The Tucson region has historically relied on groundwater to meet the community’s water demand. To meet the Tucson Active Management Area’s goal of safe-yield by the year 2025, water providers are employing a variety of water sources, one being effluent. Wastewater treatment facilities adjacent to the Santa Cruz River treat a portion of the effluent to reclaimed water standards and convey it back to the city for reuse.

Constructed facilities are utilized to recharge effluent, where 100% recharge credits are accrued by stakeholders. Effluent discharged to the Santa Cruz River is conveyed through Managed Underground Storage Facilities where infiltration occurs in the natural streambed, accruing only a 50% recharge credit. High in nutrient concentration, the effluent creates a clogging layer in the streambed, drastically decreasing the infiltration rates. The effluent conveyed downstream beyond the facilities is considered “lost opportunities”, as it is not utilized in any way or receiving recharge credit.

Initiatives by stakeholders have been conducted to increase recharge rates of effluent in the Santa Cruz River. On a small scale, excavation and diversions requiring a significant amount of labor and maintenance, have demonstrated increased recharge rates temporarily.

With the value of reclaimed water increasing and a 100% recharge credit off of the river, there is no incentive for stakeholders to discharge effluent into the river, which provides an environmentally and culturally important riparian corridor. Stakeholders need to derive sustainable initiatives to improve the recharge rates of the effluent dependant Santa Cruz River, address the legislative constraints hindering the motivation to recharge in the river, and prioritize the health of the effluent dependent riparian corridor in their long term planning efforts.
INTRODUCTION

In Arizona, the water demand is met by four sources: surface water, Colorado River water, groundwater and reclaimed water or effluent (Avery et al., 2007). Pioneering the use of wastewater, Arizona was the first state to acknowledge effluent as a separate, usable source of water (WEF and WRRC, 2007). As an entire state, effluent accounts for three percent (3%) of Arizona’s water use (Megdal et al, 2011).

In the Tucson Active Management Area (Tucson AMA), groundwater has historically been the primary water supply to meet the demand of all sectors: municipal, industrial, agricultural, Indian, and riparian. The statutory goal of the Tucson AMA is to achieve safe-yield by the year 2025 and maintain it thereafter (ADWR Tucson AMA, 2010).

In the attempt to achieve safe-yield, multiple varieties of the four sources are being utilized as supplies to meet the demand: groundwater, poor-quality groundwater, in-lieu groundwater, Colorado River water through direct use of Central Arizona Project (CAP), recovered CAP water, reclaimed water, recovered reclaimed water, and surface water (ADWR Tucson AMA, 2010).

Without the availability of other surface water resources, Tucson has increasingly utilized its CAP allocation. With the city completely committed to complete to its CAP allocation 148,420 acre-ft per year (AF/year) (City of Tucson: Water Use), the need to acquire more supplies and reduce demand is essential. The City of Tucson’s Water Plan: 2000-2050 (published in 2004), projected “other” water sources would be required in the year 2020 to fulfill the projected demand (Figure 1). Other resources would include a variety of groundwater, surface water, and effluent supplies.

Effluent, and its use as reclaimed water, is playing an ever greater role in the city’s water portfolio. To address a projected shortfall in 2020, the City of Tucson recognized the potential to “fully utilize effluent for future supply”:

*Tucson Water recommends that by the year 2014 a commitment should be made to no longer discharge the City’s effluent that is not used in the reclaimed system to the Santa Cruz River.*

In southern Arizona, some riparian corridors have become dependent on the discharge of effluent from wastewater treatment facilities. The Santa Cruz River, downstream of Tucson is designated as *Aquatic and Wildlife, Effluent Dominated Water; Partial Body Contact, e.g. Wading (A&Wedw, PBC)* in Arizona’s Water Quality Standards (Tellman, 1992). Riparian richness is primarily driven by water availability,
generally declining with distance from the wastewater treatment facility discharging effluent to the stream (White, 2011).

![Figure 1: Projected Total Demand and Resources: 2000:2050](image)

Effluent discharged to the Santa Cruz River only accrues a 50% credit (A.R.S. §45-852.01.C.1), and when it is recharged at a constructed basin the recharge credit is 100%. Effluent use is also maximized when treated to reclaimed water standards and delivered to water providers for reuse.

Historically in Southern Arizona, effluent treated at wastewater facilities has been discharged to an adjacent river or wash only to be conveyed downstream to be removed from the region’s ecosystem, treated as a byproduct of the socio-economic formula. In recent decades, the value of effluent as an effective water resource has been identified and increasingly managed. Stakeholders in effluent are taking greater initiatives to treat the effluent to a reclaimed water standard to use directly or recharge at greater rates to accumulate recharge credits, which suggests more water being taken off the river.

This paper will evaluate the generation and utilization of effluent in the Tucson metropolitan area, specifically the effluent being discharged to the Santa Cruz River for managed recharge and delivered to basins for constructed recharge. Hydrologic studies demonstrate how human activity in the effluent dominated corridor has increased the recharge rates in the Santa Cruz River, if only temporary. Planning initiatives, legislative constraints, and recommendations of future initiative are also addressed.

**EFFLUENT ENTITLEMENT**
In 1979 the City of Tucson and Pima County approved and signed the 1979 Intergovernmental Agreement (IGA), Resolution No. 1979-78. The IGA assigned operational control of wastewater conveyance and treatment to the Pima County Regional Wastewater Reclamation Department. The City of Tucson was granted ownership of 90% of the effluent generated from Metropolitan Facilities, which at the time were Roger Road Wastewater Reclamation Facility (WRF) and Ina Road WRF. The remaining 10% is entitled to Pima County (Figure 2).

As part of the Southern Arizona Water Rights Settlement Act (SAWRSA) of 1982 (P.L. 97-293) and the subsequent Arizona Water Settlements Act of 2004 (P.L. 108-451-10/10/2004), the United States Department of Interior receives 28,200 AF/year of secondary treated effluent generated by the Metropolitan Facilities, on behalf of the Tohono O’Odham Nation. The utilization of effluent is managed by the Bureau of Reclamation.

Figure 2: Metropolitan Facility Effluent Entitlements

In 1989, the Arizona Supreme Court (Ariz. Pub. Serv. Co. v. Long) held the decision that effluent was neither surface water nor groundwater. Cities could put effluent to any reasonable use as they deemed appropriate and are not required to deliver effluent to any downstream appropriators (Megdal, 2011). The SAWRSA entitlement was grandfathered into the effluent entitlements of the Santa Cruz River, and is not affected by the 1989 court ruling. This makes SAWRSA a unique senior rights holder to the effluent generation.
The Conservation Effluent Pool (CEP) was identified in the Supplemental Intergovernmental Agreement (IGA) of 2000 between the City of Tucson and Pima County, which is a specified quantity of effluent to be used for conservation and riparian restoration projects. To utilize the CEP, both the City of Tucson and Pima County, the two parties to the IGA must agree upon its use. The maximum annual entitlement to the CEP is 10,000 AF. Through 2011, none of the CEP has been used.

In 2003, the IGA between the City of Tucson and Pima County (Resolution No. 2003-286) included Randolph Park WRF as a Metropolitan Facility. The Managed Recharge IGA in 2003 included other regional water providers a percentage to the City of Tucson’s 90% entitlement, and initialized the Lower Santa Cruz River Managed Recharge Project.

RECLAIMED WATER

Direct use of reclaimed water in the Tucson Active Management Area (Tucson AMA) has increased every year from 1988 to 2010. In 2006, 10% of Tucson Water’s demand was met by reclaimed water (ADWR: Tucson AMA, 2010), at a cost of $610 per AF (City of Tucson Annual Report, 2006). In 2013, the usage charge of Tucson Water’s reclaimed water has increased to $797 per AF (City of Tucson Reclaimed Water Rates), excluding the monthly service fees.

As part of the city’s long-range water supply plan, Tucson is committed to increasing the use of effluent as a non-potable resource. As population is anticipated to increase 2.5-3% annually, the City of Tucson is anticipating effluent for non-potable reuse to support the current percentage of the total water demand through the year 2050 (Tucson Water, Dotson).

UNDERGROUND STORAGE FACILITIES

Storage of water occurs at underground storage facilities (USFs) or groundwater savings facilities (GSFs). USFs are typically constructed basins (Megdal, 2007), injection wells or percolation basins. The water that infiltrates the constructed basin directly recharges the aquifer below (ADWR: Tucson AMA, 2010).

Adjacent to the Santa Cruz River, northwest of Tucson, two constructed USFs recharge CAP water via basins. The Lower Santa Cruz Replenishment Project (USF 71-561366, 11/28/23003 – 02/28/2019) is permitted to recharge 50,000 AF annually, not to exceed 600,000 AF; the Avra Valley Recharge Project (USF 71-564896, 03/27/1998 – 02/27/2018) is permitted to recharge 11,000 AF annually (Figure 7).
Managed recharge is accomplished without any construction in a river’s streambed (Megdal, 2007). A Managed USF utilizes the natural water-transmissive properties to allow water to percolate into the aquifer without the aid of constructed devises (ADWR: Tucson AMA, 2010).

“Managed underground storage facility” means a facility... that is designed and managed to utilize the natural channel of a stream to store water underground... through artificial and controlled releases of water other than surface water naturally present in the stream (A.R.S. §45-802.01.12).

The Santa Cruz River is designated as a Waters of the United States and is regulated in part by the Arizona Department of Environmental Quality (ADEQ). Permitting approved for Pima County Regional Wastewater Reclamation Department (PCRWRD), allows the discharge of effluent from the treatment facilities. The Arizona Pollution Discharge Elimination System (AZPDES) grants the authority to discharge treated domestic wastewater to the Santa Cruz River; the Aquifer Protection Permit (APP) grants authority to operate facilities on grounds in the Tucson AMA with known groundwater below the surface (PCRWRD, 2013).

As part of the Underground Storage and recovery Program, a non-recoverable percentage of recharge is obligated in most cases. The “cut to the aquifer” is to benefit the overall health of the aquifer and to aid in offsetting the over-drafting of groundwater. The cut to the aquifer varies among facility type and water type being recharged. CAP water recharged in a constructed basin holds a 5% cut to the aquifer; effluent (or reclaimed water) being recharged in a constructed basin has a zero percent cut; effluent being recharged in a Managed USF holds a 50% cut to the aquifer. Before the cut to the aquifer is calculated for Managed USFs, the riparian water demand is subtracted from the delivery to the USF. Therefore, the riparian water demand, typically calculated as an evapotranspiration (ET) loss of the effluent dependent riparian corridor, is not accounted for when calculating the 50% cut to the aquifer for effluent recharge in a Managed USF (ADWR: Tucson AMA, 2010).

**EFFLUENT GENERATION**

In 2011, Pima County Regional Wastewater Reclamation Department (PCRWRD) operated eleven wastewater reclamation facilities (WRF). Roger Road WRF, Ina Road WRF and Randolph Park WRF are identified as the three Metropolitan Facilities and service the vast majority of the Tucson region. In 2011, the Metropolitan Facilities generated 63,917 acre-ft (AF) of effluent (Figure 3).
The other eight facilities are considered the Sub-Regional Facilities: Arivaca Junction WRF, Avra Calley WRF, Corona de Tucson WRF, Green Valley WRF, Marana WRF, Mt. Lemmon WRF, Pima County Fair Grounds, WRF, Rillito Vista WRF. The Sub-Regional Facilities generated 6.3% (4,305 AF) of the effluent generated in 2011 and are not a focus of this investigation. However, Marana WRF, a Sub-Regional Facility, does discharge effluent to a channel tributary of the Santa Cruz River (289 AF in 2011). Marana WRF is not addressed in this study because of its very low discharge rate and is not part of the SAWRSA.

The vast majority of effluent generated and utilized from the Metropolitan Facilities come from Roger Road WRF and Ina Road WRF, both discharging treated effluent to the Santa Cruz River and are responsible for approximately 91% of the effluent generated in Pima County. None of the effluent generated at Randolph Park WRF is discharged to the Santa Cruz River, as all of it is conveyed to the City of Tucson’s reclaimed water system.

From 2004 to 2011, the Metropolitan Facilities generated the most effluent in 2006 (69,067 AF) and the least effluent in 2011 (63,917), and has experienced a reduction of effluent generation of approximately 720 AF/year ($R^2 = 0.74$) (Figure 4). The recent reduction in effluent production may be the result of economic conditions and water conservation efforts.
The influent conveyed to the Metropolitan Facilities is utilized in four ways: AZPDES discharge to the Santa Cruz River, delivered to the City of Tucson Reclaimed Water System, reused onsite, and as processed water. Processed water is not counted as part of the effluent total. In 2011, the Metropolitan Facilities received approximately 66,595 AF of influent, delivering 13,417 AF (20%) to the City of Tucson Reclaimed System and discharging 50,354 AF to the Santa Cruz River under the AZPDES permit. The remaining 4% was utilized as reuse onsite, processed water or unaccounted for.

From 2004 to 2011, effluent discharged to the Santa Cruz River has also declined on an average of 552 AF/year ($R^2 = 0.91$), based on a linear regression (Figure 6). In the same time period, the effluent deliveries from the Metropolitan Facilities to the City of Tucson Reclaimed Water System have remained constant. From 2005 to 2011 the annual deliveries have averaged approximately 15,517 AF/year, constantly representing 23% of the effluent generated.
EFFlUENT RECHARGE

Four USFs are utilized to recharge effluent generated by Roger Road WRF and Ina Road WRF (Figure 7): Sweetwater Recharge Facilities (SRF), Marana High Plains Effluent Recharge Project (MHPERP), Santa Cruz Managed Recharge Project (SCMRP), and Lower Santa Cruz River Managed Recharge Project (LSCRMP) (ADWR USF Report, 2008).

SWEETWATER RECHARGE FACILITIES
Sweetwater Recharge Facilities (Permit No. USF 71-520083.0001: 05/19/2008 – 05/19/2028) is permitted to City of Tucson/Tucson Water and utilizes effluent generated at Roger Road WRF. Effluent delivered to Sweetwater Recharge Facilities (SRF) is accounted for as deliveries to the City of Tucson Reclaimed System. Under the IGA of 2003, effluent generated by Pima County at the Metropolitan Facilities will be delivered to the City of Tucson at the Sweetwater Recharge Facilities and at Randolph Park WRF, where direct delivery will be employed.

SRF officially began operations in 1983. From 1984 to 1989, SRF conducted its Demonstration Phase; from 1989 to 1997 the Development Phase was completed. Now in its Full-Scale Phase, SRF currently utilizes eight recharge basins totaling 17.3 acres and six extraction wells for recovery (Figure 8).

![Figure 8: Sweetwater Recharge Facilities Site Map](image)

Demonstration basins were utilized to determine the hydrologic feasibility of the basin recharge process and potable water was delivered to the basins to determine infiltration rates. The wetting cycles ranged from 18 to 83 days and the average infiltration rates were slightly greater than 1 ft/day.

In 1989 basins RB-001 through RB-004 were constructed on the west bank of the Santa Cruz River. The basins were excavated 10 to 15 feet below the ground surface to expose the more permeable sediments. Tertiary-treated effluent was delivered from the Reclaimed Water Treatment Plant to the
basins, which produced algae growth and decreased infiltration rates. To maintain the optimum rates of infiltration, the duration of drying was increased, which allows the fine sediments and algae to be cracked and reduce clogging. “Ripping” a basin uses mechanical equipment to break-up the surface of the basin which has been clogged. In 1994, secondary effluent started being delivered to the basins.

In 1997 basins RB-005 through RB-008 and the Sweetwater Wetlands were completed on the east bank. The permitted recharge was increased to from 3,200 AF/year to 6,500 AF/year and infiltration rates averaged approximately 2.3 ft/day. The current permit allows for 13,000 AF/year of recharge, which is in anticipation for planned expansion of SRF (Figure 9).

Off-channel basins are being investigated as well as Constructed In-Channel facilities (Tucson Water, Kmiec and Thomure). The current operations of Sweetwater maintain 100% of its recharge credits, as they are elements of a constructed USF outside of a natural channel and are recharging effluent. The Silverbell Expansion and the Northeast Expansion would also maintain 100% recharge credits. It is unclear how the Constructed In-Channel facilities will be managed or even allowed.
MARANA HIGH PLAINS EFFLUENT RECHARGE PROJECT

Marana High Plains Effluent Recharge Project (MHPERP) (Permit No. USF 71-563876.0006: 11/24/2008 – 11/24/2028) is permitted to Pima County Regional Flood Control District and the Town of Marana, and recharges surface water diverted from the Santa Cruz River. As the majority of surface flow in the Santa Cruz River is effluent, the project focuses on the recharge of effluent during non-storm conditions. The facility consists of an equalization basin and four recharge cells, totaling 4.5 acres (Figure 10). Fine sediments are settled in the equalization basin before effluent is conveyed to the recharge cells.

Figure 10: Marana High Plains Effluent Recharge Project Site Map

MHPERP has progressed in three phases. In Phase 1, MHPERP was permitted to recharge 350 AF/year using the four (4) recharge cells and the equalization basin, constructed in 2002. During Phase 2, the permitted recharge was 450 AF/year after the enhancement trenches were constructed in Recharge Cells 1, 3, and 4. In Phase 3 (through 2011), MHPERP is permitted to recharge 600 AF/year utilizing the re-excavation of Recharge Cell 2. The USF Permit allows the facility to carry out enhancement projects to maximize recharge and increase the permitted recharge accordingly.

In the first three years of operation, from 2004 to 2006, MHPERP averaged 155 AF/year of recharge with 18% lost to evapotranspiration (ET); from 2009 to 2011, the facility averaged 408 AF/year of recharge with 4% lost to ET (Figure 11).

In 2007, the recharge rate nearly doubled from the previous year. No direct indicator was acknowledged for the significant increase in the Annual Monitoring Report of 2007. In 2011, the
average monthly infiltration rates ranged from 0.11 ft/day in September to 2.43 ft/day in November. The average annual infiltration rate for 2010 and 2011 were 0.57 ft/day and 0.54 ft/day, respectively.

Regular maintenance performed to the recharge cell bottoms has been observed to increase recharge significantly. The presence of fine grain materials at the recharge cell bottoms is believed to be responsible for less than expected recharge rates.

Similar to Sweetwater Facilities, MHPERP is recharging effluent off channel in a constructed facility and maintains 100% of its recharge credits. No cut to the aquifer is required for MHPERP.

SANTA CRUZ MANAGED RECHARGE PROJECT

Santa Cruz Managed Recharge Project (SCMRP) (Permit USF 71-545944: 05/05/2000 – 05/31/2019) is permitted to the City of Tucson/Tucson Water and the United States Bureau of Reclamation. SCMRP is approximately 5.1 miles of the Santa Cruz River, from Roger Road to Ina Road (Figure 7). SCMRP utilizes effluent generated at Roger Road WRF as its source water, which is discharged to the Santa Cruz River. Effluent conveyed beyond Ina Road is not recharged within the SCMRP.

The SCMRP is permitted to recharge 9,307 AF/year. In 2011, the SCMRP recharged 6,100 AF. Daily discharge volumes from Roger Road WRF, Ina Road WRF, and the USGS stream gauge at Cortaro Road are utilized to calculate the daily recharge volumes for SCMRP:

\[
Recharge_{SCMRP} = 0.732(Roger\ Rd.+Ina\ Rd.-Cortaro\ Rd.) - \frac{580}{365^*}
\]

*366 for non-leap years
Recharge is only accounted for on “Non Storm Flow Days” as the permit is only applicable to effluent. Storm flow days occur when the calculated daily recharge is negative, in which recharge is set to zero. SCMRP is a Managed USF; 50% of the recharged effluent is cut to the aquifer to contribute to the general health of the aquifer below. The remaining 50% of the recharged effluent is split 50/50 by the two permit holders: The City of Tucson and The Bureau of Reclamation.

LOWER SANTA CRUZ RIVER MANAGED RECHARGE PROJECT

Immediately downstream of the SCMRP is the Lower Santa Cruz River Managed Recharge Project (LSCRMRP) (Permit No. USF 71-591928: 11/04/2003 – 11/30/2023), permitted to City of Tucson, Town of Oro Valley, Town of Marana, Metropolitan Domestic Water Improvement District, Cortaro-Marana Irrigation District, Cortaro Water User’s Association, Avra Valley Irrigation Drainage District, Flowing Wells Irrigation District, and Pima County. The Bureau of Reclamation and the Spanish Trail Company hold Water Storage Permits and participate through separate agreements with other parties.

LSCRMRP is approximately 17.9 miles of the Santa Cruz River, from Ina Road to Trico Road (Figure 7). LSCRMRP utilizes effluent generated at Roger Road WRF and Ina Road WRF as its source water, which is discharged to the Santa Cruz River and conveyed downstream beyond Cortaro Road. Effluent conveyed beyond Trico Road is not recharged within the LSCRMRP. Similar to SCMRP, 50% of the calculated recharge is cut to the aquifer, as the LSCRMRP is a Managed USF recharging effluent in a natural channel.

LSCRMRP is permitted to recharge 43,000 AF/year. In 2011, LSCRMRP recharged 19,000 AF. Daily discharge volumes from Roger Road WRF and Ina Road, daily recharge volumes from SCMRP, and USGS stream gauges at Cortaro Road and Trico Road are utilized to calculate the daily recharge volumes for LSCRMRP:

\[ Recharge_{LSCRMRP} = Recharge_{SCMRP} - ET_{LSCRMRP} \]

ET is assigned to be constant: 1.59 AF/day for SCMRP and 2.97 AF/day for LSCRMRP. Similar to SCMRP, recharge is only accounted for on “Non Storm Flow” days as the permit is only applicable to effluent. Storm flow days occur when the daily effluent generated by Roger Road WRF and Ina Road WRF is less than the summation of daily discharge at Trico Road, SCMRP recharge and losses to ET.

Storm flow days can and have occurred separately for the SCMRP and the LSCMRP (Figure 12). From 2004 to 2011, Non Storm Flow days at Trico Road have remained fairly constant at approximately 345
days/year. During the same time period, the number of non-storm days of for the SCMRP and the LSCRMRP increased from less than 250 days/year to approximately 345 days/year.

The number of Non Storm Flow days per year has a direct impact on the annual recharge each facility accounts for. Since recharge to be accounted for can only occur on Non Storm Flow days, the more Non Storm Flow days in a given year the more available effluent is available to be counted towards recharge.

From 2004-2011, the annual recharge volumes for SCMRP and LSCRMRP and the annual Non Storm Flow days discharge at Trico Road have two distinct and inverse phases (Figure 13). Annual recharge volumes at the managed recharge projects consistently increased from 2004 to 2008, while the discharge at Trico Road consistently decreased. From 2009 to 2011 the opposite trends occurred: recharge decreased sharply in 2009 then leveled off and discharge at Trico Road increased sharply then leveled off.
The discharge of effluent at Trico Road is a major concern to the stakeholders of SCMRP, LSCMRP, and the Tucson AMA as a whole. Effluent flow at Trico Road is conveyed beyond the two managed recharge projects and out of the Tucson AMA. Considered by many as “lost opportunities”, the discharge is not recharged, or put to any beneficial use.

PIMA COUNTY REGIONAL FLOOD CONTROL DISTRICT

From 2007 to 2012, Pima County Regional Flood Control District (PCRFCD) has conducted nine augmentations to the Low Flow Bank soil-cement bank protections along the Continental Ranch Segment of the Santa Cruz River (Figure 14). From Cortaro Road to downstream of Twin Peaks Road, four repairs were performed in 2007, four (4) augmentations were performed in 2010, and one was completed in 2012 (Krieski, PCRFCD, 2012).

As the low flow channel conveys effluent downstream, the incised channel could align adjacent to the toe of the soil-cement bank protection. The consistent presence of the low magnitude discharge could cause erosive losses to the bank protection (Figure 15).

Reoccurring improvements of the soil-cement bank protection infrastructure has been necessary along the Continental Ranch Segment, as the low flow effluent channel has regularly has been aligned with the toe of the Low Flow bank protection.

Figure 14: Continental Ranch Segment, Santa Cruz River (Krieski, PCRFCD, 2012)
In May and June of 2012, two realignment projects on the effluent low flow channel were performed to divert the flow away from the east bank in preparation of repairs. On May 4, 2012, a 1600 ft channel was excavated adjacent to the west of the existing channel (Figure 16A).

Evaluating the USGS stream gauges upstream and downstream of the excavation, it is not possible to generate an outcome regarding any changes in infiltration as a result of the exaction (Figure 17A, Figure 17B). The exaction is assumed to have negligible impact on the infiltration rates of effluent being conveyed from Cortaro Road to Trico Road. The short length of the exaction, the compaction of the
soils from the heavy machinery, and the potentially low permeable soils of the alignment may all be factors to the negligible impact on the downstream surface discharge.

From May 21 to June 4, 2012, the channel was diverted to an existing dry low flow channel, parallel to the current channel. The diversion was approximately 6,100 ft and lasted for 14 days (Figure 16B).

Correlating to the same time period of the diversion, the USGS Gauge at Trico Road recorded zero cfs for seventeen complete days, from May 22 to June 7, 2012 (Figure 18A, 18B). The approved USGS data during this time period demonstrate that all of the effluent discharged to the Santa Cruz River from Roger Road WRF and Ina Road WRF was infiltrated into the streambed or lost to ET. No effluent discharge was conveyed downstream at Trico Road.

Downstream of the diversion at Twin Peaks Road, PCRFCD conducted manual stream gauge measurements on June 4, 6, 13, 20, and 29, 2012. A calibration measurement was conducted at Cortaro Road on June 4, 2012 at approximately 10:30 am (Table 1).
Table 1: Stream Gauge Calibration (06/04/2012)

<table>
<thead>
<tr>
<th>Time</th>
<th>PCRFCD Calibration</th>
<th>USGS Provisional</th>
<th>USGS Approved</th>
</tr>
</thead>
<tbody>
<tr>
<td>10:15 AM</td>
<td>--</td>
<td>23</td>
<td>25</td>
</tr>
<tr>
<td>10:30 AM</td>
<td>22</td>
<td>24</td>
<td>25</td>
</tr>
<tr>
<td>10:45 AM</td>
<td>--</td>
<td>24</td>
<td>27</td>
</tr>
</tbody>
</table>

The peak discharge attenuation (travel time) was calculating utilizing the USGS stream gauge discharge data at Cortaro Road and Trico Road. A reach of approximately 16.4 miles, the peak discharge attenuation during the diversion was approximately 13 hours (Figure 19).

![Figure 19: Peak Discharge Attenuation (05/11/2012 – 06/16/2012)](image)

The travel time correlates to a velocity of about 1.3 miles per hour (mph), or 1.9 feet per second (fps). At the calculated velocity, the attenuation from Cortaro Road to Twin Peaks Road is approximately 1.6 hours. The discharge measurements at Twin Peaks Road attempted to capture peak flow conditions. All measurements were taken within an hour of the expected peak discharge, 1.6 hours after the peak flow conditions measured and recorded by the USGS upstream at Cortaro Road (Table 2).

Table 2: Santa Cruz River Discharge and Loss (06/04/2012 – 06/29/2012)

<table>
<thead>
<tr>
<th>Date</th>
<th>Time</th>
<th>Discharge (cfs)</th>
<th>Time**</th>
<th>Discharge (cfs)</th>
<th>Loss (%)</th>
</tr>
</thead>
<tbody>
<tr>
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<td>4:45 PM</td>
<td>28</td>
<td>3:15 PM</td>
<td>44</td>
<td>16</td>
</tr>
<tr>
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<td>5:10 PM</td>
<td>30</td>
<td>3:45 PM</td>
<td>42</td>
<td>12</td>
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<td>4:00 PM</td>
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<td>3:20 PM</td>
<td>54</td>
<td>4</td>
</tr>
</tbody>
</table>
The increasing discharge at Cortaro Road is a function of the artificially controlled outflow of effluent from Roger Road WRF and Ina Road WRF. The increase in discharge at Twin Peaks Road is also a function of the effluent releases, and demonstrates a reduction in losses over the twenty-five day duration of measurements.

Similar results have demonstrated a reduction in saturated hydraulic conductivity (KSAT) since the last major storm (Figure 20). In January of 1995, following a series of winter storms, the KSAT of the effluent Santa Cruz River was measured to be 37mm/hr; after almost six months of non storm flow conditions, the KSAT decayed exponentially to 11 mm/hr (Lacher, 1996).

![Figure 20: KSAT vs. Time Since Last Major Storm Event](image)

The losses, where ET is assumed to be constant and negligible, from the PCRFCD measurements were plotted against the number of days since the end of the diversion (June 4, 2012). A logarithmic regression shows (Figure 21) very similar results to that of time since major storm (Lacher, 1996), for both losses in discharge (cfs) and losses as a percentage (%).
The losses during the diversion and the three days following the diversion were compared to the calculated recharge volumes of the LSCRMRP. The recharge rates (AF/day) and percentages (%) of the total effluent were analyzed before, during and after the no flow conditions at Trico Road (Figure 22).

During the zero flow conditions at Trico Road (May 22 to June 7, 2012), there was a clear increase in recharge volumes per day, as well as recharge as a percentage of the total effluent. It is also evident that recharge generally decreased over time during the no flow conditions at Trico Road. A linear regression of the three time periods shows distinct correlations between the total effluent and the
recharge volumes (Figure 23). Before and after the no flow conditions, recharge was equivalent to approximately 67% of the total effluent, 74% during the no flow conditions.

Figure 23: Linear Regression of Total Effluent vs. Recharge

BUREAU OF RECLAMATION

From January to October, 2011, the Bureau of Reclamation conducted the Enhanced Recharge Demonstration Project, Increasing Treated Effluent Recharge Rates in the Santa Cruz River, Tucson Arizona (ERDP). The goal of the project was to facilitate a collaborative effort that would construct, operate and evaluate multiple techniques to increase the infiltration of effluent in the stream bed of the Santa Cruz River. Excavated channels and diversions into adjacent channels were evaluated, as well as different wetting and drying cycles and different methods of maintenance.

The City of Tucson, Pima County Regional Wastewater Reclamation Department, Flowing Wells Irrigation District, Metropolitan Domestic Water Improvement District, and others contributed to ERDP.

The project planned to be in operation for six to twenty-four months, depending on the magnitude and frequency of storm flows in the Santa Cruz River and the resulting maintenance efforts. The ERDP consisted of a main excavated channel approximately 1,820 ft long and 10 ft wide. A secondary channel was excavated to divert the flows between the two, performing wet and dry cycles between the two channels. Flumes were placed at the divergence and confluence of the primary channel with the existing effluent channel to measure discharge into and out of the project (Figure 24).
The results of the project showed that spreading of surface flows across the channel bottom increase infiltration rates. After maintenance of the channel Infiltration rates increased 4-5 times, and decreased over time after the maintenance.

NOGALES INTERNATIONAL WASTEWATER TREATMENT PLANT

The Nogales International Wastewater Treatment Plant (NIWTP) is located adjacent to the confluence of the Nogales Wash with the Santa Cruz River, approximately ten miles north of the United States/Mexico international border. The facility treats approximately fifteen million gallons per day (MGD), approximately eighty percent (80%) being generated in Mexico (IBWC, Nogales). Effluent treated at the NIWTP is discharged to the Santa Cruz River, very similar to Roger Road WRF and Ina Road WRF.

In August of 2009, the NIWTP completed significant technologic upgrades. The improvements have significantly reduced the Nitrogen concentrations in the treated effluent, which has been determined to be harmful to riparian vegetation and wildlife, when in high concentrations.

Approximately 14 miles downstream of the NIWTP is USGS stream gauge: 09481740 Santa Cruz River at Tubac, AZ. To evaluate the effects on surface flow in the Santa Cruz River downstream of the NIWTP, the mean monthly discharge was analyzed for pre-upgrade (January, 2004 to August, 2009) and post-upgrade (August, 2009 – September, 2012) conditions. The average mean monthly discharge was derived for each calendar month (Figure 25).
The plot demonstrates that eleven (11) of the twelve (12) calendar months experienced reduced surface flows downstream of the NIWTP. The effluent discharge rates from the NIWTP were not evaluated in this analysis and are assumed to be constant. If ET is assumed to be negligible and constant, than the reduced surface flows demonstrates an increase in streambed infiltration of both effluent and stormwater flows, downstream of the NIWTP.

REGIONAL OPTIMIZATION MASTER PLAN

In Pima County, similar upgrades to the wastewater facilities are currently being conducted. Upgrades to Ina Road WRF are anticipated to be completed by the year 2014, and Roger Road WRF is scheduled to be completed by 2015. The improvements to the facilities will fulfill the current and future regulatory requirements of ADEQ regarding the concentrations of ammonia and nitrogen discharged into the Santa Cruz River (ROMP, PCRWRD, 2007).

The current capacities of Roger Road WRF and Ina Road WRF, are 32 MGD (35,872 AF/year) and 37.5 MGD (42,038 AF/year), respectively. The future capacities, by the year 2030, are 32 MGD (35,872 AF/year) and 50 MGD (56,050 AF/year), respectively. The increased capacity is anticipated to serve the growing population of the greater Tucson metropolitan area.

The planned improvements to Roger Road WRF and Ina Road WRF, and the subsequent improvements to the water quality of the treated effluent also have significant impacts to the Santa Cruz River and the Tucson community.
Clogging layers in the effluent dominated Santa Cruz River have been documented in previous studies (Galyean, 1996; Lacher, 1996; Treese et al., 2009; Case, 2012). Also known as “schmutzdecke”, the black anaerobic layer is the result of physical, biological and chemical processes. Algae growth and the settlement of fine sediments occur within the pore spaces of the river’s surface bottom. The clogging layer reduces the infiltration of surface flows in the river.

The discharge of high-quality, low-nutrient effluent could greatly reduce clogging in a river’s stream bed, historically dependent on effluent (Case, 2012). The ROMP upgrades are expected to increase infiltration in the Santa Cruz River downstream of Roger Road WRF and Ina Road WRF, very similar to the Santa Cruz River downstream of the NIWTP.

“CONSTRUCTED” MANAGED RECHARGE

Building infrastructure within the river bottom of the Santa Cruz River to encourage the infiltration of has been suggested by planners and designers for years. The intentions are to slow down, spread out and divert flows for greater residence time within the channel which would provide greater opportunity for infiltration (Figure 26A, Figure 26B). The feasibility to build such infrastructure is unclear, as the legislation regarding a Managed USF may not allow for such construction. The maintenance would also be extensive, excavating sediment being consistently transported by the perennial effluent flow (PCRFCD, 2011), as well from the storm flows (Meixner, 2009).

LONG TERM PLANNING

The most comprehensive planning of water management in the Tucson region is Water & Wastewater: Infrastructure Supply & Planning Study, a City of Tucson and Pima County Cooperative Project released in 2009. Both long term projections and planning strategies are presented, all very consistent with traditional water management practices: to accommodate the growing population of the region,
greater water supplies will be needed which will require thorough investigations. Diversifying the water portfolio with create a more robust and resilience to shortages. Encouraging greater efforts in water conservation, efficiency and education are increasingly necessary. Uncertainties in planning for the future are eminent; constant reevaluations of water management plans are required.

A unique component to the plan is the 2011-2015 Action Plan for Water Sustainability. The plan focuses on four (4) categories of concern in the long term plan, with recommendations to serve as the foundation of a sustainable future: water supply, demand management, comprehensive integrated planning, and respect for the environment.

The management of effluent is addressed as a concern for water supply. Traditionally used in part as reclaimed water, effluent must be considered for other uses as a way to maximize the supply portfolio of the community. The important factor is to match the needs of the user with the most effective and resource-efficient water source. According to the plan, the success of these recommendations would be indicated by an increased amount of reclaimed water deliveries as well as an increased amount of effluent recharged both in constructed and managed facilities.

To address the concern of respect for the environment, it is understood that the future of the Santa Cruz River is uncertain. The amount of effluent in the river has a direct effect on the health the river. Too much effluent causes erosive damage, and too little would reduce the riparian footprint dependant on the perennial surface flow. Increasing the acreage of riparian habitat permanently preserved or restored would indicate achievement of environmental goals.

CONCLUSIONS & RECOMMENDATIONS

Historically, treated effluent has been managed as a waste byproduct of the urban water resources infrastructure. As the water demand of an increasing population increases and the resources of water supply stay fairly limited, effluent is playing a more important role in water providers’ portfolios. Effluent treated to reclaimed water standards has increased in monetary value 30.6% in the last seven (7) years and has fulfilled a steady percentage of Tucson’s growing water demand.

Constructed recharge facilities are improving operations and keeping maintenance routines to increase the recharge rates of effluent. Plans are being explored to expand, build more recharge basins, and deliver more effluent to the constructed USFs. Recharge in the constructed off-channel basins is encouraged, as the process recovers 100% of the recharge credits.
In 2011, the Santa Cruz Managed Recharge Project and the Lower Santa Cruz River Managed Recharge Project only recharged 65% and 44% of their permitted allocation, respectively. The facilities salvage only a 50% recharge credit; the other half being claimed as a cut to the aquifer to improve the aquifer’s general health. Effluent discharged beyond the two Managed USFs and out of the Tucson AMA, is considered “lost opportunity”.

To make the most efficient use of the effluent as a resource, water providers must decide what the most valuable use of effluent is for the community, the environment, and their customers. With only a 50% recharge credit, water providers have little incentive to discharge effluent to the Santa Cruz River. The effluent has a greater value being used off the river.

Regional stakeholders do have incentive to increase recharge rates in the Managed USFs, and also have obligations to the community to maintain healthy riparian ecosystems. The collaborative efforts are a very important component to addressing the challenge. Federal and state agencies working with local water providers, university researchers and community organizations strengthen the collective efforts, unite interests, and streamline the management of data.

Constructing in-stream recharge basins have been a planning consideration for years. The maintenance requirements, however, may be too extraneous to be practical. The legal ramification may be an obstacle for implementation as well. Revising A.R.S §45-802.01.12 to include the opportunities for artificial improvements to natural channel of a stream would be necessary to implement these structures and potentially increase recharge.

The ROMP improvements to Roger Road WRF and Ina Road WRF, slated for completion in 2014-2015, may eliminate all the other concerns of effluent recharge in the Santa Cruz River. The treatment plant upgrades are expected to reduce nutrient concentration and dramatically increase the infiltration rates, similar to the upgrades of Nogales International Wastewater Treatment Plant. The effects of the ROMP improvements will be analyzed vigorously. It is possible that no effluent will flow beyond Trico Road when the upgrades are complete. With more effluent being recharged closer to the treatment facilities, greater volumes will be contained upstream and available for recovery.

With any outcomes of the ROMP improvements, the recharge credits for Managed USFs recharging effluent in a natural river should be reevaluated. The 50% recharge credit encourages water to be taken off the river for a more beneficial use. With efficient recovery operations and greater recharge rates, the Santa Cruz River could be a successful storage facility while maintaining a valued riparian corridor.
Tiered recharge credits could be utilized to encourage more recharge of effluent in the Santa Cruz River. As recharge rates are demonstrated to increase, the recharge credit will also increase while still providing a cut to the aquifer. This will incentivize stakeholders to pursue action that increase recharge rates on a greater, more reliable scale. A recovery well system along the river would have to be implemented to retrieve infiltrated effluent to be put to a beneficial use. Recent hydrologic studies have demonstrated localized increases in recharge rates on very short time scales. Moving forward, stakeholders must cooperatively address the legislative constraints and pursue more sustainable initiatives to maintain increased recharge rates.
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