a living river

CHARTING SANTA CRUZ RIVER CONDITIONS
DOWNTOWN TUCSON TO MARANA

WATER FOR THE RIVER

SUPPLEMENTARY REPORT FOR 2013 TO 2020 WATER YEARS

SONORAN INSTITUTE
PIMA COUNTY
TUCSON WATER
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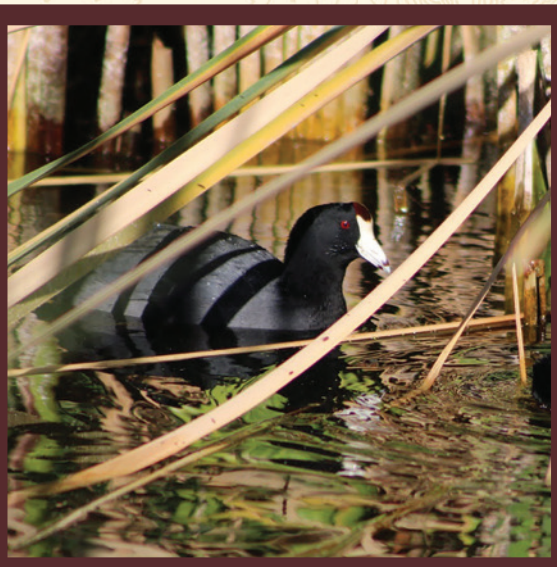
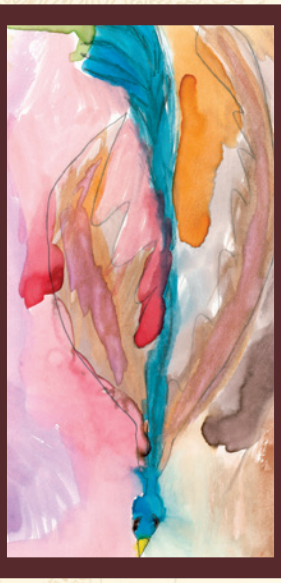
THE SANTA CRUZ RIVER
A LIVING ECOSYSTEM





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 treatment process. 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 investments. This supplementary report summarizes data from the 2013–2020 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 condition.

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:** High-quality effluent is released into the Heritage Project reach starting in June 2019. Wetland plants quickly established and dragonflies and other wildlife quickly find 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. Gila topminnow were introduced to the Heritage Project in 2020.
- **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 with fewer scouring floods and ash debris from upland wildfires possibly clogging the riverbed and reducing recharge.
- **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 reclamation process.

June 2019 Heritage Project

April 2020 Heritage Project

Gila topminnow, *Poeciliopsis occidentalis*

OTHER OBSERVATIONS

- **Total effluent released to the river has decreased:** Releases of effluent have decreased an average of 12% since 2015, with the lowest volume released in 2018. However, effluent remains the primary source of water in the river. Stormwater is also an important source of flows.
- **First dedication of water for the river's health:** With the first applications finally approved in 2021, water from the Conservation Effluent Pool will now be 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.
- **The river is popular for recreation and wildlife viewing:** Between June and September 2020, over 22,300 pedestrians and 45,500 cyclists were observed on The Loop recreational trail along the river near St. Mary's Road. During the 2020 water year, over 1,000 individuals participated in the eBird.org citizen science program and went to the river to contribute over 118,000 observations of 230 bird species.
- **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 hundreds of kids. The Santa Cruz River from northwest Tucson to Marana provided meaningful inspiration for youth art and poetry projects. To date nearly 4,000 youth have visited the river since 2015 as part of this program.

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.

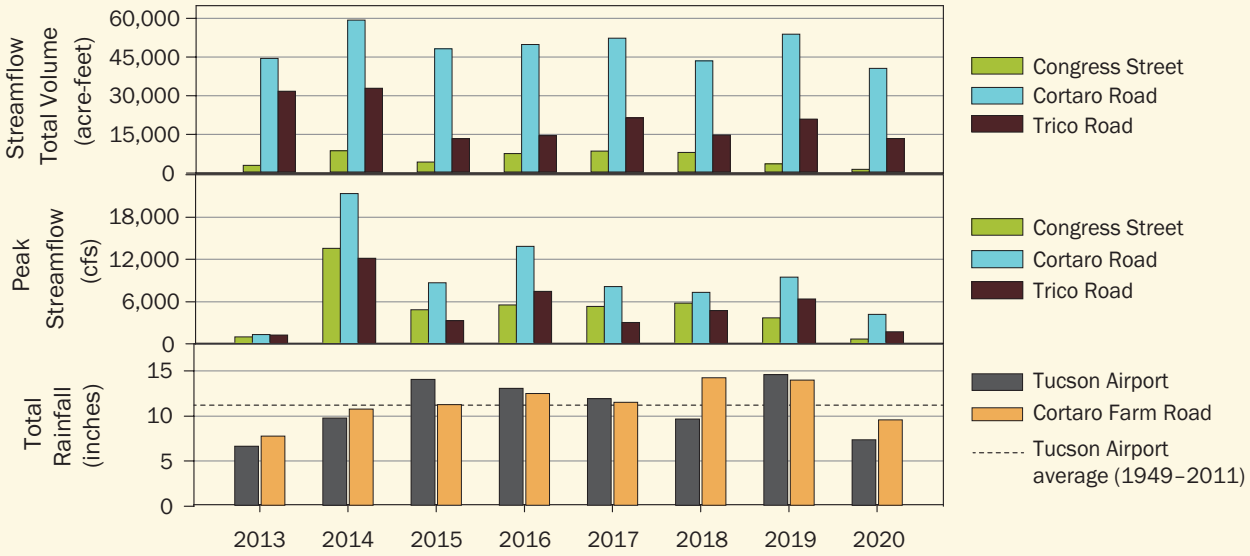
Data are collected and summarized by water year (October 1–September 30) and compared to the baseline conditions observed in the 2013 water year. This supplemental report shares data from all the water years to enable an easy viewing of trends and long-term patterns.

CATEGORY	PURPOSE	INDICATORS
Flow Extent	Water flowing in and out of the system determines available aquatic habitat.	• Miles of flow in June • Number of “dry days” 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
Social Impacts	Aesthetic factors directly impact people living or recreating along the river.	• Odor at reclamation facilities • Recreational use of river corridor

*Riparian vegetation 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.



2013–2020 STREAMFLOW

Streamflow, measured in cubic feet per second (cfs), is the volume (cubic feet) of water flowing past a fixed point in a specific time period (1 second). Streamflow is measured with gages at Congress Street (in the Heritage Project reach) and at Cortaro and Trico Roads—both are downstream of the Tres Ríos 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 decreased since the facility upgrades were complete in December of 2013. There are now days with no flow at Trico Road (see Flow Extent). Peak flows at all sites were highest in 2014 and have declined since.

2013–2020 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 had an annual average of 11 inches of rain. The most rain fell in 2015 and 2019 with about 14 inches each year. The historical average from 1949 to 2011 is 11 inches.

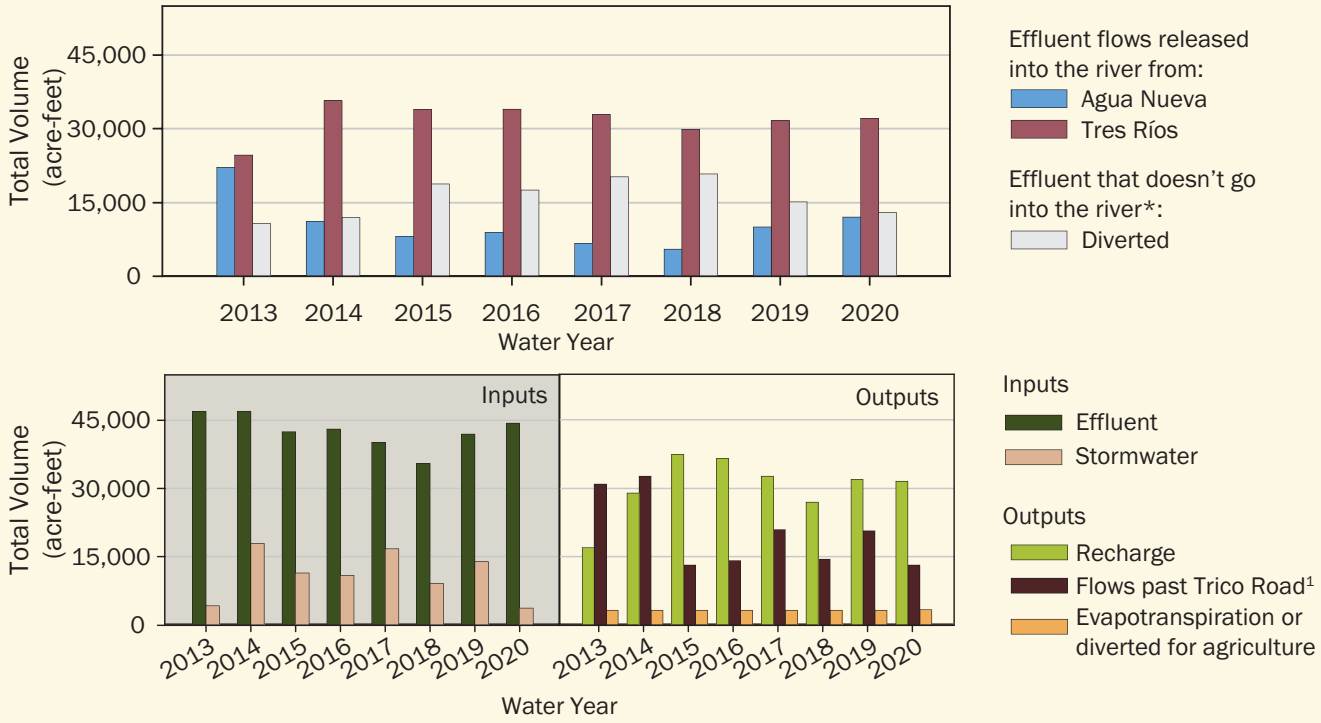
- Winter rains averaged 3 inches (range: 1–6)
- Summer monsoon rains averaged 5 inches (range: 2–9)

CFR had an 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 4 inches (range: 1–6)
- Summer monsoon rains averaged 5 inches (range: 2–10)

Streamflow, Rainfall, and Water Budget, cont.

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 local groundwater. Volumes are totaled in acre-feet (AF), the number of acres that would be covered with water one foot deep. Along the river in this 23-mile stretch 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

2013–2020 WATER BUDGET NORTHWEST TUCSON TO MARANA REACH

Total effluent inputs decreased an average of 12% between 2015 and 2020. 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 local aquifers. Since 2019, diverted effluent decreased by 5,000 AF (which increased Agua Nueva releases). Nearby recharge basins have reached the recharge volume allowed by permits. Now, water is diverted to recharge basins only after an equivalent volume of groundwater is pumped out, leaving more water to be released into the river. 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 this reach. In 2021, water from the Conservation Effluent Pool will guarantee the release of a weekly average of 5 million gallons a day from Agua Nueva.

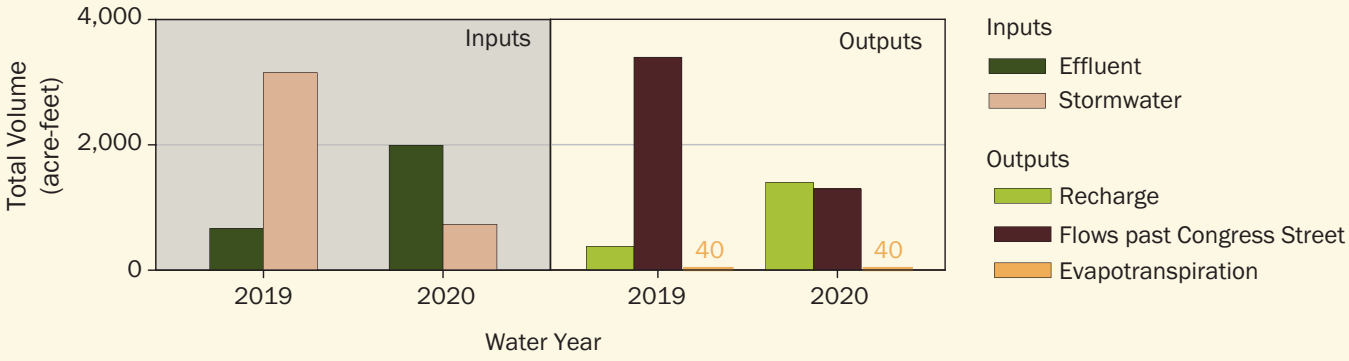
Total inputs increased with higher volumes of stormwater. Recharge also increased significantly. Increased recharge has reduced the amount of water that flows past Trico Road. Exact volumes of water diverted for agriculture and used by wetland vegetation are not known and considered as estimated constants in recharge calculations.

Streamflow, Rainfall, and Water Budget, cont.

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 (a process called 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. 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 gage at Congress Street and evapotranspiration, from the total water released into the river.



2019–2020 WATER BUDGET HERITAGE PROJECT REACH

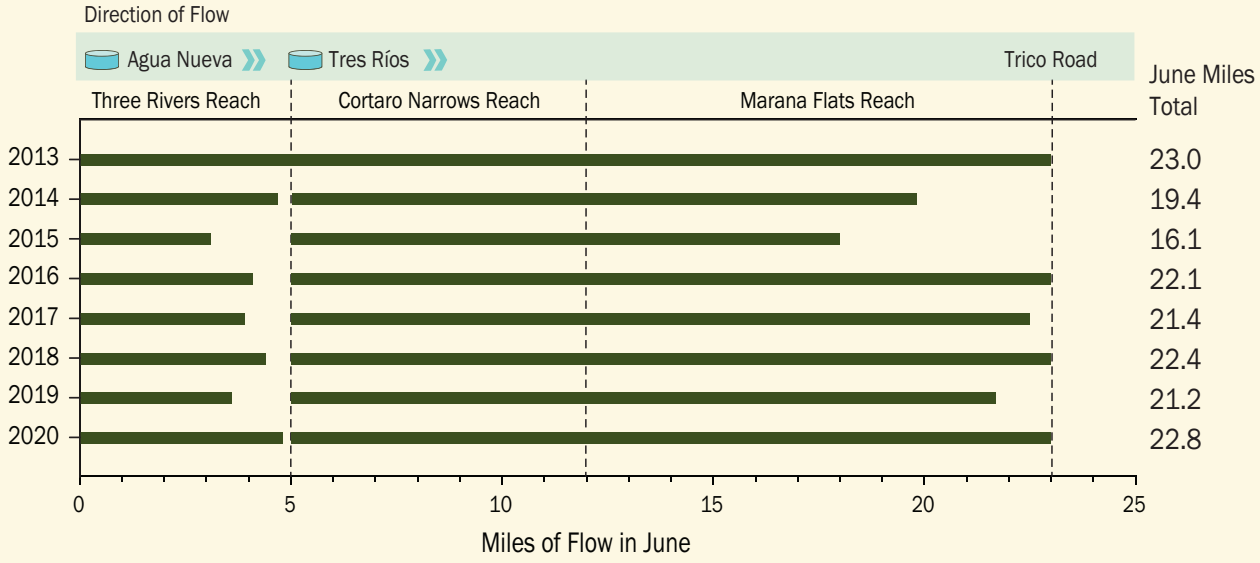
Tucson Water started adding effluent to the Heritage Project reach near downtown in June 2019. Effluent provides most of the flow in the river near downtown. This is especially true in 2020 when there was reduced water flowing from stormwater. Much of the effluent sinks into the riverbed to recharge the aquifer prior to reaching Congress Street. Exact volumes of water used by wetland vegetation are not known and considered as estimated constants in recharge calculations. Starting in 2021, water from the Conservation Effluent Pool will provide water to support the riparian and wetland vegetation in this reach.

Supplementary Data for 2013 to 2020 Water Years

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 recharge of water into the aquifer, which could decrease aquatic habitat.

Miles of flow from Agua Nueva outfall to Trico Road in June 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.



2013–2020 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. Since 2013, only the Cortaro Narrows reach had continuous flow through the reach in June. Though variable in length, dry stretches of the river formed between Agua Nueva and Tres Ríos reclamation facilities and upstream of Trico Road.

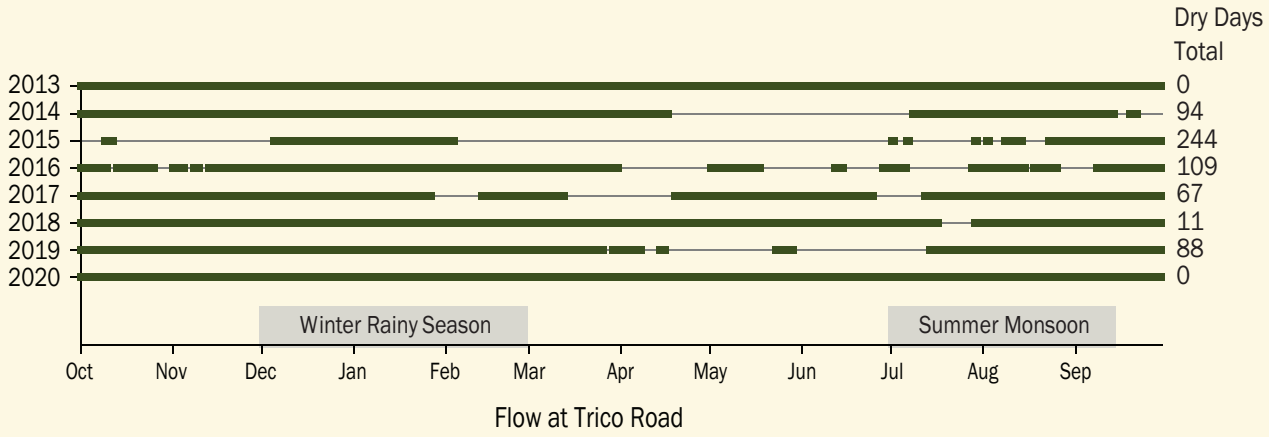
Reduced flow extent is primarily due to increased recharge following the input of cleaner water. However, many other factors influence flow extent. For example, we know that recharge increases after large floods scour the riverbed. The magnitude of the flood is important, with bigger peak flows in the previous year resulting in larger dry stretches in June. The longest dry stretch in the Three Rivers reach is 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 same period. 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 shortest number of days since the last peak flow because peak flows occurred in winter these years (see graph on next page). But factors influencing 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

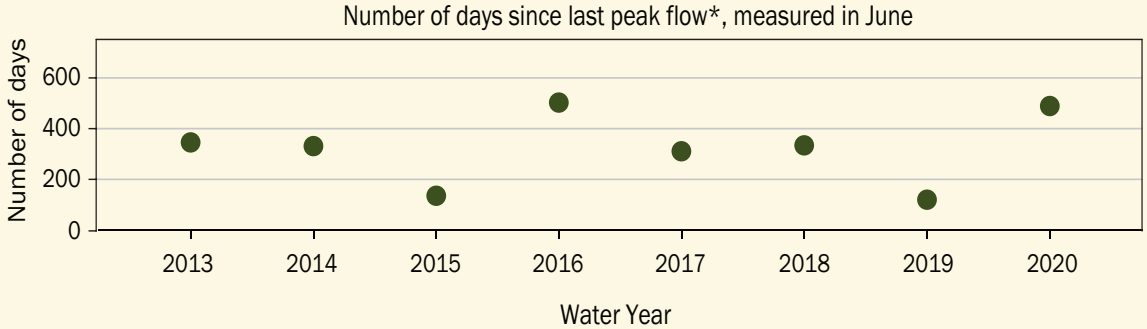
Water management is also an important factor and has likely contributed to the drying of the Three Rivers reach where releases from Agua Nueva have decreased (see Water Budget). In Marana Flats, the river is also diverted by an earthen berm into a channel to provide irrigation water for agriculture and water for recharge at Marana High Plains, a constructed recharge basin 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 may have decreased the dry days at Trico Road.

The daily flow at Trico Road has become more variable with increased dry days where there is no water in the river. 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. The river stopped flowing into the wetlands in January 2015 when a flood moved the low-flow channel again, demonstrating nature's contribution to water management. As noted earlier, 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.

Since 2017, flow at Trico Road has increased and the number of dry or no flow days reached zero for the first time since 2013. During this same time, the average volume of effluent and stormwater flowing in the river decreased (2017–2020 average total water in the river was 6,000 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.



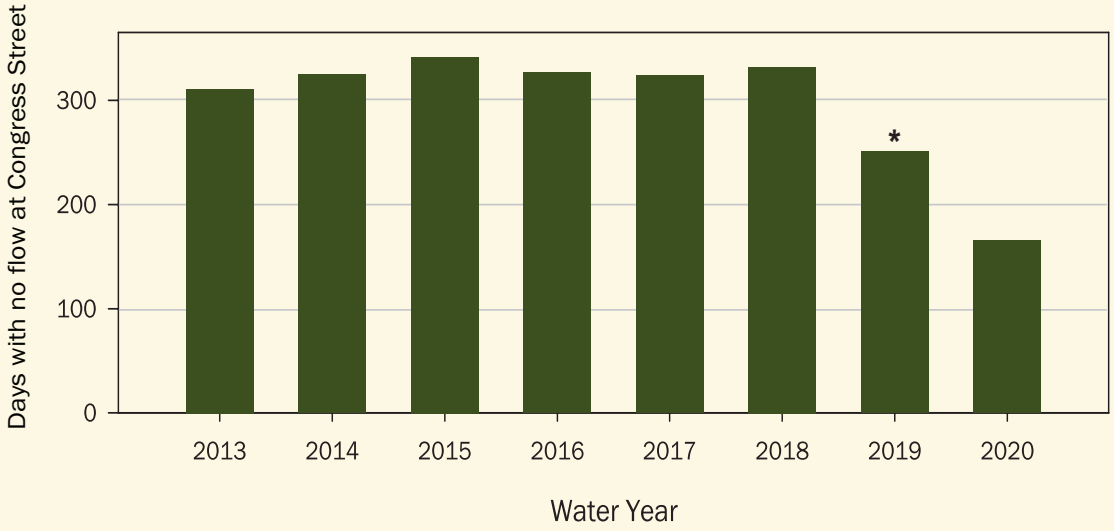
Flow at Trico Road



*Peak flow is the highest flow measured in a water year. In 2015 and 2019 peak flows occurred in winter instead of summer monsoon.

FLOW EXTENT: Heritage Project Reach

Flow extent for the Heritage Project reach is measured in two ways. **Miles of flow from the outfall in June** 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 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

2013–2020 RESULTS

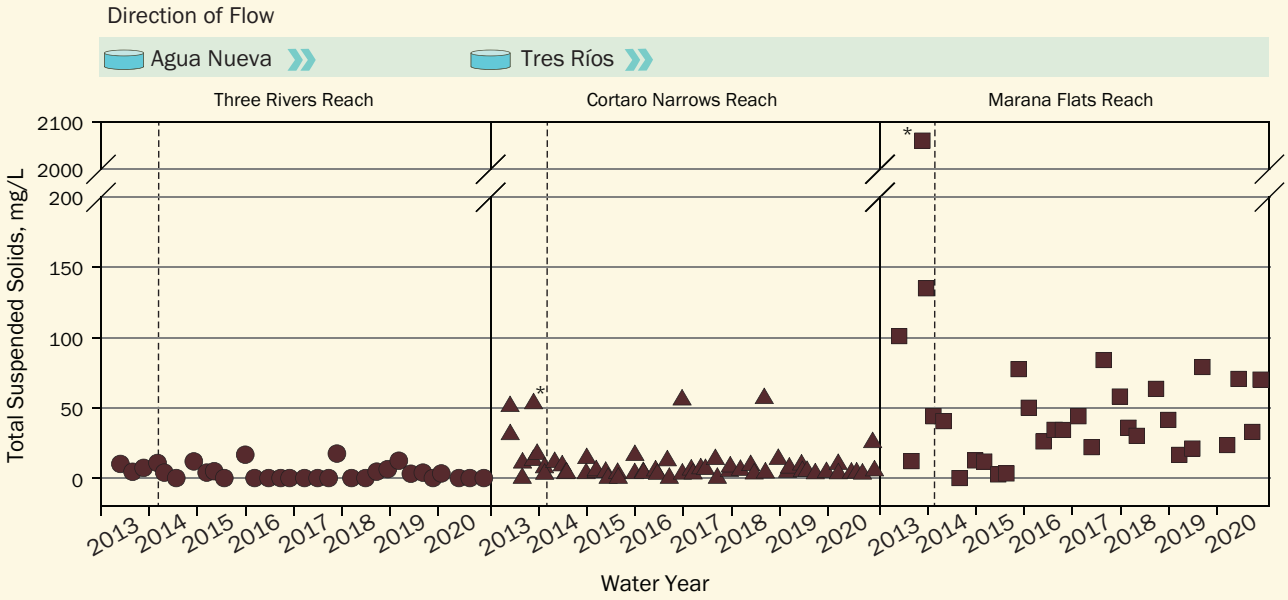
In June 2020 the river flowed approximately 2 miles from the Heritage Project outfall to Speedway. The number of days with no flow at Congress Street has significantly decreased since the Heritage Project began; prior to this, flows consisted only of stormwater. Though 2019 had 251 days with no flow 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.

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. ADEQ does not have a standard for total suspended solids. The average concentration of total suspended solids in each reach from the 2013 water year serve as a baseline.



2013–2020 RESULTS

Total suspended solids (TSS) were measured a total of 121 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.

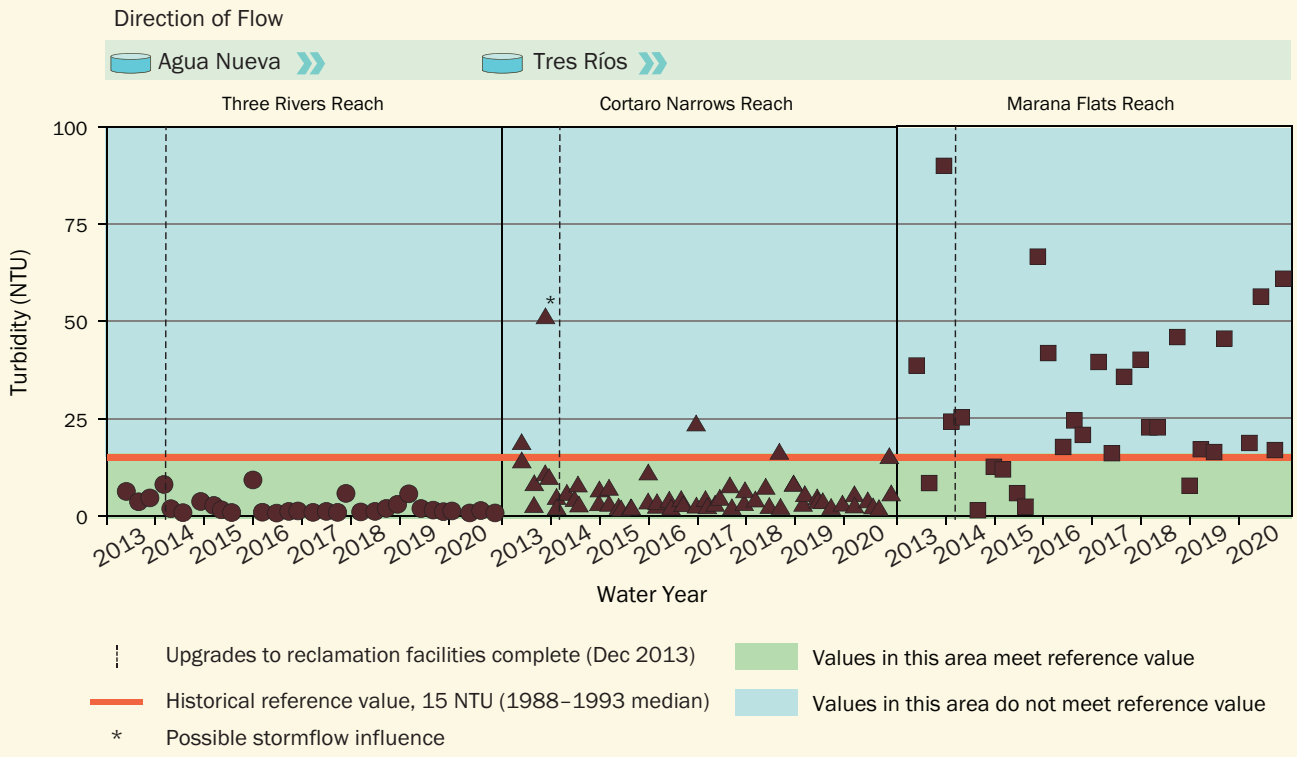
To understand how TSS levels may change with addition of stormwater, samples of stormwater were collected upstream of Agua Nueva. Four samples collected (one each year during the summer monsoon for 2013–2016) had TSS concentrations ranging from 1,050 to 46,300 mg/L and were higher than levels on normal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

Measures of TSS in the Heritage Reach began in the 2021 water year.

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.



2013–2020 RESULTS

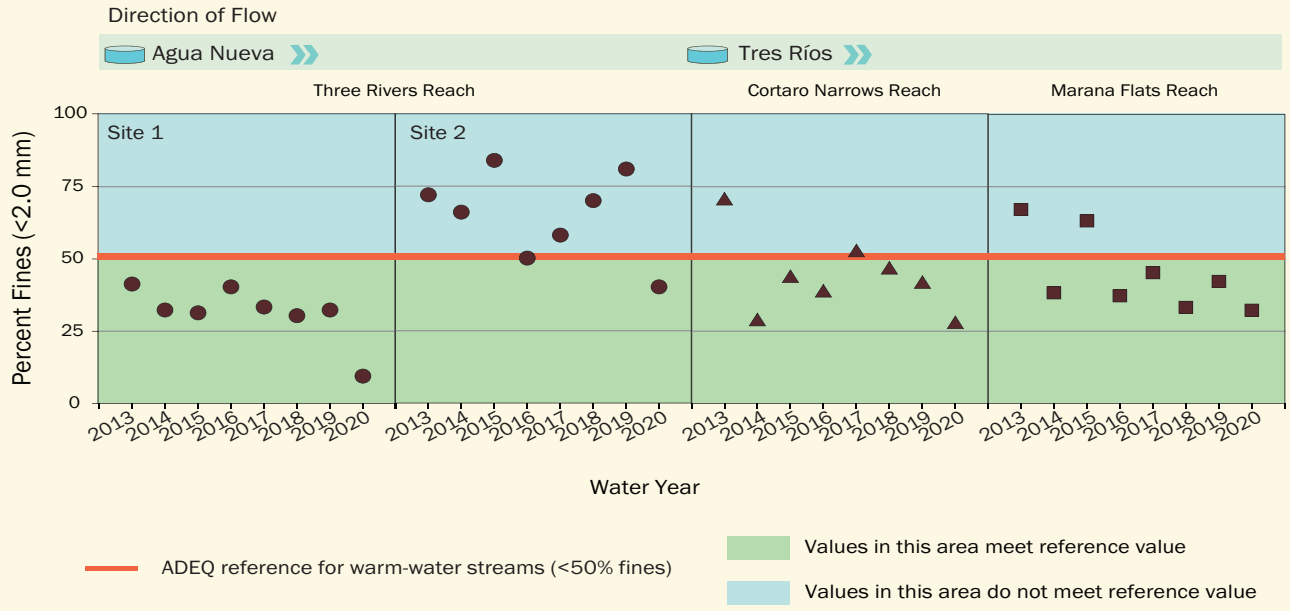
Turbidity was measured throughout the year at several locations for a total of 121 times. Overall, the reference value was met 94 times (78%). Average turbidity within Three Rivers and Cortaro Narrows has decreased since the 2013 upgrades were complete; both have averages below 10 NTU. Although average 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.

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 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%.



2013–2020 RESULTS

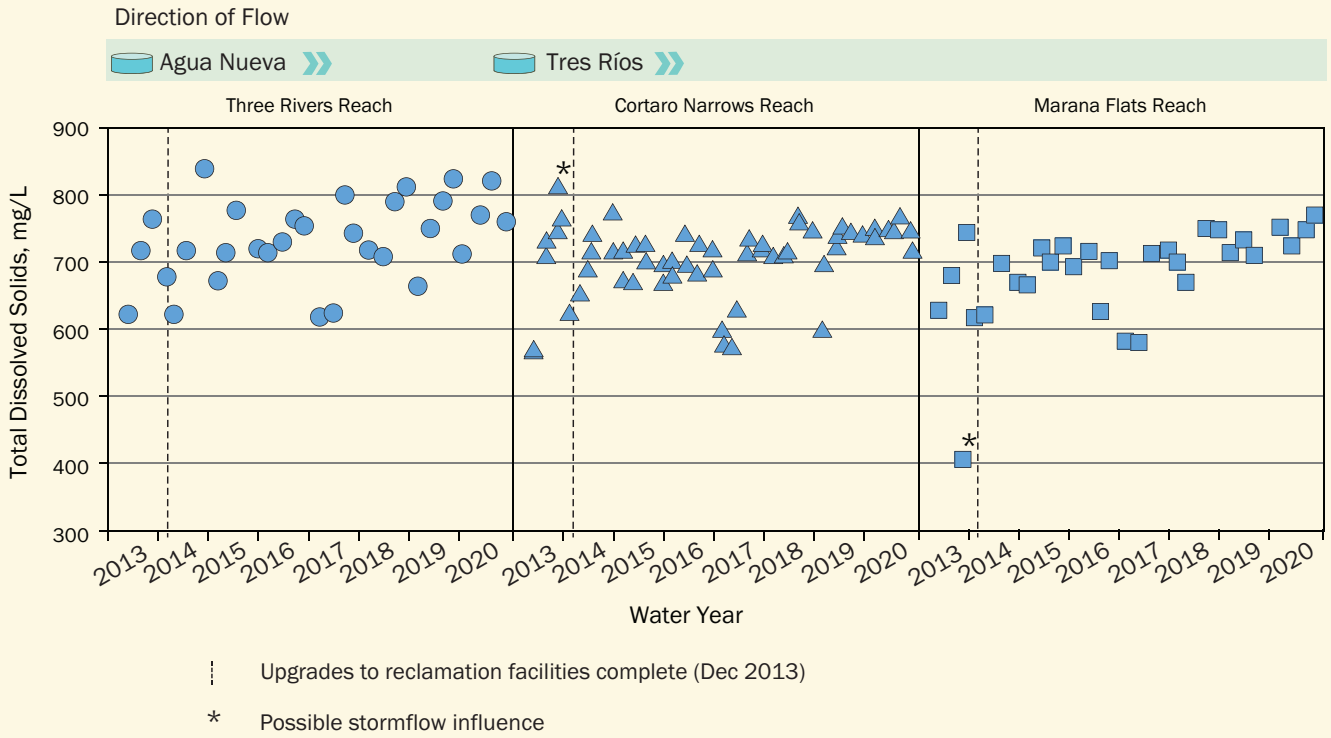
Percent fines were estimated at four sites where aquatic invertebrate samples were collected. Overall there was a reduction in the percent fines covering the riverbed at these sites, though there was a lot of variation. In 2020, all sites recorded their lowest percentage of fine materials since monitoring 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.

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 are unavailable.

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. Stormwater generally has low levels of TDS.



2013–2020 RESULTS

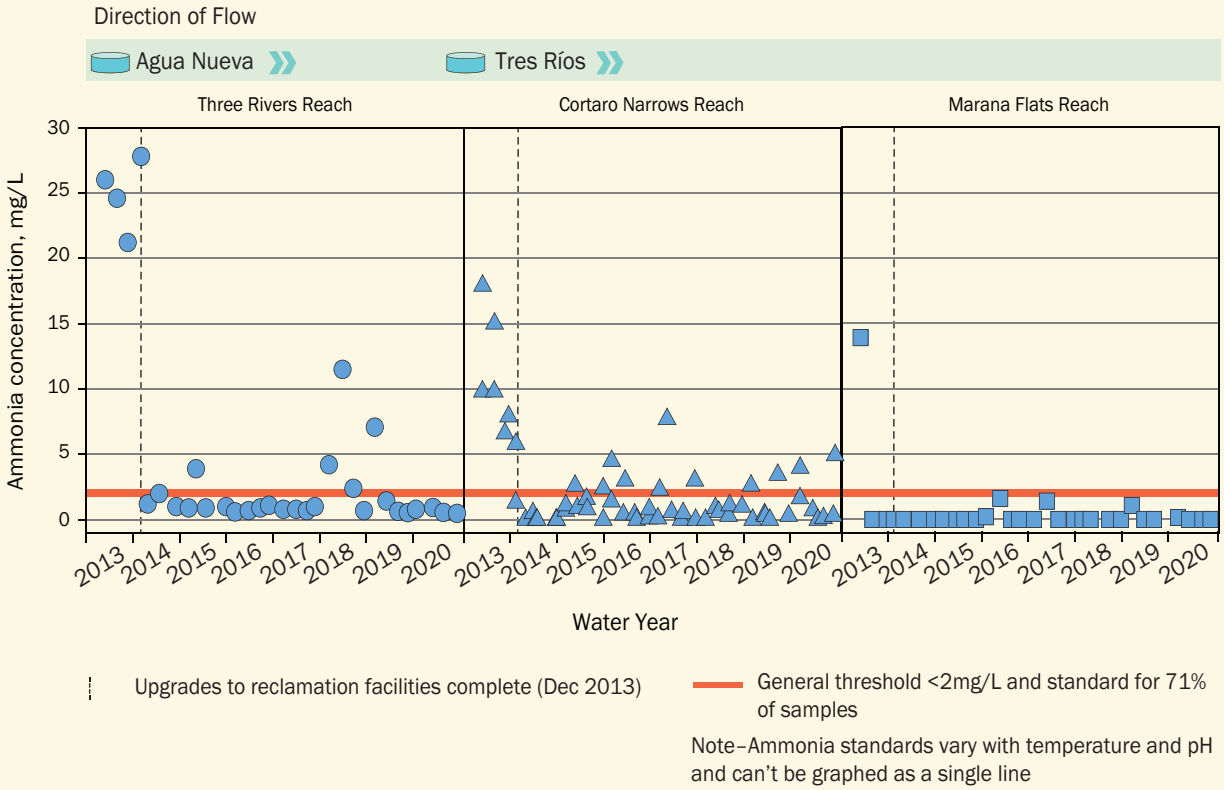
Total dissolved solids (TDS) were measured 120 times. Overall, levels of TDS were similar in all three reaches. Generally TDS hasn't changed very much, though variability in TDS levels decreased in 2015 and 2016 for unknown reasons. The lowest measure of TDS was in Marana Flats. This sample was collected 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.

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 <2mg/L to avoid toxic conditions.



2013–2020 RESULTS

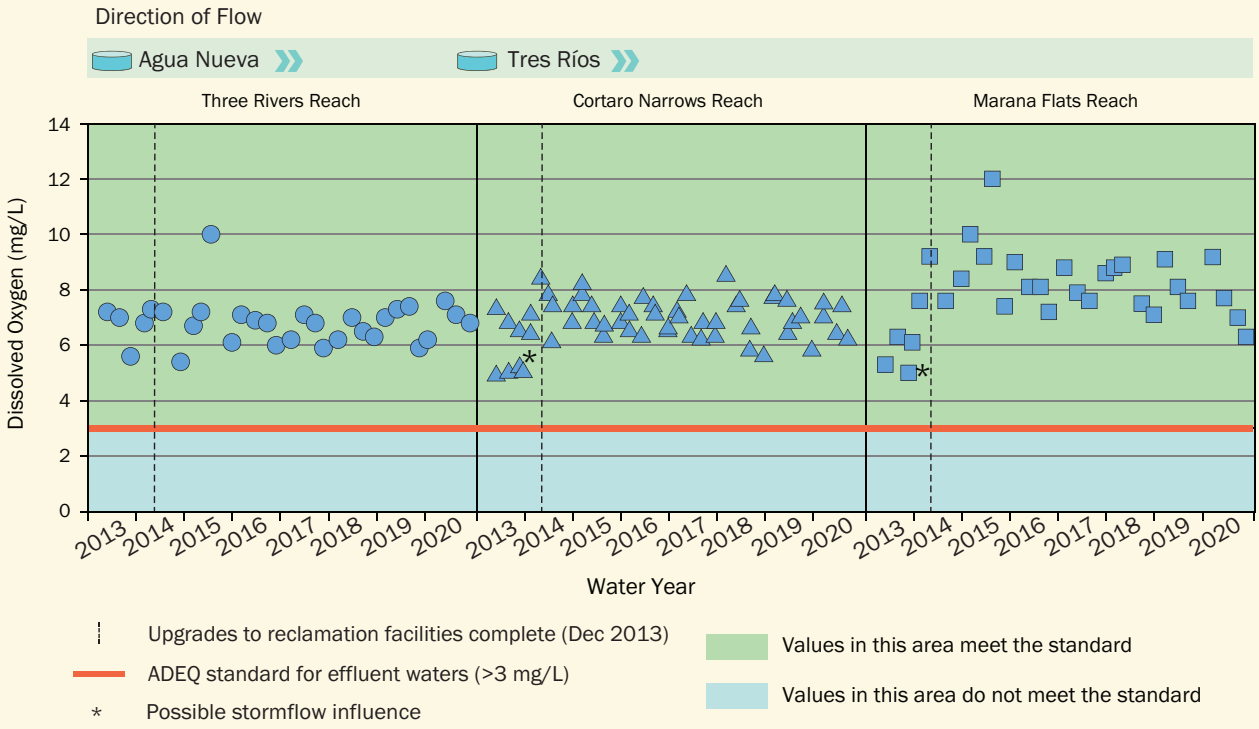
Ammonia was measured 119 times along the river. Overall the standard was met 87 of the 119 times (73%). The standard varies with pH and temperature, but was <2mg/L for 71% of the samples. Levels of ammonia have dropped significantly after the upgrade was complete in 2013. Levels of ammonia also decreased with distance from the reclamation facilities, as it converts into other forms of nitrogen while moving downstream. Measured at four locations (two locations in Coratro Narrows reach), average ammonia concentrations declined from a toxic 13 mg/L in 2013 to 1 mg/L in 2014–2020.

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. Pima County optimizes processes to better maintain the delicate balance of oxygen needed for maximum ammonia removal.

Measures of ammonia in the Heritage Reach began in the 2021 water year.

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).



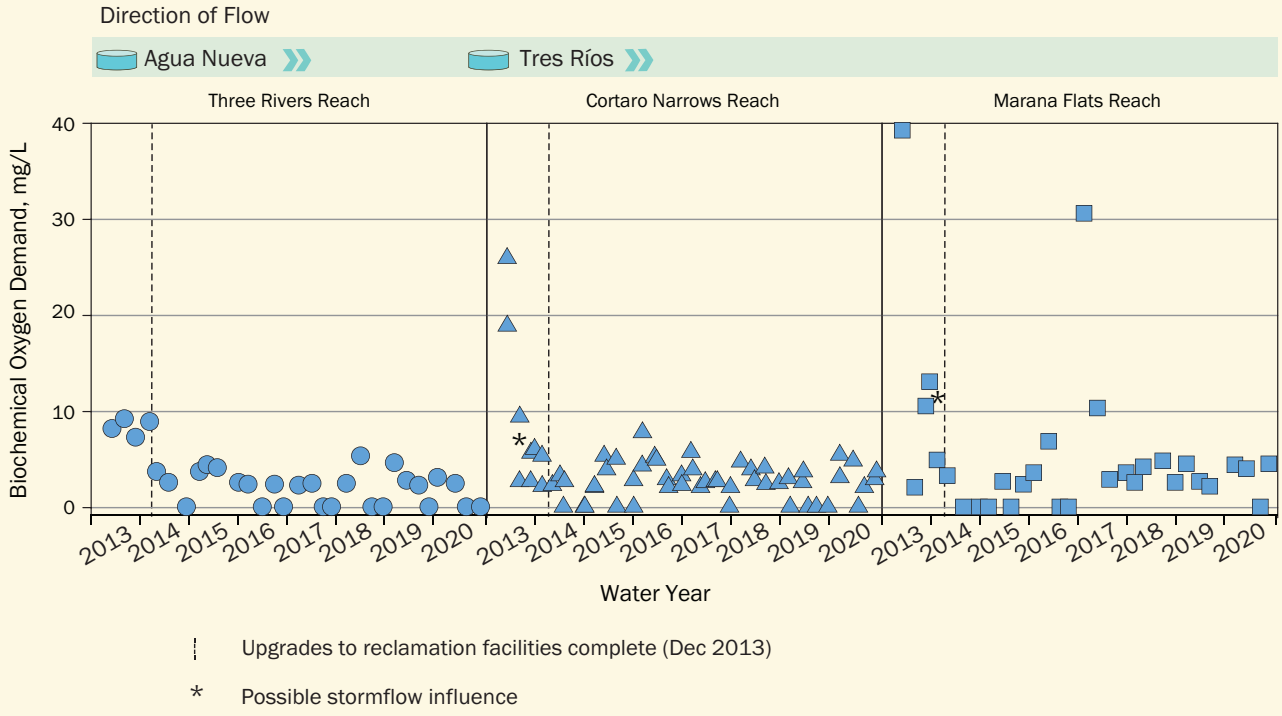
2013–2020 RESULTS

Dissolved oxygen was measured 119 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.

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.



2013–2020 RESULTS

Biochemical oxygen demand was measured 121 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.

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 »

	Three Rivers	Cortaro Narrows	Marana Flats	Marana Flats	Average Standard *standards for wildlife vary with water hardness*
Arsenic	3.8	3.0	3.2	3.4	150 ug/L*
Cadmium	ND	ND	ND	ND	3.3 ug/L
Chromium	0.7	0.6	0.5	0.4	11 ug/L*
Copper	2.1	2.1	2.1	2.1	19 ug/L
Lead	0.3	0.2	0.3	0.4	6 ug/L
Mercury	ND	ND	ND	ND	0.01 ug/L*
Zinc	51	46	43	36	241 ug/L

*set value, not an average

ND = Not Detected

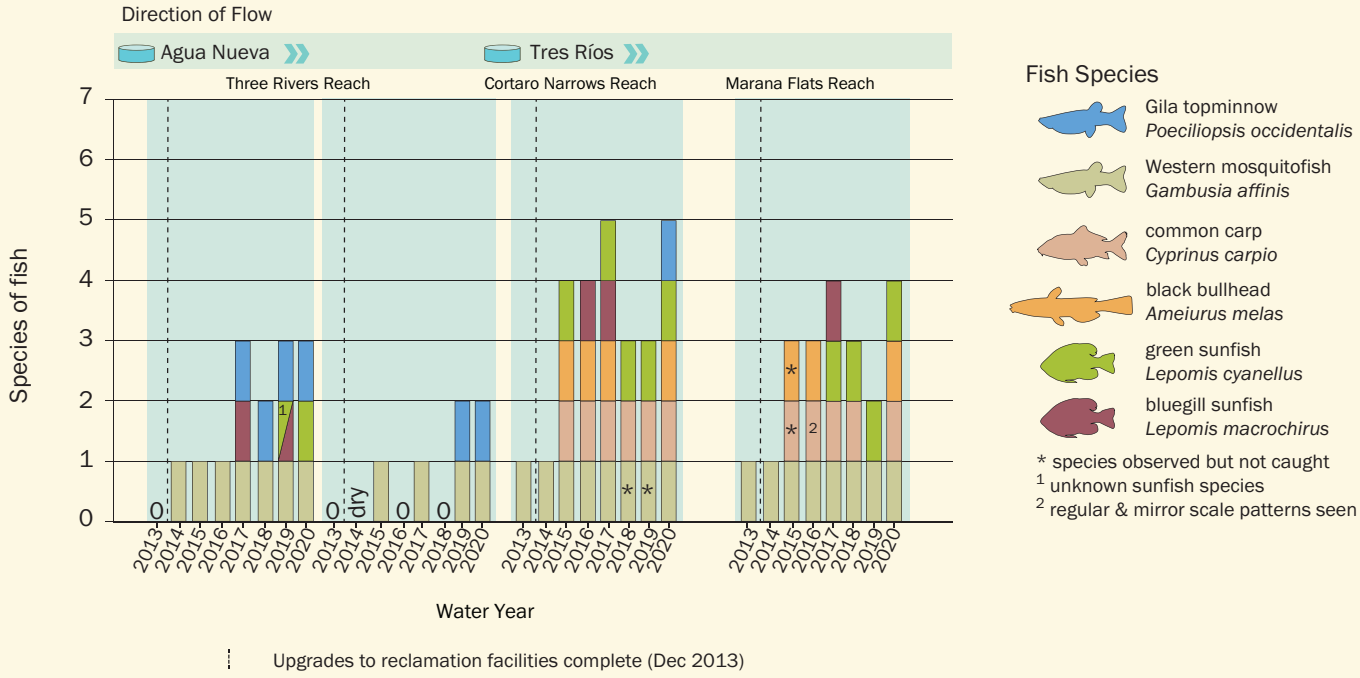
2013–2020 RESULTS

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 recharge rates.

Measures of dissolved metals in the Heritage Reach began in the 2021 water year.

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.



2013–2020 RESULTS

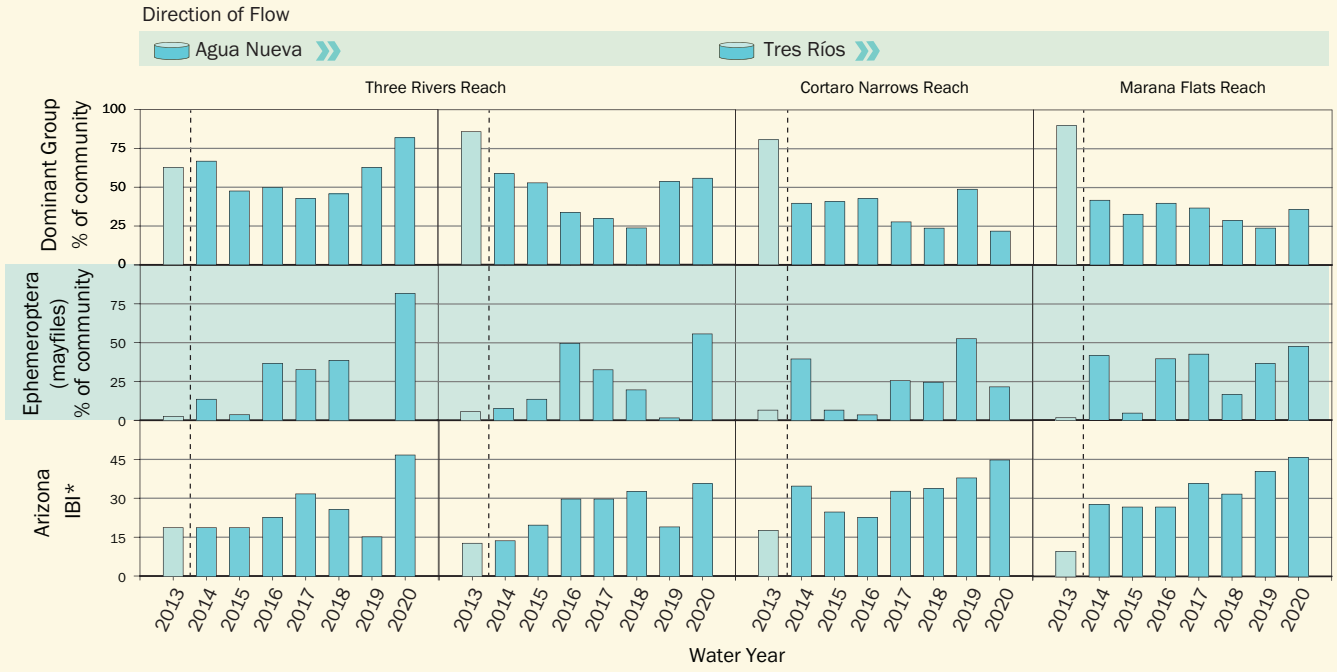
Fish surveys were conducted annually in the fall at the four locations aquatic invertebrates were surveyed. Surveys aim to detect all fish species present at a location, but do not try to assess population numbers. Improvements in water quality have allowed fish to thrive. Overall, number of fish species observed increased from one to six. All are non-native, except for the endangered Gila topminnow, which was found at one site in 2017, expanding to three sites in 2020. 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 will start in fall 2021. However, Arizona Game and Fish Department introduced Gila topminnow to this reach in October 2020.

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 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)

2013–2020 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, areas where the water surface is broken and agitated by rocks on the riverbed. This does not detect all species present, but gives a quick assessment of the site's biological integrity.

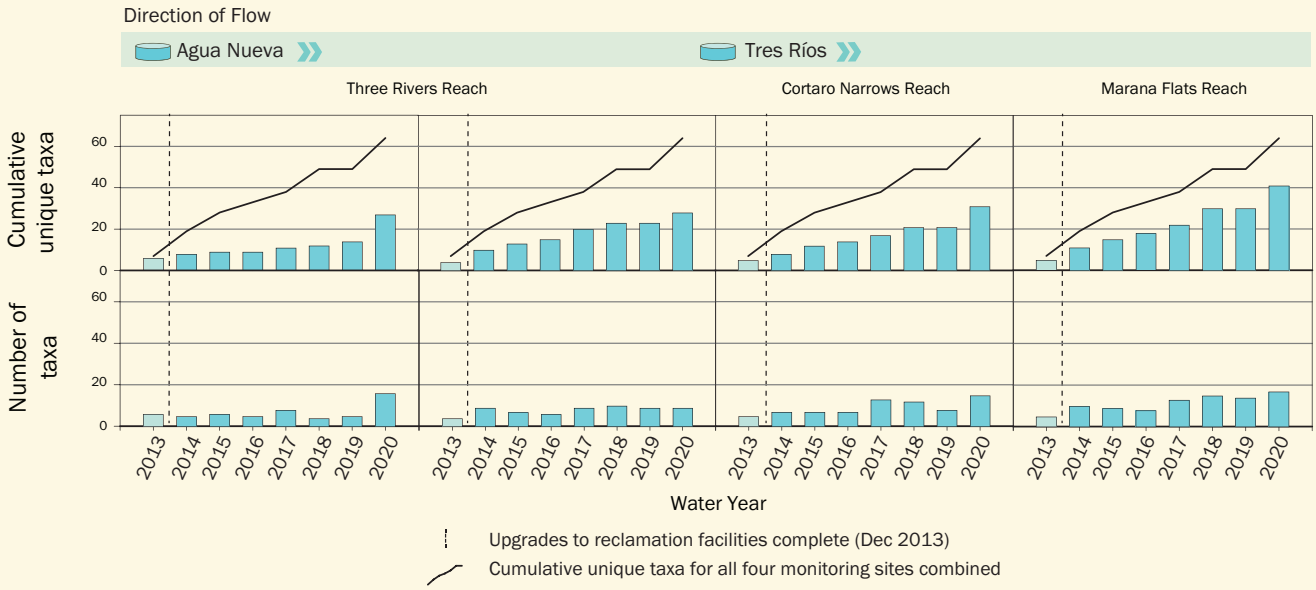
Overall, there were several signs of improvement. The percentage of the community dominated by a single group or taxa decreased (<50% meets the standard). Improvements are also supported by the increase in the percent of the community comprised of pollution-sensitive species from the order Ephemeroptera, 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. Three sites recorded scores of inconclusive in 2020 which is an improvement from previously lower scores that suggested impairment. 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 has decreased and was lowest in 2020. This may have increased the amount or quality of riffle habitat available. There were also occasional high levels of ammonia in reaches just downstream of the reclamation facilities (see Ammonia) that may impact the aquatic invertebrate community.

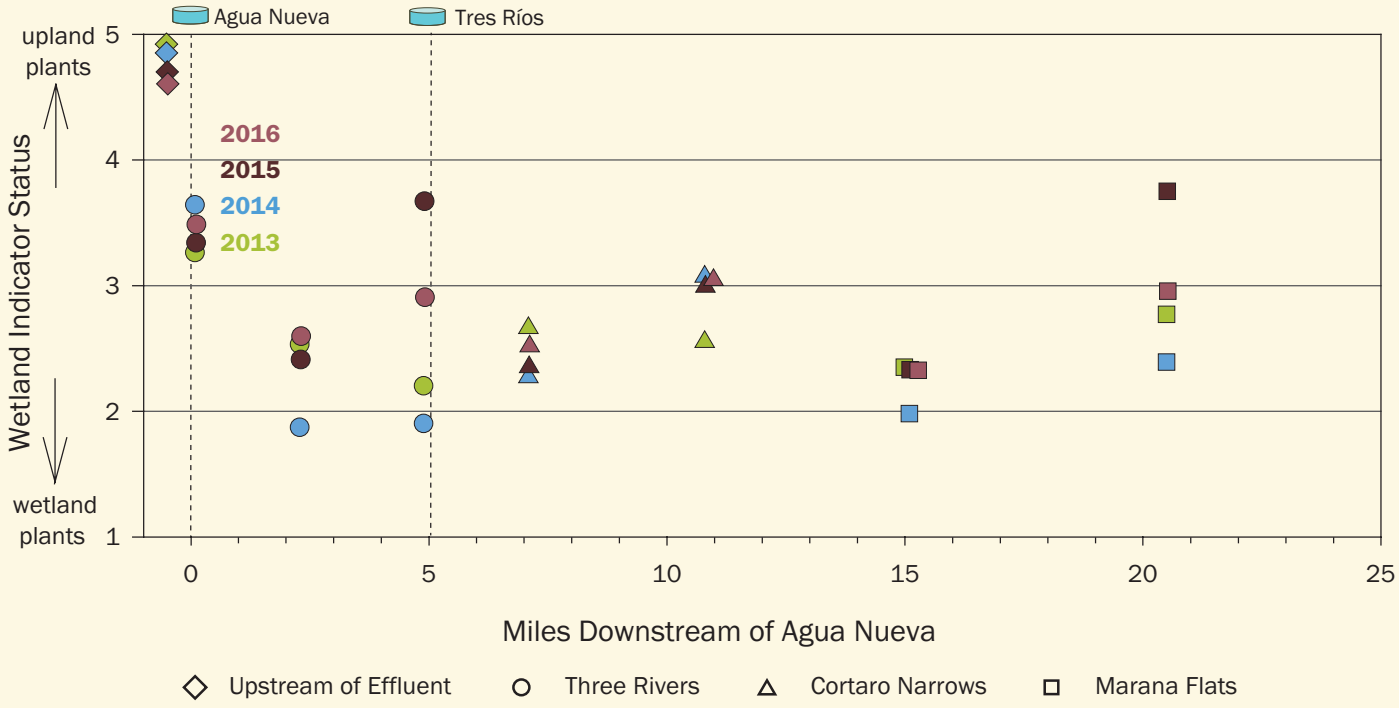
The total number of taxa found at a monitoring site has generally increased each year. The increased diversity is more apparent when you look at the cumulative total number of unique taxa found. This increases at all sites, though Marana Flats appears to have the greatest diversity.

Measures of aquatic invertebrates in the Heritage Reach began in the 2021 water year. However, dragonfly surveys conducted by the University of Arizona documented the quick arrival of dragonflies. Only days after flows began, two sites had an average of five dragonfly species. By late summer, this average was up to 21, comparable to the number of species found at a reference site in Marana. A similar pattern of colonization occurred after the return of flow following sediment removal in spring 2020.



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.

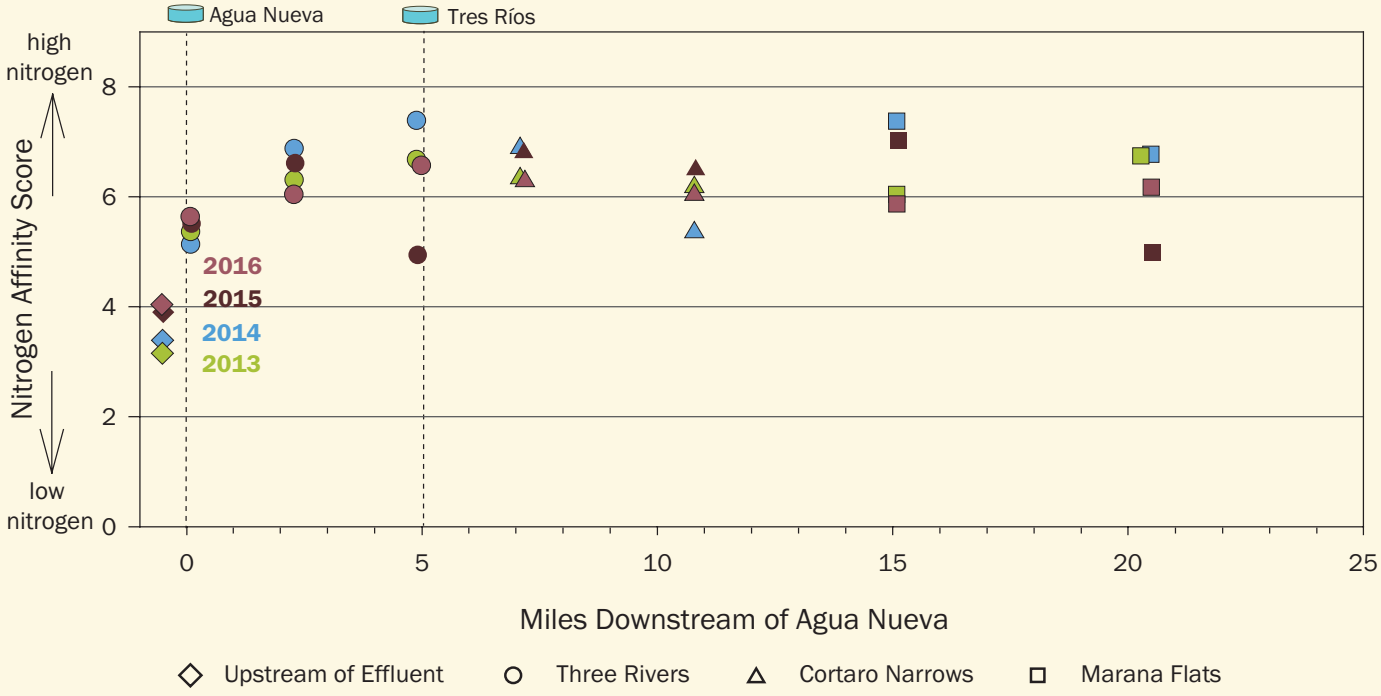


2013–2016 RESULTS

Not measured in 2017–2020. 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.

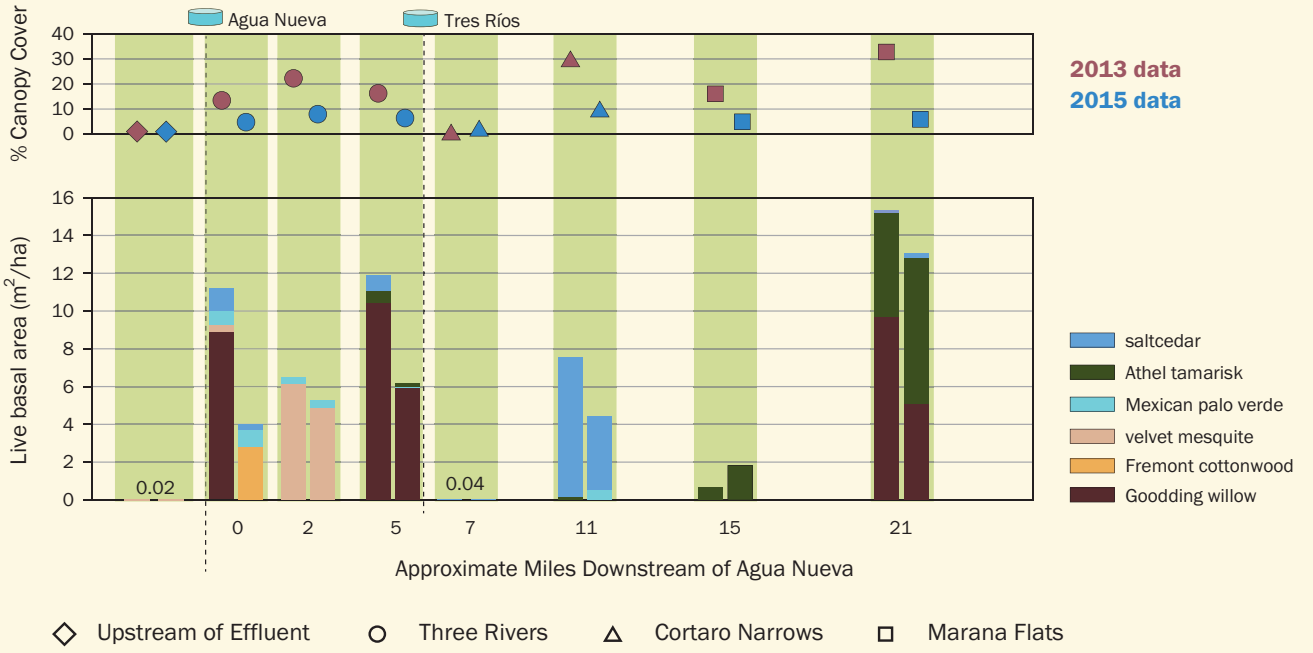


2013–2016 RESULTS

Not measured in 2017–2020. 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. There may not have been enough 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.

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 green "wedge" demonstrates how the weather station can help identify the direction wind would carry any odors escaping from the treatment process. Above photo, new pipes and decking at the headworks were installed in early 2019 to prevent odors from escaping.

2013–2020 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 were 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.

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 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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Image Credits: **cover:** Santa Cruz River by **Charlie Alolkoy**, www.alolkoyphotography.com **Page 2**: The American Coots of Sweetwater, **Gloria Brooks**, age 17, Living River of Words 2021 Independent Entry; The Water Bird, **Jasper Torrance**, age 8, Living River of Words 2021 Independent Entry; 2020 fish survey by **Bob Stinson**, Town of Marana Parks and Recreation **Page 3**: June and April photos of the outfall of the Heritage Project by **Michael T. Bogan**; Gila topminnow by **Bruce D. Taubert**.

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Sunset Reflection by Zahra Rafiyath, age 7, Independent Entry

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