– 2019 –
WATER YEAR

PROGRESS TOWARDS BINATIONAL COLLABORATION

a living river

CHARTING SANTA CRUZ RIVER CONDITIONS—NOGALES WASH TO AMADO

SUPPLEMENTARY REPORT FOR 2008 TO 2019 WATER YEARS

SONORAN INSTITUTE

SANTA CRUZ RIVER
A LIVING ECOSYSTEM

The Santa Cruz River in Santa Cruz County flows year round from Rio Rico to Amado and supports a culturally and ecologically diverse region. River flows are sustained by effluent discharges from the Nogales International Wastewater Treatment Plant (NIWTP) which treats wastewater from Nogales, Arizona and Nogales, Sonora (collectively *Ambos Nogales*). Keeping this stretch of the river flowing is critical to the viability of this ecologically rich and culturally significant area. With Mexico legally controlling over 80% of the water released into the river, any effort to permanently dedicate water to the river will require a binational solution that benefits both countries. In the last decade, two important changes in wastewater management have occurred:

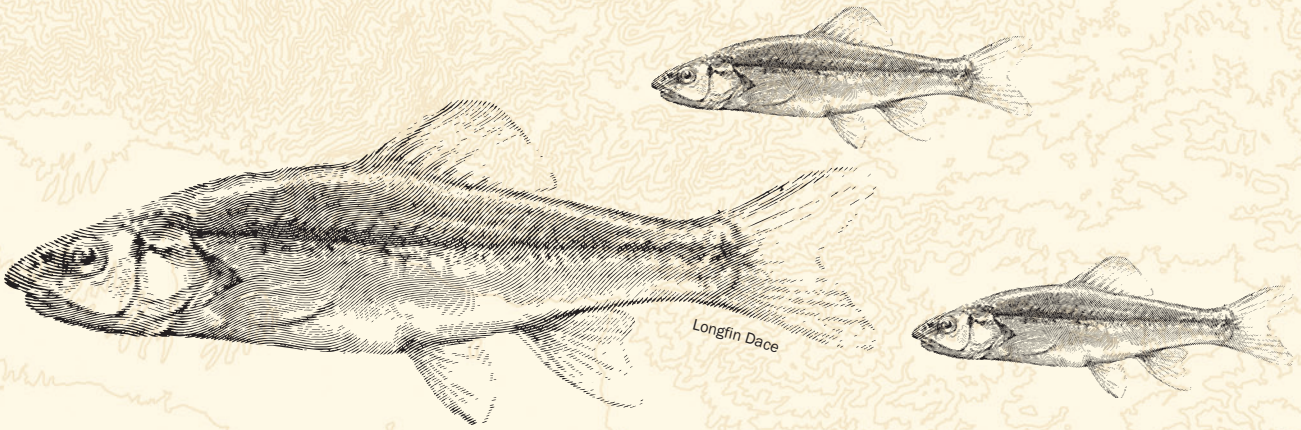
Upgraded Treatment Plant: In 2009 the NIWTP completed significant upgrades to the treatment process resulting in reduced levels of nitrogen in the released effluent.

Wastewater Diversions: In 2013 Nogales, Sonora completed construction of the Los Alisos treatment plant to divert and treat some of the wastewater that would otherwise be sent to NIWTP. Effluent generated at Los Alisos is released into a different river and flows south into Sonora.

Rivers are dynamic with conditions influenced by many factors. How do we know if management actions and other factors are influencing the conditions of this living ecosystem? Sonoran Institute's *Living River* reports were developed to annually track indicators of river conditions and determine what is changing. This assessment summarizes data from the 2008–2019 water years (each water year spans from October 1 to September 30). In 2018, we began to include conditions in Nogales Wash, an important corridor linking Ambos Nogales to the NIWTP and to the river. The pages following this executive summary provide more detail on the water context and data for 12 indicators relating to aquatic and riparian conditions.

CHANGES IN AQUATIC AND RIPARIAN CONDITIONS

- **Improved water quality with decreased nutrient pollution:** Nitrogen and phosphorus are essential nutrients for plants and animals, but too much can degrade conditions for aquatic life. Ammonia (a form of nitrogen that can be toxic to fish) and phosphorus significantly decreased in the Santa Cruz after the treatment plant upgrades were complete.
- **Availability of dissolved oxygen increases:** Dissolved oxygen, essential for aquatic life, increased in the Santa Cruz after the treatment plant upgrades were complete.
- **Pollutant metals no longer threaten aquatic wildlife:** Cadmium, a metal that is lethal to wildlife at low concentrations, has not been detected since 2011.
- **More diverse aquatic life:** Improvements in water quality have allowed aquatic life in the river to rebound. Four species of fish, including the endangered Gila topminnow, are now found. Diversity of aquatic invertebrates has increased and more pollution-sensitive species are present.
- **Reduced flow extent:** The length of the flowing river has decreased, likely the result of a combination of factors including: increased water infiltration, scouring floods, and water diversions. Since 2015, estimates of miles of flow in June suggest that minimum flow extent may be stabilizing in the Tubac reach.
- **Stressed riparian trees at the far end of the river:** Observations of branch die-back and death of some trees in the Amado Reach suggest that trees suffered following the treatment plant upgrade. Reduced flow extent is likely the primary cause of stress as flow has become more irregular through this reach.



OTHER OBSERVATIONS

- **Fecal contamination continues to be a risk during the rainy seasons:** *E. coli* levels continue to fail the water quality threshold for recreational contact. Exceedances of *E. coli* occur at all sites and primarily during rainy seasons suggesting multiple sources of fecal contamination exist throughout the watershed. Genetic analysis suggest humans and ruminants (sheep, goats, cattle, and deer) are the probable sources.
- **Groundwater levels most stable in the Tubac Reach:** Both the maximum depth to groundwater and the annual January to June decline in groundwater levels are sufficiently shallow and stable to provide optimal conditions for cottonwoods and riparian trees in the Tubac Reach.

ASSESSING CONDITIONS

This *Living River* report evaluates conditions of the Santa Cruz River from Nogales Wash to Amado using indicators organized into five categories that represent a breadth of biological, chemical, and physical 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 river conditions in Nogales Wash and at various intervals downstream of the effluent discharge point. 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 20-mile stretch of Santa Cruz River is divided into three sections, or reaches: Rio Rico, Tubac, and Amado. These reaches differ in geology and hydrology, with portions of the reaches alternating between gaining (where groundwater emerges and contributes to streamflow) and losing stream conditions (where streamflow raises the water table, lessening water flowing at the surface). There is a close connection between the surface and groundwater that can influence the aquatic and riparian ecosystems in these reaches. Most of the data for Nogales Wash come from a single survey location near Ruby Road, though occasionally data also come from a site closer to the international border.

Data are collected by several organizations. Data are summarized by water year (October 1–September 30) and compared to the baseline conditions observed in the 2008 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 or visits
Water Quality	Specific chemical conditions are necessary to sustain the river's animal and plant communities.	• Dissolved oxygen • Total phosphorus • Ammonia • *E. coli* • Metals
Aquatic Wildlife	Wildlife in the river integrate and reflect conditions of many factors of the surrounding environment.	• Fish • Aquatic invertebrates
Groundwater	Mature riparian trees require certain surface and groundwater conditions to survive.	• Maximum depth • January to June decline
Riparian vegetation*	Plant communities reflect changes in water quantity and quality.	• Forest and woodland cover

*Riparian vegetation only monitored from 2008–2010

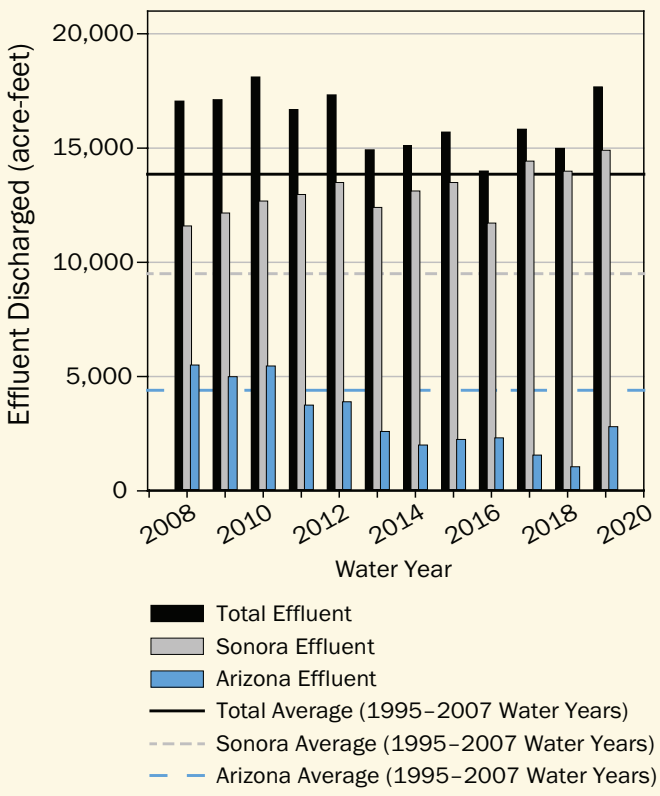
Streamflow and Rainfall

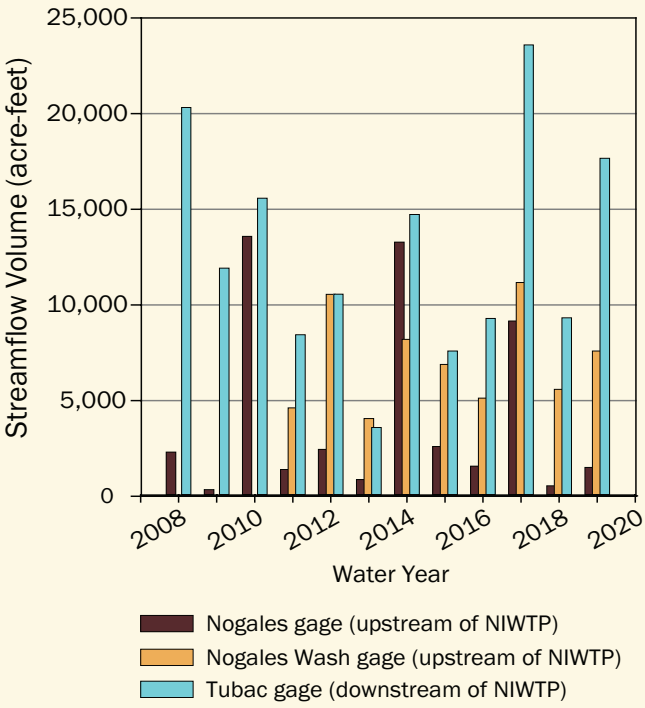
The amount of water flowing in the river provides important context when examining the indicators that track the conditions along the Santa Cruz from Nogales Wash to Amado. This water comes from two natural sources: precipitation and groundwater. A third source of water, effluent, is water that has been used by people, treated in a wastewater facility, and returned to a river. The Nogales International Wastewater Treatment Plant continuously releases effluent into Santa Cruz, just downstream of where the Nogales Wash flows into the river. Wastewater coming from Ambos Nogales flows in a pipeline, the International Outfall Interceptor (IOI), that is buried beneath Nogales Wash. Nogales Wash is also the principal waterway transporting stormwater runoff from Ambos Nogales to the river. Large, uncontrolled flows of stormwater, together with accidental sewage discharges from the IOI, have raised flood safety and water quality concerns from communities on both sides of the border.

Effluent accounts for the majority of streamflow in the Santa Cruz River from Rio Rico to Amado. However, streamflow also includes stormwater from the watershed. The Santa Cruz River watershed includes all of the land whose stormwater flows toward the river. We can get a sense of stormwater contribution to the Santa Cruz by tracking total rainfall and streamflow upstream of the treatment plant in Nogales Wash and near the international border. Seasonal floods (which can be measured by looking at peak flows) are important for scouring the riverbed, recharging aquifers, dispersing seeds, inducing seed germination, and clearing natural debris.

2008–2019 Summary

The total volume of effluent released annually into the river has varied, but remained above or at the average released between 1995 and 2007 water years. Between 2013 and 2018, the volume released decreased by an average of 2,000 acre-feet (over 650 million gallons). This represents





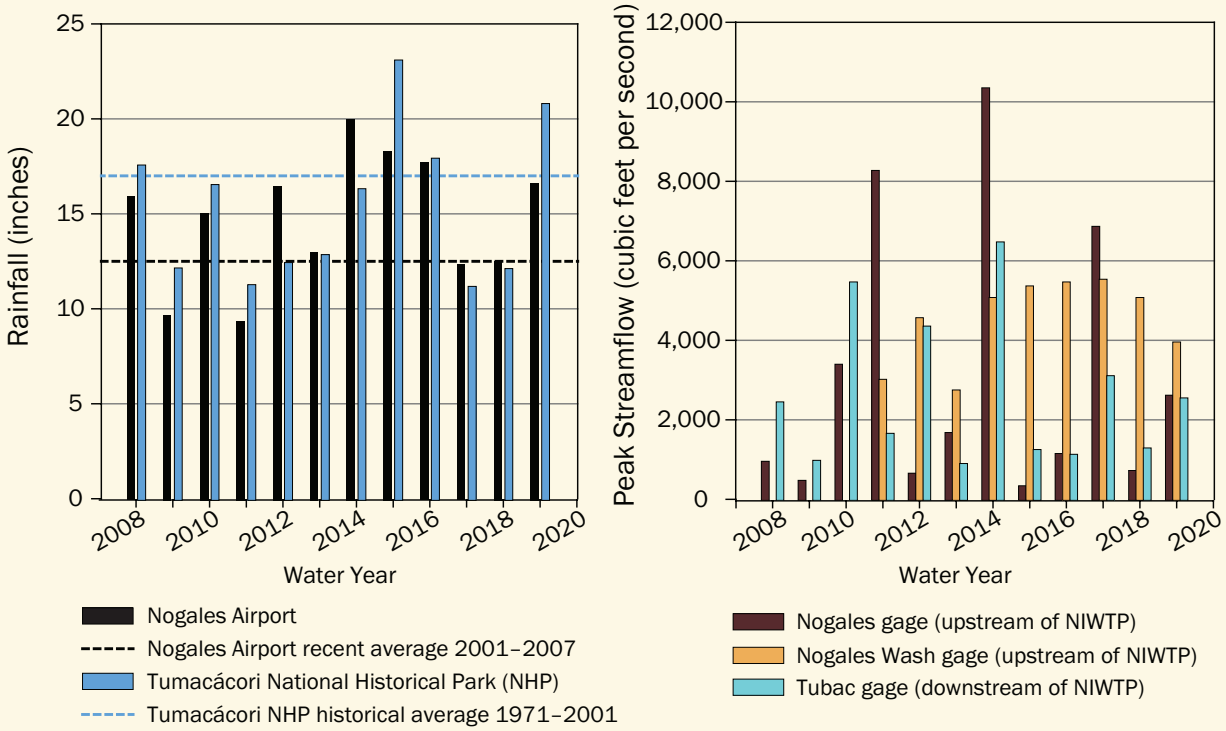
Streamflow and Rainfall cont.

about a 12% decrease compared to 2008. Although diversions of wastewater to the Los Alisos Treatment plant in Nogales, Sonora began in 2013, this decrease in effluent volume appears to result from reduced volume of wastewater attributed to Nogales, Arizona. The effluent volume released in 2019 increased to levels comparable to 2008. Exact reasons for this increase are unknown, though frequent failure of pumps diverting flows to the Los Alisos Treatment Plant in the last couple years is likely one factor.

Streamflow is measured daily in Tubac, near the international border and along Nogales Wash (since 2011). Overall, total volume of streamflow has been variable at all three locations. The greatest total volume of streamflow was measured in Tubac in the 2017 water year.

Total rainfall has hovered around the recent average at Nogales Airport. Sixteen miles to the northwest, rainfall near Tumacácori National Historical Park has generally been lower than the historical average in this area.

Peak streamflow has varied with location. Flooding conditions have often been higher upstream of the treatment plant than in Tubac with the largest flood recorded at the Nogales gage near the international border. Flows in Tubac have been variable, with the highest peak flow occurring in 2014. Nogales Wash has seen an increase in peak flow volume that has been stable since 2014.



FLOW EXTENT: Miles of Flow

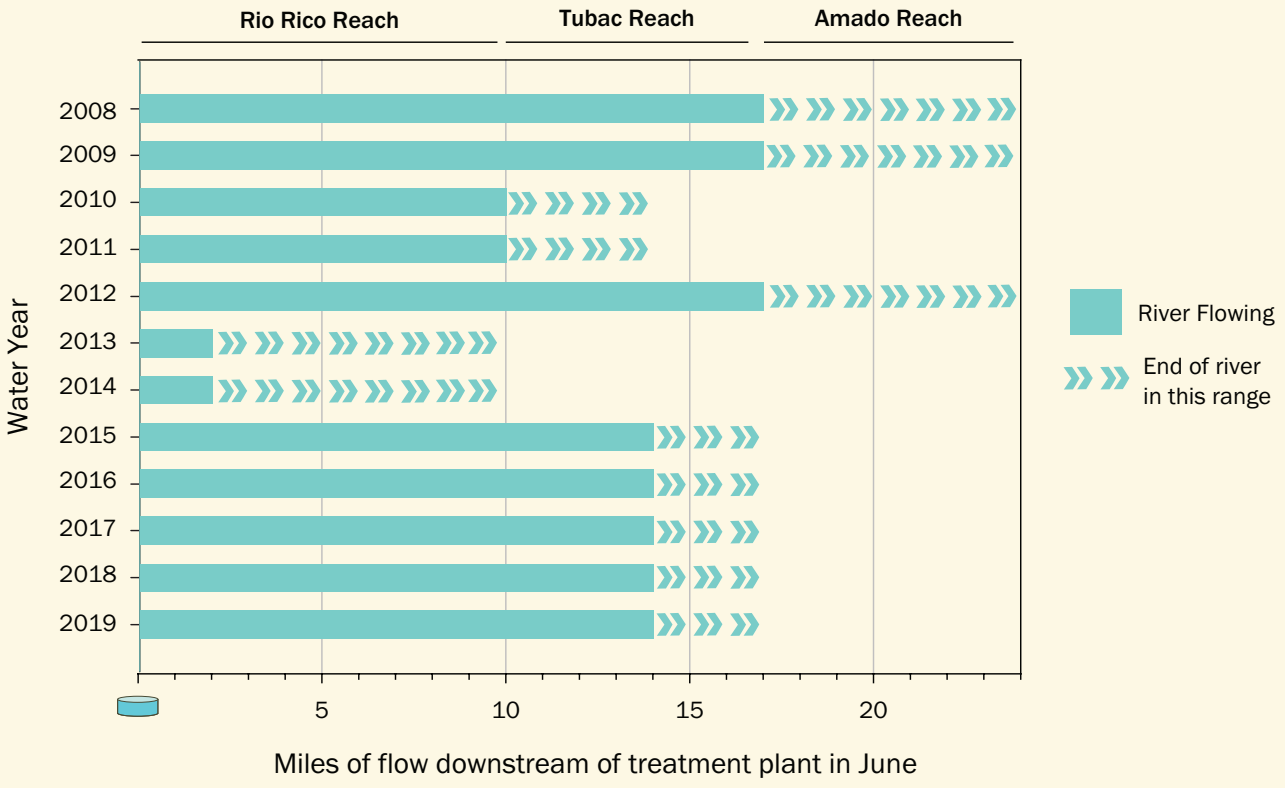
Measuring flow extent, or the distance the river is flowing, is a quick visual technique to track changes in the amount of water in the river and provides a rough estimate of the quantity of aquatic habitat available. For example, high flow extent may indicate availability of habitat for aquatic life. Low flow extent may indicate reduced water inputs, which could decrease aquatic habitat. Alternatively, low flow extent could indicate greater recharge of water into local aquifers.

Measuring miles of flow prior to the monsoon season determines the extent of flow during the driest time of year. This is typically measured in mid-June. Friends of the Santa Cruz River track river conditions monthly at three sites along the river and streamflow is monitored continuously by a USGS stream gage in Tubac. While the exact location of the "end of flow" is variable, we can track approximate location by knowing which monitoring sites are dry at the time of survey in June. Friends of the Santa Cruz River began monitoring flow extent in Nogales Wash in July 2019.

2008–2019 Summary

Miles of flow in June has decreased since the 2008 baseline. Prior to 2010, the river flowed 17 miles and into the Amado reach in June. Since the volume of effluent released into the river did not significantly decrease after the 2009 upgrade, increased recharge from improved water quality is likely a major factor for the decreased flow extent in 2010 and 2011. A further reduction in miles of flow was observed in 2013 and 2014. This coincides with the start of wastewater diversions to the Los Alisos wastewater facility in Sonora, Mexico which began in 2013. However, the total volume of effluent released into the river has decreased only by an average of 2,000 acre-feet per year, with this decrease largely attributed to decreased wastewater coming from Nogales, Arizona. Since 2014, flow extent in June has increased and stabilized.

In July 2019, flows in Nogales Wash reached all the way to the Santa Cruz River, over 9.5 miles from the U.S.–Mexico border.



FLOW EXTENT: Number of Dry Days or Visits

In addition to measuring minimum flow extent in the driest part of the year, it is helpful to understand the variation throughout the year. Although we can't know the exact length of the river at all times, quantifying the amount of time a specific location along the river is dry gives a measure of change in flow extent across the year.

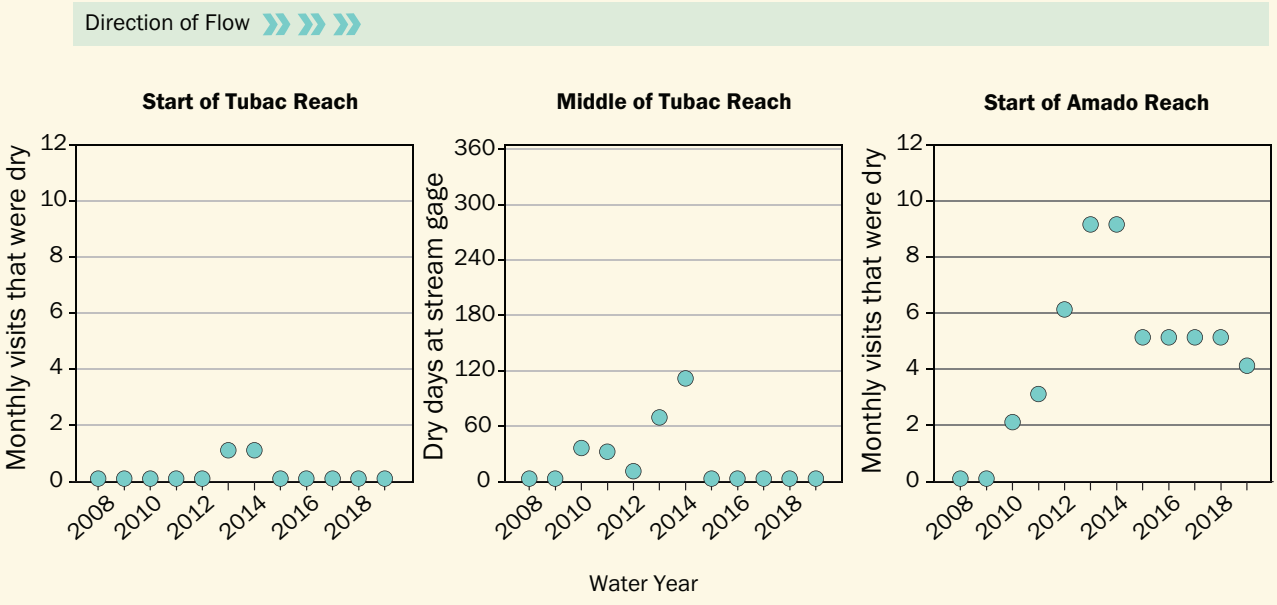
Friends of the Santa Cruz River track river conditions monthly at three sites along the river and one site on Nogales Wash. Streamflow is monitored continuously by a stream gage in Tubac managed by the U.S. Geological Survey. Measuring the number of monthly visits or days that are dry at a given location offers a glimpse at the changes in the amount of water in the river.

2008–2019 Summary

Dry days or visits have become more common at the far downstream end of the reach, indicating that flow extent has decreased. Prior to 2010, the river flowed every day at the Tubac stream gage with no zero flow days recorded since July of 2003. Between 2010 and 2014, the number of dry days increased to a high of 120, though has returned to zero and appears stable since 2015.

A similar pattern of increased dryness is seen at the start of the Amado reach. Though measured monthly rather than daily, the number of dry visits has increased. Only one dry visit was observed between 2005 and 2009. In contrast, dry visits peaked during the 2013 and 2014 water years with 9 of 12 monthly visits dry. Since 2014, dry days and visits have decreased and stabilized.

Nogales Wash has had stable flows. Only three of the monthly monitoring visits at Nogales Wash near Ruby Road found no flow. These were during the June visits of 2011, 2013, and 2014.



Note: Data from the Rio Rico reach are not displayed. No dry visits observed during the 2008–2019 water years.

WATER QUALITY: Dissolved Oxygen

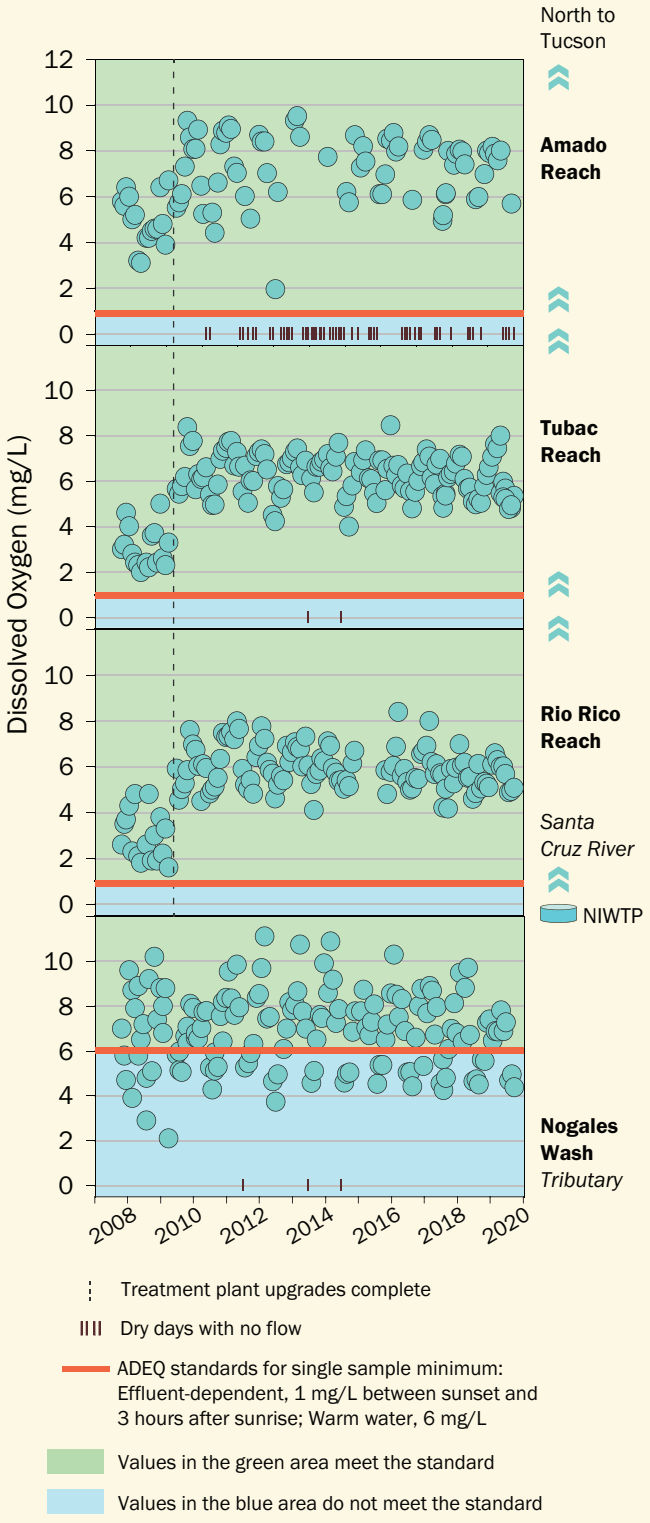
Fish and other aquatic animals need oxygen to survive. Rivers absorb oxygen from the atmosphere and aquatic plants produce oxygen. External causes of variability in dissolved oxygen levels include nutrient concentrations, groundwater discharge, shading, water temperature, and time of day.

The Arizona Department of Environmental Quality sets the minimum wildlife standard for dissolved oxygen in effluent-dependent streams at 1 milligram per liter (mg/L) measured between sunset and three hours after sunrise, and 3 mg/L at other times. Most measures were taken within three hours after sunrise, and values of dissolved oxygen greater than 1 mg/L meet the standard. Levels of dissolved oxygen in Nogales Wash are held to the dissolved oxygen standard for warm water streams which is 6 mg/L.

2008–2019 Summary

Levels of dissolved oxygen have met the standard in all three reaches of the Santa Cruz. Dissolved oxygen increased after upgrades to the treatment plant were completed in 2009. Although there have been more days with no flow in the Amado reach in recent years, when water is present, levels of dissolved oxygen have met the standard.

In Nogales Wash, levels of dissolved oxygen have been stable and 92 of 134 samples have met the warm water standard (they attained the standard 69% of the time). Treatment plant upgrades did not impact conditions in Nogales Wash.



WATER QUALITY: Total Phosphorus

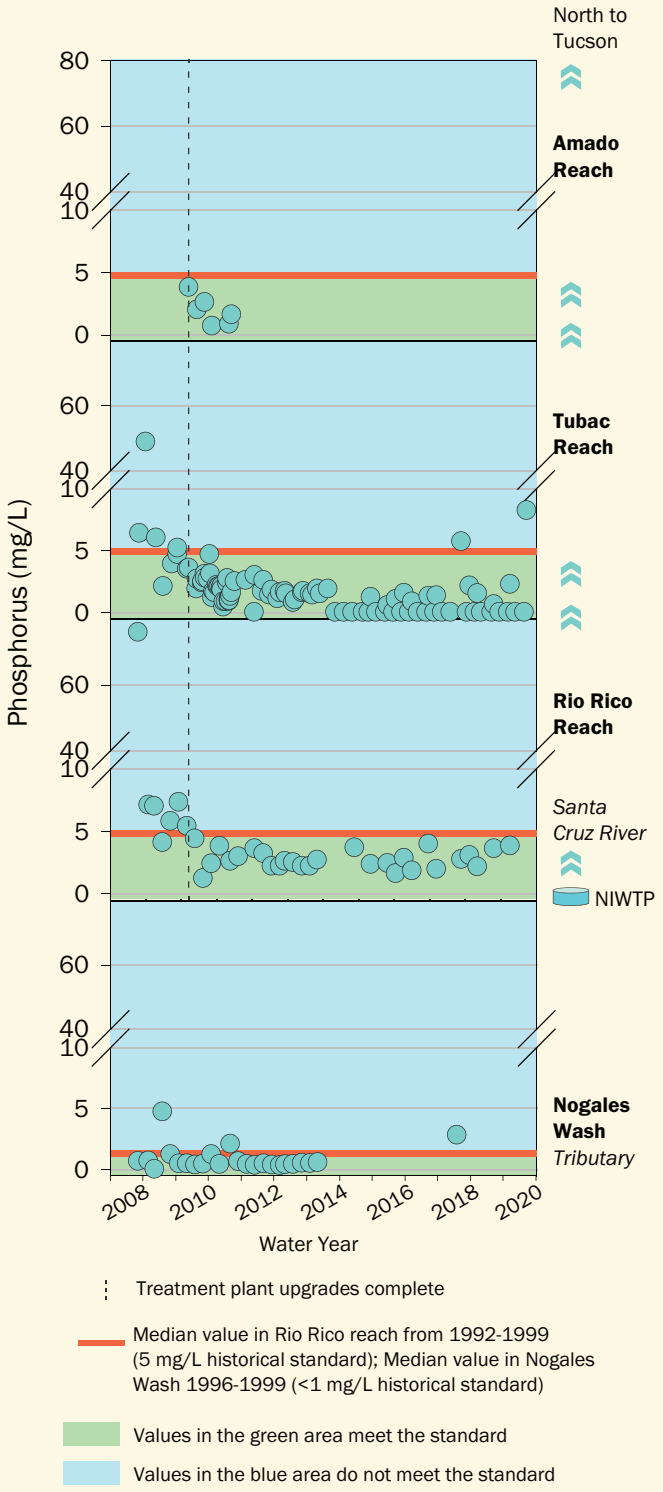
Phosphorus is an essential nutrient for plant and animal life. However, too much phosphorus can reduce the quality of aquatic habitat. Elevated levels of phosphorus can accelerate plant growth. Then when algae and plants decay in the river, dissolved oxygen decreases and aquatic animals can suffocate.

The median amount of total phosphorus measured in the Rio Rico reach from 1992–1999 was approximately 5 mg/L. Because Arizona Department of Environmental Quality does not have a standard for total phosphorus in this stretch of the Santa Cruz River, this assessment uses the 1992–1999 median of 5 mg/L as the historical standard. Similarly, there is no standard for phosphorus in Nogales Wash. This assessment uses the 1996–1999 median of <1 mg/L as a historical standard.

2008–2019 Summary

Phosphorus levels declined over the years in the Rio Rico and Tubac reaches, most notably after the upgrades to the treatment plant were complete in 2009. Data are limited for the Amado reach but measures of total phosphorus are below the historical standard.

Nogales Wash has limited data and treatment plant upgrades did not impact conditions. All but five samples met the historical standard. The only sample since 2013 was taken in 2017 during a sewage breach when untreated wastewater was flowing out of the International Outfall Interceptor and into Nogales Wash.



WATER QUALITY: Ammonia

Nitrogen is an essential nutrient for plant and animal life, but too much can lead to nutrient pollution. Ammonia (NH_3) is one form of nitrogen that can be toxic to fish. Even at low concentrations, ammonia can reduce hatching success, among other impacts. The toxicity of ammonia varies with several factors such as pH, temperature, and dissolved oxygen. The Arizona Department of Environmental Quality's wildlife standard for ammonia varies by pH and temperature. As pH and temperature increase, the toxicity of ammonia increases, thus the acceptable level of ammonia decreases with high pH and temperature.

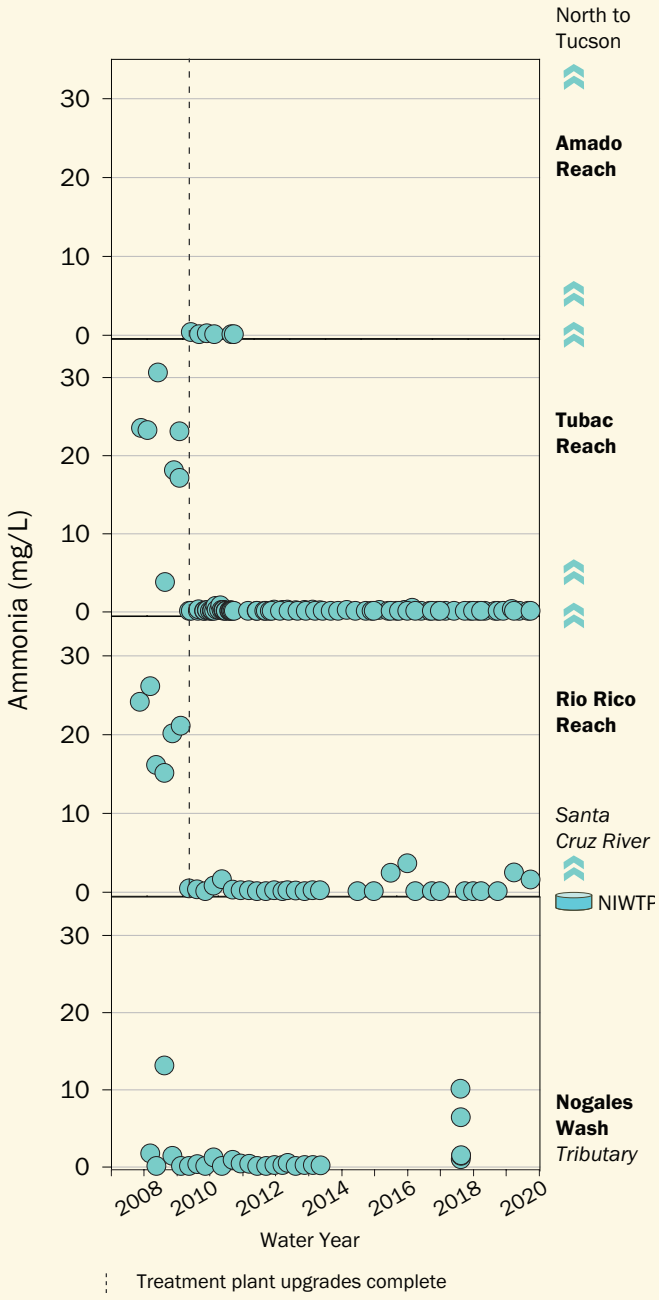
High nutrient levels can also increase the number of microorganisms that break down and use these nutrients. Living in the spaces between the sand and gravel of the streambed, these organisms can become so numerous that they create a clogging layer and prevent water from moving through the streambed to recharge the local aquifer.

2008–2019 Summary

Ammonia decreased dramatically and was often not detected in the Rio Rico and Tubac reaches after the treatment plant upgrade was complete in 2009. This improved water quality led to beneficial conditions for fish and other aquatic wildlife. Although data are limited for the Amado reach during this period, between 2000 and 2007 measures of ammonia averaged 10 mg/L and followed a similar pattern to the Rio Rico and Tubac reaches. The decreased ammonia likely reduced the clogging effect in the river bed and was a factor in the reduced flow extent observed since 2009.

Since the treatment plant upgrade, only 5 sampling events have detected elevated ammonia levels that averaged 2.25 mg/L in the Rio Rico reach. Removal of ammonia is complex. The NIWTP uses a multi-step process that features alternating oxygenated and oxygen-free zones and must regularly optimize processes to maintain the delicate balance of oxygen needed for maximum ammonia removal.

Nogales Wash was not impacted by the upgrades to the treatment plant. Ammonia levels here were low, averaging 1.4 mg/L from 2008–2013. Measures of ammonia from 2017 were taken during a sewage breach when untreated wastewater was flowing out of the International Outfall Interceptor and into Nogales Wash.



Note - Ammonia standards vary with temperature and pH and can't be graphed as a single line.

WATER QUALITY: *E. coli*

Escherichia coli (*E. coli*) is one of the common species of bacteria living in the lower intestines of mammals, and its presence in water is an indication of fecal contamination. The discovery of *E. coli* indicates the potential presence of other pathogenic microorganisms such as bacteria and viruses that might be a health risk to people swimming or wading in the river.

The Arizona Department of Environmental Quality standard for a single sample maximum for full body contact (swimming) is 235 colony-forming units per 100 milliliters of water (CFU/100mL). For partial body contact (wading), the single sample maximum is 576 CFU/100mL. The results are compared to the stricter standard, thus samples with greater than 235 CFU/100mL do not meet the standard.

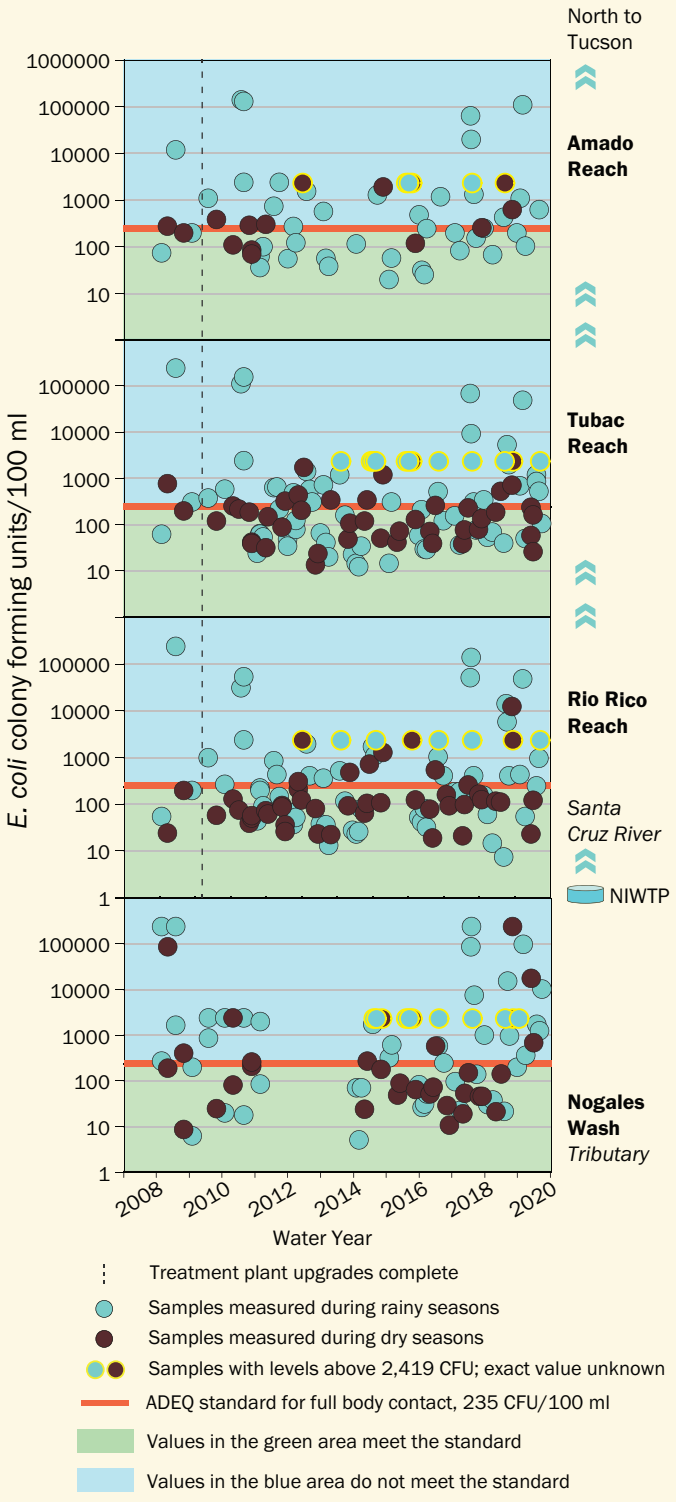
2008–2019 Summary

E. coli levels varied seasonally and were similar in all three reaches of the river and in Nogales Wash. The Nogales International Wastewater Treatment Plant has always treated for bacteria prior to release of effluent in the Santa Cruz, thus levels of *E. coli* in the effluent did not change after the upgrades were complete. Levels of *E. coli* exceeded the standard most often during the rainy seasons.

High levels at all sites during the rainy season suggest that rain is washing fecal contamination into the river from multiple sources within the watershed. Research published in 2019 reported that microbial markers associated with humans and ruminants (sheep, goats, cattle, and deer) were the markers most frequently detected and were strongly correlated with flooding conditions.[1]

High *E. coli* levels are partially linked to aging wastewater infrastructure along Nogales Wash. Several of the exceedances in Nogales Wash from 2017 were from samples taken during a sewage breach when untreated wastewater was flowing out of the International Outfall Interceptor and into Nogales Wash.

[1]Paretti, N.V., 2019, Escherichia coli in the Santa Cruz River in Tumacácori National Historical Park, Arizona: U.S. Geological Survey Fact Sheet 2019-3065, 6 p., https://doi.org/10.3133/fs20193065



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. The Santa Cruz River is exposed to metals through many sources, including industrial wastewater discharge, mine drainage, roadways, and by the release of metals naturally occurring in near-surface rocks and sediments. Arizona Department of Environmental Quality (ADEQ) set standards to protect aquatic wildlife. Results for the following metals are compared to their appropriate standard: arsenic, cadmium, copper, lead, nickel, and zinc.

2008–2019 Summary

Most of the water samples tested for dissolved metals in the Santa Cruz met the appropriate standards. Samples with concentrations above the standard included a single sample for lead, two samples for nickel, and several samples for cadmium. Cadmium is lethal to aquatic wildlife at low concentrations and comes from numerous human-produced sources such as coal combustion, electroplating processes, fertilizers, pesticides, and mine wastes. In 2009, the cadmium standard became more stringent, but in 2016 reverted back to a less stringent standard. Between 2008 and 2011, 11 (2009 standard) or 3 (2016 standard) samples tested for cadmium exceeded the standard. The NIWTP cannot remove metals, so ADEQ and the U.S. International Boundary and Water Commission worked with the cities of Nogales, Arizona and Nogales, Sonora to mitigate metals in the binational wastewater. These actions were successful as subsequent river monitoring has not detected cadmium.

Data are limited for Nogales Wash. Only two samples from 2008–2012 had metals detected above the standard.

Though concentrations are low in the river, the NIWTP continues to detect metals. Metals interfere with the efficiency of treatment processes and contaminate removed biosolids. When contaminated, removed biosolids must be landfilled instead of being used as fertilizer for agriculture.

Values for dissolved metals in water samples tested throughout all water years[a]
concentrations in micrograms/liter (µg/L), also known as parts per billion (ppb)

	Nogales Wash[f]		Santa Cruz River		**Average Standard** *wildlife standards vary with water hardness*
	Average (min–max)	Samples Above Standard	Average (min–max)	Samples Above Standard	
Arsenic	2.1 (0–4.9)	0	4.4 (0–17)	0	150 µg/L[b]
Cadmium	0.2 (0–3.9)[c]	1	0.4 (0–8.3)	9 or 3[d]	0.8 or 3.7 µg/L[e]
Copper	4.7 (0–18)	1	1.9 (0–14)	0	16 µg/L
Lead	ND	0	0.9 (0–40)	1	5.2 µg/L
Nickel	NT	NT	17 (0–100)	2	91 µg/L
Zinc	ND	0	12 (0–150)	0	211 µg/L

ND = Not detected
NT = Not tested

[a]Results listed as "not detected" were recorded as zero in the average, min, and max analysis.
[b]Not an average. Standard for arsenic does not vary with water hardness.
[c]Only one sample had a concentration detected in 2008 (which was above the standard). All others had concentrations of cadmium that were below detection level.
[d]Standard changed in 2009 and 2016. Number of samples with concentrations above the standard varies; 9 with more stringent standard or 3 with less stringent standard. No samples were above the standard since 2011.
[e]Average standard for 2009 more stringent standard or average standard for 2016 less stringent standard.
[f]Samples from Nogales Wash only available for 2008–2012 water years.

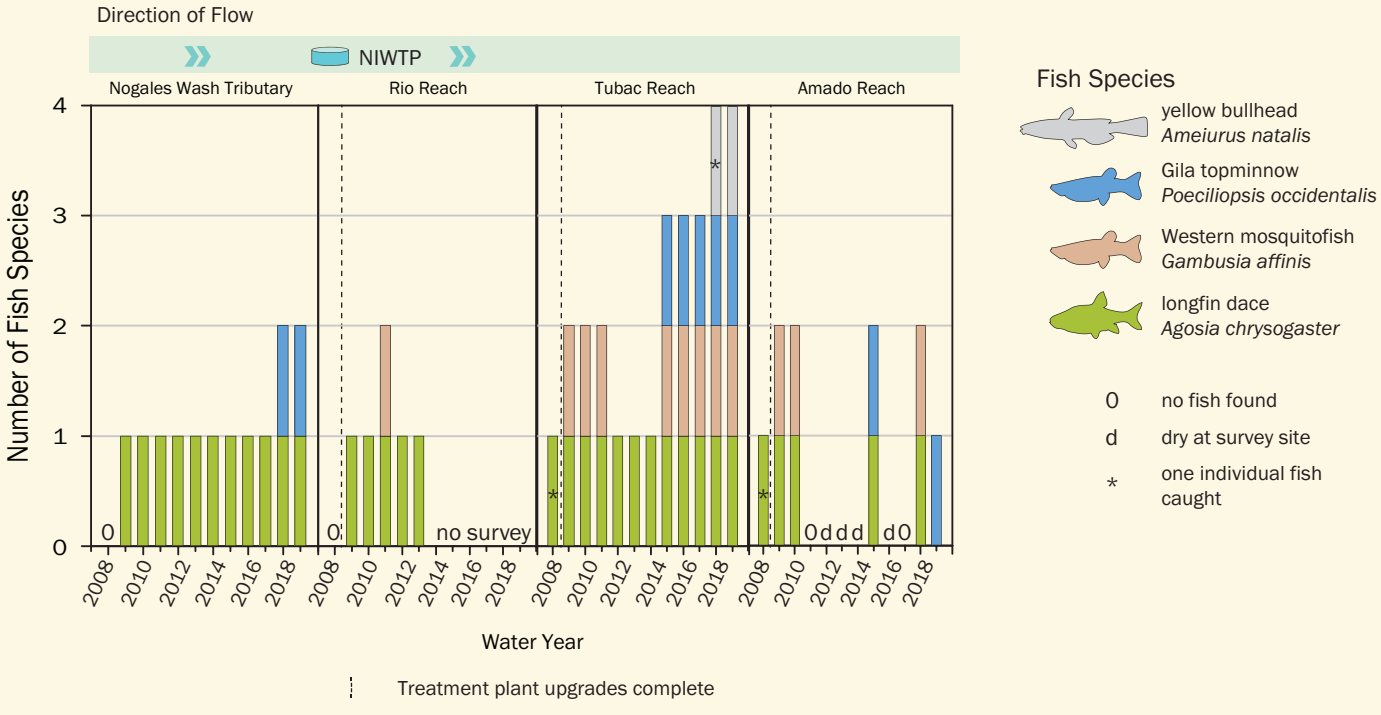
AQUATIC WILDLIFE: Fish

Fish can serve as effective longer-term indicators of river health because they live for several years and different species vary in their tolerance to pollution. Historically, the Santa Cruz River from Rio Rico to Amado supported several native fish species: Gila topminnow, desert sucker, Sonora sucker, and longfin dace. Long-term monitoring prior to 2008 has shown a decline in the number of native fish species present. Three nonnative fish species—the Western mosquitofish, green sunfish, and largemouth bass—were found in Tumacácori National Historical Park between 2001 and 2002. There is no standard for diversity of fish. The results from the 2008 water year will serve as a baseline for monitoring change.

2008–2019 Summary

Annual fish surveys in autumn determine fish presence and species in Nogales Wash and at several locations downstream of the treatment plant. In 2008, only longfin dace were found, and in very low numbers (2 individual fish caught). After the treatment plant upgrade, number of fish species has increased from one to four (two native and two non-native). The endangered Gila topminnow returned to the river in 2015 and the relative ease of capturing them during surveys suggests they are thriving. Conditions in the Amado reach have been occasionally dry at the time of survey and thus may no longer represent perennial habitat.

Though not impacted by the treatment plant upgrade, Nogales Wash has also seen an increase in fish species, most notably with the return of the Gila topminnow in 2018. Though not included in this summary, longfin dace were found in Nogales Wash in 2007. The reason why no fish were found during the baseline year is unknown.



AQUATIC WILDLIFE: Aquatic Invertebrates

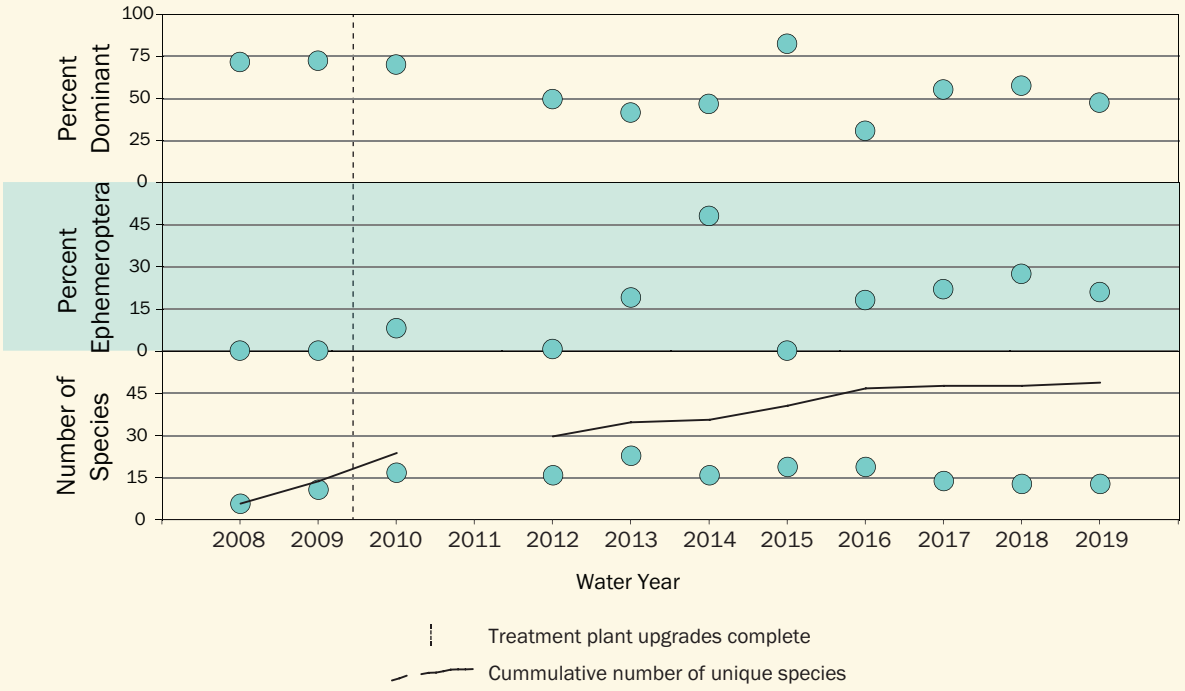
Aquatic invertebrates break down organic materials and are important prey for fish and other river-dependent species. They also differ in their tolerances to pollution. Chironomidae (midges) are pollution tolerant and are found in high numbers even with low oxygen levels and high organic matter. Ephemeroptera (mayflies) have exposed gills on the outside of their body, making them very pollution sensitive. The percent of the invertebrate community comprised of Ephemeroptera 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. Another way to look at diversity is simply looking at the total number of different invertebrate species found in the samples collected.

2008–2019 Summary

Information about the aquatic invertebrate community in the river is very limited. Nogales Wash has no aquatic invertebrate data. For the Santa Cruz, our best data set is from Tumacácori National Historical Park in the Tubac Reach. Aquatic invertebrates were sampled in 2008, and from 2012–2018 using a protocol that involved kick-net samples in riffles. Targeted riffle data of this kind are not available from 2009 and 2010. Other data collected with different methodology are included here to provide the most complete dataset. Data from 2011 are unavailable.

The percent of the community dominated by a single group has decreased, but still hovers around the 50% threshold. This suggests that the river is under environmental stress. However, the percent of the aquatic community comprised of pollution-sensitive Ephemeroptera increased after the treatment plant upgrade, suggesting improvements in aquatic conditions. Furthermore, only 6 unique species were found in 2008. Since the upgrade, the number of unique species found increased to an annual average of 15 species. Cumulative number of unique species has also increased, reaching 49 by 2019. As only 2 new species were found since 2016, the rate of increasing diversity may be slowing or reaching equilibrium.

Drier conditions and more variable flow in 2013 and 2014 may help explain some of the variability seen between 2013 and 2015. Further monitoring will be needed to determine if the aquatic invertebrate community will continue to improve.



GROUNDWATER: Maximum Depth

The interactions between riparian vegetation, surface water, and groundwater are important factors in overall riparian health. As with other southwestern rivers, cottonwoods and willows dominate the native riparian forests along the Santa Cruz River in this reach and depend on surface water and groundwater to meet their annual water requirements.

Several scientific studies have investigated the maximum depth to groundwater required to sustain mature cottonwood trees. Scientists estimate that the maximum depth to groundwater required to sustain mature Fremont cottonwoods ranges from 2.5 to 5.1 meters (approximately 8 to 16 feet).

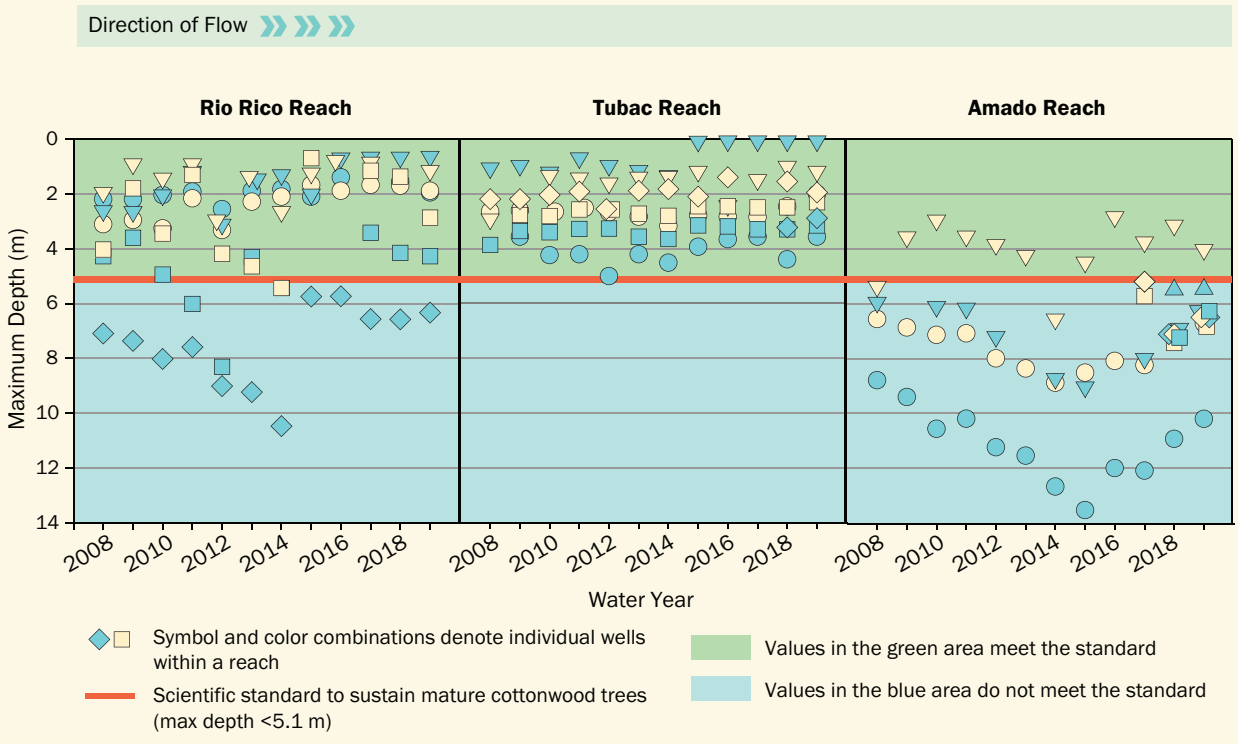
We compare maximum depths to groundwater to the upper end of the cottonwood range, thus locations with maximum depths less than 5.1 meters meet the scientific standard. It is important to note that areas with greater maximum depths to groundwater support other types of riparian vegetation.

Depths to groundwater along Nogales Wash were not compiled for this summary.

2008–2019 Summary

Number of depth measurements over the years varied by well. Some wells were measured only once a year while others were measured daily. All depth to groundwater measurements are determined relative to depths that may support cottonwoods. The Tubac reach appears to have the most stable depth to groundwater measures. Rio Rico and Amado had shallower depths recorded in recent years, suggesting increased recharge.

In Rio Rico, the wells with measurements below the standard are located near the beginning of the reach, representing wells closest to the release of effluent. In contrast, several wells in the Amado reach that were below the standard are located at the far end of the reach and represent wells that are furthest away from the release of effluent. The best conditions for supporting cottonwoods may be along the Tubac reach where geologic and hydrologic conditions are optimal and the recharge of effluent is possibly highest.



GROUNDWATER: January to June Decline

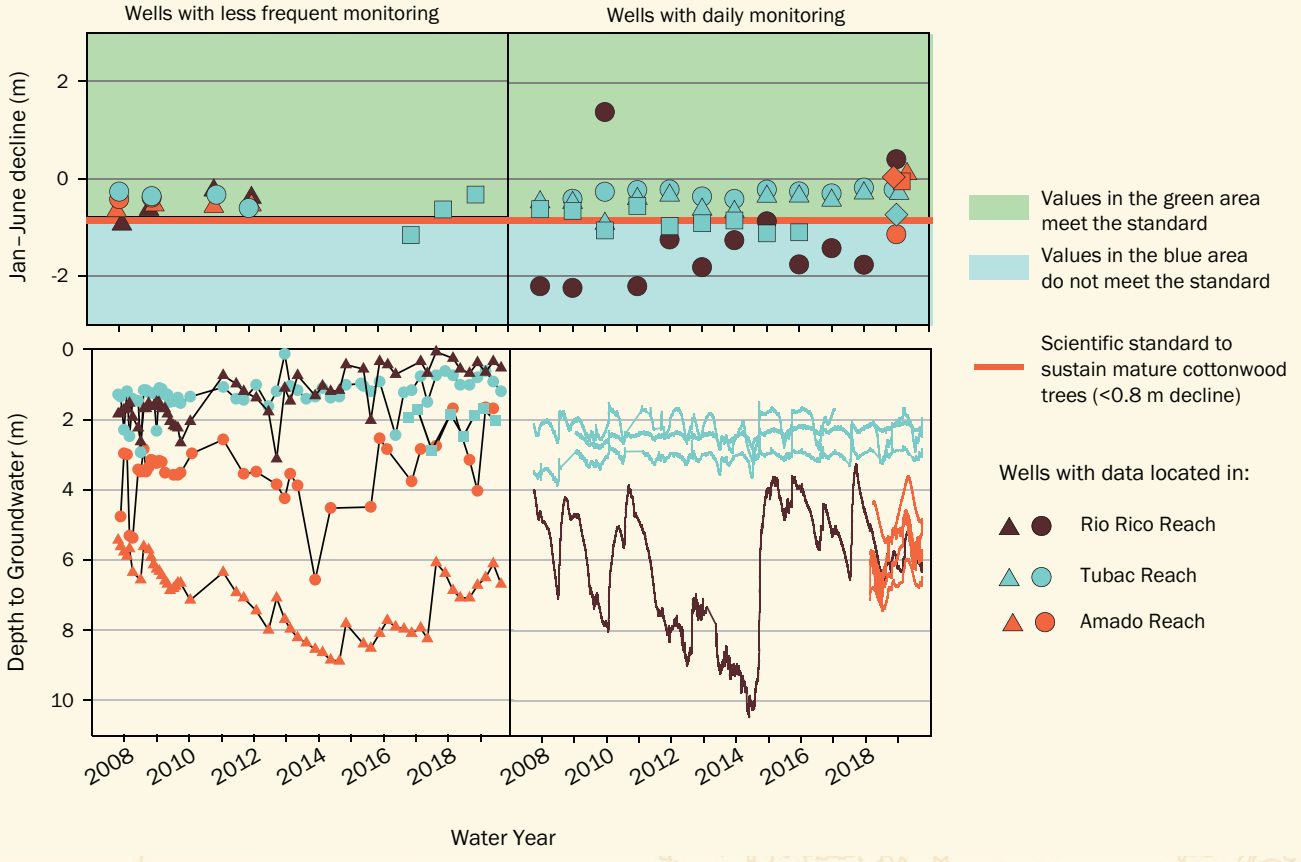
Variability in groundwater levels affects the growth and survival of riparian plants. There are several natural and human causes of groundwater variability. Naturally, groundwater levels decline after the winter rainy season ends and increase once the summer monsoons begin. Studies on the San Pedro River in Arizona indicate that cottonwood trees can withstand declines in groundwater levels up to 0.8 meters (2.6 feet) from January to June. Wells with groundwater levels that decline no more than 0.8 meters between a January and a June measurement met this scientific standard.

2008–2019 Summary

The number of wells with enough data to calculate the change in depth to groundwater from January to June varied over the years. Some wells with less frequent monitoring did not have enough data or data were collected at the incorrect time to determine the decline. As with maximum depth to groundwater, variability in depth to groundwater in the Tubac reach appears stable and the January to June standard was met at several well locations. Groundwater variability was less stable in the Rio Rico and Amado reaches, though data are limited.

Rio Rico depths to groundwater varied between two wells. The well with less frequent monitoring is close to the Tubac reach and met the standard. The Rio Rico well with daily monitoring is near the effluent release and has greater fluctuations in water levels, often failing to meet the decline standard.

Although wells in the Amado often met the standard, overall depth to groundwater may not support cottonwoods. Sonoran Institute launched a groundwater monitoring program in the Amado reach in 2018 that is providing additional data on groundwater levels.



RIPARIAN VEGETATION: Forest and Woodland Cover

Riparian vegetation represents a small percentage of the land cover in the Santa Cruz watershed, but it provides important benefits to the region. Riparian vegetation's many ecosystem services include: filtering contaminants from effluent-dominated water before it infiltrates into groundwater drinking supplies, slowing flood waters, reducing erosion potential along stream banks, increasing groundwater recharge, providing habitat for wildlife species, and providing recreational and spiritual enjoyment.

In 2006, Santa Cruz County, Friends of the Santa Cruz River, University of Arizona, and Sonoran Institute mapped the riparian vegetation along the Santa Cruz River from Rio Rico to Amado. Though there is no scientific standard quantifying the amount of riparian vegetation necessary to maintain a healthy river, a simplified version of the 2006 map establishes a baseline that is useful for measuring future changes in extent or composition of vegetation.

Types of vegetation and land use within the river's 100-year floodplain are divided into five categories: cottonwood forests and woodlands; mesquite forests and woodlands; other riparian vegetation; human infrastructure; and agriculture and pasture. Forests and woodlands have more than 10 percent cottonwood or mesquite tree cover. Other riparian vegetation includes areas not dominated by cottonwood or mesquite trees. Human infrastructure includes areas with roads, railroads, and housing. Agriculture and pasture include crop fields and pasture land.

2008–2019 Summary

As of 2010, there were no major changes in vegetation type and landcover relative to the 2006 baseline. Only about 100 acres (1.5%) of the area within the 100-year floodplain had changes in vegetation type and landcover. In total, there were over 1,000 acres (16%) dominated by cottonwoods; nearly 1,400 acres (20%) dominated by mesquites; about 2,000 acres (31%) dominated by other riparian vegetation; over 500 acres (8%) used for human infrastructure; and 1,700 acres (25%) used for crops or pastures. Of the area in the 100-year floodplain, the Tubac reach had the largest percentage dominated by cottonwoods (26%), while the Rio Rico reach had the largest percentage dominated by mesquites (28%).

A detailed analysis of vegetation change between 2010 and 2019 has not been completed. However, casual field observations of locations in the Amado reach suggest that cottonwood forest and woodland cover in this area have suffered and trees have died or are showing die-back. This is not surprising given the increased variability in flow extent following the upgrade to the treatment plant.

No vegetation analysis has been done for Nogales Wash.

LEARN MORE

Find all the *Living River* reports for Santa Cruz River at **www.tiny.cc/livingriver**.

ACKNOWLEDGEMENTS

Sonoran Institute prepared this report with funding from Tucson Electric Power and community individuals.

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.

Data sources: Arizona Department of Water Resources, Arizona Department of Environmental Quality, Friends of the Santa Cruz River, International Boundary and Water Commission, National Weather Service, National Park Service Sonoran Desert Network, Sonoran Institute, Tumacácori National Historical Park, and U.S. Geological Survey.

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SONORAN INSTITUTE has worked since our founding in 1990 to realize our vision that the Santa Cruz River, from Mexico to Marana, is a living, flowing river and the foundation of community health and prosperity.

The Sonoran Institute's mission is to connect people and communities with the natural resources that nourish and sustain them. We envision resilient communities living in harmony with the natural world, where flowing rivers and healthy landscapes enable all people and nature to thrive. Our work transcends borders, bringing together diverse communities to promote civil dialogue about complex conservation issues that know no boundaries. All aspects of our work are guided by inclusivity and collaboration to create positive environmental change in the western United States and northwestern Mexico.

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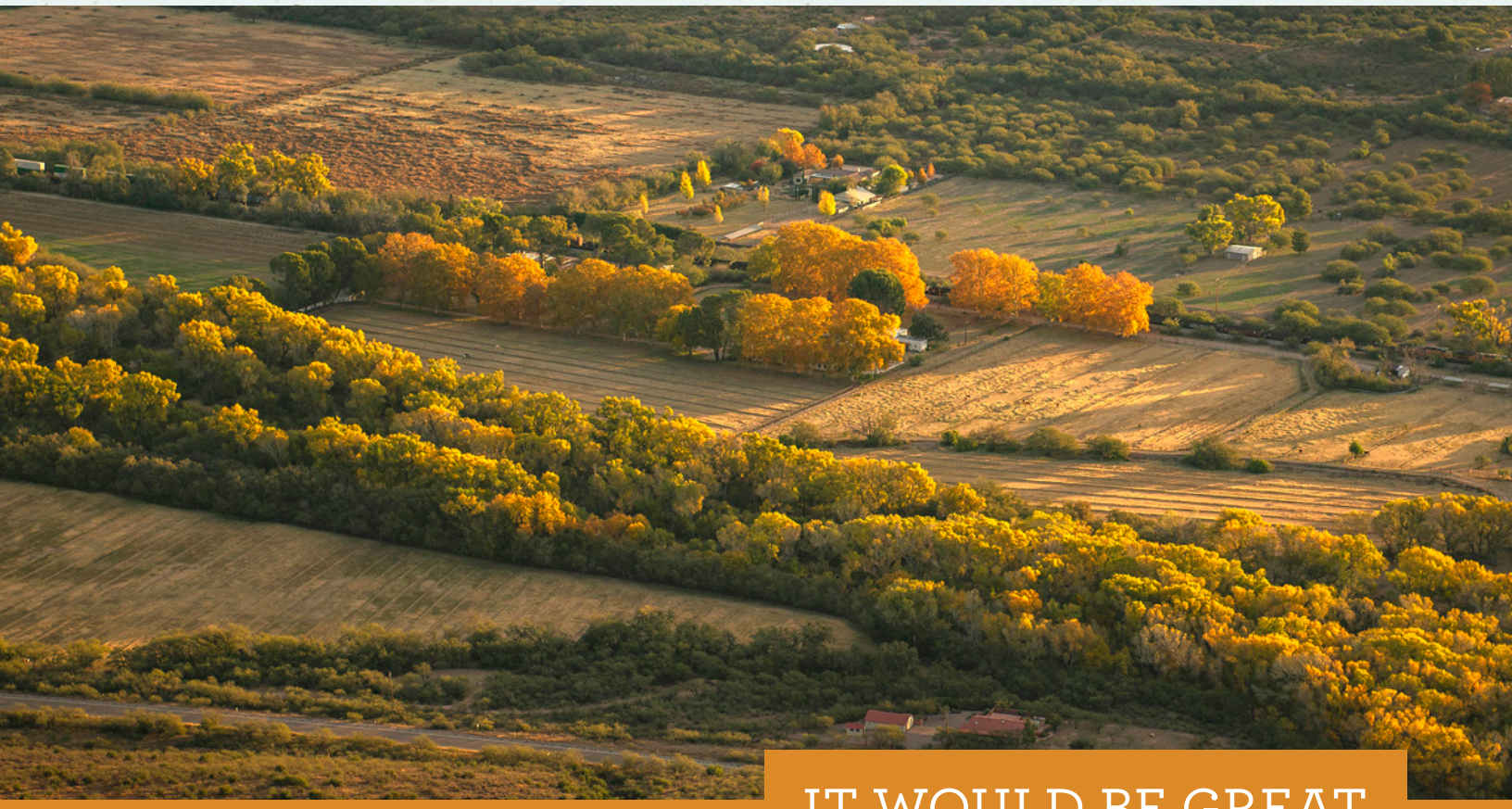

IMAGE CREDITS

Front Cover: Santa Cruz River near Tumacácori. **Back Cover**: Family farms and land along the fall-colored cottonwoods of the Santa Cruz River near Tumacácori. ©Bill Hatcher/Sonoran Institute, 2020.

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