A STUDY OF IMPROVED QUALITY EFFLUENT DISCHARGED FROM AGUA NUEVA WATER RECLAMATION FACILITY TO THE LOWER SANTA CRUZ RIVER

By

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A study of improved quality effluent discharged from Agua Nueva Water Reclamation Facility to the Lower Santa Cruz River

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Abstract

Reclaimed water is an important renewable resource because it mitigates the use of potable supplies to meet outdoor water demand. In Tucson, reclaimed water is managed through aquifer storage and recovery. Some recharge is done directly in the Santa Cruz River where credits are earned for water that infiltrates in a permitted stretch. The new Pima County water treatment facility, Agua Nueva, releases high quality Class A effluent, which infiltrates the river at higher rates than water from the previous facility. This study monitored the discharge from Agua Nueva and aimed to quantify instream recharge rates. Gaining higher spatial resolution on recharge is important for verifying current recharge credits, and modeling water demand of future effluent-use projects.

Water level was continually measured at four river monitoring stations. A mass balance method was used to estimate recharge by calculating differences in streamflow between upstream and downstream stations. Because of the highly variable outflow from Agua Nueva, this method's results were inconclusive. The study resulted in development of an effective way to temporarily deploy divers in highly variable Southwest streams experiencing intense monsoons. The water level data gathered provided new insight to patterns of effluent flow in the Lower Santa Cruz River.

Introduction

Effluent is an important water source in Tucson, as it alleviates the use of potable groundwater and Central Arizona Project water for non-potable uses. Effluent, or reclaimed water, is highly treated wastewater used mainly for large-scale turf irrigation, such as parks and golf courses. In Tucson, the effluent also provides environmental benefits when a portion of it is released directly into a stretch of the otherwise dry Santa Cruz River, creating a riparian corridor, which supports various native plants and wildlife. The Santa Cruz River's headwaters begin in southern Arizona, flow south into Mexico, and then turn north to flow back into Arizona. It is an ephemeral stream that flows mainly during summer monsoon events. Only two sections experience year round streamflow, and these are fed by treated wastewater, or effluent. The first section receives flow from a wastewater treatment plant in Nogales, and the second from Pima County's treatment plants. The sections with perennial flow can be seen in the Santa Cruz River watershed map in Figure 1.

Water discharged into the river infiltrates through the streambed, and some of it recharges the underlying aquifer. This is the Lower Santa Cruz Managed Aquifer Recharge Project. Based on a calculation of the recharge amount, the City of Tucson is issued reclaim credits, which is an amount of water it has the right to withdraw from the reclaim system at a later time. Accumulating these credits allows the city to meet especially high reclaim demands during the peak summer months. Quantifying the infiltration of the effluent in the Santa Cruz is essential to verify that the appropriate amount of credits is issued.

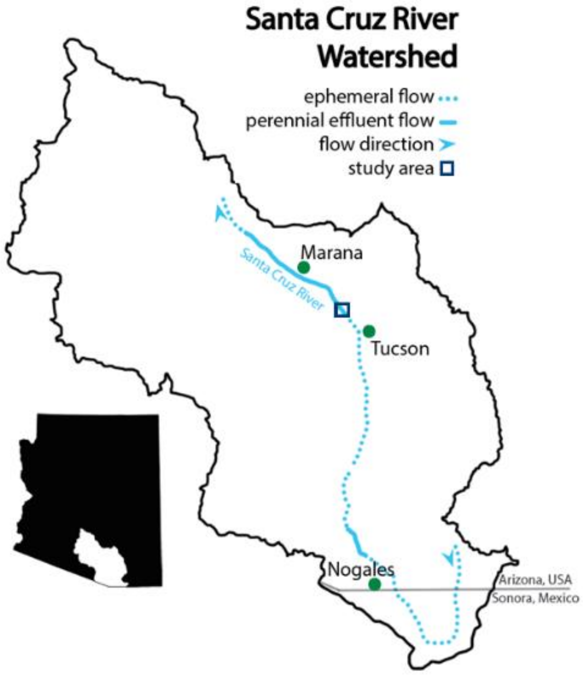

Figure 1: Map of Santa Cruz River in context of the watershed, showing ephemeral and perennial sections

Pima County operates two treatment facilities, Tres Rios Water Reclamation Facility (WRF) and Agua Nueva WRF, the latter of which replaced the old Roger Road WRF in 2013. This was the largest public works project ever completed by Pima County; it amounted to over $600 million in upgrades. The effluent released now is considered Class A, which is a much improved water quality compared to the Class B effluent released by the old Roger Road WRF. The class rating of effluent is determined by it meeting a variety of water quality standards. A simply described difference is that while neither meets drinking water standards, Class A is rated as safe for full bodily contact while Class B is not. This change in effluent standards is important for recharge because the improved quality water infiltrates through the streambed at a higher rate. The dramatic reduction in nitrogen species resulted in reduction of the biological clogging layer, which previously caused more of a restriction on streambed infiltration.

There are two sections on the Lower Santa Cruz (defined as the reach from Agua Nueva to Trico Road seen in in Figure 2) in which reclaim credits can be earned, each with different stakeholders. The first is based on effluent that recharges instream between Agua Nueva and Tres Rios. In this section, Tucson Water and the Bureau of Reclamation are the only two stakeholders, and they share the credits 50-50. The next section for consideration of credits is downstream, from Tres Rios to Trico Road at the end of Marana. Here, there are many stakeholders including the Bureau of Reclamation, Tucson Water, Marana Water, Metro Water, and others. Because there are more stakeholders, Tucson Water has a much smaller cut of the credits in this stretch of the River, as compared with the section between Agua Nueva and Tres Rios. The fact that most of Tucson Water's reclaim credits come from this upstream section, coupled with the possible underestimation of credits in this section due to increased infiltration, provided the study motivation to estimate recharge of the improved quality effluent in this area.

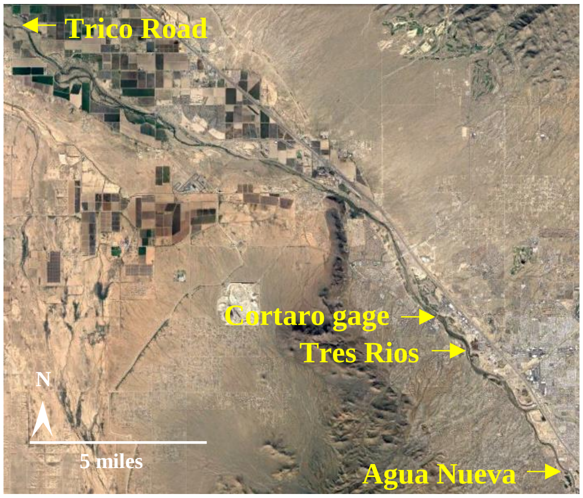

Figure 2: Map of Lower Santa Cruz River with location of reclamation facilities and point that define sections on which credits will be earned for recharge

The permit for reclaim credit earned in the upper portion of the Lower Santa Cruz, from Agua Nueva to Tres Rios, was issued by the Arizona Department of Water Resources (ADWR) to the City of Tucson in 1999 when the Roger Road plant was still in place. The current permit uses a mass balance approach to quantify recharge credits. The inflows are discharge from Agua Nueva and discharge from Tres Rios. The outflows are flow past Cortaro gage and evapotranspiration. Cortaro gage is downstream of Tres Rios, but is the closest USGS gaging station (Figure 2). To calculate recharge in the section, the sum of the outflows is subtracted from the sum of the inflows. Of the total recharge from Agua Nueva to Cortaro gage, 73.2% is attributed to the upper reach between the two treatment facilities (Holway 1999). In Arizona, laws require a certain percent of the volume of water recharged to be considered irrecoverable to benefit the aquifer; this is known as a “cut to the aquifer.” For the managed recharge of effluent, a 50% cut of the total calculated recharge is given to the aquifer, and the remaining 50% is the credit split between Tucson Water and the Bureau of Reclamation. In contrast, recharge that occurs in constructed basins (as opposed to a naturally-existing waterway) receives a 100% credit and is not subject to the 50% cut to the aquifer from instream recharge (Arizona Department of Water Resources, 2015). This was originally implemented to encourage direct use of effluent, as poor instream infiltration rates meant that effluent that flowed past project boundaries (Trico Road in this case) would be considered a lost opportunity that could not earn credit or be used by the stakeholder. Another interesting point of the permitting is that no credits are issued on days when stormflow contributes to flow at Cortaro gage, as there is no way to parse out storm flow from effluent flow (Holway 1999).

Because the Class B water from the previous Roger Road WRF did not infiltrate well, it would flow instream well past the Cortaro gage and into Marana. Now that Agua Nueva WRF discharges Class A effluent, the water infiltrates much more effectively, and the flow extends only 4-5 miles downstream before the river is dry again. This clearly indicates that more recharge is occurring in the upper section between the two plants. The current recharge rates should be evaluated to reassess the accuracy of the assumption that 73.2% of the recharge occurs in the upper reach of the river between the two treatment facilities.

This study aimed to use low-cost methods and a temporary installation to monitor surface water flow in the river, and quantify recharge of effluent from the Agua Nueva discharge point to El Camino del Cerro bridge- approximately one mile of channel length. The estimation of recharge on a small scale, as opposed to the large volumetric quantity currently determined by mass balance, is important for the planning of future projects using effluent in-stream. The Agua Dulce plans propose to restore a few miles of flow to the Santa Cruz River in downtown Tucson. Recharge in that small spatial context needs to be understood if those projects want to be permitted for managed aquifer recharge and subsequently earn water credits.

Literature Review

Most current research focuses on the conditions of the river prior to the development of Agua Nueva WRF, which greatly increased the water quality and changed the flow extent of the Lower Santa Cruz (e.g. Lacher 1996, Prietto and Winter 2014).

The Sonoran Institute develops “A Living River” reports, which document the health of the effluent-dependent Lower Santa Cruz. It has released annual reports since 2013, one year prior to Agua Nueva’s development. Its 2013 report (Dubois et al.) provides baseline conditions against which the results of this study may be compared. They reported the 2013 water budget of the river as follows; 31,000AF (acre-feet) flowed past Trico gage (leaving project boundaries), 1,500AF was lost to evapotranspiration (ET), and 16,000AF recharged the local groundwater. The report also found that in 2013, the gage at Trico Road experienced zero dry days, so the flow extent of Class B effluent from the two treatment plants always reached project boundaries. This baseline condition can be compared with the 2015 report (Canfield et al.) whose authors calculated a much different water budget that reflects the higher infiltration rate of the new, Class A effluent. In 2015, 13,200AF flowed past Trico gage (leaving town boundaries), 1,650AF were lost to ET, and 37,500AF recharged the local groundwater. The flow extent was also greatly reduced: the Trico gage experienced 244 dry days. The increased number of dry days at Trico gage is the biggest indicator of increased infiltration rates.

Prietto and Winter (2014) modeled infiltration rates in the Lower Santa Cruz from the Roger

Road Wastewater Reclamation Facility (prior to Agua Nueva) to the Cortaro gage just past the Tres Rios facility. He implemented a large-scale mass balance and performed a linear regression to determine the effect of the following variables on effluent discharge: concentration of total suspended solids (TSS); concentration of biochemical oxygen demand (BOD); and the amount of discharge from the treatment facility in AF per day. The seasonal averages of infiltration ranged from 2.3-7.9 AF per day per mile. In addition, BOD and TSS were negatively correlated with streambed infiltration and this relation varied seasonally. During the non-monsoon season, BOD and TSS concentrations were more important controls on infiltration rates. However, as initially reported by Lacher (1996), summer monsoon flows are a more dominant control on infiltration. Monsoon storms produce strong enough flows to churn the streambed and displace sediment. This breaks apart a biotic clogging layer which limits infiltration during other times of the year. When monsoon stormflow is not occurring, the composition of the effluent contributes to the development of a clogging layer, which becomes the dominant control on the infiltration of water. It would be interesting for future studies to investigate the decrease in the development of the clogging layer in response to the improved quality effluent from Agua Nueva.

The goal of this study is to quantify effluent infiltration on a smaller spatial scale than the typical large scale mass balance approach, to yield better resolution of recharge rates. In the best case scenario, these results could help negotiate appropriate, accurate recharge credits upon re-permitting with Arizona Department of Water Resources in 2019. Accurate recharge credits are important because reclaimed water is an important renewable resource in Tucson, for both environmental and economic benefits.

In their 2013 report, Thomure and Kmiec explain the importance of the reclaimed water system to the economic vitality of the city of Tucson. The reclaimed distribution system was expanded primarily to meet the needs of the destination resort golf industry. These golf courses can use as much as 800 acre-feet of water per year. Initially established using mined groundwater, large turf users have been forced to find alternative sources of irrigation as water table levels decline. Reclaimed water has become the main alternative and has allowed the golf industry to continue expanding and investing in Tucson. With a reclaimed infrastructure network now in place to meet these needs, reclaimed water is also used by parks and schools, for turf and other non-potable uses. With this renewable water now meeting the majority of increased seasonal demands of water, seasonal peaks in potable supplies are reduced.

To illustrate the connectedness of the golf industry, regional reclaim system, and economic development, the Thomure and Kmiec (2103) report presented a case study of the Match Play Championship. In 2009, hotel and golf facilities began construction in anticipation of this annual tournament. Permitting for the project was allowed only because of access to the reclaim system for irrigation purposes. Projected revenue for the hotel in 2013 alone was $67 million and the town of Marana was projected to receive $2.2 million in property tax revenues. Beyond that, the tournament raised over $1.5 million for local charities in a single year (Thomure and Kmiec 2013). This illustrates the importance of the reclaimed system infrastructure to providing opportunities for potential investors, and its affects the local economy.

Site Description

Two Pima County-operated wastewater treatment plants deliver effluent to the Lower Santa Cruz River: Agua Nueva WRF discharges upstream, and Tres Rios WRF discharges about 5 miles downstream. This study focuses on quantifying infiltration rates of effluent in the river from the Agua Nueva discharge point to just north of El Camino del Cerro Bridge- approximately 1 mile of channel length. Figure 3 shows the extent of the study area, and can be put into a broader context by referencing Figure 1.

Four monitoring stations were set up along this stretch to find differences in discharge as flow progresses downstream (Figure 3). These station locations were chosen based on points of access that allowed for entry into the river. The first transect is at the Agua Nueva discharge point. The second is about a quarter mile downstream just west of the treatment plant. The third is another half mile downstream, and the final gaging station is just north of the El Camino del Cerro bridge. The stations "bookend" three sections in which to estimate recharge by mass balance. The channel width at these stations range from approximately 20 to 30ft. Streamflow measurements were taken from June 2016-January 2017.

Figure 3: Overview of study area. Four monitoring stations were set up, beginning at the Agua Nueva outflow to the Santa Cruz River (Station 1) and spanning approximately 1 mile of channel length. The stations "bookend" three sections for recharge estimation.

Materials and Methods

Recharge in this reach of the Lower Santa Cruz River was estimated using a simple mass balance approach based on the streamflow (Q) at the upstream and downstream ends of a section, and losses due to evapotranspiration (ET).

$$Recharge = Q_{upstream} - Q_{downstream} - ET$$

Streamflow measurements were performed along a transect at each station using standard USGS specifications for the velocity area method, with a flowmeter and topset rod (Turnipseed and Sauer 2010). Evapotranspiration estimates could be obtained from the Sonoran Institutes' *Living River Report* (Canfield et al., 2015).

Pressure transducers with internal data loggers (divers) were installed at each monitoring station to continuously monitor surface water levels. This was achieved by inserting a screened metal drivepoint 3ft into the streambed and suspending the diver within that installation. The diver was attached to a radio device, which allowed for wireless downloads of the data, and topped with a weighted metal cap to help prevent it from being carried downstream if dislodged (Figure 3). This low-cost setup could be easily relocated if storm events caused significant sediment relocation in the stream.

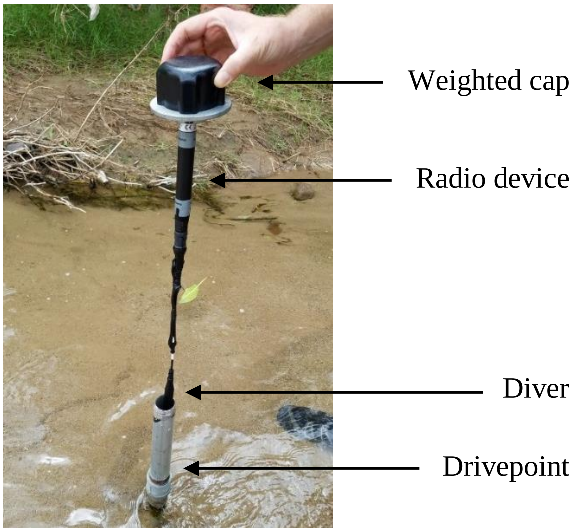

Figure 4: Diver being inserted into drivepoint installation at Station 2

The divers collected hydraulic head (water level) readings at 20 second intervals. These readings were used to estimate a travel time from an upstream station to the downstream station by finding the difference in time between peak flows. Streamflow measurements were lagged according to these time estimates.

Results and Discussion

Flow Patterns in the Lower Santa Cruz

Tucson Water was aware of the fact that water levels in the Lower Santa Cruz varied daily, but had not quantified these changes. The authors first analyzed the outflow from Agua Nueva and found dramatic changes in discharge levels on very short time scales. Figure 5 shows a graph of discharge from the facility over time for a 24-hour period. A drop in flowrate from 20 cfs (cubic feet per second) to 10 cfs occurs in just 10 minutes (around 10:00am)

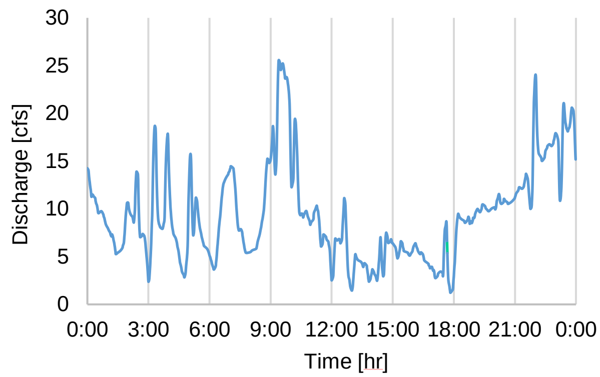

Figure 5: Reported outflow from Agua Nueva on 10/18/2016 showing high variability on small time frames

This outflow data is reported from Agua Nueva by mass balance. The outflow to the river is not gaged, but sensors are in place to let the facility know how much water is coming into the facility, and how much it is sending elsewhere (constructed recharge basins, parks, golf courses, etc.). The remainder is calculated by finding the difference between inflow and known outflows and reported as discharge to the river, down to a 1 minute average. Because of this method, it is possible that this data is especially noisy, but it shows high variability in outflow nonetheless.

To learn more about daily trends in river flow on a broader scale, peaks in daily outflow were of interest. The 24-hour outflow from Agua Nueva was analyzed for 366 days to find the hour of the day in which peak outflow occurred. This data was then normalized to reflect the probability of peak outflow occurring at a certain time. Figure 6 shows the results of this analysis, in which two daily peaks can be seen. The first occurs at 10:00 a.m., and the second around midnight. These peaks reflect peaks in household indoor water use. Water use is high in the morning when people take showers, brush teeth, etc. before leaving for school and work. This water travels to the facility, goes through treatment, and is released to the river around 10:00 a.m. Similarly, water use is high at the end of the day due to showers, dishwasher use, washing machines, etc.

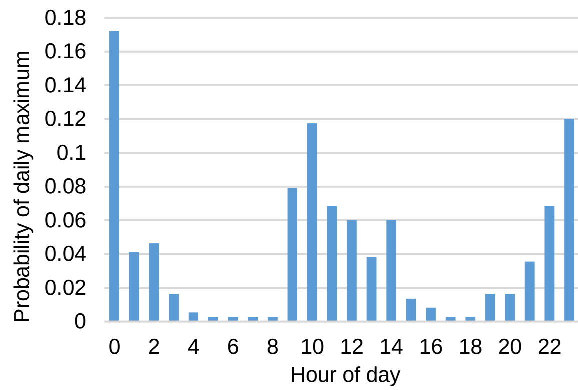

Figure 6: The histogram shows the probability of maximum discharge occurring during each hour of the day and reveals two daily peaks in outflow, at 10:00 a.m. and 12:00 a.m.

In addition to the discharge variation on short time scales, the amount of water sent to the river varied from day to day. On days when more water was sent to recharge basins or out for direct use, the river would experience low flow days during which the sand/gravel streambed was completely exposed. On other days, more water could be sent to the river, resulting in a full channel. Monsoon events also caused major irregularity in instream flow and transported large amounts of sediment. This disruption to the streambed made a simple stage-discharge relationship difficult to establish. Figure 7 displays these different states of the river.

Figure 7: A) Flow near Station 2 on a low flow day with the streambed exposed; B) Flow near Station 2 on a higher flow day with a full channel; C) Murky water near Station 4 after a monsoon event, showing evidence of significant sediment transport and disruption of the loosely-packed sand and gravel streambed

Travel Time Estimation

Travel times between stations were estimated by analyzing water level data and matching peaks between upstream and downstream locations. These travel times were highly variable and dependent on the level of discharge from Agua Nueva. Figure 8 shows water levels at Station 2 and downstream at Station 3 over a 12-hour period. A high peak occurring around 5:00 a.m. travels from Station 2 to 3 in 20 minutes, but a lower peak seen around 9:00am has a 36-minute travel time. In order to prepare for this variable travel time, a high and low estimate from station-to-station was obtained in order to have a different lag time to use during streamflow measurements on high- and low-flow days.

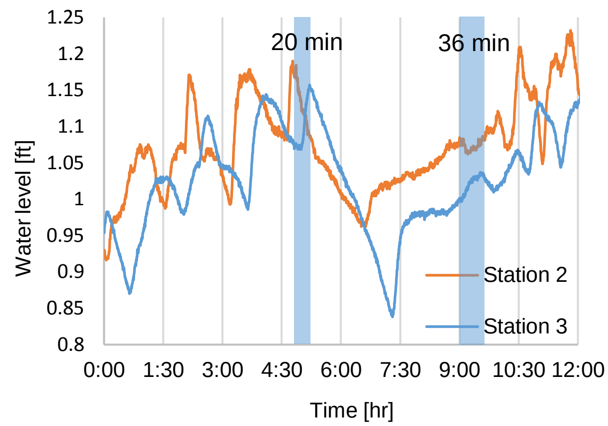

Figure 8: Water level at Station 2 and Station 3 show that travel time is dependent on river stage and varies depending on the level of the peak

Results of Mass Balance

When implementing the first part of the mass balance, i.e. subtraction of downstream discharge from upstream discharge, reproducible results were not obtained. Figure 9 shows select results for calculating recharge in each section on four different days. On each of these days, one or more sections were calculated as having negative recharge, which is, of course, an error. This reflects the application of an inaccurate lag time during streamflow measurements. If the upstream measurement was done after a peak had just passed, but the downstream measurement was done while the peak was present, the streamflow measurements reflected higher discharge downstream than upstream, resulting in a mass balance erroneously showing negative recharge.

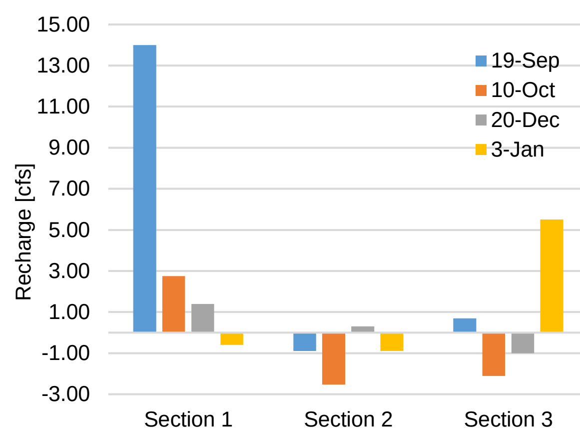

Figure 9: Select results from mass balance show negative recharge caused by inaccurate lag times applied to streamflow measurements

It is interesting to note that recharge in Section 1 was generally positive. It is unlikely that accurate travel times were more often applied when taking streamflow measurements in this section, but the results do reflect the increased infiltration in this reach. Section 1 was closest to the outflow where the stream experienced turbulent conditions from water falling out of the pipe, and the streambed was more loosely packed than further downstream. Even when an inaccurate travel time was applied, the magnitude of infiltration happening in this section likely dampened those effects and showed positive recharge when applying the mass balance.

Conclusions

The mass balance method did not provide conclusive results for this small-scale experiment. High temporal variability in outflow rate from the plant created significant error when downscaling this method from the large, volumetric scale for which it is currently used.

The method of deploying divers for surface water monitoring was successful in creating a temporary, low-cost installation that withstood monsoon conditions and continually measured water levels in a Southwestern stream. Results from surface water monitoring revealed the cyclic nature of daily water levels in the effluent-fed Lower Santa Cruz River.

Future Research

To better estimate recharge credits, an improved method is needed for determining effluent recharge. One option is to obtain high-resolution point measurements of infiltration rates, and apply them to a groundwater model, such as MODFLOW (Harbaugh, 2005). Temperature methods of infiltration measurement may provide better results, as the temperature gradient through the streambed is not as sensitive to sudden changes in outflow. The effects of bank storage also need to be quantified. During times of low flow, the river banks are unsaturated. As water levels rise, some of the water that appears to be lost to infiltration is likely stored in the banks. A study should asses the amount of recharge to the banks, and whether that reaches the local aquifer.

Ultimately, the method should be applied to a larger scale, spanning from Agua Nueva to the Tres Rios Water Reclamation Facility. This is the stretch of the Santa Cruz in which recharge credits are possibly being underestimated.

Further study should also assess the effect of extreme water level variability on the riparian habitat the river supports.

Acknowledgements

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