a living river

CHARTING SANTA CRUZ RIVER CONDITIONS
DOWNTOWN TUCSON TO MARANA

Santa Cruz River in Marana

SUPPLEMENTARY REPORT FOR 2013 TO 2021 WATER YEARS

SONORAN INSTITUTE

PIMA COUNTY

CITY OF TUCSON

TUCSON WATER

THE SANTA CRUZ RIVER
A LIVING ECOSYSTEM

The Santa Cruz River near downtown Tucson and from northwest Tucson to Marana flows year-round and provides the principal wetland habitat in the Tucson metro area. River flows are sustained by the release of effluent (highly-treated wastewater) from two regional reclamation facilities. In December 2013, Pima County completed the largest public works project in southern Arizona by investing over $600 million to upgrade the regional water reclamation facilities. Improved treatment affords the opportunity to improve the aquatic environment along the river, enhance cultural and recreational connections to the river, and increase re-use of reclaimed water.

The *Living River* reports were developed to annually gauge the health of this valuable ecosystem and track the impacts of our community's investment. This supplementary report summarizes data from the 2013–2021 water years. This series expanded in 2020 to include available data for the Heritage Project reach near downtown Tucson where Tucson Water started releasing effluent in 2019. The pages following this executive summary provide details on the water context and data for diverse indicators of river conditions.

All *Living River* reports can be found on the Sonoran Institute website at **www.sonoraninstitute.org**

CHANGES IN WATER QUALITY AND WETLAND CONDITIONS

- **Ammonia no longer limiting life:** Ammonia, which can be toxic to aquatic organisms, remains at low levels since the 2013 upgrade.
- **Oxygen availability not a stressor:** Essential for aquatic life, dissolved oxygen remained steady or increased.
- **Water clarity much improved:** Sediments and other particles carried in the water decreased, resulting in clear river water on normal non-flooding days. Elevated sediment levels in the water can increase water temperature, thereby decreasing available dissolved oxygen.
- **New flows near downtown Tucson:** Starting in June 2019, Tucson Water began releasing high-quality effluent into the Heritage Project reach. Wetland plants quickly established and dragonflies and other wildlife quickly found the new flows.
- **More diverse life:** Improvements in water quality allowed aquatic life in the river to rebound. Six species of fish, including the endangered Gila topminnow, and increased diversity of aquatic invertebrates (which include insects, crustaceans, and worms) have been observed. Longfin dace were released in the Heritage Project and downstream of Agua Nueva in 2022.
- **Variable flow extent:** The length of the flowing river has decreased and is more variable due to a combination of factors, including increased water infiltration from reduced nutrient levels, scouring floods, and flow management. In recent years flow extent has increased in some areas with fewer scouring floods and ash debris from upland wildfires possibly clogging the riverbed and reducing infiltration.
- **Wetland plants reduced in intermittently dry sections:** The release of effluent supports wetland plants and trees. There is a decrease in willows and increased variability in streamside plants in the sections of river that are periodically dry with the more variable flow extent.
- **Odors prevented from escaping from the reclamation facility:** New odor treatment technologies that are monitored daily have virtually eliminated odor complaints associated with the treatment process.

Monsoon flow in Heritage Reach

Cyclists on The Loop

Longfin dace, *Agosia chrysogaster*

OTHER OBSERVATIONS

- **Total effluent released to the river has decreased:** Since 2015, total effluent released into the northwest Tucson to Marana reach has decreased by an average of 13% compared to the 2013 baseline. Though stormwater is an important source of flows, effluent is still the primary source of water.
- **First dedication of water for the river's health:** With the first applications finally approved in 2021, water from the Conservation Effluent Pool is now used to sustain river flows specifically to benefit plants and aquatic wildlife.
- **Increased infiltration rates and groundwater recharge:** The amount of water that recharged local aquifers more than doubled between 2013 and 2020. This is likely from increased rates of infiltration resulting in part from improved water quality. Recharge decreased in 2021.
- **The river is popular for recreation and wildlife viewing:** Between June and September 2021, over 50,000 pedestrians and cyclists were observed on The Loop recreational trail along the river near St. Mary's Road. During the 2021 water year, 2,064 individuals participated in the eBird citizen science program, observing 251 different bird species along the river.
- **Many kids are seeing a flowing river for the first time:** The Living River of Words youth art and science program continues to provide the first contact with a flowing stream for local kids. The Santa Cruz River from northwest Tucson to Marana provided meaningful inspiration for youth art and poetry projects. To date over 4,500 young students have visited the river since 2015 as part of this program. In 2021, the program also included students from Ajo.

ASSESSING CONDITIONS

The Living River report evaluates conditions of the Santa Cruz River in the Heritage Project reach and from northwest Tucson to Marana using indicators (see table below) organized into six categories that represent a breadth of biological, chemical, physical, and social properties of the river. The indicators relate to conditions in the river channel and in the riparian areas, the areas next to and affected by the river.

The purpose of the Living River series is to monitor and report on wetland and riparian conditions at various intervals downstream of the effluent discharge points. As effluent flows downstream, it impacts and is impacted by the natural conditions of soils, vegetation, and the surrounding ecosystem. For the purposes of this study, the river is divided into a 1-mile Heritage Project reach and a 23-mile northwest Tucson to Marana reach. The latter is further divided into three sections delineated by their differing hydrology, geology, and adjacent land use: Three Rivers, Cortaro Narrows, and Marana Flats.

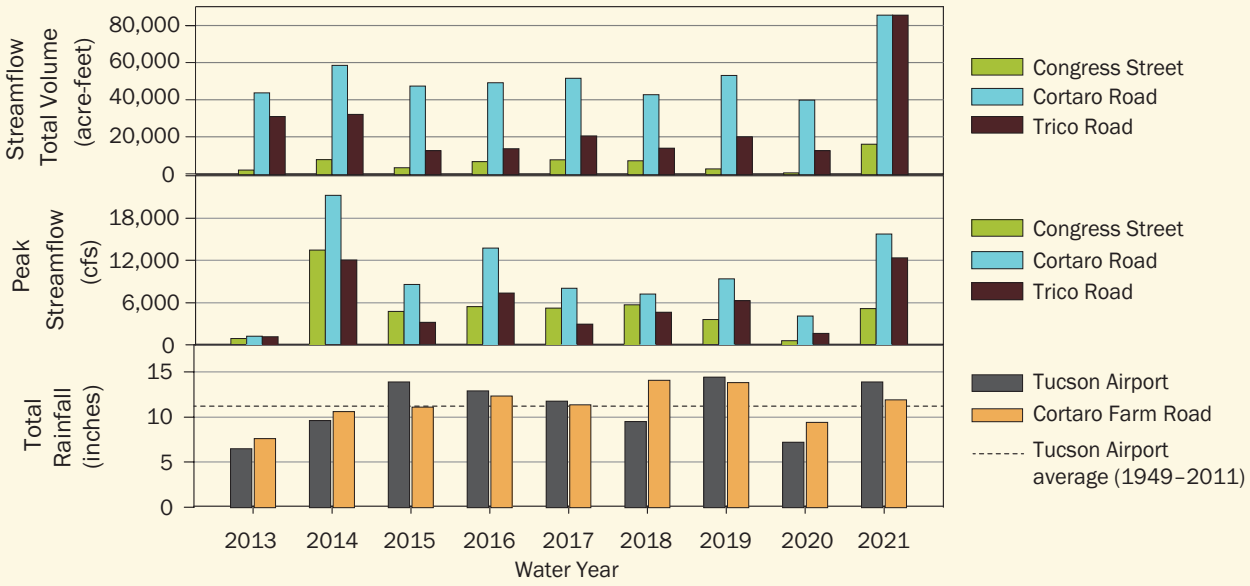
Data are collected and summarized by water year (October 1–September 30) and compared to the baseline conditions observed in the 2013 water year. This supplemental report shares data from all the water years to enable an easy viewing of trends and long-term patterns.

CATEGORY	PURPOSE	INDICATORS
Flow Extent	Water flowing in and out of the system determines available aquatic habitat.	• Miles of flow in June • Flow at Congress Street and Trico Road
Water Clarity	Solid particles in the water and on the riverbed can impact habitat and conditions for aquatic life.	• Total suspended solids • Turbidity • Percent fines on riverbed
Water Quality	Specific chemical conditions are necessary to sustain the river's animal and plant communities.	• Total dissolved solids • Ammonia • Dissolved oxygen • Biochemical oxygen demand • Metals
Aquatic Wildlife	Wildlife in the river integrate and reflect conditions of many factors of the surrounding environment.	• Fish • Aquatic invertebrates
Riparian vegetation*	Plant communities reflect changes in water quantity and quality.	• Wetland indicator status • Nitrogen affinity score • Riparian tree cover • Composition and cover in Heritage reach
Groundwater	Depth to groundwater provides a measure of aquifer recharge and must be monitored in highly managed ecosystems.	• Depth to groundwater
Social Impacts	Aesthetic factors directly impact people living or recreating along the river.	• Odor at reclamation facilities • Pedestrian and cyclist use of The Loop • Bird-watching

*Some riparian vegetation indicators only monitored from 2013–2016

Streamflow, Rainfall, and Water Budget

Streamflow, or the amount of water flowing in a river, provides an important context for the results of the indicators. Reclamation facilities continuously release water into the river, which accounts for the majority of daily streamflow. However, streamflow also includes stormwater, which is influenced by rainfall and the amount of impervious area (e.g., roadways) in the watershed. The Santa Cruz River watershed includes all of the land where stormwater flows toward the river. Seasonal floods are important for recharging aquifers, dispersing seeds, inducing seed germination, and clearing natural debris.



2013–2021 STREAMFLOW

Streamflow, measured in cubic feet per second (cfs), is the volume (cubic feet) of water flowing past a fixed point in one second. Streamflow is measured with a gage at Congress Street (in the Heritage Project reach) and gages at Cortaro and Trico Roads (both downstream of the Tres Ríos Water Reclamation Facility). Total volume sums all the water passing a gage, allowing comparisons of streamflow between water years. Peak streamflow is the largest volume of water flowing past a gage, allowing tracking of flood conditions.

At Congress Street and Cortaro Road, total streamflow has remained steady over the years. Flows at Trico Road have varied since the facility upgrades were completed in December of 2013, with increased days when there is no flow (see Flow Extent). With higher monsoon rainfall, total streamflow in 2021 was higher at all sites than any previous year since 2013.

2013–2021 RAINFALL

Rainfall totals from the Tucson International Airport (TIA) and near the river at Cortaro Farms Road (CFR) provide a general idea of how stormwater may have increased streamflow.

TIA has an annual average of 11 inches of rain. The most rain fell in 2019 with 15 inches (14 inches in 2015 and 2021). The historical average from 1949 to 2011 is 11 inches.

- Winter rains averaged 3 inches (range: 1–6)
- Summer monsoon rains averaged 6 inches (range: 2–12)*

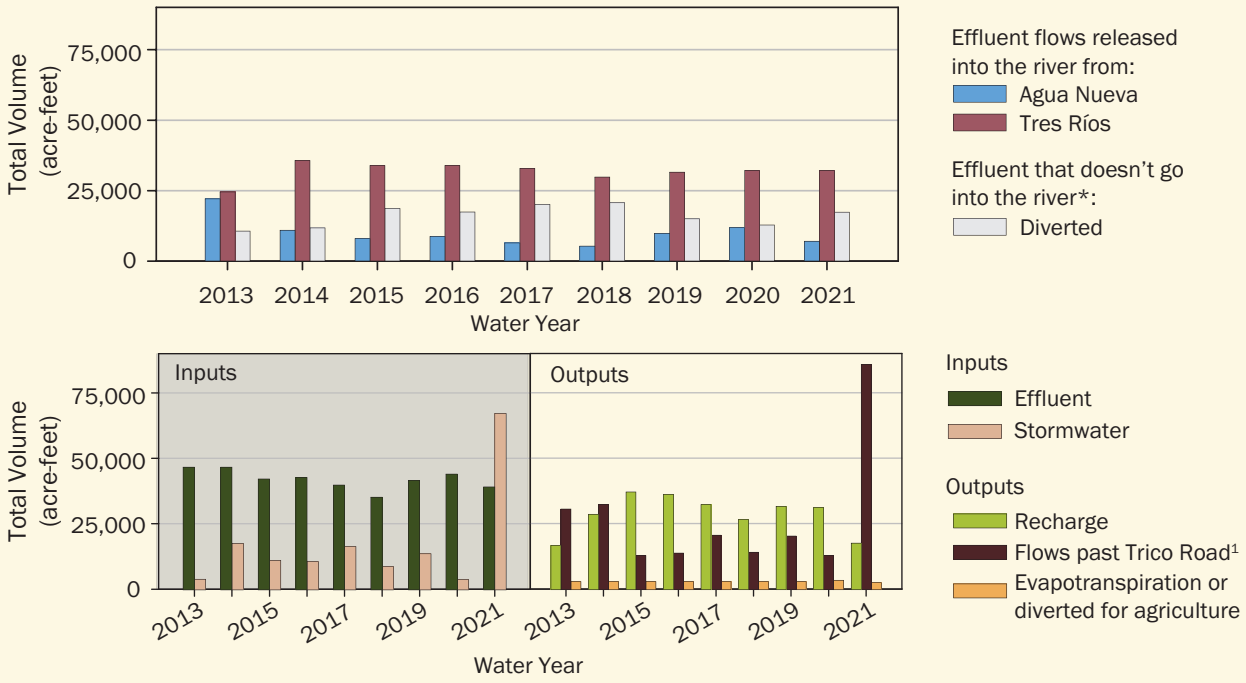
CFR has an annual average of 11 inches of rain. The most rain fell in 2018 and 2019 with 14 inches each year. This station was set up in 2012 and has no historical data.

- Winter rains averaged 3 inches (range: 1–6)
- Summer monsoon rains averaged 5 inches (range: 2–10)*

*2021 monsoon rainfall was double the average at both stations.

Streamflow, Rainfall, and Water Budget Continued

A water budget quantifies the water inputs and outputs. Inputs are effluent and stormwater, while outputs include water that does one of the following: flows past Trico Road (the end of the study area), evaporates or is used by wetland vegetation (a process called evapotranspiration), is diverted for off-channel recharge or agricultural use, or sinks into the riverbed to recharge the local aquifer. Volumes are totaled in acre-feet (AF), the number of acres that would be covered with water one foot deep. In this 23-mile stretch of river there are two managed recharge projects. Total recharge volume is calculated for effluent only and does not include stormwater. On days when the flow in the river includes stormwater, recharge is assumed to be zero for accounting purposes. Recharge is calculated by subtracting the sum of the flow past the Trico Road gage, evapotranspiration, and off-channel diversions from the total water released into the river.



* Includes effluent that is diverted from Agua Nueva either to the reclaimed system for irrigation or to recharge basins located outside the river channel.

1 Excluding days with stormwater, the volume of effluent flowing past Trico Road is: 2013 = 26,800 AF; 2014 = 13,400 AF; 2015 = 2,100 AF; 2016 = 3,800AF; 2017 = 3,700 AF; 2018 = 6,000 AF; 2019 = 6,000 AF; 2020 = 10,800 AF, 2021 = 16,800 AF

2013–2021 WATER BUDGET NORTHWEST TUCSON TO MARANA REACH

Starting in 2015, total effluent inputs have deceased by an average of 13% compared to the 2013 baseline. Total volume released from each facility changed in 2014 when the facility upgrades resulted in some wastewater being redirected to Tres Ríos and released downstream. From 2015–2018, more effluent was diverted from the river into nearby basins to recharge the local aquifer. Since 2019, diverted effluent decreased by an average of 4,000 AF (which increased Agua Nueva releases). Nearby recharge basins have previously reached the volume allowed by permits, but have now been below this level for several years. Reduced effluent from Agua Nueva and variable drying of the river in this reach (see flow extent) increased concerns for the endangered Gila topminnow. In 2021, water from the Conservation Effluent Pool guaranteed the release of a weekly average of 5 million gallons a day from Agua Nueva.

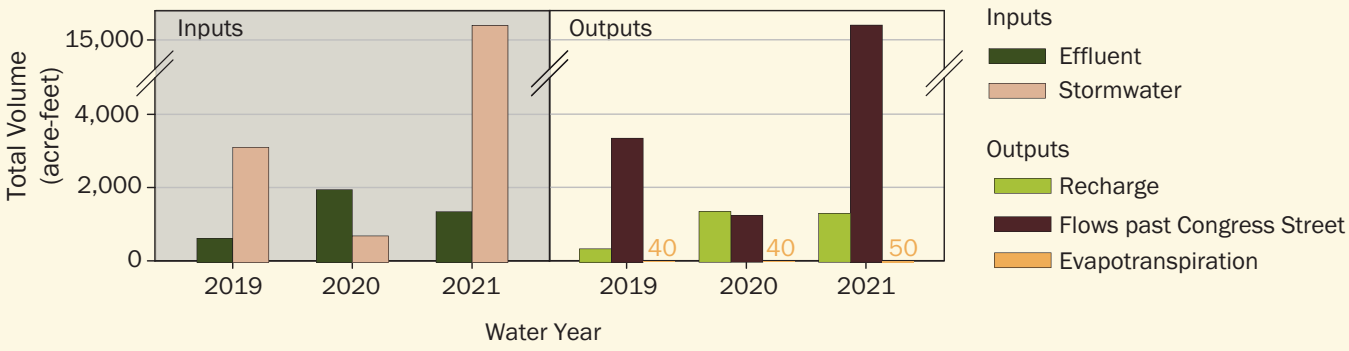
Total inputs increased with higher volumes of stormwater, especially in 2021 with its record monsoon rainfall. Recharge increased significantly, although it dropped in 2021 after ash flows following the 2020 Bighorn Fire covered the riverbed. Overall, increased recharge has reduced the amount of water that flows past Trico Road. Volumes of water diverted for agriculture or used by wetland vegetation are calculated annually or daily, respectively, for recharge calculations.

Streamflow, Rainfall, and Water Budget Continued

In the Heritage Project reach, the inputs are effluent and stormwater. Outputs include water that flows past Congress Street, evaporates or is used by wetland vegetation through evapotranspiration, or sinks into the riverbed to recharge local groundwater.

Tucson Water calculates the recharge in this roughly 1-mile long reach. Total recharge volume is calculated for effluent only and does not include stormwater.

Recharge is calculated by subtracting the sum of the flow past the gage at Congress Street and evapotranspiration, from the total water released into the river.



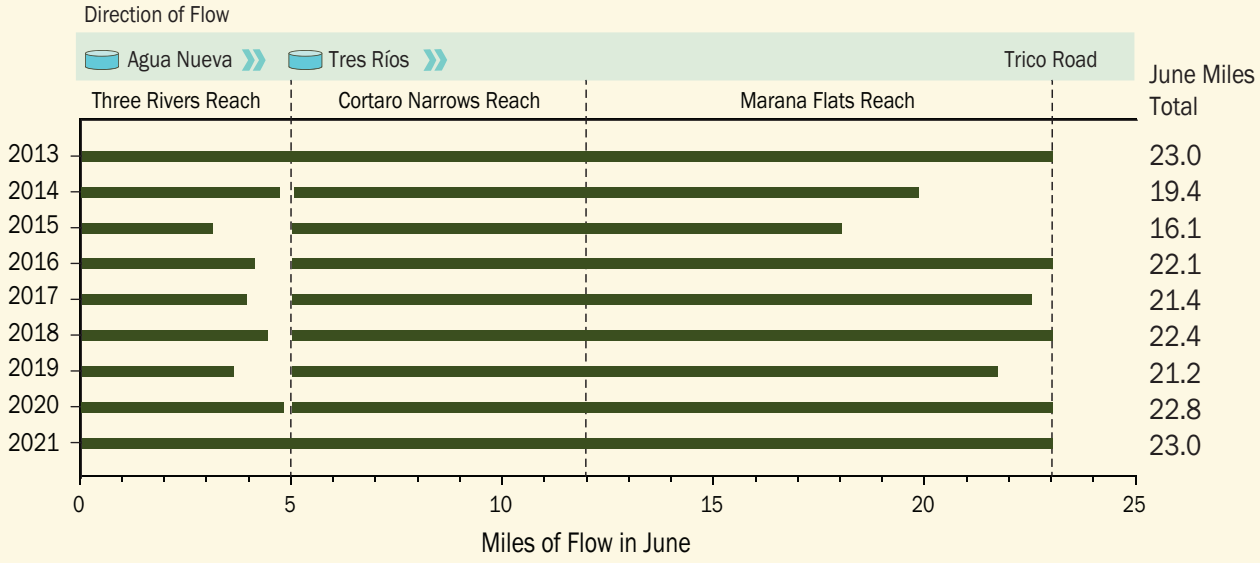
2019–2021 WATER BUDGET HERITAGE PROJECT REACH

Tucson Water started adding effluent to the Heritage Project reach near downtown in June 2019. Effluent provides most of the flow in the river near downtown. This was especially true in 2020 when stormwater flows were minimal. Much of the effluent sinks into the riverbed to recharge the aquifer prior to reaching Congress Street. The volumes of water used by wetland vegetation are considered as estimated constants in recharge calculations. Starting in 2021, water from the Conservation Effluent Pool provides water to support the riparian and wetland vegetation in this reach, although strong monsoon activity in 2021 also contributed a high volume of stormflow.

FLOW EXTENT: Northwest Tucson to Marana Reach

Measuring flow extent, or the distance the river is flowing, is a quick visual way to track changes in water inputs and outputs, while providing a rough measure of the quantity of aquatic habitat available. For example, longer flow extent may indicate high inputs and availability of habitat for aquatic life. Shorter flow extent may indicate reduced inputs or greater infiltration of water into the aquifer, which could decrease aquatic habitat.

Miles of flow in June from Agua Nueva outfall to Trico Road prior to the monsoon season determines the minimum extent of flow in each reach during the driest time of year. This is typically measured on one morning in mid-June. **Flow at Trico Road** estimates daily changes in maximum flow extent by counting the "dry days," or number of days with no streamflow at Trico Road, located at the downstream end of the study area.



2013–2021 RESULTS

Flow extent decreased and was more variable after the December 2013 upgrades. In June 2013, the river flowed uninterrupted to the end of the 23-mile study area, and continued another 5 miles further into Pinal County. Uninterrupted river flow occurred again in June 2021 for the first time since 2013, with the river reaching past the 23-mile study area. In other years, dry river stretches of varying lengths have formed between Agua Nueva and Tres Ríos reclamation facilities, and upstream of Trico Road.

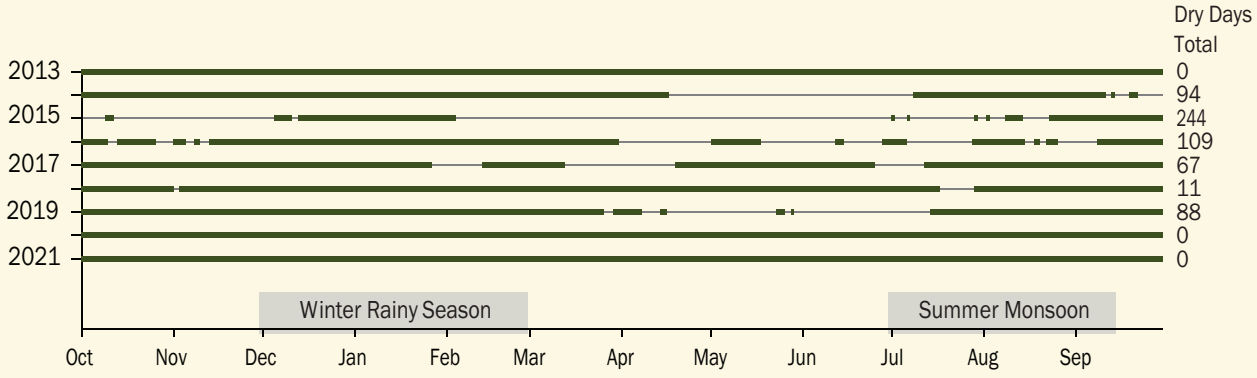
Reduced flow extent is primarily due to increased recharge following the input of cleaner water. However, many other factors influence flow extent. For example, we know that recharge increases after large floods scour the riverbed. The magnitude of the flood is important, with bigger peak flows in the previous year resulting in larger dry stretches in June. The longest dry stretch in the Three Rivers reach was in 2015. This follows the largest flood recorded during this study (see Streamflow)—one that peaked in 2014 at 21,200 cfs near the Tres Ríos facility, which is over twice the average flood peak during this study. Timing of floods may also play a role. Interestingly, the two years with the longest dry stretch in the Three Rivers reach (2015 and 2019) occurred in years with the least number of days since the last peak flow, because peak flows occurred in winter these years (see graph on next page). Conditions that influence the factors impacting flow extent vary by reach. These two relationships (magnitude and timing of peak floods) are not as predictive when trying to understand the variability in length of dry stretches we've seen in the Marana Flats reach.

FLOW EXTENT: Northwest Tucson to Marana Reach Continued

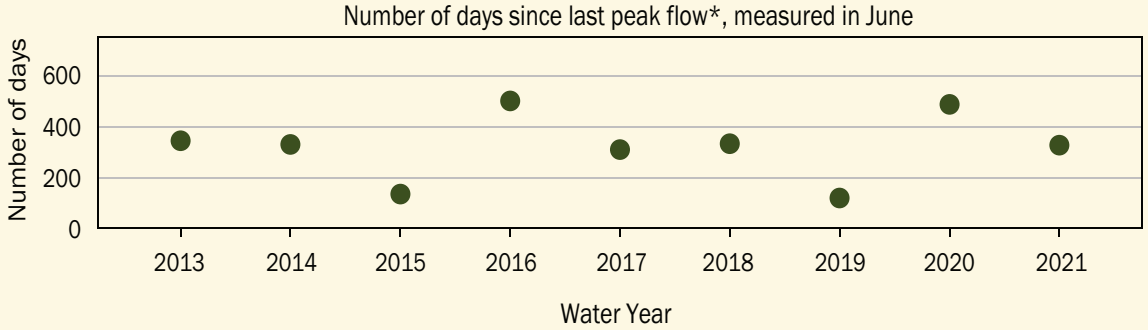
Water management is also an important factor and has likely contributed to the drying of the Three Rivers reach where releases from Agua Nueva have decreased (see Water Budget). In Marana Flats, the river is also diverted by an earthen berm into a channel to provide irrigation water for agriculture and water for recharge at Marana High Plains, a constructed recharge facility adjacent to the river. Flow extent in this area may temporarily increase on occasion when the berm fails and needs to be rebuilt. For example, the berm failed several times in 2016 and once again in 2020, and may have decreased the number of dry days at Trico Road at those times.

The daily flow at Trico Road has become more variable with dry days when there is no water in the river. The highest number of dry days occurred in 2015 and 2016 and has been declining since. In addition to increased recharge and human management of river flow, natural flood processes have likely influenced conditions at Trico Road. In September 2014, floodwaters moved the location of the low-flow channel and breached a berm along the El Rio Preserve, a former borrow pit near the start of Marana Flats. This allowed water to flow into the pit and form the wetlands at El Rio Preserve. In addition, the 2014 peak flood was the largest since the 2013 upgrade and may have further increased the infiltration rate. This combined with diversion of flow into the wetlands may have increased the number of dry days recorded in 2015. Floods also bring nutrients and sediments. Ash flows from the Catalina Mountains following the 2020 Bighorn Fire covered parts of the riverbed and contributed to the decrease in infiltration that allowed the river to flow farther.

Since 2017, flow at Trico Road has increased and in 2020 the number of dry or no flow days was zero for the first time since 2013. During this same time, the average volume of effluent and stormwater flowing in the river decreased (average total water in the river in 2017–2021 was 5,000 acre-feet less than the average total in 2014–2016). More flow at Trico Road even with less water in the river may suggest the rate of recharge is stabilizing or even decreasing.



Flow at Trico Road

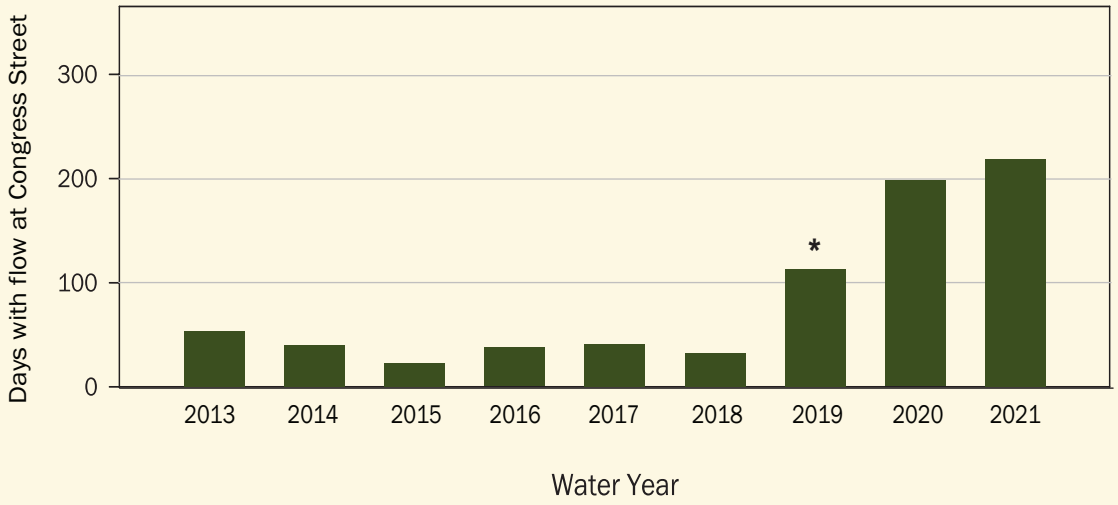


Water Year

*Peak flow is the highest flow measured in a water year. Number of days were fewest in 2015 and 2019 when peak flows occurred in winter just prior to the June measurement, and longest in 2016 and 2020 when the peak flows occurred in winter of the preceding water year.

FLOW EXTENT: Heritage Project Reach

Flow extent for the Heritage Project reach is measured in two ways. **Miles of flow in June** from the outfall prior to the monsoon season determines the minimum extent of flow during the driest time of year. This is typically measured on one morning in mid-June. Measuring June flow extent started in 2021. **Flow at Congress Street** estimates daily changes in flow extent by counting the "dry days," or days with no streamflow at Congress Street, located a little over 1 mile downstream of the outfall. A stream gage managed by U.S. Geological Survey has been recording streamflow at Congress Street from long before the Heritage Project started releasing flows. Since the Heritage Project is still so new and flows are highly dependent on the volume of water released, monthly monitoring of flow extent began in 2021.



*Santa Cruz River Heritage Project flows began June 24, 2019

2013–2021 RESULTS

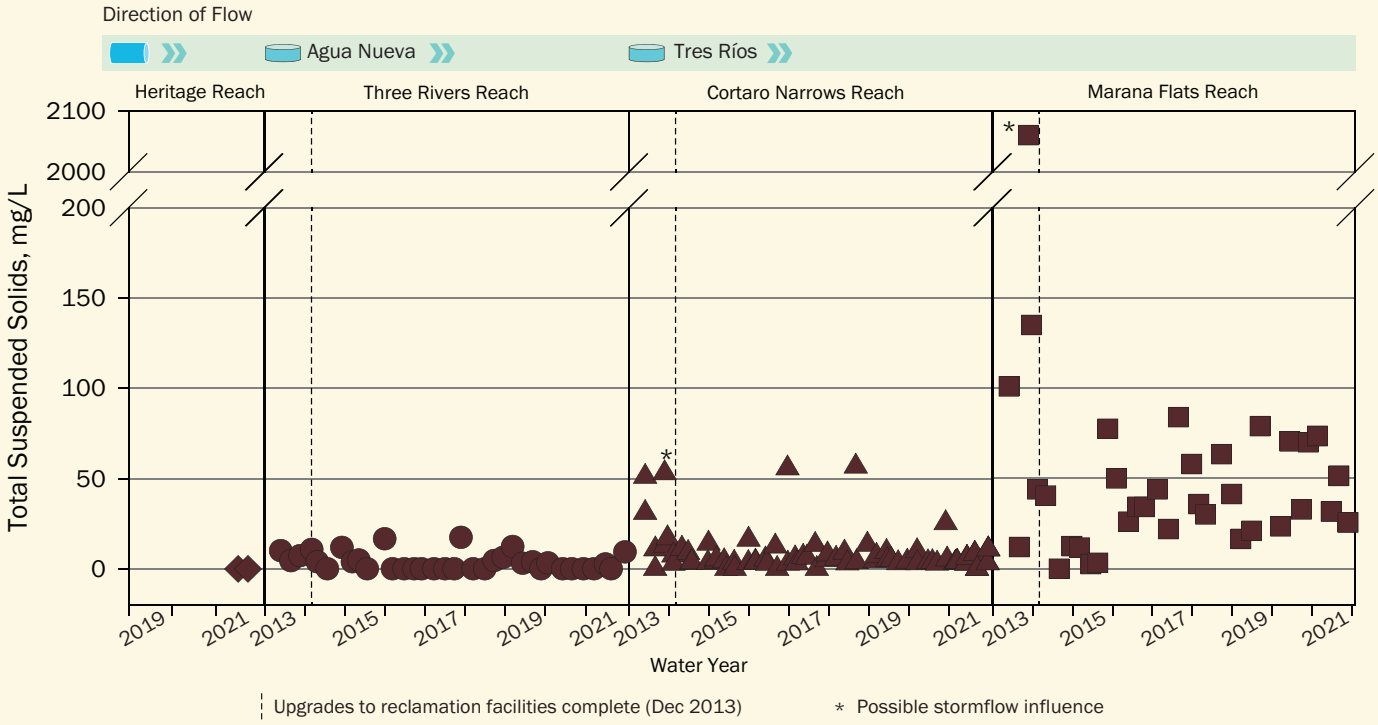
In June 2021, the river flowed approximately 1.6 miles from the Heritage Project outfall, past the Congress Street bridge, compared to approximately 2 miles from the Heritage Project outfall to Speedway in June 2020. The number of days with flow at Congress Street has significantly increased since the Heritage Project began. Prior to this, flows consisted only of stormwater. Though 2019 had 251 days with no flow at Congress Street, only 14 of these days occurred after June 24 when effluent flows were added to this reach of the river. In 2020, there were only 166 days with no flow at Congress Street. At least 31 of these days occurred during May 2020 when flows had to be reduced or turned off for a project to remove accumulated sediment in the riverbed. There were 145 dry days at Congress Street in 2021, the majority of which occurred between late February and late June.

WATER CLARITY: Total Suspended Solids

Rivers naturally move sediments, wildfire ash, and other small particles of algae or detritus downstream. High concentrations of materials in the water can create "dust storm" conditions and can impact conditions for aquatic life.

Total suspended solids is an estimate of the number of particles in the water, or the intensity of the "dust storm."

Levels of total suspended solids naturally increase during flooding conditions with extra stormwater. The Arizona Department of Environmental Quality (ADEQ) does not have a standard for total suspended solids. The concentration of total suspended solids in each reach from the 2013 water year serves as a baseline.



2013–2021 RESULTS

Total suspended solids (TSS) were measured a total of 139 times during normal flow conditions. Levels of TSS are lowest and least variable in Three Rivers. Cortaro Narrows had decreased levels of TSS since 2013, with only occasional high levels observed. Marana Flats had the most variable levels of TSS. From 2014–2015, TSS briefly decreased in Marana Flats after the upgrades were complete. After 2015, TSS levels in Marana Flats increased though remained lower than levels recorded before the upgrade.

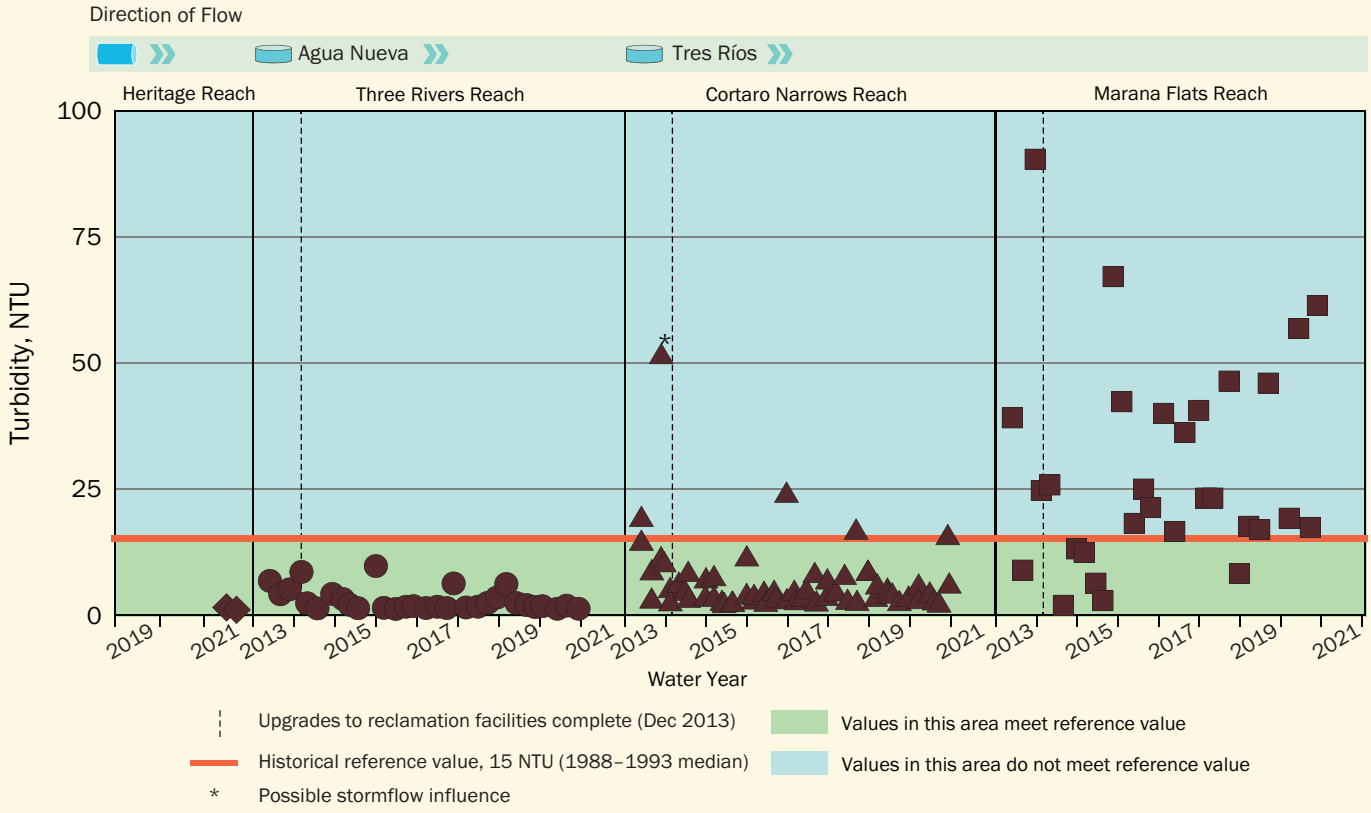
To understand how TSS levels may change with addition of stormwater, samples of stormwater were collected upstream of Agua Nueva. Four samples collected (one each year during the summer monsoon for 2013–2016) had TSS concentrations ranging from 1,050 to 46,300 mg/L and were higher than levels on normal flow conditions. Higher levels of sediment in stormwater is expected.

Measures of TSS in the Heritage Reach began in the 2021 water year and were very low.

WATER CLARITY: Turbidity

Under chronically high "dust storm" conditions when there are high concentrations of suspended sediments in the water, sunlight doesn't travel as deep into the water. Aquatic plants may not receive enough sunlight to photosynthesize and aquatic predators may not be able to see well enough to capture prey.

Turbidity measures water clarity, or how far you can see through the "dust storm," and is reported in Nephelometric Turbidity Units (NTU). High NTU indicates the water is cloudy and hard to see through. The 1988–1993 median level of turbidity in the Cortaro Narrows reach was 15 NTU. ADEQ does not have a standard for turbidity, so this assessment uses 15 NTU as a historical reference value. This is slightly higher than a typical value of 10 NTU for a river with normal base flow and no stormwater influence.



2013–2021 RESULTS

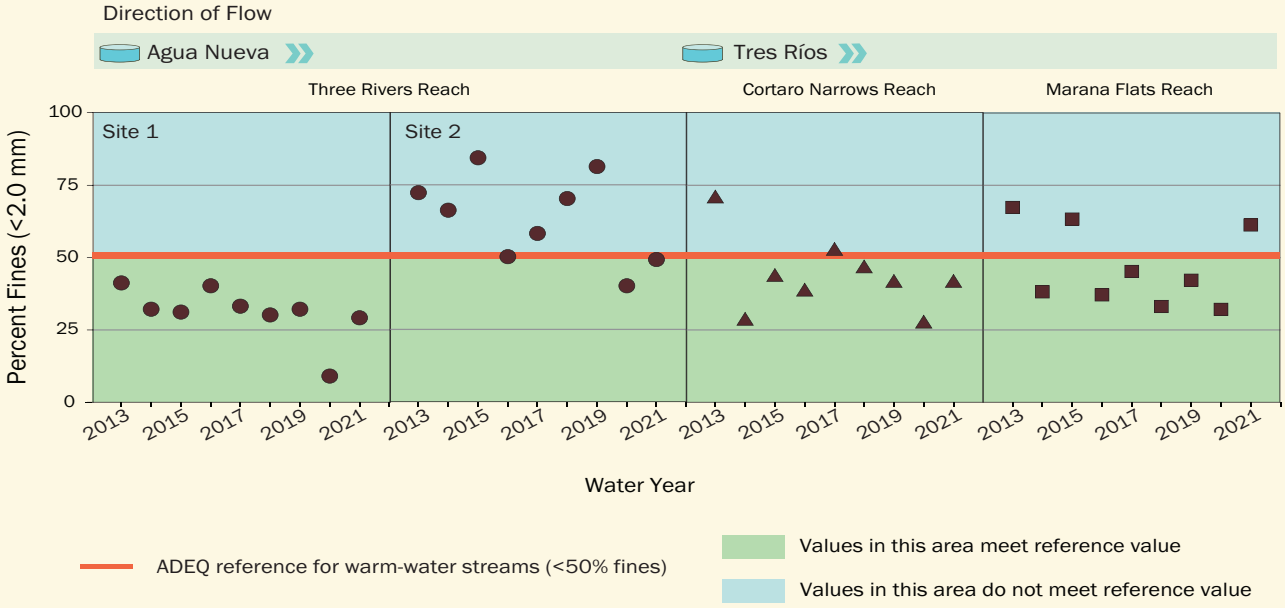
Turbidity was measured throughout the year at several locations for a total of 139 times. Overall, the reference value was met 108 times (78%). Average turbidity within Three Rivers and Cortaro Narrows has decreased since the 2013 upgrades were complete; both have averages below 10 NTU. Although average turbidity decreased in Marana Flats following the upgrades, values have been higher and most variable in this reach since 2016.

Measures of turbidity in the Heritage Reach began in the 2021 water year and were far below the two reference values.

WATER CLARITY: Percent Fines

Rivers naturally leave deposits of the sediments, wildfire ash, and other small particles of algae or detritus that are carried downstream. This process provides an important influx of nutrients and materials. However, fine materials that settle out of the water onto the riverbed can become so abundant that they smother aquatic life and habitat, and reduce infiltration of water through the riverbed. Monitoring changes in fine materials can provide important context for changes in direct measures of aquatic life such as diversity of fish and aquatic invertebrates.

Percent fines is an estimate of the portion of the riverbed comprised of small sediments (≤2 mm in diameter). ADEQ does not have a standard for rivers dominated by effluent. This assessment uses the reference value for warm-water streams, percent fines <50%.



2013–2021 RESULTS

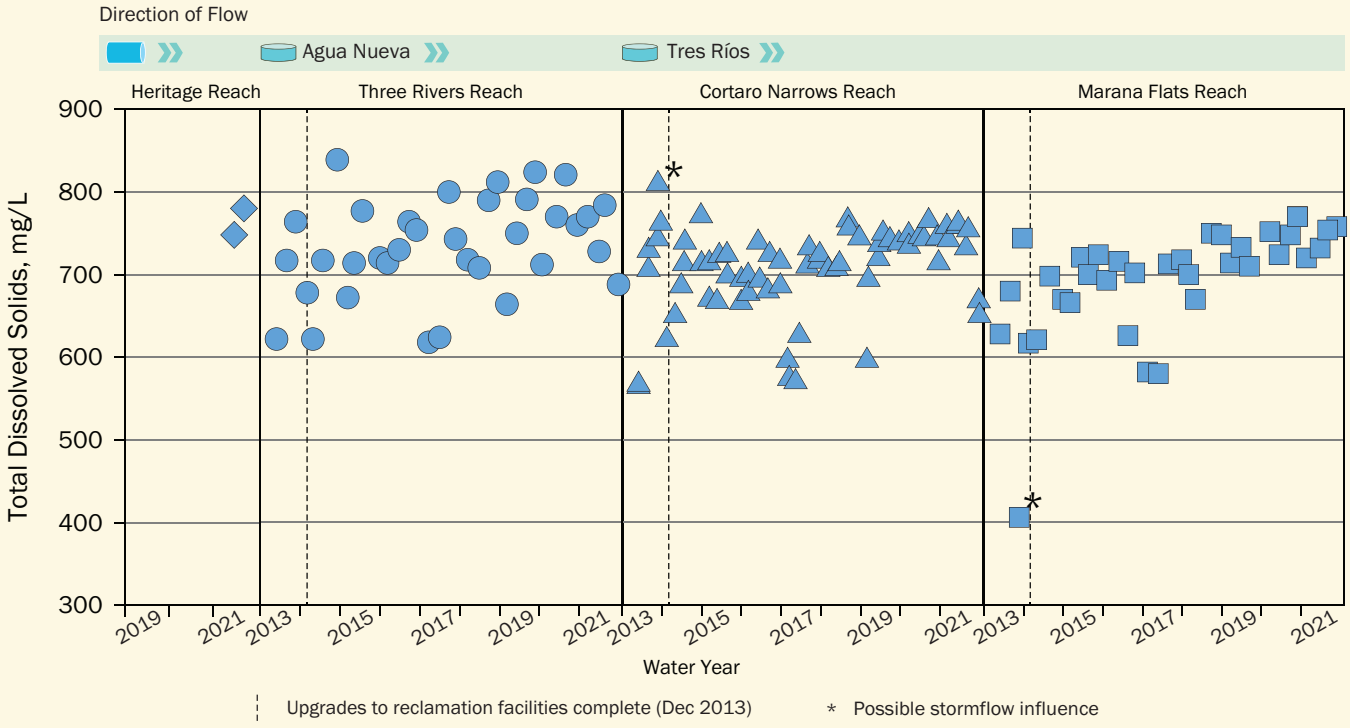
Percent fines were estimated at four sites at the time aquatic invertebrate samples were collected in May of each year. Overall there was a reduction in the percent fines covering the riverbed at these sites, though there was a lot of variation. In 2020, all sites recorded their lowest percentage of fine materials since monitoring efforts began. For unknown reasons, the second site in Three Rivers had a very linear increase in percent fines between 2016 and 2019 prior to decreasing significantly in 2020. All sites showed an increase again in 2021, although the second site at Three Rivers did not reach the same level as before. Marana Flats had the highest percentage at this site since 2015.

Due to reductions in flow extent, the second survey site in Three Rivers and the survey site in Marana Flats had to be shifted upstream in 2015 and 2014 respectively.

Measures of percent fines in the Heritage Reach have not been conducted.

WATER QUALITY: Total Dissolved Solids

Many of the dissolved solids are essential nutrients for plants and animals, but when too abundant they can produce unhealthy conditions for aquatic life and riparian vegetation. Thus, measuring **total dissolved solids** (TDS) is commonly used to monitor salts in the water. TDS in the effluent has been rising since the 1990s with increased use of Colorado River water in the Tucson area. The Colorado River has greater TDS, mostly in form of dissolved salts, than the local groundwater. Because there is no standard for TDS (often standards are for individual elements that contribute to TDS), the results from the 2013 water year will serve as a baseline. Freshwater generally has TDS <1,000 mg/L and stormwater generally has low levels of TDS.



2013–2021 RESULTS

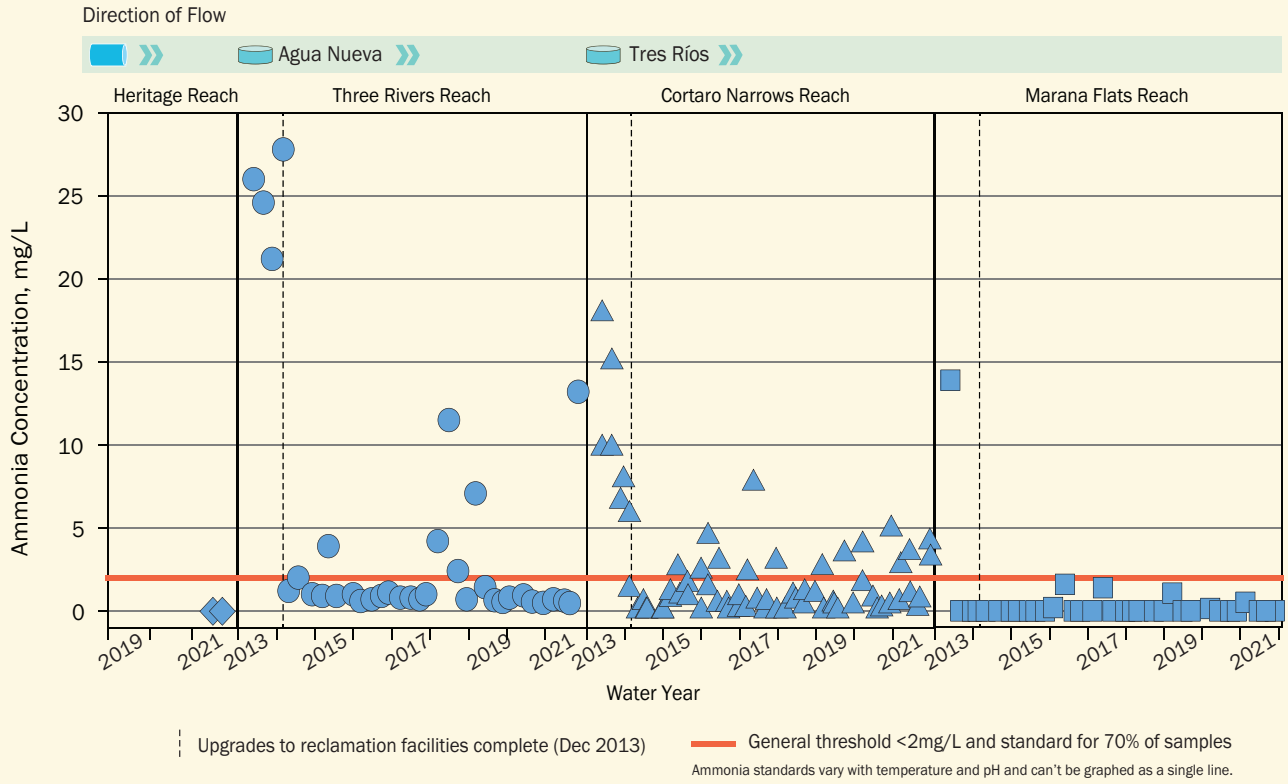
Total dissolved solids (TDS) were measured 138 times. Overall, levels of TDS were similar in all three reaches. Generally TDS hasn't changed very much, though variability in TDS levels decreased in 2015 and 2016 for unknown reasons. The lowest measure of TDS was in Marana Flats. This sample was collected on a day where there was possible stormwater influence. Thus, the addition of water with lower TDS levels may have diluted the levels in this reach of the Santa Cruz River. Samples of stormwater are collected upstream of Agua Nueva when possible. Four samples collected (one each year during the summer monsoon in 2013–2016) averaged 280 mg/L.

Measures of TDS in the Heritage Reach began in the 2021 water year and were comparable to levels in the other reaches.

WATER QUALITY: Ammonia

Nitrogen is an essential nutrient for plant and animal life, but too much can contribute to nutrient pollution. Nutrient pollution, such as high levels of nitrogen and phosphorus, enters the river from air pollution, fertilizer, surface runoff, and the release of effluent. While elevated nutrient levels can benefit riparian plants, they can also lead to poor water quality conditions for aquatic wildlife.

Ammonia (NH_3) is one form of nitrogen that can be toxic to fish and amphibians. Even at low concentrations, ammonia can reduce hatching success, among other impacts. The ADEQ standard for ammonia varies with pH (level of acidity) and temperature. As pH and temperature increase, the toxicity of ammonia increases; thus, the acceptable level of ammonia decreases with high pH and temperature. A general threshold often used is <2 mg/L to avoid toxic conditions.



2013–2021 RESULTS

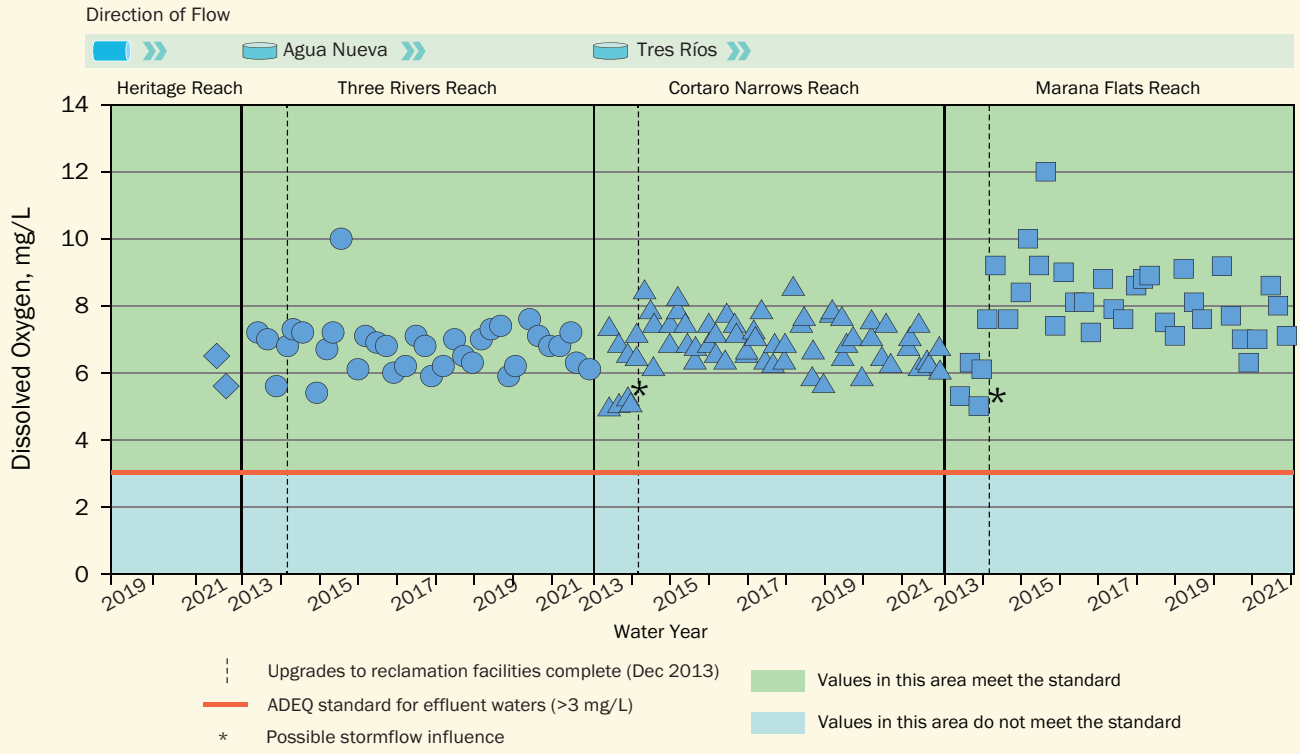
Ammonia was measured 137 times along the river. Overall the standard was met 100 of the 119 times (73%). The standard varies with pH and temperature, but was <2 mg/L for 70% of the samples. Levels of ammonia have dropped significantly after the upgrade was complete in 2013. Levels of ammonia also decreased with distance from the reclamation facilities, as it converts into other forms of nitrogen while moving downstream. Measured at four locations (two locations in Cortaro Narrows reach), average ammonia concentrations declined from a toxic 13 mg/L in 2013 to 1 mg/L in 2014–2021.

Occasional elevated levels of ammonia are observed near the Agua Nueva and Tres Ríos Water Reclamation Facilities. Removing ammonia is a complex process. The facilities use a five-stage process that features alternating oxygenated and oxygen-free zones. To prevent any occaisonal spikes in ammonia, Pima County regularly optimizes processes to better maintain the delicate balance of oxygen needed for maximum ammonia removal.

Analyses of ammonia in the Heritage Reach began in the 2021 water year. Ammonia was not detected in either sample.

WATER QUALITY: Dissolved Oxygen

Fish and other aquatic animals need **dissolved oxygen** to survive. Rivers absorb oxygen from the atmosphere, and aquatic plants and algae produce oxygen during photosynthesis. Natural causes of variability in dissolved oxygen levels include nutrient levels, shading, water temperature, decay of organic materials, and time of day. ADEQ sets the minimum standard for dissolved oxygen in streams dominated by effluent at 3 milligrams per liter (mg/L) during the day (3 hrs after sunrise to sunset).



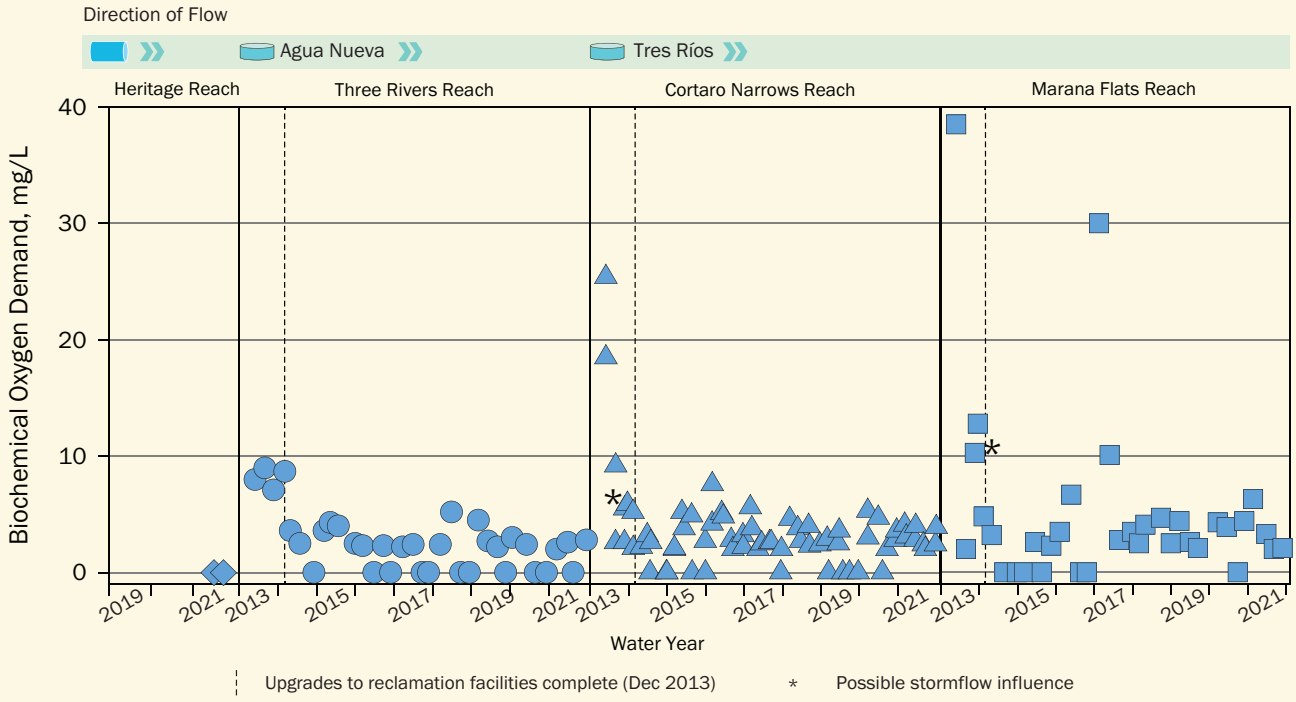
2013–2021 RESULTS

Dissolved oxygen was measured 137 times along the river. All of the samples met the standard for dissolved oxygen (100%). Levels of dissolved oxygen stayed fairly constant in Three Rivers and Cortaro Narrows. However, Marana Flats saw an increase in dissolved oxygen after the facility upgrades were completed.

Measures of dissolved oxygen in the Heritage Reach began in the 2021 water year and the two measures met the standard.

WATER QUALITY: Biochemical Oxygen Demand

Biochemical oxygen demand (BOD) is an estimate of how much dissolved oxygen is being used. Microorganisms in the river consume dissolved oxygen as they break down organic materials such as leaves and woody debris, dead plants and animals, and animal wastes. If there are a lot of organic materials in the water, these microorganisms become so numerous that they consume much of the dissolved oxygen and deprive other aquatic animals of the oxygen they need to survive. Though there are standards for BOD in the wastewater reclamation process, there is no standard for BOD in rivers. The results from the 2013 water year will serve as a baseline.



2013–2021 RESULTS

Biochemical oxygen demand was measured 139 times along the river. BOD has decreased since the upgrades to the reclamation facilities were completed. The high levels observed in Cortaro Narrows are absent after the 2013 water year. This pattern is generally the same in Marana Flats. However, for reasons unknown, measures of BOD in the first half of 2017 were similar to the high levels observed during the 2013 baseline.

Measures of BOD in the Heritage Reach began in the 2021 water year. The two measures of BOD resulted in non-detections.

WATER QUALITY: Metals

Metals in high concentrations endanger wildlife in aquatic ecosystems by lowering reproductive success, interfering with growth and development, and, in extreme cases, causing death. Most metals build up in aquatic food chains and may pose long-term threats to all organisms in the aquatic environment. Rivers are exposed to pollutant metals through numerous sources, including mine drainage, roadways, and by the release of metals naturally occurring in near-surface rocks and sediments. ADEQ has set standards for the protection of aquatic wildlife. Results for the following metals are compared to their appropriate standard: arsenic, cadmium, chromium, copper, lead, mercury, and zinc.

Average values for dissolved metals tested throughout the year
concentrations in micrograms/liter (ug/L), also known as parts per billion (ppb)

Direction of Flow: Agua Nueva » Tres Ríos

	Heritage	Three Rivers	Cortaro Narrows	Marana Flats	Average Standard *standards for wildlife vary with water hardness*
Arsenic	3.9	3.7	3.0	3.1	3.4	150 ug/L*
Cadmium	ND	ND	ND	ND	ND	3.5 ug/L
Chromium	0.3	0.7	0.6	0.5	0.4	11 ug/L*
Copper	0.7	2.0	2.0	2.1	2.1	19 ug/L
Lead	ND	0.3	0.2	0.3	0.4	6 ug/L
Mercury	ND	ND	ND	ND	ND	0.01 ug/L*
Zinc	22	52	46	42	36	244 ug/L

*set value, not an average

ND = Not Detected

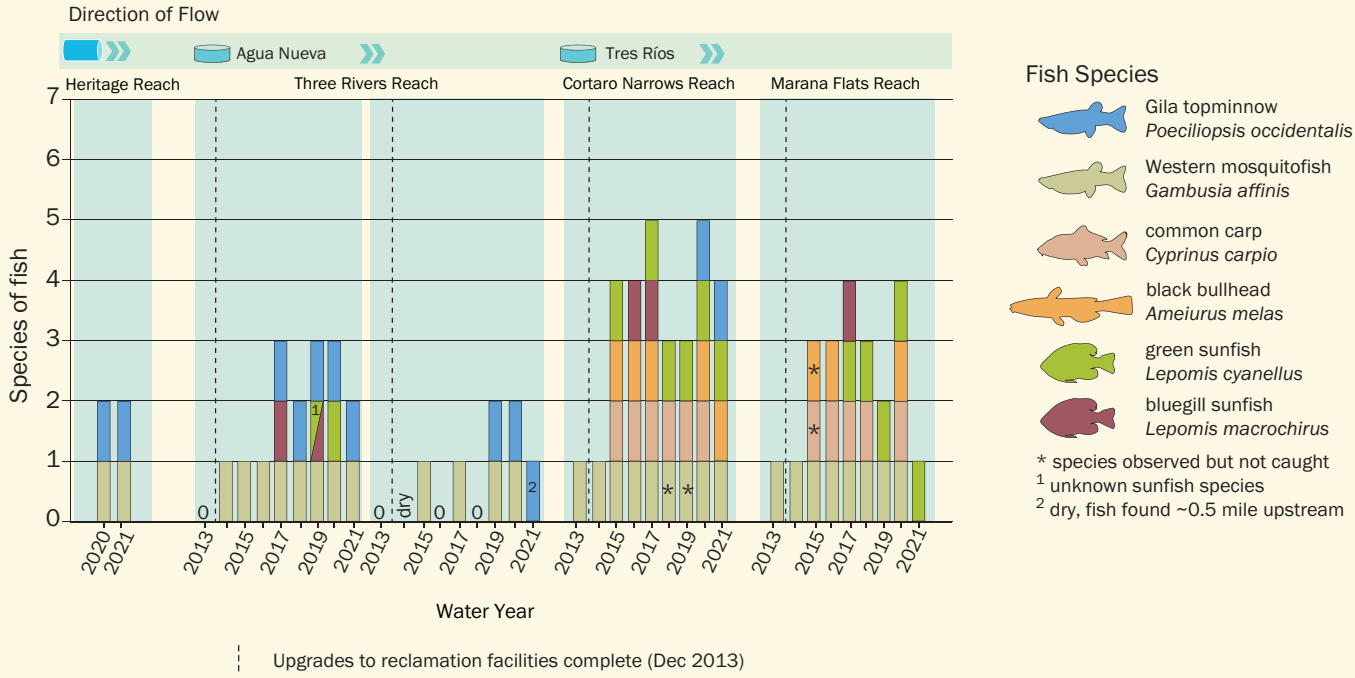
2013–2021 RESULTS

All samples tested at four sites over the years have met the appropriate standard for the following dissolved metals: arsenic, cadmium, chromium, copper, lead, mercury, and zinc. The samples taken within Marana Flats were from three different sites and averaged here. The sample location had to be moved several times due to reduced flow extent and inconsistent flows following increased infiltration rates.

Measures of dissolved metals in the Heritage Reach began in the 2021 water year. Levels met all standards and were comparable or lower than levels in the other reaches.

AQUATIC WILDLIFE: Fish

Fish can serve as effective indicators of river health because they live for several years and vary in their tolerance to pollution. Historically, the Santa Cruz River supported several native fish species: Gila topminnow, Gila chub, desert sucker, Sonora sucker, longfin dace, and a pupfish species that went extinct when the river ceased to flow year-round. There is no standard for abundance or diversity of fish. The results from the 2013 water year will serve as a baseline for measuring change in subsequent years.



2013–2021 RESULTS

Fish surveys were conducted annually in the fall at the four locations aquatic invertebrates were surveyed. Surveys aim to detect all fish species present at a location, but do not try to assess population numbers. Improvements in water quality have allowed fish to thrive. Overall, number of fish species observed increased from one to six. All are non-native, except for the endangered Gila topminnow, which was found at one site in 2017, three sites in 2020, and three in 2021. Exactly how this native fish returned is unknown. Genetic analysis suggests the Gila topminnow in the river near Tucson are most similar to fish found in the Cienega Creek watershed. One possibility is that the fish may have come down with stormwater flows in the Rillito from Sabino Canyon where the closest population lives.

Recording the most species, Cortaro Narrows may provide the most diverse habitat for fish. Flows in Three Rivers are often very shallow and may favor smaller fish like the Western mosquitofish and Gila topminnow, although occasional sunfish have been seen.

Fish surveys in the Heritage Reach started in fall 2021. However, Arizona Game and Fish Department introduced Gila topminnow to this reach in October 2020, with individuals collected from the Tubac reach in Santa Cruz County.

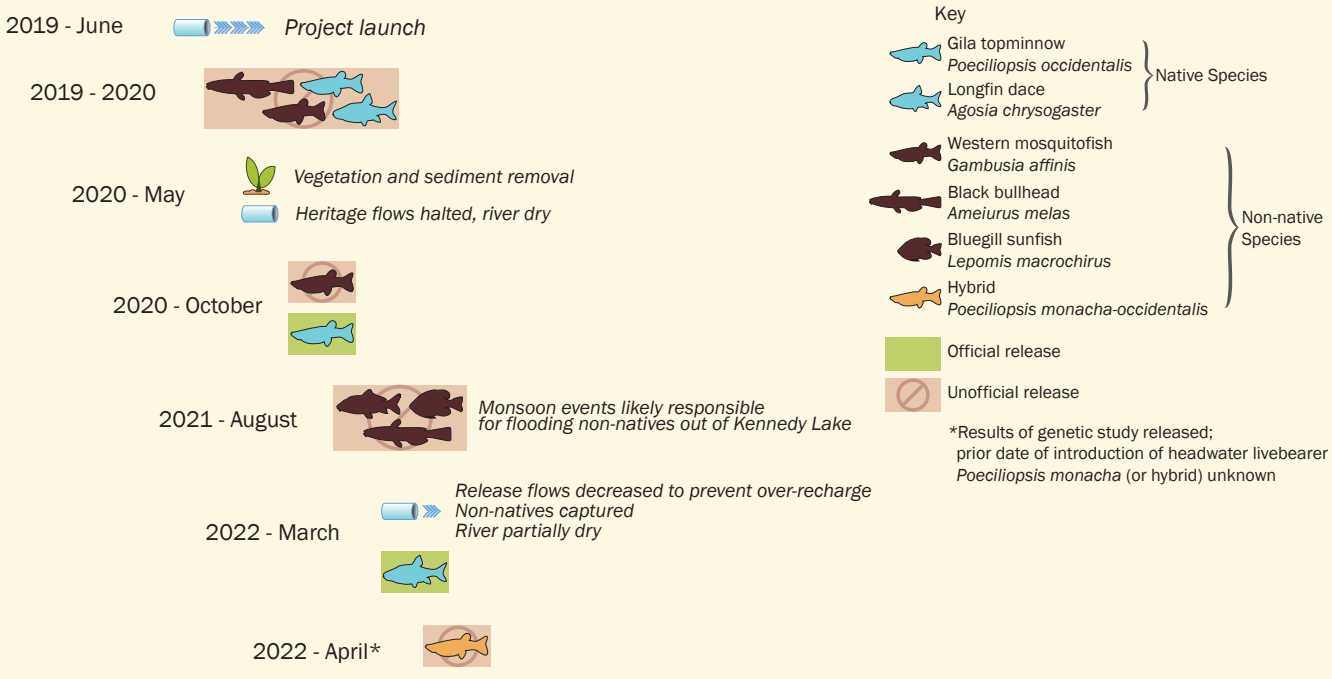
AQUATIC WILDLIFE: Fish Continued

Introductions like that of the Gila topminnow in 2020 to the Heritage reach reflect the success of conservation work on the Santa Cruz River. However, the unplanned release or translocation of any wildlife or plant can negatively impact efforts to re-establish native species and manage the river ecosystem—any such actions are illegal and subject to heavy fines.

Illegal introductions have been observed in the Heritage Reach from the beginning of the project. After its launch in 2019 multiple species were discovered in pools that subsequently dried, resulting in the death of those populations. Similar fates were met by fish released around the time of the sediment removal project. Western mosquitofish that were discovered in the Heritage Reach in 2020, just prior to the planned release of Gila topminnow, are now an established non-native species that poses an ongoing threat to the native's success.

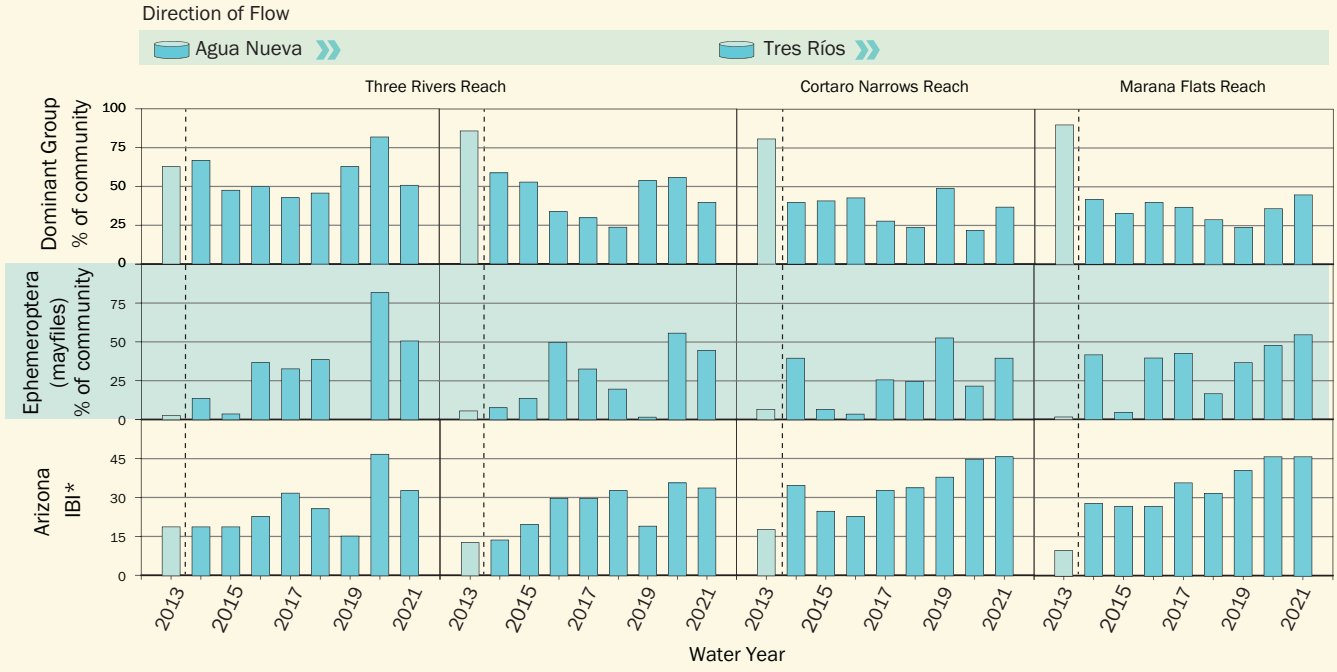
The latest evidence of an introduction to the Santa Cruz is a new species of fish normally found only in Mexico. Researchers from the U.S. Fish and Wildlife Service identified the presence of *Poeciliopsis monacha-occidentalis*, a hybrid species of the endangered Gila topminnow (*Poeciliopsis occidentalis*) and the Mexico native Headwater Livebearer (*Poeciliopsis monacha*). The hybrid exploits Gila topminnow for reproduction but discards the male genome and produces offspring that are clones of hybrid females. The presence of these hybrid fish further complicates monitoring efforts: Western mosquito fish and Gila topminnow are difficult to tell apart and must be identified by trained experts, but the hybrid species can only be distinguished from Gila topminnow in the lab by looking at teeth under a microscope or with genetic analysis.

Timeline of Heritage Reach Introductions



AQUATIC WILDLIFE: Aquatic Invertebrates

Aquatic invertebrates break down organic materials and are important prey for fish and other species. They also differ in their tolerances to pollution. Chironomidae (midges) are pollution-tolerant and found in high numbers even with low oxygen levels and high organic matter. Ephemeroptera (mayflies) have exposed gills on the outside of their body, making them very pollution-sensitive. There are several common metrics used to assess aquatic invertebrate communities. The percent of the invertebrate community comprised of Ephemeroptera taxa is commonly used to help track changes in water quality. Regardless of sensitivity to pollution, if a single species or group accounts for more than 50% of the community, this lack of diversity suggests a stream is impaired. The Arizona Department of Environmental Quality has defined an index of biological integrity (IBI) for warm water streams in Arizona that combines many metrics into a single standard. Although there is no index for effluent-dependent streams, the warm-water index can be used as a reference: a value of >50 meets the standard, 42–50 is inconclusive, and <42 is impaired. A final way to look at diversity is simply looking at the total number of unique invertebrate taxa found in the samples collected.



Upgrades to reclamation facilities complete (Dec 2013)

*Arizona Index of Biological Integrity (reference standard for warm-water streams that compiles several metrics into an index score; scores <42 suggests impairment, 43–49 inconclusive, >50 attaining; no index established for effluent-dependent waters)

2013–2021 RESULTS

The aquatic invertebrate community was surveyed annually at the four locations that fish were surveyed. Invertebrates were sampled using the standard operating procedure developed by the Arizona Department of Environmental Quality, which involves kick-net samples in riffles or areas where the water surface is broken and agitated by rocks on the riverbed. This does not detect all species present, such as species that may not occur in riffle habitat, but gives a quick assessment of the site's biological integrity.

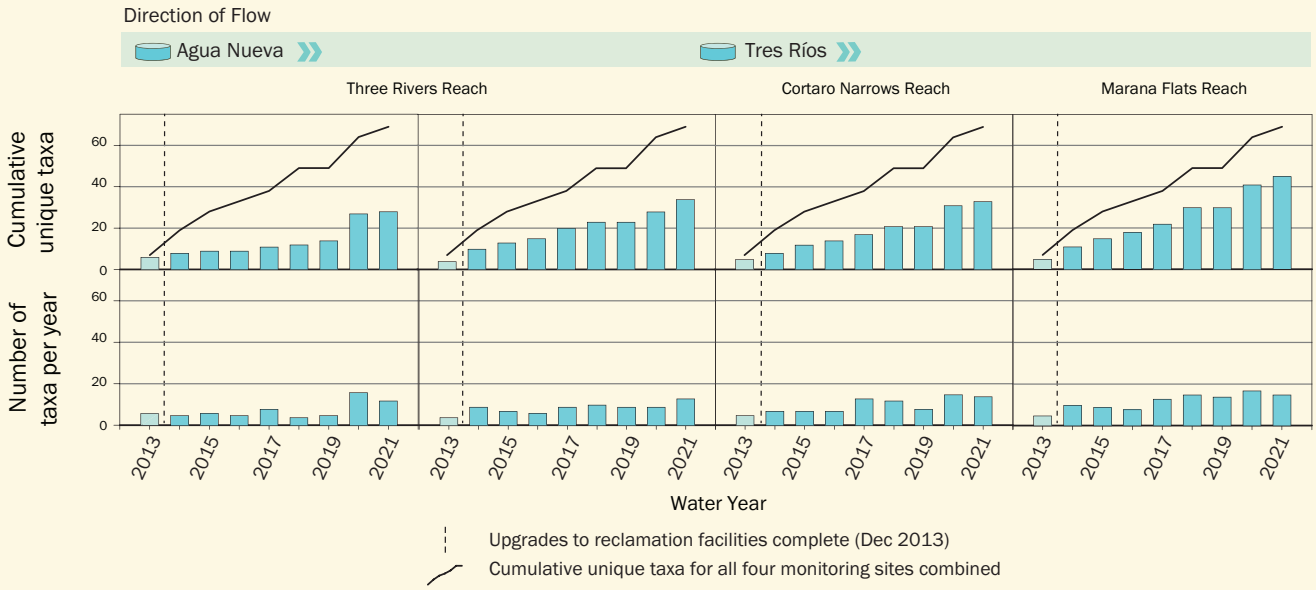
Overall, there were several signs of improvement. The percentage of the community dominated by a single group or taxa decreased (<50% meets the standard). Improvements are also supported by the increase in the percent of the community comprised of pollution-sensitive species from the order Ephemeroptera, or mayflies. While all sites saw an increase, the

AQUATIC WILDLIFE: Aquatic Invertebrates Continued

percentage of mayflies has been variable from year to year. The Arizona Index of Biological Integrity (IBI) has also increased at all sites, reaching a new high in 2020 with three sites recording scores of inconclusive, an improvement from previous scores that suggested impairment. In 2021 these numbers dropped slightly, just outside of the threshold for inconclusive, to a level that suggests impairment once more. Invertebrate communities are impacted by many factors, thus knowing exactly what causes increases or decreases in any metric is difficult. The percent of the riverbed covered by fine sediments decreased and was lowest in 2020, which may have increased the amount or quality of riffle habitat available. This percent increased again in 2021, and may have negatively impacted the IBI. There have also been occasional high levels of ammonia in reaches just downstream of the reclamation facilities (see Ammonia) that could have impacted the aquatic invertebrate community and IBI.

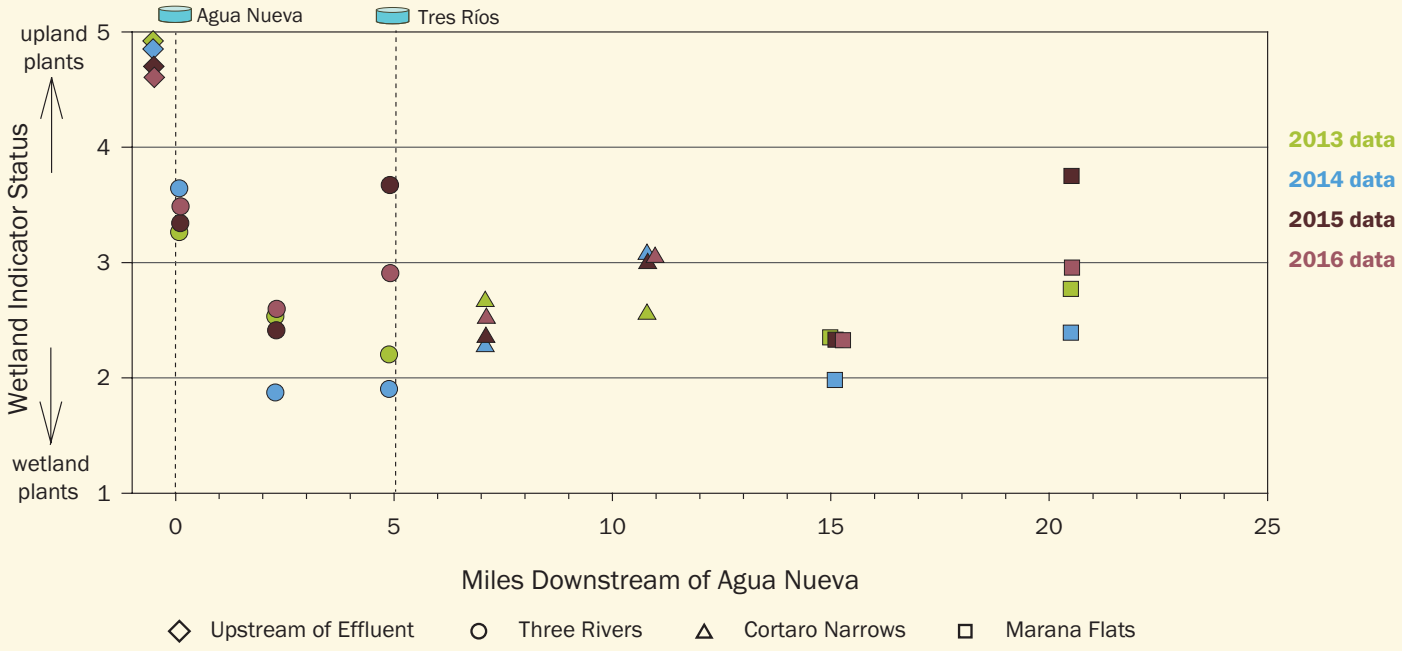
The total number of taxa found at a monitoring site has generally increased each year. The increased diversity is more apparent when you look at the cumulative total number of unique taxa found. This increases at all sites, although Marana Flats appears to have the greatest diversity.

Measures of aquatic invertebrates in the Heritage Reach began in the 2021 water year, which was the first sample to be collected under ADEQ methodology. There were 16 taxa observed in this stretch. The pollution-sensitive taxa Ephemeroptera represented 41% of the community and were the most dominant taxa. Dragonfly surveys conducted by the University of Arizona documented the quick arrival of dragonflies; only days after flows began in June 2019, two sites had an average of five dragonfly species. By late summer of that year, the average was up to 21, comparable to the number of species found at a reference site in Marana.



RIPARIAN VEGETATION: Wetland Indicator Status

Wetland indicator status measures abundance of stream-side plants that vary in their need for permanent water in the river channel. Scores range from 1 to 5. Low scores (<4) indicate that the majority of plants at a given location are wetland plants like watercress and cattails, which depend on consistent presence of water in the river. High scores (>4) indicate that the majority of plants are upland plants like burrobrush and different grasses; these do not depend on consistent presence of water in the river and usually are not found in wetlands. Results from the 2013 water year will serve as a baseline to help track future changes in wetland plants.

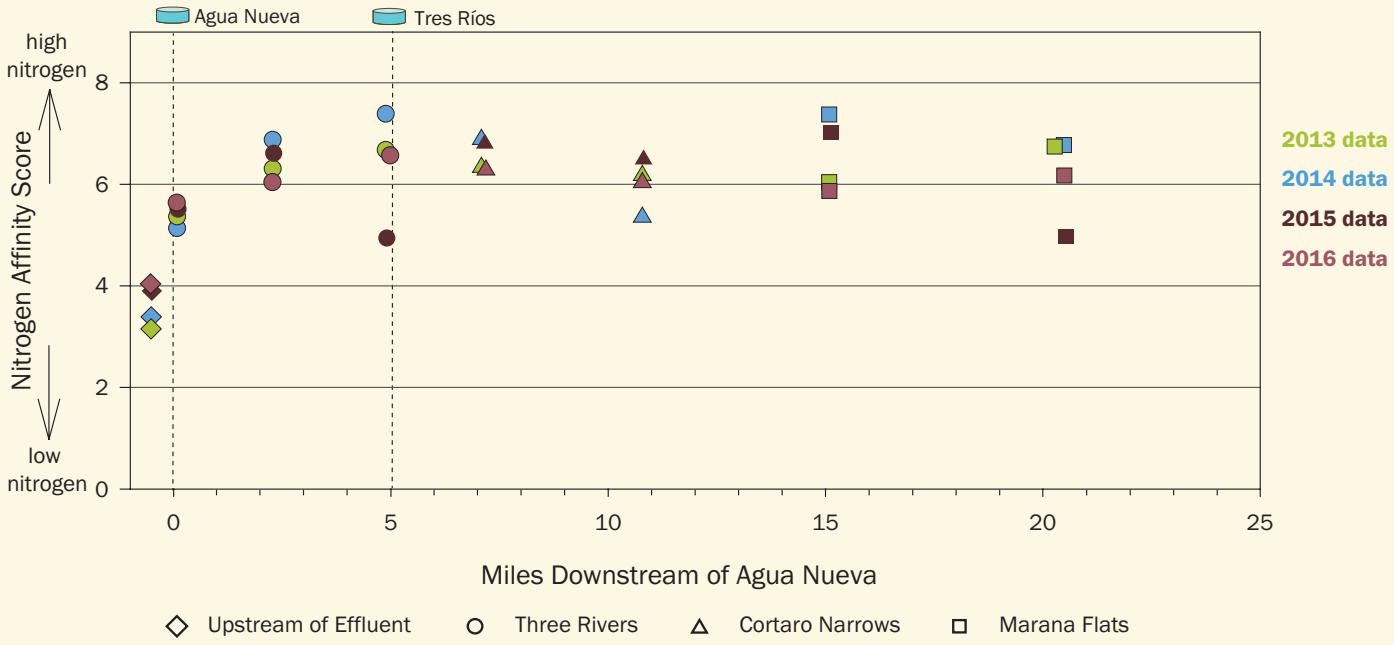


2013–2016 RESULTS

Only measured 2013 - 2016. Wetland indicator status (WIS) was determined for eight total locations along the river. Overall, scores have remained similar at most sites. Scores averaged 2.7 downstream of Agua Nueva. This suggests greater presence of wetland plants instead of upland plants as the river flowed away from the reclamation facilities. Just upstream of the study area, a reference site had the highest scores and was dominated by upland plants. Two sites (approximately 5 and 20 miles downstream) appeared to shift toward more upland plants with increased scores in 2015. This may be in part explained by changes in flow extent, as these sites experienced dry conditions more frequently in water year 2015. However, these same sites were wet again when surveyed in 2016, and stream-side plants shifted back toward wetland plants.

RIPARIAN VEGETATION: Nitrogen Affinity Score

Although nitrogen is an essential nutrient, too much can undermine plant growth or favor the growth of plants that thrive in high-nitrogen environments. **Nitrogen affinity score** measures the abundance of stream-side plants that vary in their tolerance of nitrogen. Scores range from 1 to 9. Low scores (<5) indicate that the majority of plants at a given location grow well with low levels of nitrogen, like burrobrush and different grasses. High scores (>5) indicate that the majority of plants grow well with high levels of nitrogen, like cattails and common sunflowers. Changes in nitrogen affinity scores likely reflect changes in water quality, either an increase or decrease in nutrients in the water. Results from the 2013 water year will serve as a baseline.

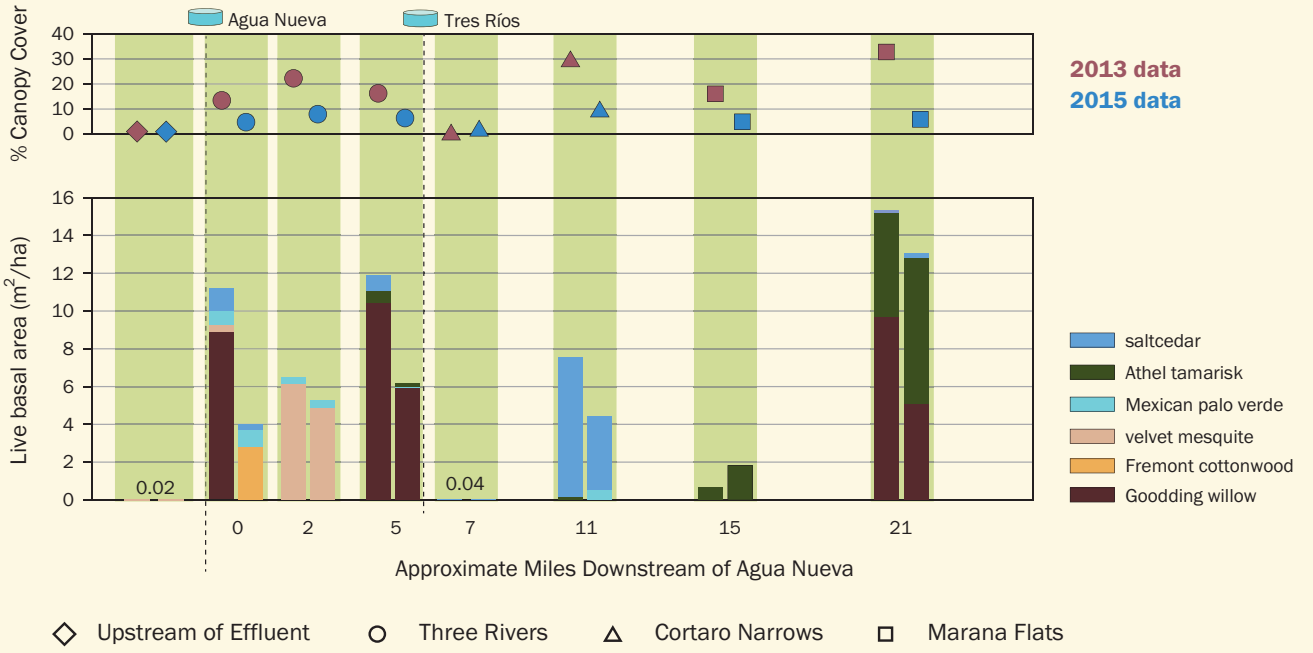


2013–2016 RESULTS

Only measured 2013 - 2016. Nitrogen affinity score was determined for eight total locations along the river. Overall, scores have remained similar at most sites. Scores averaged 6.2 downstream of Agua Nueva. This suggests that stream-side plants that grow well in high-nitrogen environments were most common immediately downstream of the reclamation facilities. Just upstream of the study area a reference site had the lowest scores and was dominated by plants that grow well with low levels of nitrogen. Two sites (approximately 5 and 20 miles downstream) appeared to shift toward more low-nitrogen plants in 2015. Though we may expect this shift from reduced nutrient pollution, reduction in water presence and soil moisture may be the bigger factor. Both of these sites experienced dry conditions more frequently in water year 2015 and were dry at time of survey in 2015. These same sites shifted back towards nitrogen-loving plants in 2016, when water was present again at time of survey. So both nitrogen affinity and wetland indicator seem to indicate presence of permanent water in the channel or high soil moisture. This is supported by a high correlation of the nitrogen scores with wetland scores; plants with high nitrogen scores had very low wetland scores, or more simply, the wetland plants in our area love nitrogen.

RIPARIAN VEGETATION: Riparian Tree Cover

Riparian tree cover measures the abundance of adult trees along the river and in the adjacent floodplain. High tree cover indicates the presence of sufficient soil moisture to support riparian trees. Tree cover is commonly reported as basal area. Basal area, measured in square meters per hectare (m^2/ha), is the area covered by trees in one hectare (10,000 m^2, or approximately two football fields). In addition, riparian tree species differ in their tolerance to declines in soil moisture. Native cottonwoods and willows have shallow roots and are more sensitive to reductions in soil moisture. Velvet mesquite and non-native tamarix species, such as Athel tamarisk and saltcedar, have deeper roots and can tolerate a greater range of soil moisture. Trees grow slowly, and amount of cover is not likely to change on an annual basis, unless vegetation is affected by sustained drying or large floods. Tree cover was measured in 2015, and results from the 2013 water year serve as a baseline.

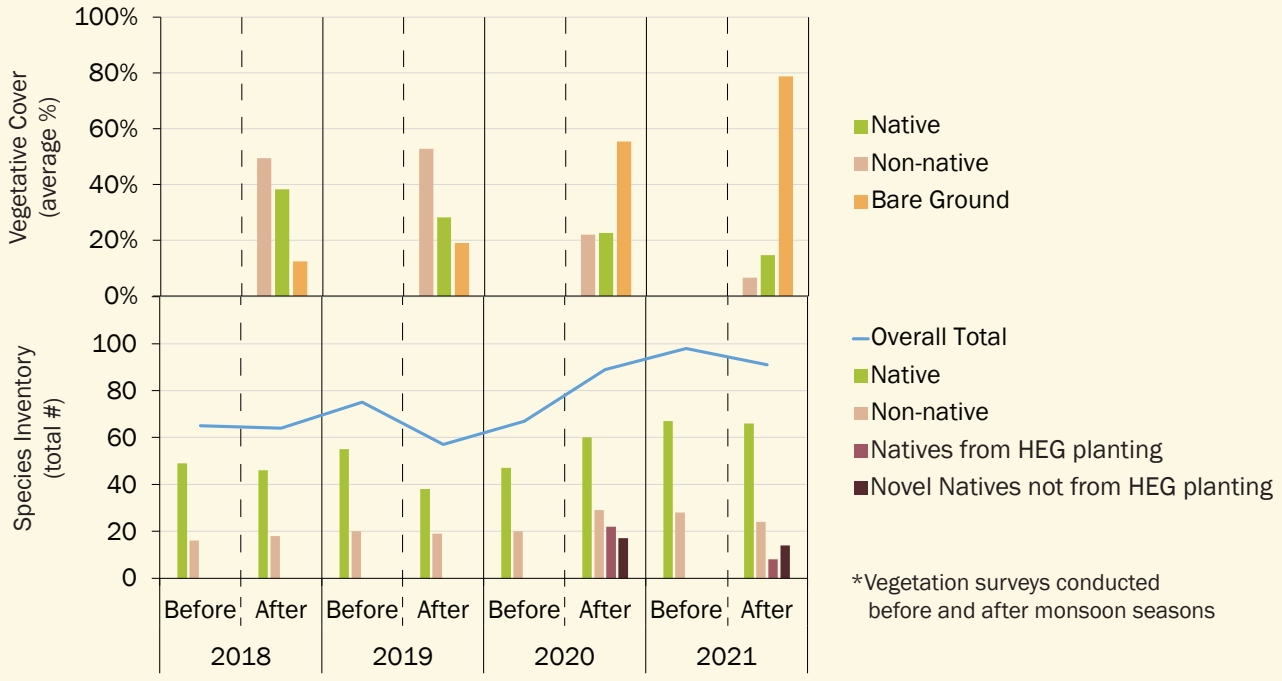


2013–2015 RESULTS

Only measured in 2013 and 2015. Overall tree cover, as measured by basal area and percent canopy cover, decreased between 2013 and 2015. Most notable was the decrease in cover of Goodding's willow. Decrease in cover of mature trees is likely the result of decreased flow extent, which is in turn correlated with increased recharge of underground aquifers. Thus, there may not have been enough accessible moisture to support more shallow rooted trees like Goodding's willow. More monitoring will be needed to determine if effluent continues to support mature riparian trees in all three reaches, and whether the community shifts to deeper rooted trees such as velvet mesquite and non-native tamarix species.

RIPARIAN VEGETATION: Composition and Cover in Heritage Reach

Riparian vegetation benefits flood management, groundwater recharge, wildlife habitat, and more. The Heritage Project was primarily developed for aquifer recharge but also supports riparian and wetland plants. Tucson Water aims to develop this vegetation by increasing the native shrubs, grass, and other cover, while eliminating trees that increase flood risk in the narrow corridor. Harris Environmental Group (HEG) surveys vegetation **composition and cover** biannually, and disperses native seeds in the Heritage Reach. Surveys began in 2018 and seeding in 2019, prior to a sediment removal project conducted by Pima County Regional Flood Control District in 2020 to improve conveyance of floods through downtown. Surveys before the monsoon monitor changes in vegetation in response to human and natural conditions: water release, flood control, re-seeding and planting, weather and general ecological change. Surveys after the monsoon aim to identify monsoon influence on vegetation and monitor species planted or seeded. Biannual seeding intends to help restore the riparian vegetation and re-establish native species. The initial surveys from 2018 and 2019 help establish a baseline for ongoing monitoring.



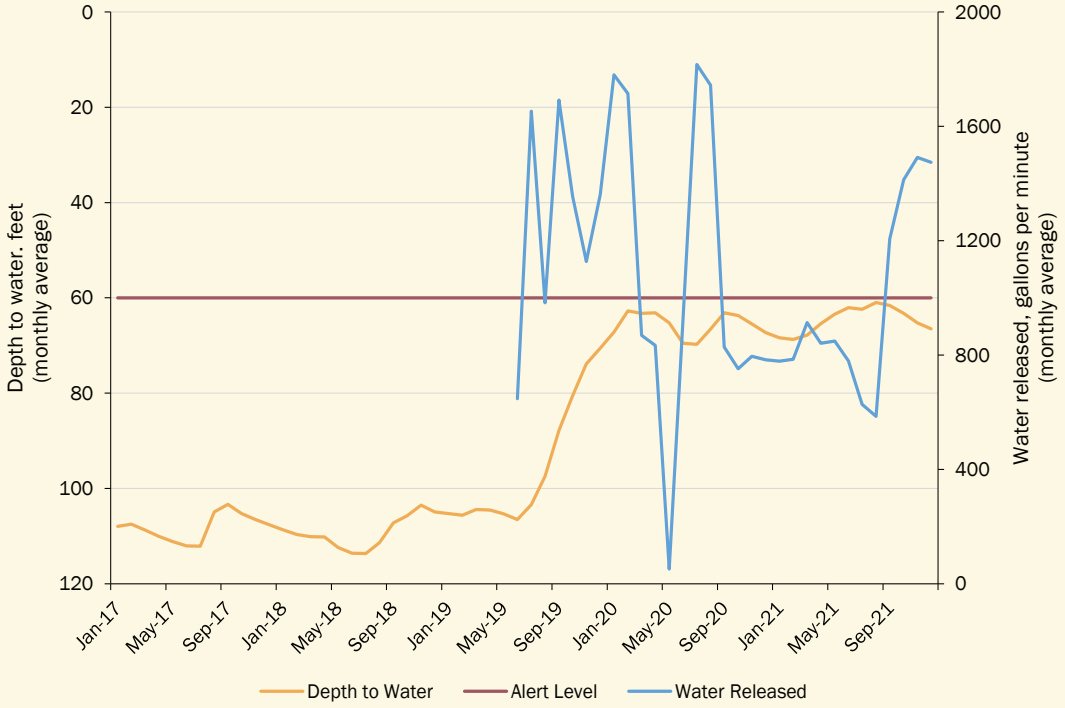
2018–2021 RESULTS

Overall, trends for native species and bare ground are increasing. The 2021 pre-monsoon survey recorded 98 total species, 71% of which were native. Land with no cover increased from 12% in 2018 to 79% in 2021. Likely factors leading to this change include the sediment and vegetation removal effort in 2020 by Pima County Flood Control District, and monsoon flooding in 2021. The average percent vegetative cover of native species has increased and surpassed the average percent of cover by non-native species: from 38% native and 49% non-native in 2018, to 15% native and 7% non-native in 2021. Comparisons of the species inventory after the monsoon in 2020 and 2021 show native species increasing from 67% to 73%. Of these, 37% (22) in 2020 were from HEG planting or seeding, compared to 12% (8) in 2021, a decrease in success that can be attributed to the 2021 monsoons transporting and dispersing seeds downstream and outside of the Heritage reach. Novel (not previously recorded) native species that were not planted by HEG also emerged in 2020 (17 species) and 2021 (14). Invasive buffelgrass continues to persist along the reach but the overall presence of this and Bermuda grass has decreased.

GROUNDWATER: Depth to Groundwater

Historic groundwater pumping in the Tucson area was a major factor contributing to the drying of the Santa Cruz River and the depletion of local groundwater aquifers. Releasing effluent into the river is a natural and economical way to recharge the aquifer, but it must be carefully managed in some reaches. **Depth to groundwater** is one measure to track the effect of effluent releases on recharge. Many natural factors influence recharge, and thus depth to groundwater. Dense riparian vegetation can slow flow and create pools that increase recharge. Floods can increase recharge by clearing sediment and natural debris, while at other times reduce recharge by depositing sediments like ash from forest wildfires.

The Heritage Project is a good example of a highly managed reach of the Santa Cruz. Due to its proximity to downtown Tucson, historic landfills are adjacent to the Heritage Reach. To protect the aquifer from potential contamination from these landfills, groundwater levels are monitored and managed to stay below a particular depth, referred to as the alert level (60 ft). The alert level is a management safe guard that provides a significant buffer zone between the top of the groundwater table and bottom of the landfill.



2020–2021 RESULTS

The Heritage Project began releasing water into the Santa Cruz river in June 2019, and within 6 months of the project's start a strong replenishment of the aquifer was observed. Groundwater levels rose approximately 45 feet. While groundwater recharge is a primary goal of the Heritage Project, management of water deliveries is limited by the 60 ft alert level, and the rate of water being released is decreased when necessary to maintain the water table below this level. In May 2020, water deliveries were also temporarily ceased to allow for the sediment removal project by Pima County. During the summer of 2020, there were very few monsoon floods. Speedwell, a common wetland plant in this reach, became so abundant that water was ponding near one groundwater monitoring well. This led to increased recharge in a localized area and water levels approached the alert level. Tucson Water staff removed some of the vegetation to reduce ponding and encourage flow to continue downstream. Since monsoon floods scoured the riverbed in summer 2021, recharge increased all along the reach, which reduced the flow extent. Groundwater levels have been high due to this increase in recharge, although not close enough to the alert level to raise alarm since September 2021, even with steady water releases.

SOCIAL IMPACTS: Odor at the Water Reclamation Facilities

Water reclamation facilities are restoring a piece of the river heritage and supporting important wetland habitats by releasing effluent into the river. However, unpleasant odors associated with the reclamation process can lead to negative perceptions of the river for those living near or recreating along the river. The most common offender is hydrogen sulfide (H_2S), or the "rotten egg" smell. Odor treatment systems and advanced monitoring equipment, coupled by a computer program that can track odor trajectories, help prevent **odor at the water reclamation facilities** from leaving the site. Minimizing both the extent and intensity of disagreeable odors coming from the facilities was one of the goals of the reclamation facility upgrades.

Monitoring odor at the Tres Ríos Water Reclamation Facility

Green squares mark locations where odor is monitored continuously. The weather station can also help identify the direction wind would carry any odors escaping from the treatment process (illustrated here with green "wedge"). Above photo, new pipes and decking at the headworks were installed in early 2019 to prevent odors from escaping.

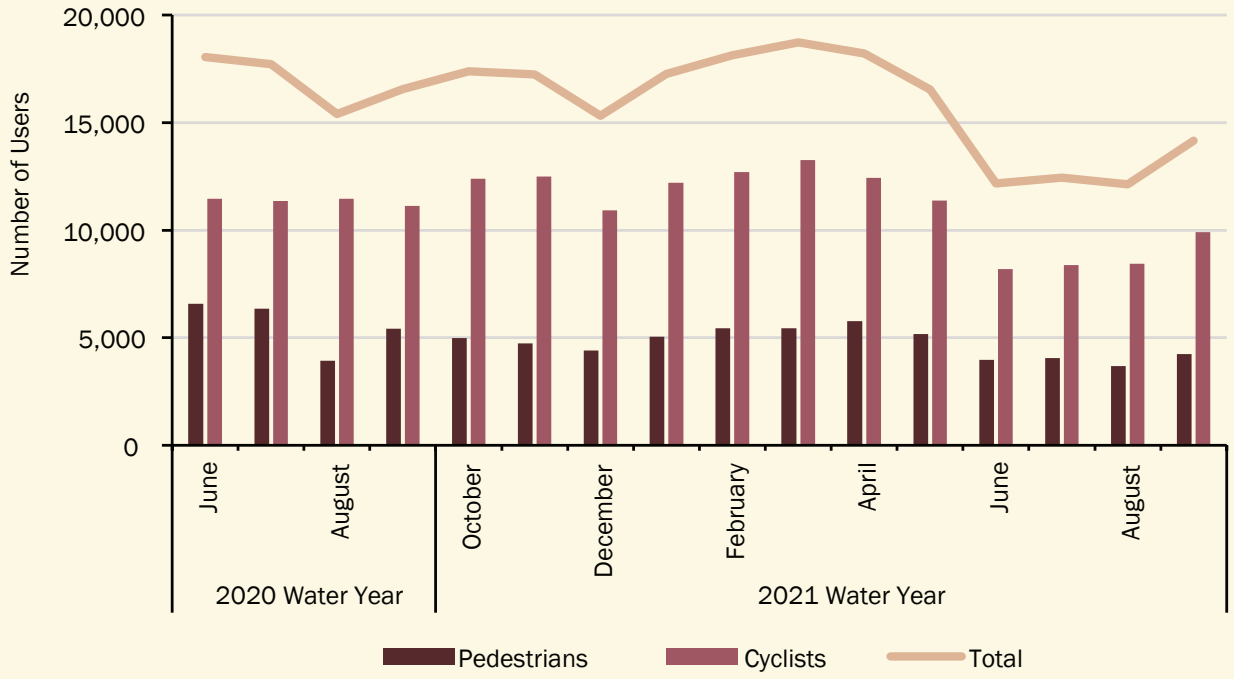
2013–2021 RESULTS

Prior to upgrades, unpleasant odors often left the facility boundaries. Most unpleasant odors are produced in the early phases of treatment, including at the headworks. In 2013, new odor treatment systems were designed and implemented, which reduced the odor emanating from the reclamation facilities. Large fans move air to odor treatment units that remove unpleasant odors. The air released from these odor treatment units is monitored continuously to ensure they are operating optimally, minimizing the possibility of odors that drift across surrounding fence lines.

Since January 2014, there have been no odor complaints at Agua Nueva. Levels of H_2S at Tres Ríos were also low. However in 2016, there were isolated odor complaints from the people using the adjacent sports park. In 2017, Pima County investigated odors escaping from loose decking near the headworks. Repairs were made and more piping installed to capture foul air. Since project completion in early 2019, Tres Ríos has not received an odor complaint. A Process Optimization Team continuously monitors the odor treatment systems and odor detection equipment at all of the water reclamation facilities to ensure that odor levels remain invisible to the public.

SOCIAL IMPACTS: Pedestrian and Cyclist Use of The Loop

The Santa Cruz River is not just for wildlife. The Chuck Huckelberry Loop trail and numerous parks along the river corridor provide popular destinations for people to enjoy the river as well. **Pedestrian and cyclist use of The Loop** trail is one way to monitor recreational use along the river. The Loop has more than 136 miles of paths extending throughout the greater Tucson area and in January 2018 the "loop" feature was completed by connecting the Rillito and Pantano River Parks. Users in the Santa Cruz River Park can now connect with the Rillito and Pantano Parks, Harrison Greenway, and Julian Wash on a 53.9-mile circuit. Over the past two years, Pima County has installed counters to monitor activity along the multi-use path, with one counter along the river between the flowing reaches. These counters differentiate between cyclists and pedestrians, allowing trends of use to be studied.

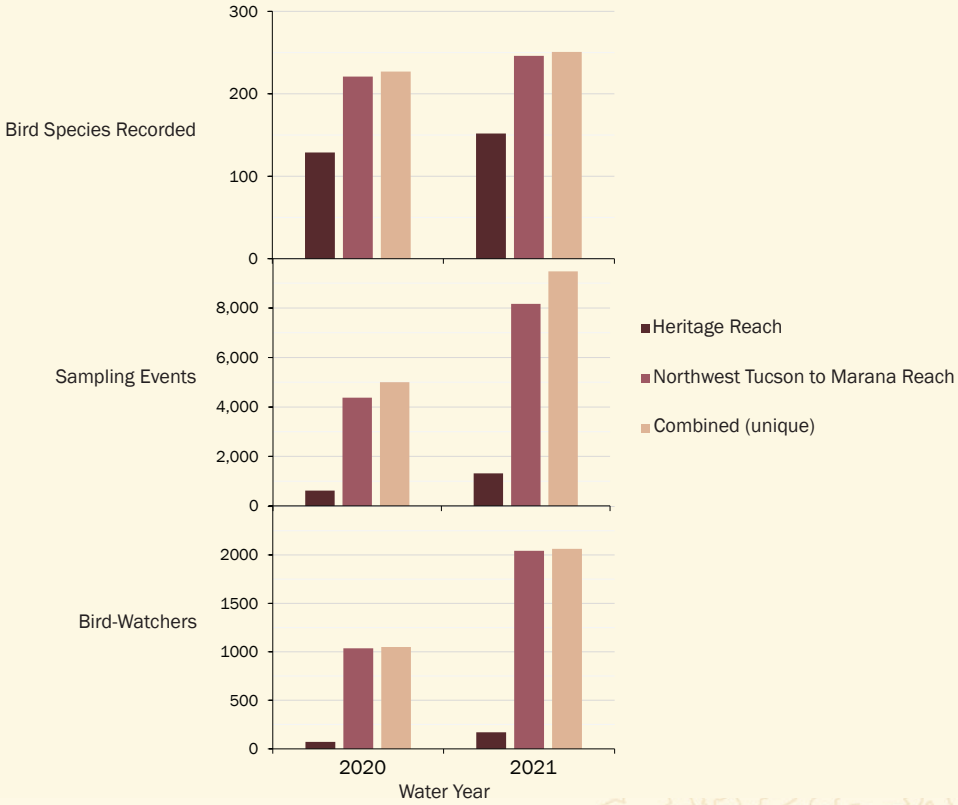


2020–2021 RESULTS

In the Santa Cruz River Park, from Speedway to Saint Mary's Road, counter data shows a steady use year-round, with the lowest numbers in the 2021 water year occurring from June to September. Even the lowest monthly total was an impressive 12,144 people, recorded in August 2021. The same period of the 2020 water year did not show similar low-use numbers, but this may be attributed to drier and hotter conditions during the 2020 monsoon season. The highest monthly total was recorded in March 2021, with 18,728 people (13,275 cyclists and 5,453 pedestrians). This higher proportion of cyclists is a trend seen every month so far. Apart from seasonal dips, most months showed a total ranging from 14,000–18,000 users.

SOCIAL IMPACTS: Bird-watching

The flowing water and rich riparian vegetation of the Santa Cruz River support a diverse array of bird and wildlife species. **Bird-watching** is thus an easy way to understand the importance of wildlife viewing as a type of recreational use of the river and adjacent parks. We can also track the number of different bird species seen along the river. A citizen-science bird-watching program run by Cornell Lab of Ornithology, eBird (www.ebird.org), offers interested passersby an opportunity to take part in data collection by recording bird species they see along the river, thus providing river managers with an ongoing source of information. For this analysis, we include only observations collected during traveling or stationary counts of species making use of the river corridor and adjacent parks. Birds simply flying over, and those that are exotic or domestic, are excluded to focus on the effectiveness of the area as wildlife habitat.



2020–2021 RESULTS

Observed diversity was higher in 2021, with a combined total of 251 species recorded by 2,064 observers. For comparison, 227 species were recorded along the Santa Cruz River by 1,050 birders in 2020. The number of bird-watchers recording observations has especially increased in the Northwest Tucson to Marana reach: 2,044 participants versus 171 along the Heritage Project, spotting 246 species versus 152. In total, there were 9,482 sampling events by bird-watchers along the river, observing many native species, including some that are rarely seen in the Tucson valley. Efforts like this demonstrate the potential of citizen-science efforts, and the latent willingness of communities to be involved in our natural areas.

ACKNOWLEDGEMENTS

Sonoran Institute, Pima County, and Tucson Water prepared this report with generous funding from Pima County Regional Wastewater Reclamation Department, Pima County Regional Flood Control District, Tucson Water, and community stakeholders. We are grateful for the expert guidance from our Living River Technical Committee, and for the support of our project partners, including Arizona Department of Environmental Quality, Arizona State University, Tucson Audubon Society, University of Arizona, and the U.S. Geological Survey.

In 2012, the Sonoran Institute convened a Living River Technical Committee of ecology, hydrology, and wildlife experts to bring the best available science to bear on the development of the *Living River* health assessments. The Technical Committee provided guidance by selecting and aggregating indicators of river health, identifying reference values or standards for evaluating and tracking changes in river conditions, and reviewing the development of this report. The information presented in this report grew out of discussions involving these experts and represents the product of a collective effort; it does not reflect the opinions or viewpoints of any individual member of the technical team. The viewpoints and opinions expressed in the discussions of the group and captured in this report also do not reflect the opinions or viewpoints of the agencies, institutions, or organizations with whom the technical team members and external reviewers are associated or employed. Any errors or omissions contained herein are solely those of the Sonoran Institute.

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Sunny and Stormy by Grant Peterson, age 8, Coyote Trail Elementary School — Katie