recharge Facility

Infiltration rates for ANWTP water show a distinct increase from RRWTP water in all recharge basins except for RB-007, which sees negligible change (Fig. 6). As discussed in the site description, RB-007 has not been maintained properly in the past, and has yet to undergo sediment removal. Therefore, the failure of RB-007 to respond to the water quality improvement may be caused by a pre-existing build-up of organic material and soil clogging that was allowed to reach an irriversible level. When RB-007 is excavated and its sediments are replaced, RB-007 should be compared again to the old infiltration rates to see if infiltration rate improves to match the rest of the ANWTP data. Depending on the basin, infiltration rates improve anywhere between 30 to 70 percent in all basins besides RB-007, indicating that in the recharge basins at the SRF, water quality improvement appears to be a valid method of infiltration rate improvement.

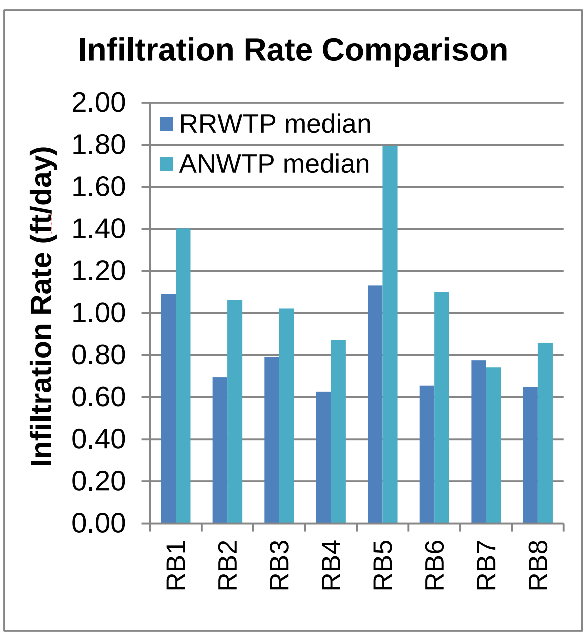

Figure 6. Comparison of median RRWTP Infiltration Rates (dark blue) compared to median ANWTP Infiltration Rates(teal) in RB-001 through RB-008

5.2 The Lower Santa Cruz River

Despite the decrease in water released to the Santa Cruz River, the volume of water recharged between the SRF and the Cortaro Road stream gaging station increased dramatically after the improvement in water quality (Fig. 7). Even after the addition of RB-009 through RB-011, the volume of water recharged into the river bed is slightly higher than it was when receiving RRWTP water. Thus, the removal of nitrogen and phosphorus also appears to increase the infiltration rate of the effluent water in the river.

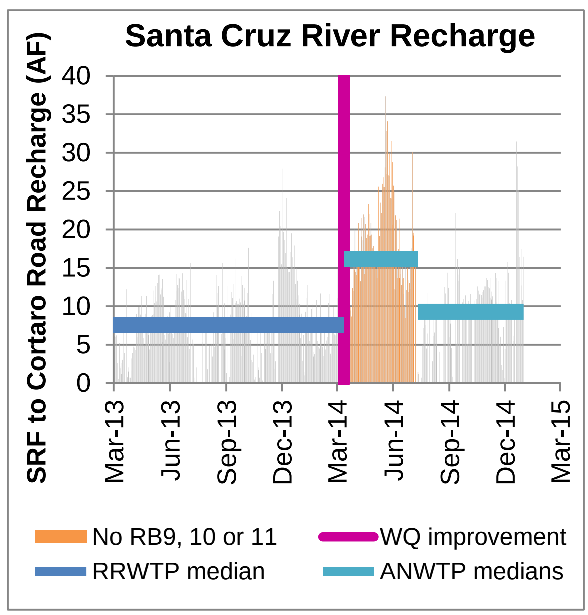

Figure 7. Santa Cruz River recharge between the release point at the SRF and USGS gaging station at Cortaro Rd.

6 CONCLUSIONS

The Sweetwater Recharge Facility uses soil aquifer treatment to treat and store water for the Reclaimed Water System. This process helps to conserve the potable groundwater of the region by ensuring that the Reclaimed Water System always has water to deliver to large irrigation sites like golf courses, parks and schools, even when water demand is high.

In this study, the removal of nearly 90 percent of nitrogen and 50 percent of phosphorus was shown to increase the infiltration rates at the Sweetwater Recharge Facility and in the Lower Santa Cruz River. Because previous research has shown nitrogen, phosphorus and sulfate to play a large role in soil clogging processes, the improvement in infiltration rates likely due to reduced soil clogging. Prevention of schmutzdecke build up also reduces algal contributions to organic material, since an unclogged medium will not experience significant ponding and the corresponding prolonged exposure to sunlight.

As predicted, the improvement in infiltration at the Sweetwater Recharge Facility has increased the volume of water stored and available to the Reclaimed Water System. Because effluent availability and water demands will only continue to increase with population growth, the Reclaimed Water System may be a valuable method of water conservation in the future.

7 ACKNOWLEDGEMENTS

The author acknowledges Tucson Water for providing access to company data and research sites. She also acknowledges her coworkers Dick Thompson and Alyssa Miller for their analysis assistance, and her thesis mentor Thomas Meixner for his guidance.

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