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Status of Climate and Water Resources at Tumacácori National Historical Park

Water Year 2018

Natural Resource Report NPS/SODN/NRR—2019/1972

ON THE COVER

Retrieval of sampling equipment on the Santa Cruz River, Tumacácori National Historical Park. NPS photo.

Status of Climate and Water Resources at Tumacácori National Historical Park

Water Year 2018

Natural Resource Report NPS/SODN/NRR—2019/1972

Prepared by
Evan L. Gwilliam[1]
Laura Palacios[1]
Kara Raymond[2]

[1]Sonoran Desert Network
National Park Service
12661 E. Broadway Blvd.
Tucson, AZ 85748

[2]Southern Arizona Office
3636 N. Central Ave., Suite 410
Phoenix, AZ 85012

Editing and Design
Alice Wondrak Biel
Sonoran Desert Network
National Park Service
12661 E. Broadway Blvd.
Tucson, AZ 85748

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Executive Summary

Climate and hydrology are major drivers of ecosystems. They dramatically shape ecosystem structure and function, particularly in arid and semi-arid ecosystems. Understanding changes in climate, groundwater, streamflow, and water quality is central to assessing the condition of park biota and key cultural resources. This report combines data collected on climate, groundwater, and surface water at Tumacácori National Historical Park (NHP) to provide an integrated look at climate and water conditions during water year 2018 (October 2017–September 2018).

Overall annual precipitation was 74% of normal. Rainfall was higher than normal in February and near normal in June–August. All other months received substantially less rainfall than normal. Temperatures at Tumacácori NHP tended to be warmer than normal—except during the summer months, which were slightly cooler. The reconnaissance drought index indicated that the drought that began in 2000 continued through WY2018, while the five-year running mean of total annual precipitation indicated the drought has been less severe during the last five years.

Two monitored wells at Tumacácori NHP (MW-1 Deep and the Mission unit's water supply well) indicated that mean groundwater levels in WY2018 were generally higher than the mean of the data record for each well (0.21–1.35 ft). The third well, MW1-Shallow, was missing data for nearly a quarter of the year, and an annual mean was not calculated. Water levels in both the shallow- and deep-aquifer wells peaked after a large storm event in February, then dropped in response to dry spring conditions, and quickly increased with monsoon precipitation and flow events. Seasonal variability was more dramatic in the shallow aquifer.

Streamflow data for this report were recorded at USGS gauge 09481740, on the Santa Cruz River at Tubac, Arizona. This gauge is located five kilometers downstream from the index sampling site in Tumacácori NHP. Streamflow on the Santa Cruz River through the park was slightly below average in WY2018. Peak flow occurred on August 23. There were several smaller flow events on August 9, August 14, and September 19. Recorded discharge was typical for October–May, then decreased through the pre-monsoon, dry, hot period of late May and June. The pre-monsoon period, along with a slight decrease of discharge during the monsoon, led to the decreased mean and median values for WY2018 compared to the gage record. Water samples were collected from the Santa Cruz River at the Santa Gertrudis index site. Of 90 individual analyses associated with Arizona surface-water criteria, there were two exceedances: one for *E. coli,* and one for cyanide; that is, almost 98% of samples were compliant with state standards. Relative to macroinvertebrates, the Arizona Index of Biological Integrity value has been at or below impaired status since WY2012 (although there is not an established index threshold for effluent-dominated streams in Arizona). Fish were collected during collaborative sampling at the Santa Gertrudis index reach. The metric for longfin dace (*Agosia chryogaster*) decreased in WY2018. In WY2018, workers collected and summed the number of fish from the family Poeciliidae, including Gila topminnow and western mosquitofish. The metric for Poeciliidae increased in WY2018 (35.78 fish/minute) from previous years. The continued presence of longfin dace and Poeciliidae are positive indicators of the animals' response to improved water quality and habitat features on this reach.

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We thank Chief of Resource Management Roger Dorr, Superintendent Bob Love, and the staff of Tumacácori National Historical Park for their onsite support of the monitoring effort. Courtney Giebank, Drew Jackson, Ed Kuklinski, Misa Kupkova, David Mácк, Terezia Machová, and Kate McNicholas assisted with data collection and processing. Kristen Bonebrake led the management and posting of all data products. Macroinvertebrate identifications were determined by the Utah State University BugLab. TestAmerica (Arizona) processed the water-chemistry samples. Colleen Filippone and Andy Hubbard contributed to this report.

1 Introduction

Climate and hydrology are major drivers of ecosystems. They dramatically shape ecosystem structure and function, particularly in arid and semi-arid ecosystems. Understanding changes in climate, groundwater, streamflow, and water quality is central to assessing the condition of park biota and key cultural resources. This document summarizes climate and water-resource conditions for water year (WY) 2018 (October 2017–September 2018) at Tumacácori National Historical Park (NHP), a small (360-ac) National Park Service unit in southeastern Arizona. Detailed analyses of trends will follow in subsequent reports as the period of record warrants such assessments. For details on monitoring protocols, park setting and resources, and information on other resources of management focus, please see http://www.nps.gov/im/sodn/.

2 Climate

2.1 Background and methods

Climate is the suite of characteristic meteorological conditions of the near-surface atmosphere at a given place (Strahler 2013), and is the primary driver of ecological processes on earth. A broader temporal scale (seasons to years) is what distinguishes climate from the instantaneous conditions reflected by the term, "weather."

Climate mediates the fundamental properties of ecological systems, such as soil–water relationships, plant–soil interactions, net primary productivity, the cycling of nutrients and water, and the occurrence, extent, and intensity of disturbances—in short, the underpinnings of the natural resources that the National Park Service manages and protects.

Tumacácori NHP has operated a National Oceanic and Atmospheric Administration (NOAA) Cooperative Observer Program (COOP) weather station (TUMACÁCORI NM, ID#0268865) since 1946 (Davey et al. 2007). The record from this station provides a reliable, long-term climate dataset used for the analyses in this report.

In 2014, the National Park Service (NPS) Sonoran Desert Network (SODN) installed a Davis weather station at Tumacácori NHP to provide real-time weather conditions. This station is linked to the NOAA Citizen Weather Observer Program. Data from this station are accessible through www.climateanalyzer.org. More detailed information about methods and data handling can be found in the Sonoran Desert Network climate monitoring protocol (Hubbard et al. in prep).

An aridity index (UNEP 1992), based on long-term average annual precipitation relative to average annual potential evapotranspiration, can be a useful tool for contrasting the local climate of national parks (Figure 2-1). Used globally to classify climate zones, aridity indices seek to answer the question, "How dry is dry?" (Tsakiris and Vangelis 2005). Using the period of record (1946–present), the climate of Tumacácori NHP is categorized as semi-arid.

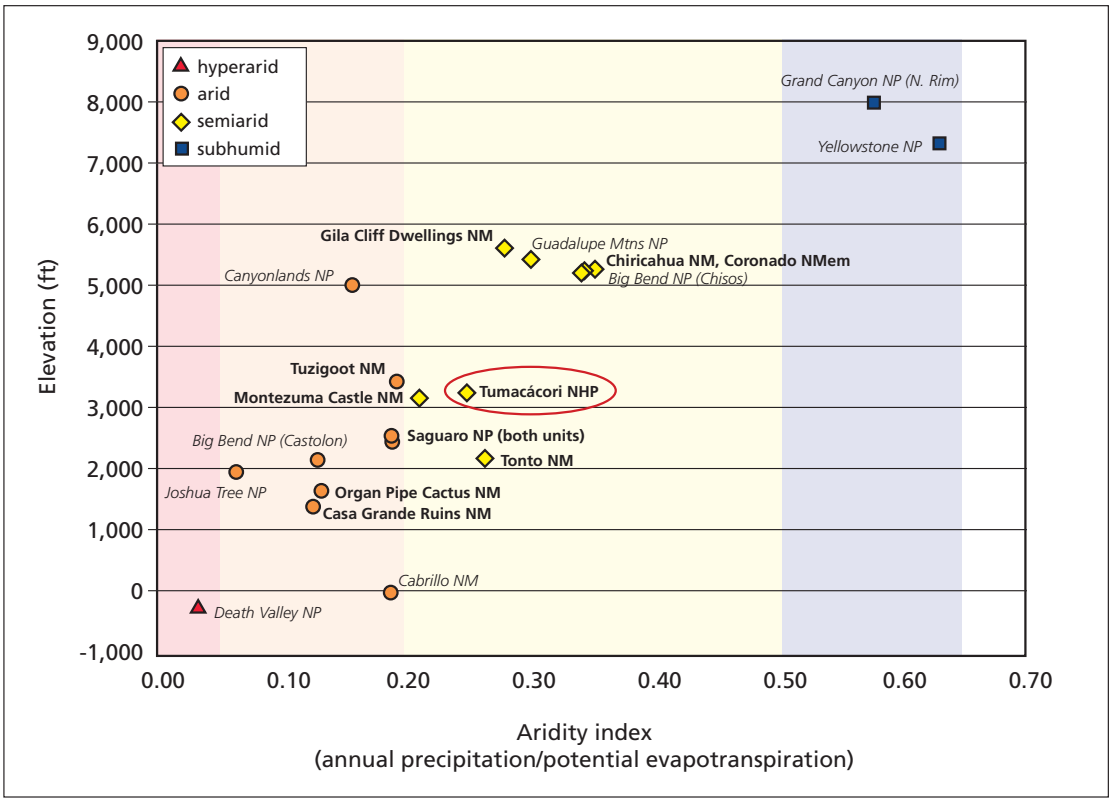


Figure 2-1. Aridity index vs. elevation of selected southwestern national parks, including Tumacácori National Historical Park. Figure from Hubbard and others (in prep).

2.2 Results and discussion

Data quality during WY2018 was good. Eight days were missing temperature data, and only one day was missing precipitation data.

2.2.1 Departures from 30-year normals (1981–2010)

Overall annual precipitation was 74% of normal (1981–2010) for Tumacácori NHP (12.18" vs 16.56").

2.2.1.1 Cool season (October–March)

Air temperatures were generally warmer than normal (1–8°F), especially in November (Figure 2-2). Overall precipitation was approximately half of normal (55%, or -2.77") for fall and winter WY2018. Precipitation in February was 263% of normal, owing to a 1.5" storm event. Precipitation in all other cool-season months was ≤50% of normal, with minimal or no rainfall in October, January, and March (Figures 2-2 and 2-3).

2.2.1.2 Warm season (April–September)

Maximum and minimum springtime air temperatures started off warmer than normal in April, followed by temperatures 0–3°F cooler than normal for June through September. The warm season was drier than normal (84%, -1.61"). No rain fell in April or May. Monsoon precipitation was near normal in June–August, but tapered off in September.

2.2.2 Reconnaissance Drought Index

Reconnaissance drought index (Tsakiris and Vangelis 2005) provides a measure of drought severity and extent relative to long-term climate based on the ratio of average precipitation to average potential evapotranspiration over shorter periods of time (seasons to years). The reconnaissance drought index for Tumacácori NHP reflects the extended regional drought since 2000, which continued through WY2018 (Figure 2-4). However, the five-year running mean of total annual precipitation was slightly below the long-term precipitation average (1981–2018) (Figure 2-5), suggesting that during the last five years, the drought has been less severe.

2.2.3 Extreme weather events

Stochastic events, such as air-temperature extremes and unusually intense precipitation events, may be as important to understanding ecological patterns as long-term climate averages are. Although high air temperatures are a defining feature of warm deserts, extreme frost events also have important consequences. In particular, sustained low air temperatures can damage or even kill long-lived keystone plants, such as the velvet mesquite trees (*Prosopis velutina*; Glinski and Brown 1982) that dominate Tumacácori's bosque woodlands, as well as the sensitive Father Kino heritage fruit trees. Extreme precipitation events can cause localized flooding and erosion events, spur or inhibit plant productivity and reproduction, and modify animal behavior. Cultural resources, such as the Mission and other historic buildings and artifacts at Tumacácori NHP, can be particularly susceptible to erosion and exposure from extreme precipitation events.

Extremely cold days (<26°F, 5th percentile of 1981–2010 data) occurred 17% less often than normal (11 days vs. 13.3 ± 1.4 days) in WY2018, and were of a similar duration (1.8 consecutive days vs. 2.1 ± 0.1 days).

There was one extreme precipitation event (>1") in WY2018, compared to an average 3.23 days per year for 1981–2010. The single large event on February 15 (1.5").

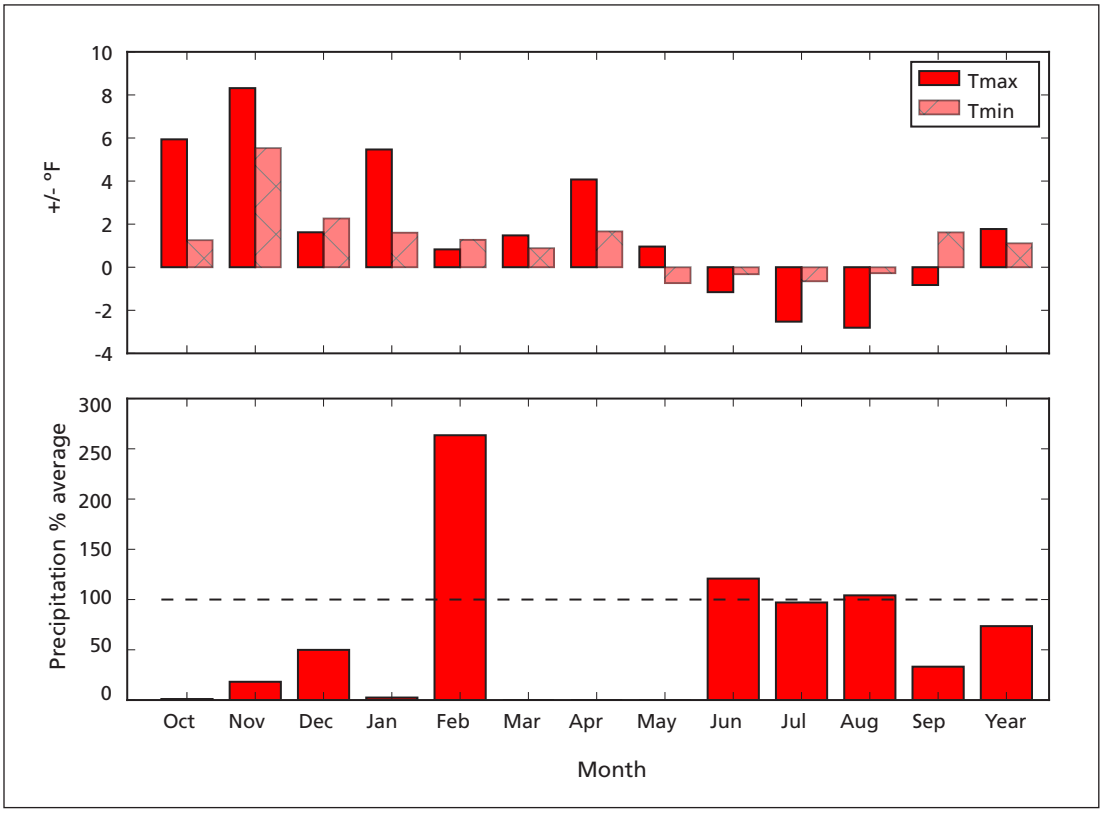


Figure 2-2. Departures from 30-year (1981–2010) normal minimum and maximum air temperatures and precipitation, Tumacácori National Historical Park, WY2018. Graphics generated by climate-analyzer. org.

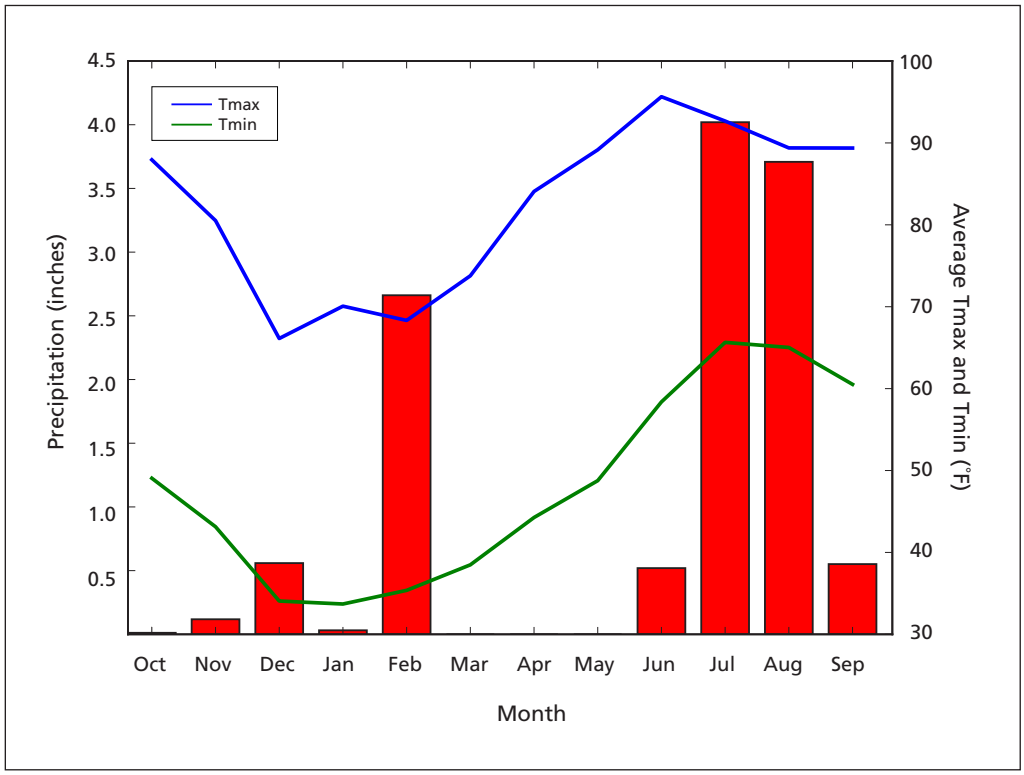


Figure 2-3. Climogram for water year 2018, Tumacácori National Historical Park. Graphics generated by climateanalyzer. org

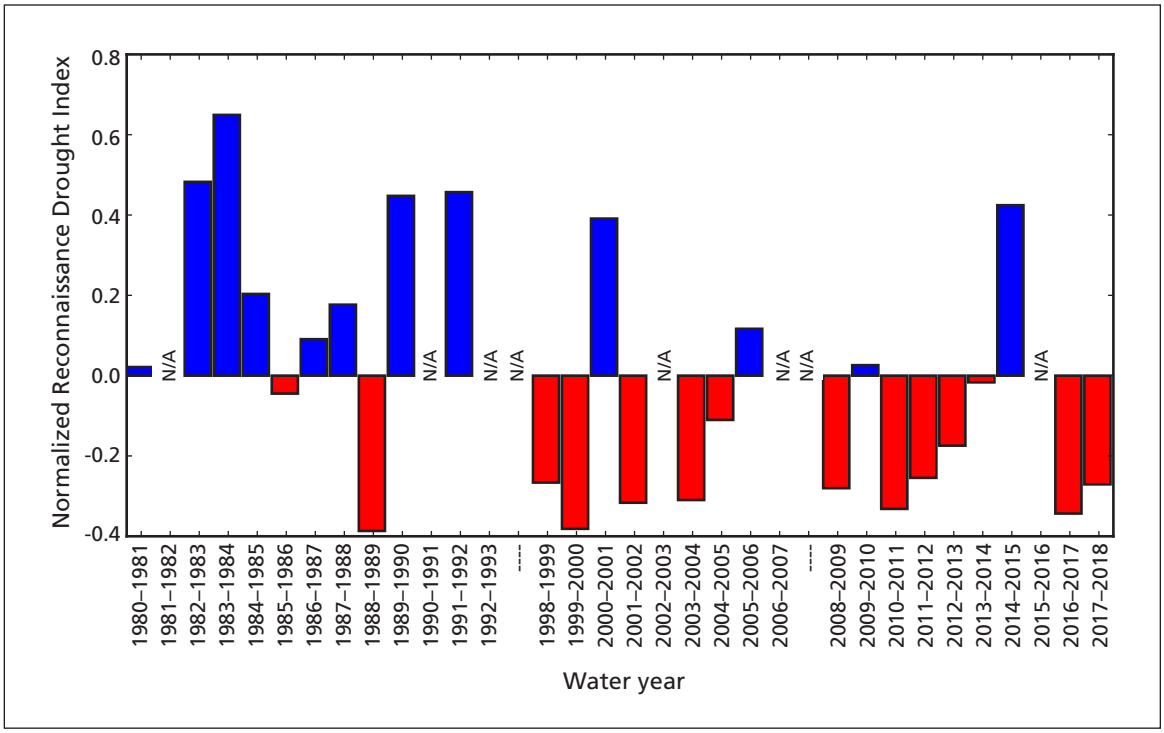


Figure 2-4. Reconnaissance drought index (RDI), Tumacácori National Historical Park, water years 1981–2018. "N/A" = insufficient data to generate reliable RDI estimates. The station had an extended period without data collection (1992–1997). Drought index calculations are relative to the time period selected. Graphics generated by climateanalyzer.org.

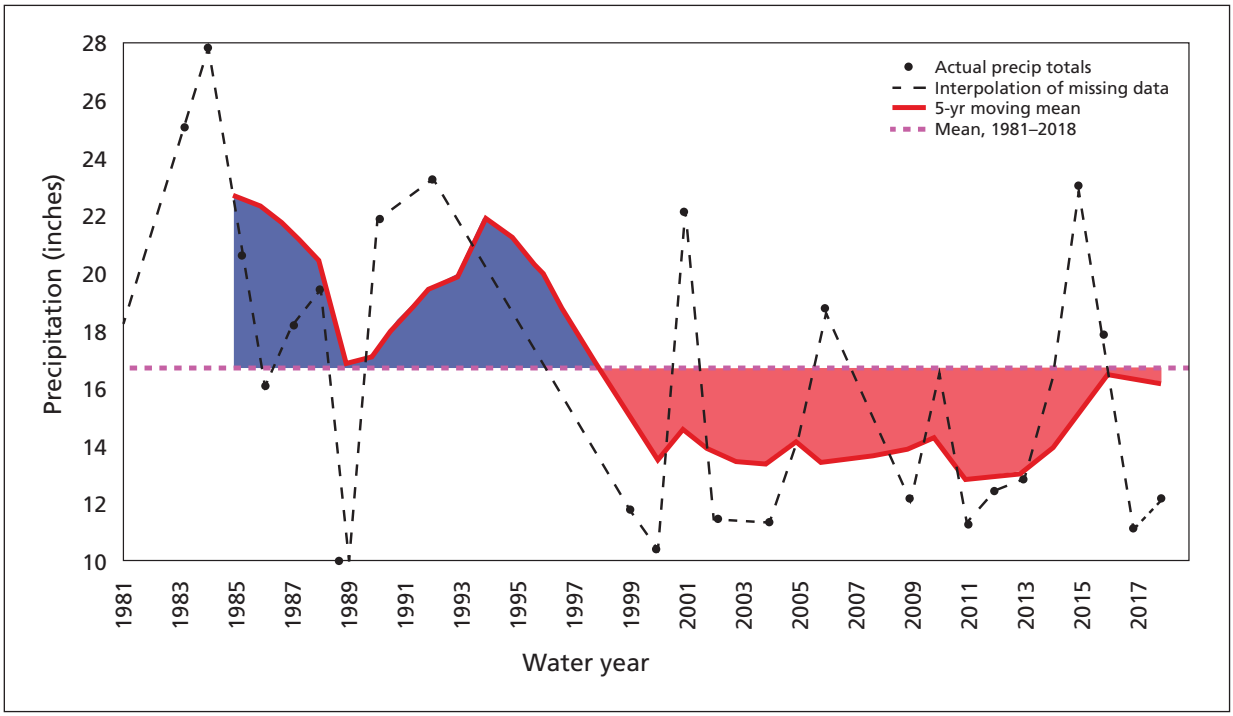


Figure 2-5. Five-year moving mean of annual precipitation, Tumacácori National Historical Park, water years 1981–2018. The moving mean (solid red line) is based on a timeseries with 28.9% (11 of 38) missing values, and includes the current year and previous four years. Missing years are linearly interpolated (dashed gray lines). Graphics generated by climateanalyzer.org.

3 Groundwater

3.1 Background and methods

Groundwater is one of the most critical natural resources of the American Southwest, providing drinking water, irrigating crops, and sustaining rivers and streams throughout the region. Groundwater is closely linked to long-term precipitation patterns and surface waters, as ephemeral flows sink below ground to reappear months, years, decades, or even centuries later as perennial and intermittent streams and springs. Groundwater also sustains trees and shrubs that are common throughout the region, and is the primary source of water for almost all humans in the southwestern U.S.

Groundwater therefore interacts either directly or indirectly with all key ecosystem features of the arid and semi-arid Sonoran Desert and Apache Highlands ecoregions. At Tumacácori NHP, groundwater monitoring is conducted via automated and manual sampling of water wells at various depths. More detailed information on monitoring methods may be found in the SODN groundwater monitoring protocol (Filippone et al. 2014).

3.1.1 Shallow and deep aquifers

Tumacácori NHP is situated above both shallow and deep aquifers. The deep aquifer lies beneath the shallow aquifer. The shallow, unconfined aquifer, along the Santa Cruz River, is influenced by infiltration from streamflow, groundwater subflow, regional pumping for potable water and irrigation, and transpiration by riparian trees and shrubs. As such, this aquifer exhibits relatively low-magnitude daily cycles. This shallow aquifer has the most direct connection to streamflow, and serves as the primary water source for riparian vegetation.

The deep aquifer at Tumacácori NHP occurs in clayey-sand sediments of the Older Alluvium (Scott et al. 1997), which consists of locally stratified lenses of boulders, gravel, sand, silt, and clays with cemented zones, or caliche. This unit forms the terraces rising above the Santa Cruz River floodplain, and is visible at the roadcut where the northbound access road approaches Interstate 19, near the park. The deep aquifer is buffered from individual weather events and fine-scale variability in flow and evapotranspiration along the Santa Cruz River, and is the source of much of the drinking water in the area, including the park.

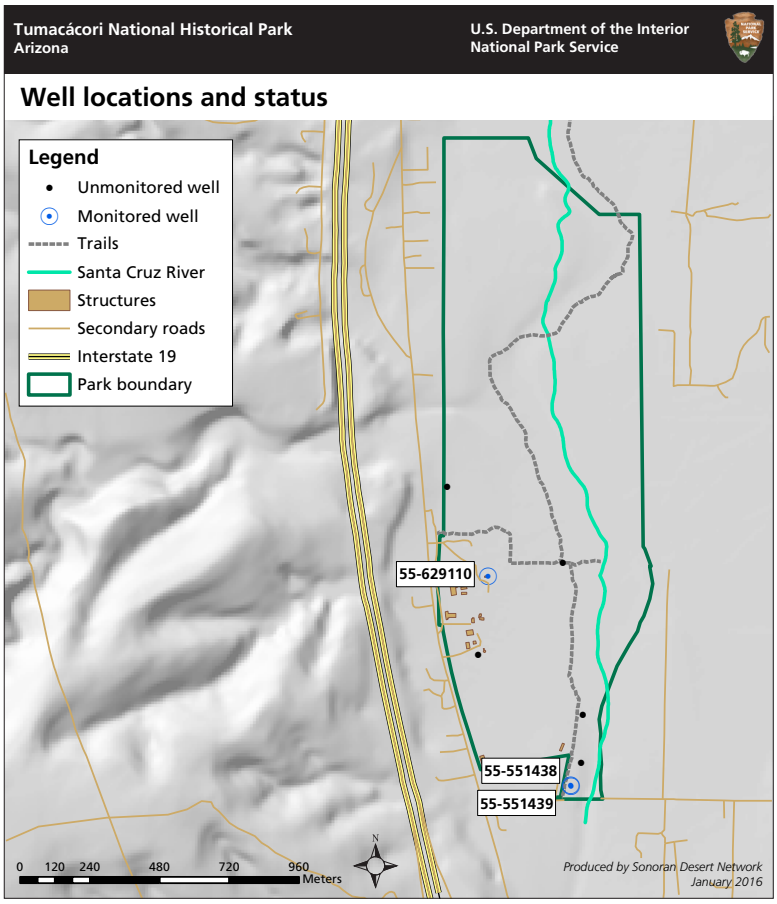


Figure 3-1. Monitoring well locations at Tumacácori National Historical Park.

3.1.2 Monitoring wells

Three wells at Tumacácori NHP are currently used for groundwater monitoring (Figure 3-1). The University of Arizona installed two wells just north of Santa Gertrudis Lane in the Mission unit in 1995; however, water-level data are only available from 2005. MW-1 Shallow (ADWR 55-551439) is 65 feet deep, screened at a depth of 30–60 feet. MW-1 Deep (ADWR 55-551438) is 120 feet deep, screened at a depth of 100–115 feet. Both wells are monitored continuously via pressure transducers operated by the Arizona Department of

Water Resources (ADWR), which also collects 2–4 manual measurements every year.

In addition to the Santa Gertrudis Lane wells, the Mission unit's water-supply well (ADWR 55-629110), established in 1959 at a depth of 150 feet to supply potable water for the park, has been monitored intermittently since 1960. Since 1998, the ADWR has monitored it several times per year. All ADWR data reported in this document may be retrieved by entering well-identification information at https://gisweb.azwater.gov/waterresourcedata/wellregistry.aspx.

3.2 Results

3.2.1 Shallow aquifer (MW-1 Shallow)

Because the data record for MW-1 Shallow was missing data on 82 days in WY2018, a mean depth-to-water (DTW) was not calculated. The lowest water level recorded was 10.55 feet bgs (below ground surface) on July 6, a few days prior to the onset of the monsoon season (Figure 3-2). The highest water level in WY2018 (9.22 feet bgs), occurred on February 16, the day after the largest storm event of the year (1.5") and a 399-cfs (cubic feet per second) flow event on the Santa Cruz River at the U.S. Geological Survey (USGS) gage at Tubac (USGS 09481740) (Figure 3-3). The range between the minimum and maximum recorded water levels was 1.33 feet. The shallow aquifer (most closely linked with weather conditions and streamflow events) exhibits seasonal variability, with groundwater lows during the hot, dry, early summer months.

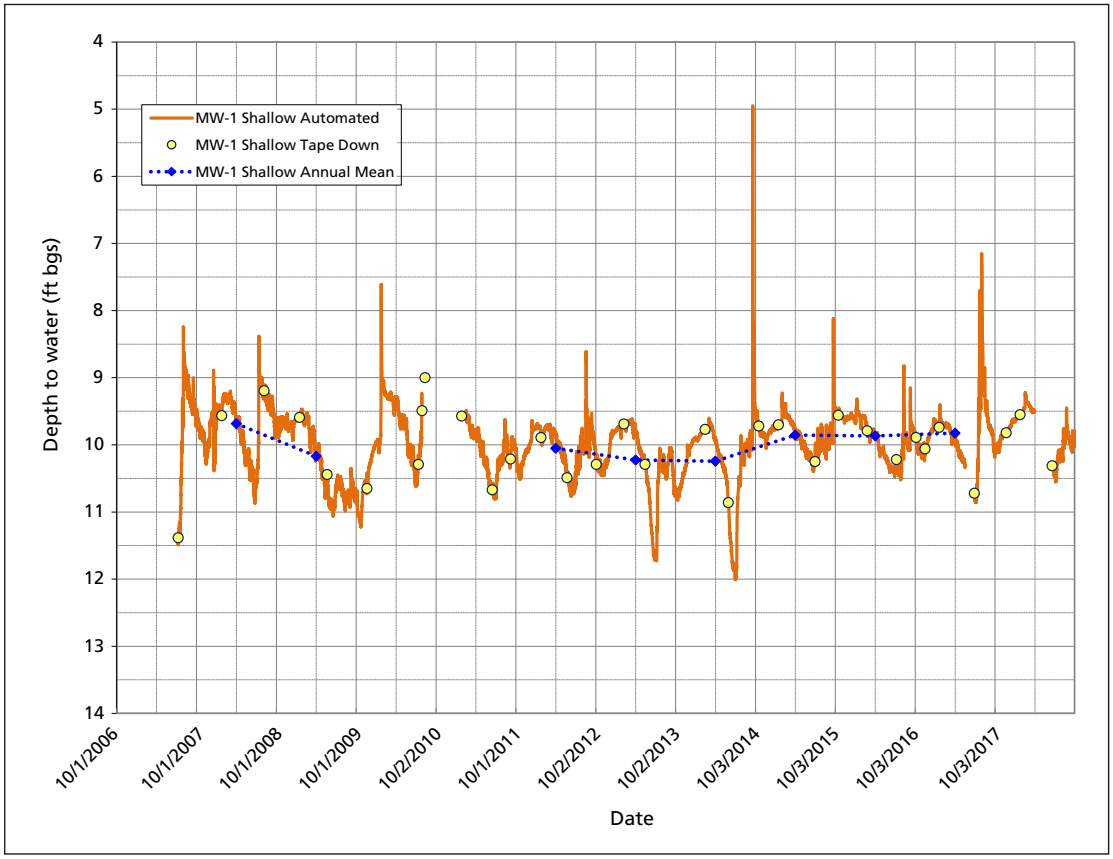


Figure 3-2. Depth-to-water at MW-1 Shallow (ADWR 55-551439), Tumacácori National Historical Park, water years 2007–2018. Annual mean depth-to-water was not calculated for WY2007, 2010, 2011, and 2018 due to gaps in the data record. "bgs" = below ground surface.

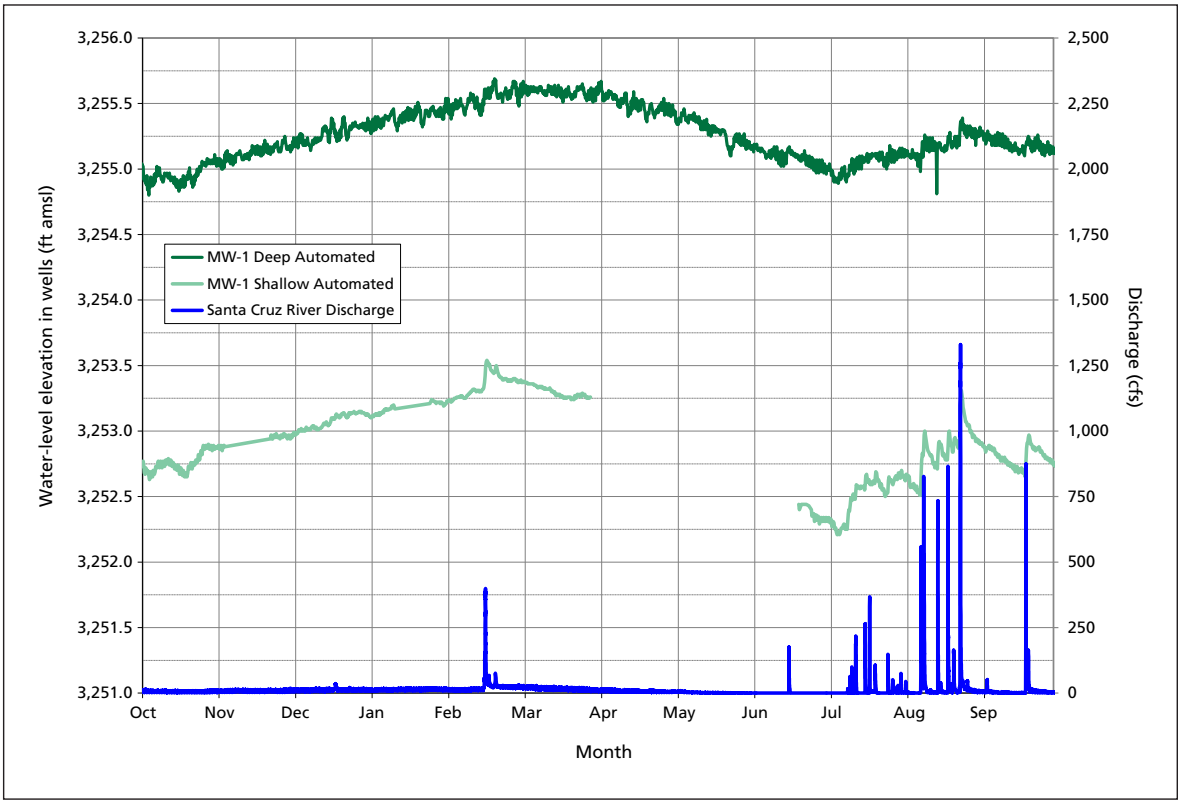


Figure 3-3. Water-level elevations at deep and shallow monitoring wells, Tumacácori National Historical Park, and discharge at USGS gage, Santa Cruz River at Tubac, Arizona, water year 2018. "amsl" = above mean sea level. "cfs" = cubic feet per second.

3.2.2 Deep aquifer (MW-1 Deep)

The mean DTW at MW-1 Deep in WY2018 was 7.34 feet bgs, which was 0.63 feet higher than the annual mean for WY2010–2017 (Figure 3-4). The highest water level at MW-1 Deep (6.91 feet bgs) occurred on February 19, three days after MW-1 Shallow recorded its highest water level. The lowest water level (7.80 feet bgs) occurred on October 4, following a relatively dry August and September of the previous water year. The range between the minimum and maximum water level was 0.89 feet, demonstrating an annual variation 0.44 feet less than the mean annual range for WY2010–2017. Relative to the shallow aquifer, the deep aquifer exhibits a narrow range of fluctuation of hydraulic head (i.e., the total energy of the water, consisting of the sum of the potential energy of elevation and the pressure energy at a given point in an aquifer), as indicated by depth-to-water in the well. This is expected, as the deeper aquifer is more buffered from individual flow and precipitation events.

However, these observations are suspect, for the following reason: During a three-hour/7.9-gallons-per-minute pumping test on May 30, 1996, cascading water was heard entering MW-1 Deep, originating at 20–25 feet bgs (Scott et al. 1997). Total drawdown in MW-1 Deep during the pumping period was 40 feet. During this same test, virtually no drawdown was observed at the nearby MW-1 Shallow, indicating that the deeper aquifer is confined or semi-confined at this location. Scott and others (1997) interpreted these observations as indicative of a defect in the deep well casing at about 20 feet below land surface. For these reasons, fluctuations shown in Figure 3-4 are likely caused (at least in part) by fluctuations in the shallow aquifer via the apparent leak in the deep well casing.

Contrasting the data from the deep and shallow wells (see Figure 3-3) illustrates that hydraulic head (shown here as water-level elevation) in the deep aquifer is generally about 1.5–2 feet higher than in the shallow aquifer, except during flood peri-

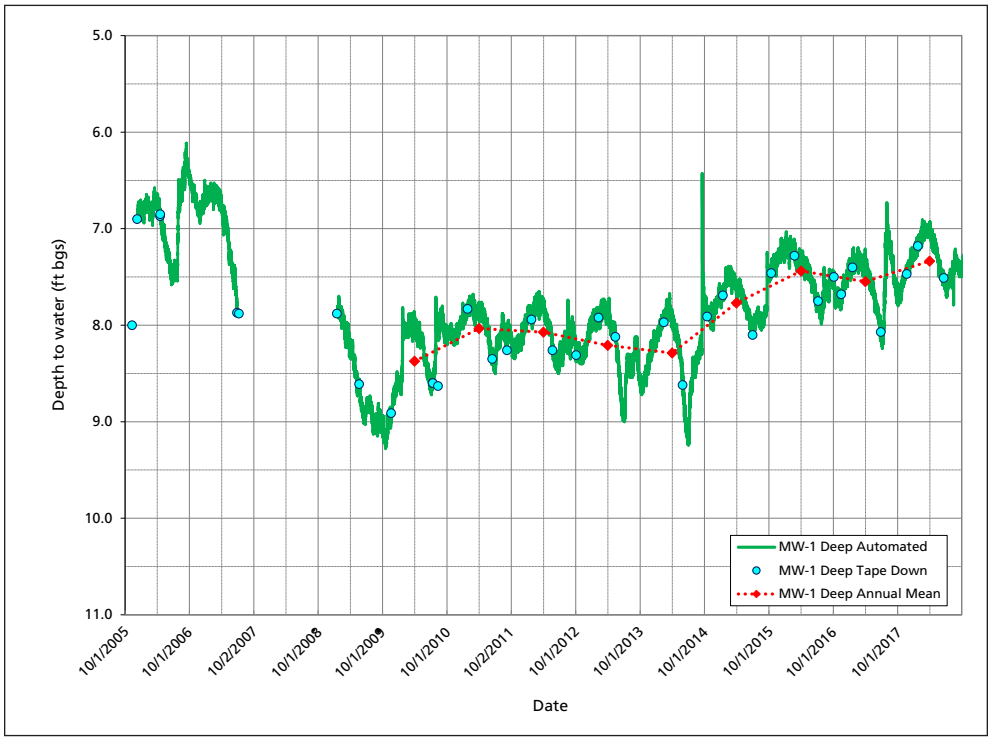


Figure 3-4. Depth-to-water at MW-1 Deep (ADWR 55-551438), Tumacácori National Historical Park, water years 2006–2018. Annual mean depth-to-water not calculated for WY2006–2009 due to gaps in the data record. "bgs" = below ground surface.

ods. Over the relatively short distance between the monitoring intervals (about 40 feet), this constitutes a significant upward vertical gradient. The magnitude of vertical flow occurring as a result of this gradient depends on the hydraulic properties of the subsurface between the shallow- and deep-screened intervals.

However, it is likely that water from the deep aquifer is continuously flowing vertically upward and into the shallow aquifer through the defect in the deep-well casing.

3.2.3 Mission unit's water-supply well

Four water-level measurements were made at the Mission unit's water-supply well in WY2018 (Figure 3-5). The mean was 10.65 feet bgs, suggesting that the mean water level for WY2018 was above the mean for the historic record (11.98 ft bgs).

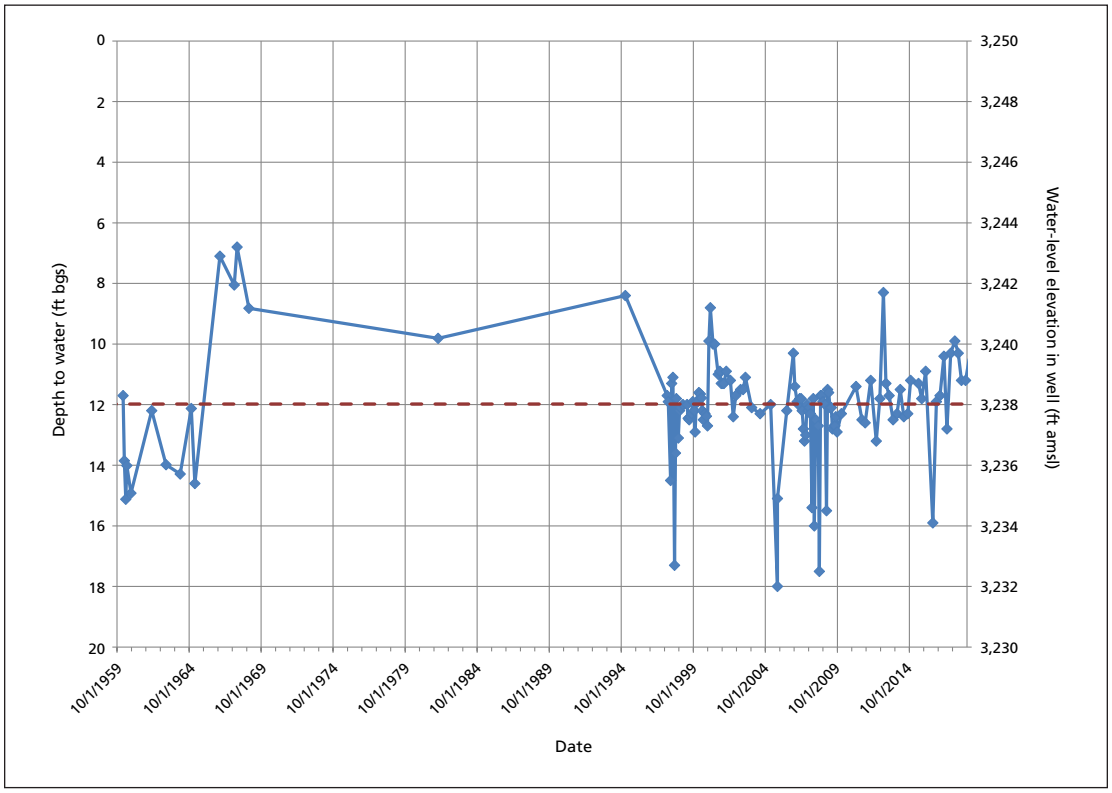


Figure 3-5. Depth-to-water and water-level elevation at Mission unit's water-supply well (ADWR 55-629110), Tumacácori National Historical Park, water years 1960–2018. "bgs" = below ground surface. "amsl" = above mean sea level.

4 Surface Water

4.1 Background

Historically, the Santa Cruz River has been an intermittent stream (Norman et al. 2013). Today, however, the Santa Cruz River at Tumacácori NHP is an effluent-driven system, with most surface water provided by the Nogales International Wastewater Treatment Plant (NIWTP). The NIWTP has been discharging treated effluent into the Santa Cruz River since 1951. In 2011, the NIWTP discharged ~13–15 million gallons per day (mgd) of water into the Santa Cruz River. Approximately 9–12 mgd of this water originated in Mexico. This artificial flow alters natural conditions but provides an otherwise unavailable quasi-perennial supply, allowing for the persistence of a diverse riparian habitat for wildlife within Tumacácori NHP (Norman et al. 2013).

There are several concerns regarding the current status of the Santa Cruz River, including water quality and drought. The Arizona Department of Water Quality has designated the 4.8-mile section of the Santa Cruz River from Josephine Canyon to Tubac Bridge—which runs through the park—as impaired for aquatic life and wildlife (due to ammonia), and for partial body contact (due to *E. coli* levels that exceed Arizona water-quality criteria) (ADEQ 2012). In the past, nutrient and bacterial contamination sometimes resulted from agricultural land use and upstream sewage-treatment facilities. In 2009, however, the NIWTP upgraded wastewater treatment methods, greatly reducing the nitrogen content of the effluent (Norman et al. 2013).

The U.S. Southwest has been in a drought since approximately 2001 (Blunden and Arndt 2013). Reduced precipitation levels have reduced the amount of surface flow in regional rivers, as well as groundwater levels. Effluent from the NIWTP has reduced the drought's effects on the portion of the river that runs through the park, but the stream channel often runs dry near the park's northern boundary during springtime. An international treaty allows Mexico to send

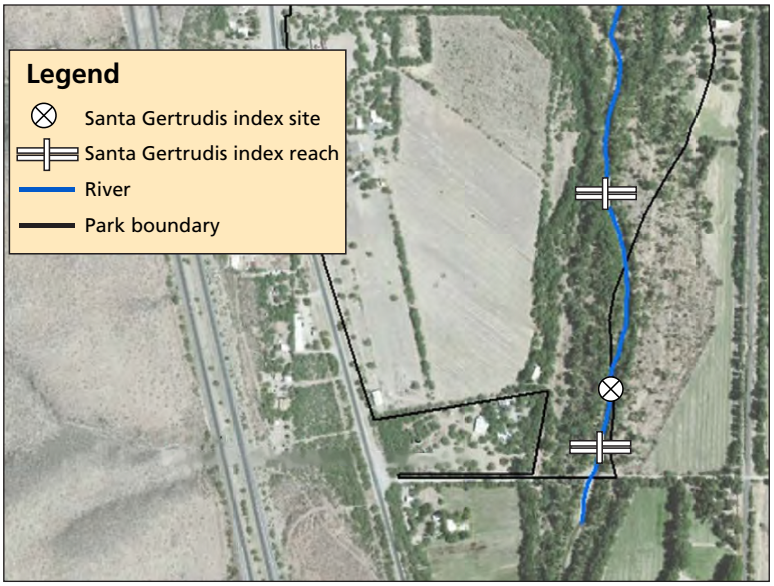


Figure 4-1. Map of Santa Cruz River, Tumacácori National Historical Park, with SODN water-quality sampling locations.

up to 9.9 mgd to the NIWTP. In years past, that amount was exceeded by an average ~2.6 mgd (Norman et al. 2013). In 2012, however, Mexico opened the Los Alisos wastewater treatment plant, capable of treating and redistributing 5 mgd. This (and any future increase in Mexican treatment capacity) may impact the amount of flow in the Santa Cruz River through Tumacácori NHP.

4.2 Methods

Water-quality monitoring occurred at the Santa Gertrudis index site, ~150 meters downstream from the park's southern boundary (Figure 4-1). This is where discrete and continuous water-quality samples and measurements were collected, in addition to discharge measurements.

Macroinvertebrate and fish sampling occurred on the Santa Gertrudis index reach, a 460-meter length of the Santa Cruz River directly downstream of the southern boundary of the park's main (Mission) unit.

A brief description of the data collection and processing methodologies followed by SODN staff at Tumacácori NHP during WY2018 is presented below. Detailed descriptions of these procedures are available in the SODN streams monitoring protocol (Gwilliam et al. 2018).

4.2.1 Water quantity

Streamflow data for this report were recorded at USGS gage 09481740, on the Santa Cruz River at Tubac, Arizona. This gage is located five kilometers downstream from the Santa Gertrudis index site. Data on mean daily flow are downloaded from the USGS website to the SODN server and processed.

4.2.2 Water quality core parameters

Core water-quality parameters are a group of ecologically important metrics that provide the most basic level of information about water quality (Irwin 2008). Parameters sampled by SODN included water temperature, pH, specific conductivity, dissolved oxygen, turbidity, and discharge. During each visit, we noted the hydrologic conditions and sampled core parameters using the following methods:

- On arrival at the site, a multi-parameter sonde (YSI Professional Plus) was calibrated and deployed in a well-mixed part of the stream channel, logging temperature, pH, specific conductivity, and dissolved oxygen data at one-minute intervals. The meter was left in the stream for the entire visit. Turbidity samples were collected and analyzed within one hour using a portable turbidimeter (HACH 2100P). Discharge was measured using a FlowTracker Acoustic Doppler Velocimeter.
- In addition to regular sampling, we collected data on temperature, pH, specific conductivity, and dissolved oxygen at 15-minute intervals for a minimum of two weeks every quarter, using a logging multi-parameter instrument (YSI XLM600 V2).

4.2.3 Water quality samples

During each site visit, water samples were collected in a three-liter Nalgene sample-collection bottle, following USGS non-isokinetic sampling methods as described in the National Field Manual for the Collection of Water Quality Data (USGS 2006). Sample water was then transferred to smaller bottles and vials for analysis of bacteria, turbidity, metals, and other constituents. The sample water was filtered and/or treated as required, kept on ice, and delivered to the contract laboratory. For WY2018, that lab was TestAmerica, in Phoenix, Arizona.

4.2.4 Aquatic macroinvertebrates and habitat

To ensure compatibility of monitoring samples, SODN macroinvertebrate sample collection coincides with the index period used by the Arizona Department of Environmental Quality. The index period for warmwater streams is April–May (Lawson 2005).

The index reach at Tumacácori NHP is 460 meters long, starting at the park's southern boundary. The reach contains 11 equally spaced transects. At each transect, we measured wetted width, water depth, velocity, and canopy cover, and estimated substrate size, bank erosion (using the Rosgen Bank Erosion Hazard Index), and diversity of aquatic habitat. Two types of samples were collected in the reach:

- A quantitative sample was collected from five targeted riffle habitats to provide data on organism abundance. A total of 12 replicate samples were collected from a 0.09-m^2 area, using a kick-net with a 0.3-meter opening for one minute. At each of the five habitats, we also measured depth, velocity, particle size, and particle embeddedness.
- A qualitative sample was collected to develop a comprehensive list of species present in the reach. Using nets, samples were actively collected from all habitat types within the reach during a one-hour collection period and compiled into one composite sample. Aquatic macroinvertebrate samples were sent to the National Aquatic Monitoring Center's BugLab, a Bureau of Land Management laboratory at Utah State University in Logan, Utah. The goal was to have a taxonomist, certified by the North American Benthological Society, identify all aquatic macroinvertebrates to the lowest taxonomic level possible.

4.2.5 Fish

Representatives from the Friends of the Santa Cruz River, the U.S. Fish and Wildlife Service (USFWS), Arizona Game and Fish Department (AGFD), and the National Park Service used standardized methods to collect fish samples, including dip-netting, a beach seine (6' × 10', 1/8" mesh); and a backpack electroshocker (Halltech). No sample reach was sampled more than once each year. The sampling reach was generally consistent in depth and substrate composition. Fish were counted and identified to species in the field by AGFD and USFWS staff. Statistics (fish per unit work) were generated to normalize results.

4.2.6 Data handling and analysis

All data on water quality and quantity were stored on the SODN server. This report includes all discrete water-quality data collected except for turbidity, coliform, and *E. coli* samples, for which the mean of the triplicate samples are presented. For total coliforms and *E. coli* samples, most probable numbers (MPN/100 mL) are reported; these were determined using IDEXX MPN Generator software (IDEXX Inc.). The continuous multi-parameter sonde measurements are presented with the minimum, first quartile, median, third quartile, and maximum to demonstrate variability. When applicable, this report compares SODN water-quality data to the State of Arizona's water-quality standards (ADEQ 2009) and notes any exceedances.

4.3 Results

4.3.1 Water quantity

The USGS stream gage at Tubac, Arizona, (09481740) is used as a proxy for stream-discharge dynamics at the Santa Gertrudis index site (Gwilliam et al. 2016). The USGS's WY2018 annual summary for the Tubac gage provided the necessary data (USGS 2018). Figure 4-2 shows the mean daily flow for WY2018 compared to the mean daily flows for the 23-year gage record.

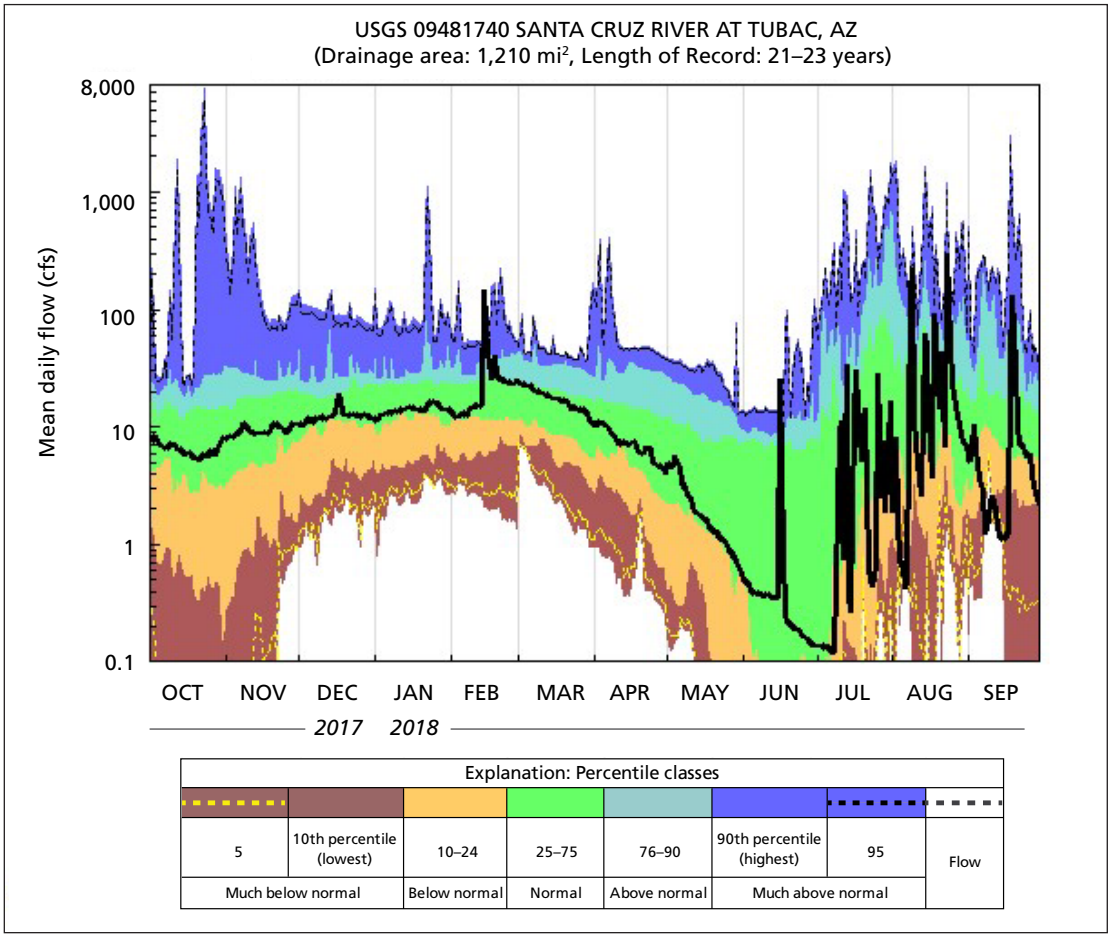


Figure 4-2. Hydrograph from USGS gage 09481740, near Tubac, Arizona, water year 2018. The black line represents flow in water year 2018.

Stream discharge recorded on the Santa Cruz River during WY2018 was between the 25th and 75th percentile for most of the year, falling below the 25th percentile only during the monsoon season. It is likely there were not any "no-flow" events at the Santa Gertrudis index site during WY2018. However, there was likely discontinuity of flow in the stream segment at Tumacácori, especially in the northern (downstream) portion of the segment. This is typical for this section of the Santa Cruz River.

The peak mean daily flow (MDF) of 298 cfs occurred on August 23, 2018. The maximum instantaneous flow (MIF) recorded was 1,330 cfs, on the same date. There were several smaller flow events, on August 9 (MIF: 827 cfs); August 14 (MIF: 743 cfs), and September 19 (MIF: 874 cfs).

The median MDF was 8.81 cfs in WY2018, compared to the gage-record median value of 11.6 cfs. The mean annual MDF was 12.8 cfs, compared to the gage-record value of 25.5 cfs. The median and mean discharge at the gage site during WY2018 were less than the median and mean values for the gage record. The recorded discharge was typical for October–May, then decreased through the pre-monsoon, dry, hot period of late May and June. This decrease was not abnormal; the WY2018 data fell in a region of the hydrograph representing the middle 50% of data from this gage. However, this pre-monsoon period, along with a slight decrease of discharge during the monsoon, led to the decreased mean and median values for WY2018 compared to the gage record. This indicates that generally, discharge at the park was slightly below normal.

4.3.2 Water quality

In WY2018, SODN staff made four sampling visits to the Santa Gertrudis index site. Discrete samples were collected during each sampling visit. Continuous sampling was conducted using a multiparameter logging sonde, deployed during each sampling visit, each quarter (Table 4-1).

In WY2018, 240 discrete water-quality samples were collected; 90 of these had associated state standards. There were two exceedances during WY2018: one for *E. coli* (see Table 4-4) and one for cyanide (see Table 4-8), resulting in 97.8% compliance with state standards. These exceedances occurred during the fourth-quarter (summer) sample.

There have been frequent exceedances of *E. coli* standards at this site, with elevated estimated counts typically occurring after flow events. The *E. coli* is from non-point sources (surface runoff occurring during rain events) (Paretti et al. 2017).

4.3.2.1 Core parameters

Discrete sampling—. The discrete measurements shown in Table 4-2, collected in the field, represent conditions at the Santa Ger-

Table 4-1. Dates of discrete sampling and continuous measurements, Santa Cruz River, Tumacácori NHP, WY2018.

Quarter	Date of discrete sampling	Date of continuous sampling	Continuous samples collected*
Q1	11/17/2017	11/17/2017–11/29/2017	1,249
Q2	2/12/2018	2/12/2018–2/27/2018	1,438
Q3	5/15/2018	4/25/2018–5/15/2018	1,916
Q4	8/20/2018	8/20/2018–9/5/2018	1,538

*Number of distinct measurements collected during a three-week deployment. Data were censored to meet QA/QC requirements.

trudis index site during site visits in WY2018. The results were all within the expected range for an effluent-driven system in southern Arizona.

Continuous sampling—. A logging multiparameter sonde was deployed for approximately two weeks during each quarter (see Table 4-1) to collect data on temperature, pH, specific conductivity, and dissolved oxygen at 15-minute intervals. During WY2018, more than 6,100 measurements were collected. Figure 4-3 summarizes the seasonal variability in water temperature, pH, specific conductivity, and dissolved oxygen. The results were generally within the expected range, with the following exceptions:

- *Specific conductivity.* The median specific-conductivity value for all four quarters was generally high, with all values at or above the 75th percentile. The median value for Q2 was above 95% of the Q2 records for this station. The Q2 data were heavily censored due to flow events during the Q2 deployment; this high median specific-conductivity value is likely a data artifact. The cause of the high median specific-conductivity values for the other quarters is unknown.
- *Dissolved oxygen.* Dissolved oxygen concentration did not meet the minumum standard during Q3 (<3 mg/L 3 hours after sunrise to sunset). This can likely be attributed to low flow and high air and water temperatures during sampling (note that the median water temperature was at the 75th percentile in Q3).
- *Second-quarter flow events.* During Q2 sampling, the USGS Tubac gage recorded flooding events on February 15, 16, 17, and 19, flowing at 392, 56.5, 62.1, and 70.4 cfs, respectively (see Figure 4-2). Upon retrieval, the probe was found buried under sediment, so the data were determined to be unusable after the flooding event on February 15. Data during this series of flow events were censored from analysis. This censoring led to the anomalous reading during the Q2 pH summary (Figure 4-3), with the median value below the observed range for WY2011–2017. The entire Q2 dataset was processed following prescribed methods (USGS 2006). However, the value for this deployment should be considered with caution.

Table 4-2. Discrete data summary for core water quality parameters, Santa Cruz River, Tumacácori NHP, WY2018.

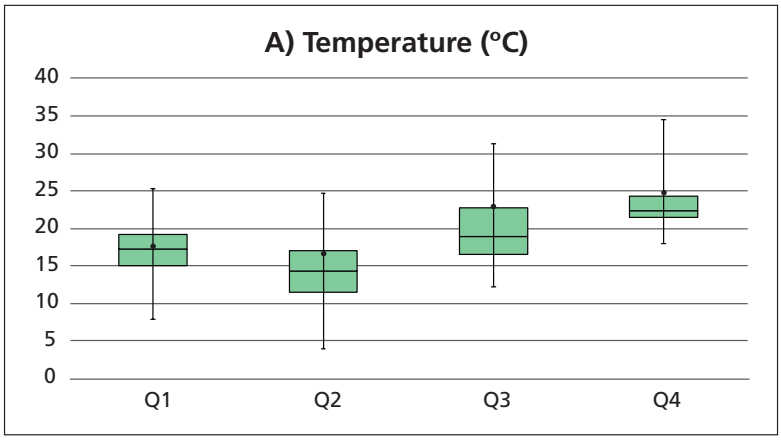
Parameter	Quarter				Arizona State standard	
	Q1	Q2	Q3	Q4	Measure[a]	Beneficial use
Temperature (°C)	19.0	18.0	25.1	26.2	NS[b]	–
Specific conductivity (µS/cm)	723	756	778	552	NS	–
pH	7.83	7.62	7.82	7.79	6.5–9.0	Partial body contact, Aquatic and wildlife effluent dependent water, Agricultural livestock watering
Dissolved oxygen concentration (mg/L)	7.30	8.06	6.71	6.65	>3[c]	Aquatic and wildlife effluent dependent water (acute)
Turbidity (NTU)	3.23	2.4	0.66	181.7	NS	–
Discharge (cfs)	4.76	NC[d]	2.27	11.21	–	–

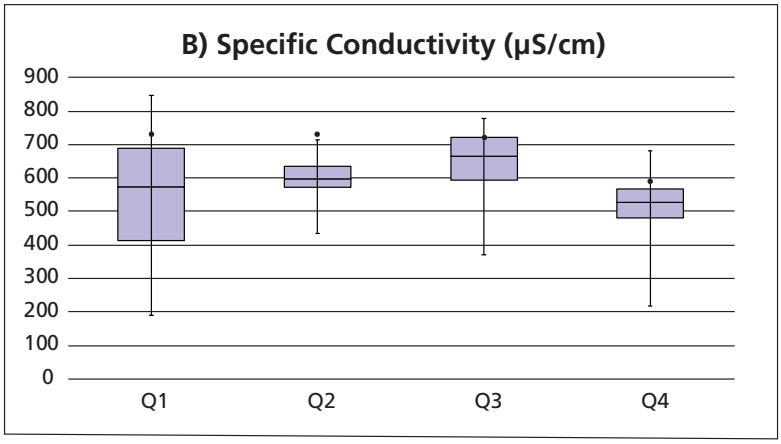
[a]NS = no standard

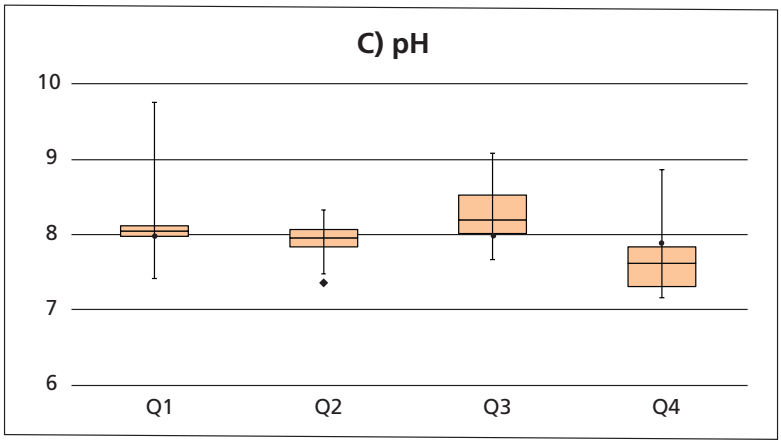
[b]Maximum allowable increase in ambient water due to a thermal discharge is 3.0°C.

[c]Dissolved oxygen concentration of 3.0mg/L applies from three hours after sunrise to sunset, 1.0 mg/L applies sunset to three hours after sunrise.

[d]Not collected (equipment malfunction)







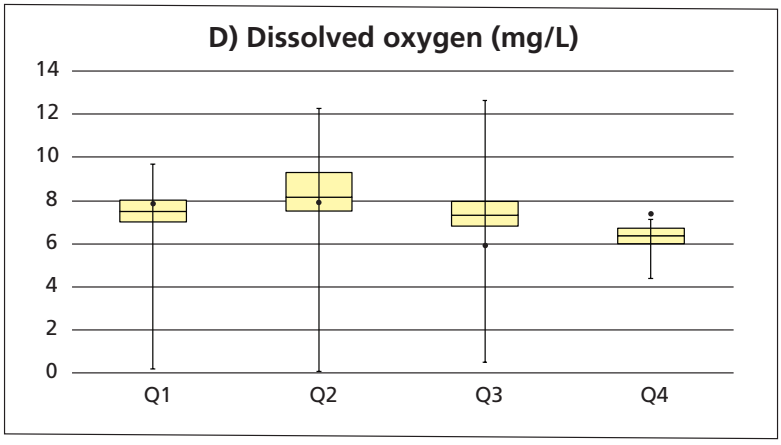


Figure 4-3. Data on (A) water temperature, (B) specific conductivity, (C) pH, and (D) dissolved oxygen concentration, from the Santa Cruz River, Santa Gertrudis index site, Tumacácori National Historical Park, water years 2011–2018. The boxes indicate the 25th (bottom of box) to 75th (top of box) percentile of the data, with the line in the middle as the median value. The uppermost whisker represents the 95th percentile; the lowermost whisker represents the 5th percentile. The solid black dots mark the median value from WY2018 sampling for each parameter.

The WY2018 median value for pH was outside the observed range (WY2011–WY2017), and is represented by a black diamond. This is the result of a flow event during the WY2018 deployment that buried the sonde. The Q2 median value for specific conductivity was also impacted by this event. Despite QA/QC data assessment, the value is much higher than other observed values and should be considered with caution. The Q4 median value for dissolved oxygen was also high, due to two flow events that limited the amount of data used for analysis. The impact of the flow events made the rating of this data poor. Caution should be used interpreting these data.

4.3.2.2 Nutrient dynamics

Nutrient samples were collected during each quarter during WY2018 (Table 4-3). There were no exceedances of state standards for any nutrient samples.

Only parameters with results are reported. It should be noted that parameters not reported were not zero, just below the detection limit of the analytical equipment. They may be present, but in very low concentrations.

4.3.2.3 Biological condition

Network data for total coliforms and *E. coli* are expressed as a most probable number (MPN) per 100 mL of stream water, a statistical estimate of the number of bacteria. Although water-quality criteria are expressed as colony-forming units (cfu) per 100 mL (which, unlike MPN, does not assume estimation), the two units are comparable. The criterion for a single sample of *E. coli* is 575 cfu/100 mL.

There was an exceedance of the state standard for *E coli* during the Q4 (summer) sample (Table 4-4). These exceedances are frequent at the Santa Gertrudis index site. The bacterium *E. coil* is used as an indicator of human fecal contamination. However, this taxon is relatively ubiquitous in the environment, found in decaying material, soil, and in the guts of mammals, including humans (Paretti et al. 2017). The exceedances occurred during and after flow events resulting from precipitation that washed soil and other material, most likely including *E. coli*, into the Santa Cruz River.

4.3.2.4 Metal and metalloids

During WY2018, there were no exceedances of state or federal water-quality standards from samples collected at the Santa Gertrudis index site (Tables 4-5 and 4-6). Concentrations were generally similar to those observed in previous years (Gwilliam et al. 2014; Gwilliam et al. 2016).

Only parameters with results are reported. It should be noted that parameters not reported were not zero, just below the detection limit of the analytical equipment. They may be present, but in very low concentrations.

4.3.2.5 Suspended and total sediment

During WY2018, results for suspended and total sediment were in the range detected in previous years (Gwilliam et al. 2014; Gwilliam et al. 2016). The result from WY2018 Q4 was elevated (670 mg/L, Table 4-7). The increase was likely the result of solids entrained in the stream flow by monsoon activity.

Table 4-3. Results of nutrient sampling, Santa Cruz River, Tumacácori NHP, WY2018.

Analyte	mg/L				Method	Arizona state standard	
	Q1	Q2	Q3	Q4		Measure[a]	Beneficial use
Nitrate - Dissolved	7.3	6.7	5.4	2.8	EPA 300.0	3,733	Partial body contact
Nitrate + Nitrite	8.4	7.3	6.9	3.1	EPA 353.2	NS	–
Total Nitrogen	8.4	7.3	6.9	3.1	Calculated	NS	–

[a]NS = no standard

Table 4-4. Results of biological condition sampling, Santa Cruz River, Tumacácori NHP, WY2018.

Analyte	Measurement				Method[a]	Arizona state standard[b]	
						Measure	Beneficial use
Total organic carbon (mg/L)	NC[c]	NC[c]	NC[c]	3.1	SM 5130B	NS	–
***E. coli* (MPN)**	76.5	29.9	127.6	**>2,419.6[d]**	SM 9223B	575 MPN/100 mL	Full/partial body contact

[a]SM = standard method (Eaton et al. 2005); [b]NS = no standard; [c]NC = not collected; [d]Exceedance indicated in bolded red. Value indicated represents the upper limit of the test; actual value may be higher.

Table 4-5. Results from metal and metalloids (dissolved) sampling, Santa Cruz River, Tumacácori NHP, WY2018.

Analyte	mg/L				Method[a]	Arizona state standard	
	Q1	Q2	Q3	Q4		Measure[b]	Beneficial use
Arsenic	<0.015	<0.015	<0.015	0.0072	EPA 200.7/200.8	0.15	Aquatic & wildlife
Barium	NC[c]	NC[c]	NC[c]	0.057	200.8	NS	–
Boron	0.15	0.13	0.16	0.17	EPA 200.7	NS	–
Calcium	57	62	67	51	EPA 200.7	NS	–
Copper	<0.015	<0.015	<0.015	0.004	EPA 200.7/200.8	0.015	Aquatic & wildlife[d]
Magnesium	10	11	11	7.2	EPA 200.7	NS	–
Manganese	0.017	0.025	0.013	0.0064	EPA 200.7/200.8	NS	–
Molybdenum	<0.02	<0.02	<0.02	0.0047	EPA 200.7/200.8	NS	–
Nickel	NC[c]	NC[c]	NC[c]	0.007	200.8	0.086	Aquatic & wildlife[d]
Potassium	10	10	8.8	8	EPA 200.7	NS	–
Silica	38	37	37	29	EPA 200.7	NS	–
Sodium	81	83	73	49	EPA 200.7	NS	–
Uranium	NC[c]	NC[c]	NC[c]	0.0023	200.8	NS	–

[a]Methods are from USEPA (1983); [b]NS = no standard; [c]NC = not collected; [d]Calculated using hardness

Table 4-6. Results from metal and metalloids (total) sampling, Santa Cruz River, Tumacácori NHP, WY2018.

Analyte	mg/L				Method[a]	Arizona state standard	
	Q1	Q2	Q3	Q4		Measure[b]	Beneficial use
Aluminum	0.15	<0.1	<0.1	6.7	EPA 200.7/200.7 Rev 4.4	NS	–
Arsenic	<0.015	<0.015	<0.015	0.0094	EPA 200.7/200.8	0.2	Agricultural livestock watering
Barium	NC[c]	NC[c]	NC[c]	0.11	200.8	98	Partial body contact
Boron	0.17	0.13	0.17	0.17	EPA 200.7/200.7 Rev 4.4	187	Partial body contact
Calcium	59	61	71	55	EPA 200.7/200.7 Rev 4.4	NS	–
Chromium	NC[c]	NC[c]	NC[c]	0.0036	EPA 200.8	1	Agricultural livestock watering
Copper	<0.015	<0.015	<0.015	0.017	EPA 200.7/200.8	0.5	Agricultural livestock watering
Iron	0.14	<0.1	<0.1	4.9	EPA 200.7/200.7 Rev 4.4	NS	–
Lead	<0.009	<0.009	<0.009	0.0093	EPA 200.7/200.8	0.015	Partial body contact
Magnesium	9.6	10	11	9.1	EPA 200.7/200.7 Rev 4.4	NS	–
Manganese	0.04	0.035	0.017	0.2	EPA 200.7/200.8	131	Partial body contact
Molybdenum	<0.02	<0.02	<0.02	0.0037	EPA 200.7/200.8	NS	–
Nickel	NC[c]	NC[c]	NC[c]	0.011	200.8	28	Partial body contact
Potassium	11	9.9	9.2	9.5	EPA 200.7/200.7 Rev 4.4	NS	–
SiO2, Silica	42	37	40	57	EPA 200.7/200.7 Rev 4.4	NS	–
Sodium	81	80	74	51	200.7 Rev 4.4	NS	–
Uranium	NC[c]	NC[c]	NC[c]	0.0028	EPA 200.7/200.8	2.8	Partial body contact
Zinc	<0.02	<0.02	<0.02	0.035	EPA 200.7/200.8	25	Agricultural livestock watering

[a]Methods are from USEPA (1983); [b]NS = no standard; [c]NC = not collected

Table 4-7. Results from suspended and total sediment sampling, Santa Cruz River, Tumacácori NHP, WY2018.

Analyte	mg/L				Method[a]	Arizona state standard[b]
	Q1	Q2	Q3	Q4		
Total Dissolved Solids	480	490	500	670	SM 2540C	NS
Total Suspended Solids	5.6	<4	<4	170	SM 2540D	NS

[a]SM = standard method (Eaton et al. 2005); [b]NS = no standard

Only parameters with results are reported. It should be noted that parameters not reported were not zero, just below the detection limit of the analytical equipment. They may be present, but in very low concentrations.

4.3.2.6 General water quality and inorganics

During WY2018, results for the general water quality and inorganics group (Table 4-8) were in the range detected in previous years (Gwilliam et al. 2014; Gwilliam et al. 2016), with the exception of total cyanide.

During the WY Q4 sample, total cyanide exceeded the chronic standard for aquatic and wildlife effluent-dependent water (Table 4-8). Total cyanide has been detected nine times between 2007 and 2017. Concentrations in the past were between 0.002 and 0.004 mg/L, below the standard of ~0.009 mg/L. SODN currently samples total cyanide during the Q4 (summer) sample only. This persistent detection likely indicates a relatively constant source of cyanide in the watershed. Cyanide is found in surface water from many sources: natural wearing of cyanide bearing minerals, as a part of animal waste and plant decay, and from mining and industrial waste.

The Nogales International Wastewater Treatment Plant has detected total cyanide in the waste stream entering the facility at maximum concentrations of ~0.66 mg/L, with typical total-cyanide concentrations below the analytical detection limit of 0.01 mg/L (Huth 2017). Measurements of total cyanide of treated effluent (i.e., water leaving the plant) are below the analytical detection limit. This indicates the facility likely treats the effluent to concentrations less than 0.01 mg/L. From the available SODN data, which has lower analytical limits, the treated effluent has a typical concentration of ~0.004 mg/L as measured at the Santa Gertrudis index site. The WY2018 Q4 exceedance of state standards indicates there was a source of cyanide downstream capable of more than quadrupling the typical concentration of cyanide in the stream. The source of this cyanide is unknown.

Only parameters with results are reported. It should be noted that parameters not reported were not zero, just below the detection limit of the analytical equipment. They may be present, but in very low concentrations.

Table 4-8. Results from general and inorganic sampling, Santa Cruz River, Tumacácori NHP, WY2018.

Analyte	mg/L				Method[a]	Arizona state standard	
	Q1	Q2	Q3	Q4		Measure[b]	Beneficial Use
Alkalinity as $CaCO_3$	170	170	190	140	SM 2320B	NS	–
Bicarbonate Alkalinity as $CaCO_3$	170	170	190	140	SM 2320B	NS	–
Chloride	57	48	57	35	EPA 300.0	NS	–
Cyanide, Total	NC[c]	NC[c]	NC[c]	**0.019**[d]	SM 4500 CN E	0.0097	Aquatic and wildlife effluent dependent water (chronic)
Fluoride	0.56	0.53	0.57	<0.5	EPA 300.0	140	Partial body contact
Sulfate	89	86	97	59	EPA 300.0	NS	–
Total Hardness	190	200	220	180	SM 2340B	NS	–
Anion/Cation Balance	-0.27%	5.2%	-1.9%	2.2%	SM 1030E	NS	–

[a]SM = standard method (Eaton et al. 2005); other methods are from Pfaff (1993); [b]NS = no standard; [c]NC = not collected; [d]Exceedance indicated in bolded red.

4.3.3 Macroinvertebrates

Macroinvertebrate biological samples and associated habitat data were collected at the Santa Gertrudis index reach on May 14, 2018. The samples were received by the analytical lab on May 30, 2018, and the report from the lab was issued on July 26, 2018. A list of taxa collected from the index reach on the Santa Cruz River can be found in Appendix A.

The Santa Gertrudis index reach has been sampled annually since WY2012. There is not an established index threshold for effluent-dominated streams in Arizona (ADEQ 2009; ADEQ 2012). Consequently, the Arizona Index of Biological Integrity (AZIBI) value has been at or below impaired status since WY2012 (Figure 4-4). A similar situation exists for the U.S. Environmental Protection Agency's Environmental Monitoring and Assessment Program (EMAP) macroinvertebrate index of biological integrity (IBI). The EMAP Xeric IBI indicates a system that has been in the "most disturbed" category from WY2012 to WY2018 (Figure 4-5). This index is not calibrated to effluent-dominated systems.

There has been a decrease in overall insect abundance for the index reach from WY2012 to WY2018, with a year of low abundance in WY2015, as seen in targeted riffle samples (2,000–3,500 individuals prior to WY2015, vs. 500–1,000 individuals after WY2015) (Figure 4-6).

This pattern was not observed in the reach-wide samples, likely because the target-riffle samples were focused on the benthic habitat favored by the taxa driving the decrease in overall insect abundance: the midge family, Chironomidae (see Section 4.2.4 for differences in reachwide and targeted-riffle sampling).

There was also a shift in community structure before and after WY2015. From WY2012 to WY2014, the Chironomidae subfamily, Orthocladiinae, was the most abundant insect taxa collected. After WY2015, the most abundant insect taxa collected was the Chironomidae subfamily, Chironominae.

The cause of these patterns is unkown. Possible explanations include prolonged drying events, floods, these in combination, or other factors. SODN will continue to investigate this phenomenon.

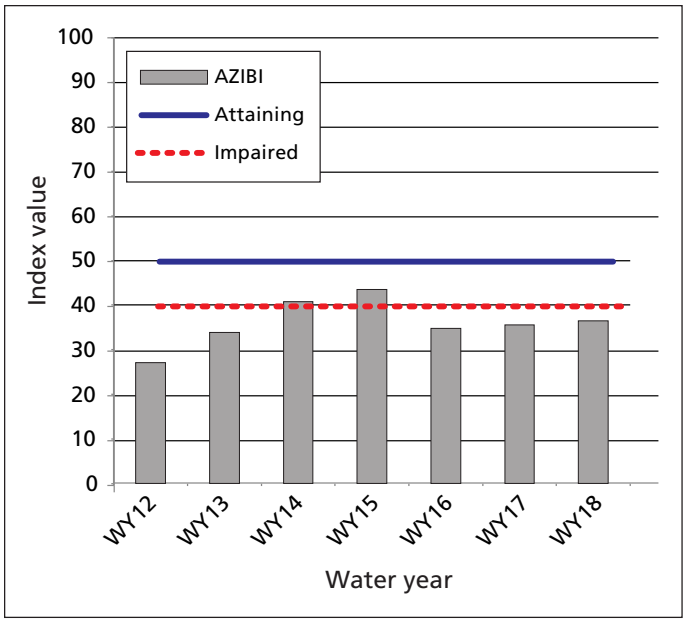


Figure 4-4. Arizona Index of Biological Integrity, Santa Gertrudis index reach, Santa Cruz River, Tumacácori National Historical Park, water years 2012–2018.

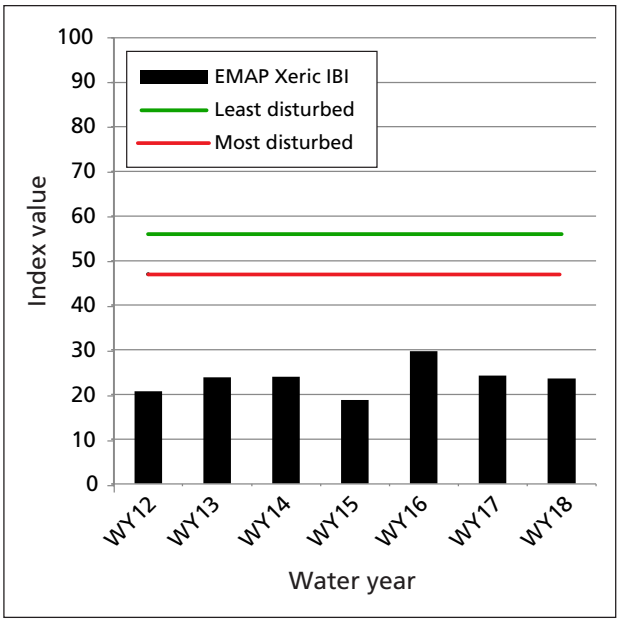


Figure 4-5. Environmental Monitoring and Assessment Program macroinvertebrate index (xeric region), Santa Gertrudis index reach, Santa Cruz River, Tumacácori National Historical Park, water years 2012–2018.

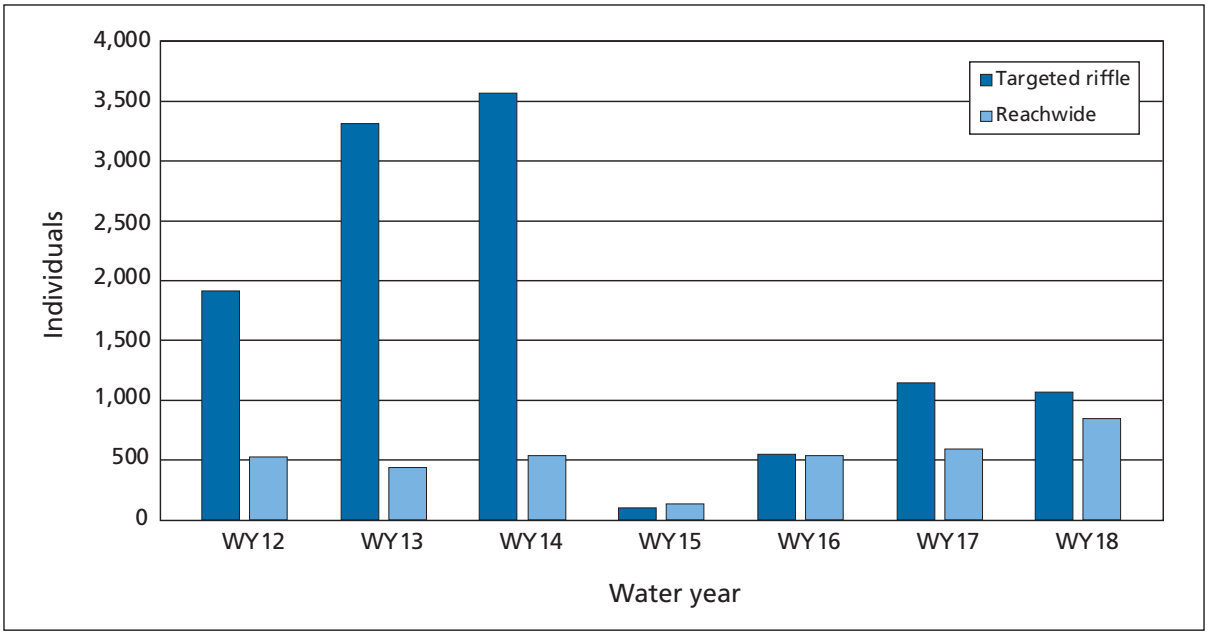


Figure 4-6. Insect abundance at targeted riffles and reachwide, Santa Gertrudis index reach, Santa Cruz River, Tumacácori National Historical Park, water years 2012–2018.

4.3.4 Fish

The current collaborative fish-sampling project on the Lower Santa Cruz River has been occurring since 2008 (AGFD 2014), including a sampling site at the Santa Gertrudis index reach at Tumacácori NHP. In WY2018, 503 fish were collected (44.95 fish/minute). Three fish taxa were found: longfin dace (*Agosia chryogaster*), western mosquitofish (*Gambusia affinis*), and the federally endangered Gila topminnow (*Poeciliopsis occidentalis*).

The metric for longfin dace decreased in WY2018 (9.17 fish/minute). In WY2018, workers collected and summed the number of fish from the family Poeciliidae, including Gila topminnow and western mosquitofish. Juvenile members of western mosquitofish and Gila topminnow may have been collected, but definitive identification of juvenile members of these taxa was not possible (Figure 4-7). Reported by family instead of by species, the metric for Poeciliidae increased in WY2018 (35.78 fish/minute) from previous years. Observations indicate that most of the identifiable fish were Gila topminnow and the number of mature western mosquitofish was very low.

The continued presence of longfin dace and the likely increase in the Gila topminnow metric is a positive indication of the animals' response to improved water quality and habitat features.

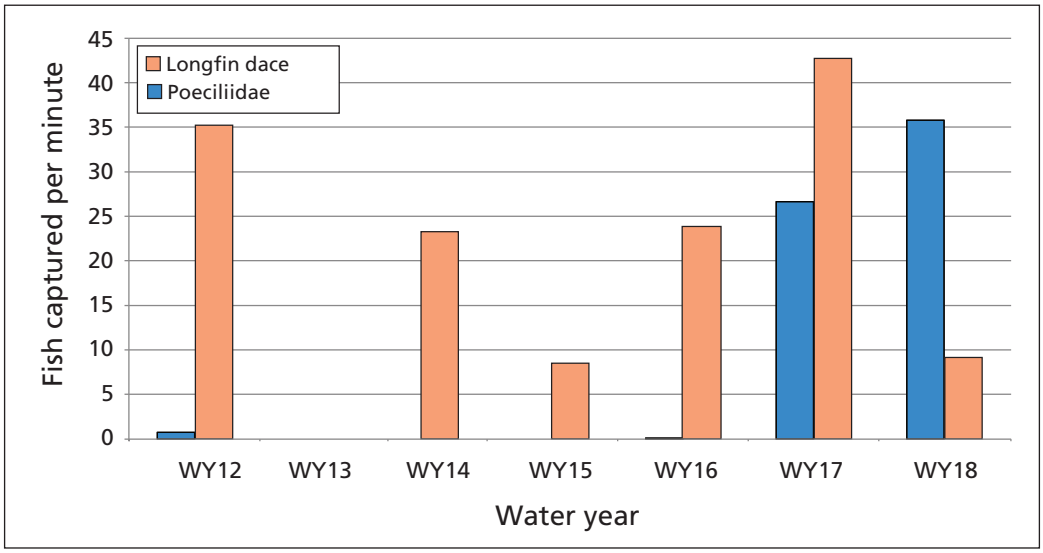


Figure 4-7. Fish per unit effort at Santa Gertrudis index reach, Tumacácori National Historical Park, WY2012–2018.

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Appendix A. Taxa Collected from the Index Reach on the Santa Cruz River, Tumacácori NHP, WY2018.

Table A-1. Macroinvertebrate taxa list, Tumacácori NHP, WY2018.

Phylum	Class	Order	Family	Genus	Species
Annelida	Clitellata	(blank)	(blank)	(blank)	(blank)
Arthropoda	Arachnida	Trombidiformes	Lebertiidae	Lebertia	(blank)
Arthropoda	Arachnida	Trombidiformes	Sperchonidae	Sperchon	(blank)
Arthropoda	Arachnida	Trombidiformes	Torrenticolidae	Torrenticola	(blank)
Arthropoda	Arachnida	Trombidiformes	(blank)	(blank)	(blank)
Arthropoda	Entognatha	Collembola	(blank)	(blank)	(blank)
Arthropoda	Insecta	Coleoptera	Dytiscidae	Liodessus	obscurellus
Arthropoda	Insecta	Coleoptera	Dytiscidae	Uvarus	(blank)
Arthropoda	Insecta	Coleoptera	Elmidae	Heterelmis	(blank)
Arthropoda	Insecta	Coleoptera	Elmidae	Microcylloepus	pusillus
Arthropoda	Insecta	Coleoptera	Elmidae	Neoelmis	caesa
Arthropoda	Insecta	Coleoptera	Haliplidae	Peltodytes	(blank)
Arthropoda	Insecta	Coleoptera	Hydraenidae	Ochthebius	(blank)
Arthropoda	Insecta	Coleoptera	Hydrophilidae	Berosus	(blank)
Arthropoda	Insecta	Coleoptera	Hydrophilidae	(blank)	(blank)
Arthropoda	Insecta	Coleoptera	Psephenidae	Psephenus	(blank)
Arthropoda	Insecta	Coleoptera	Psephenidae	(blank)	(blank)
Arthropoda	Insecta	Diptera	Ceratopogonidae	Bezzia	(blank)
Arthropoda	Insecta	Diptera	Ceratopogonidae	Dasyhelea	(blank)
Arthropoda	Insecta	Diptera	Ceratopogonidae	Probezzia	(blank)
Arthropoda	Insecta	Diptera	Ceratopogonidae	(blank)	(blank)
Arthropoda	Insecta	Diptera	Chironomidae	(blank)	(blank)
Arthropoda	Insecta	Diptera	Culicidae	Anopheles	(blank)
Arthropoda	Insecta	Diptera	Dixidae	Dixella	(blank)
Arthropoda	Insecta	Diptera	Empididae	Hemerodromia	(blank)
Arthropoda	Insecta	Diptera	Empididae	Wiedemannia	(blank)
Arthropoda	Insecta	Diptera	Empididae	(blank)	(blank)
Arthropoda	Insecta	Diptera	Simuliidae	Simulium	(blank)
Arthropoda	Insecta	Diptera	Simuliidae	(blank)	(blank)
Arthropoda	Insecta	Diptera	Stratiomyidae	(blank)	(blank)
Arthropoda	Insecta	Diptera	Stratiomyidae	Nemotelus	(blank)
Arthropoda	Insecta	Diptera	Tabanidae	Tabanus	(blank)
Arthropoda	Insecta	Diptera	Tipulidae	Limonia	(blank)
Arthropoda	Insecta	Diptera	Tipulidae	Dicranota	(blank)
Arthropoda	Insecta	Diptera	(blank)	(blank)	(blank)
Arthropoda	Insecta	Ephemeroptera	Baetidae	Acentrella	(blank)
Arthropoda	Insecta	Ephemeroptera	Baetidae	Baetis	(blank)
Arthropoda	Insecta	Ephemeroptera	Baetidae	Baetodes	(blank)

Table A-1. Macroinvertebrate taxa list, Tumacácori NHP, WY2018, cont.

Phylum	Class	Order	Family	Genus	Species
Arthropoda	Insecta	Ephemeroptera	Baetidae	Callibaetis	(blank)
Arthropoda	Insecta	Ephemeroptera	Baetidae	Camelobaetidius	(blank)
Arthropoda	Insecta	Ephemeroptera	Baetidae	Fallceon	(blank)
Arthropoda	Insecta	Ephemeroptera	Baetidae	(blank)	(blank)
Arthropoda	Insecta	Ephemeroptera	Caenidae	Caenis	(blank)
Arthropoda	Insecta	Ephemeroptera	Heptageniidae	(blank)	(blank)
Arthropoda	Insecta	Ephemeroptera	Leptohyphidae	Tricorythodes	(blank)
Arthropoda	Insecta	Ephemeroptera	Leptohyphidae	(blank)	(blank)
Arthropoda	Insecta	Ephemeroptera	Leptophlebiidae	(blank)	(blank)
Arthropoda	Insecta	Ephemeroptera	(blank)	(blank)	(blank)
Arthropoda	Insecta	Hemiptera	Belostomatidae	Abedus	(blank)
Arthropoda	Insecta	Hemiptera	Belostomatidae	(blank)	(blank)
Arthropoda	Insecta	Hemiptera	Corixidae	(blank)	(blank)
Arthropoda	Insecta	Hemiptera	Gerridae	(blank)	(blank)
Arthropoda	Insecta	Hemiptera	Naucoridae	Ambrysus	(blank)
Arthropoda	Insecta	Hemiptera	Veliidae	Microvelia	(blank)
Arthropoda	Insecta	Hemiptera	Veliidae	Rhagovelia	(blank)
Arthropoda	Insecta	Hemiptera	Veliidae	(blank)	(blank)
Arthropoda	Insecta	Lepidoptera	Crambidae	Petrophila	(blank)
Arthropoda	Insecta	Megaloptera	Corydalidae	Corydalus	cornutus
Arthropoda	Insecta	Odonata	Calopterygidae	Hetaerina	americana
Arthropoda	Insecta	Odonata	Calopterygidae	Hetaerina	(blank)
Arthropoda	Insecta	Odonata	Coenagrionidae	Argia	(blank)
Arthropoda	Insecta	Odonata	Coenagrionidae	Enallagma	(blank)
Arthropoda	Insecta	Odonata	Coenagrionidae	(blank)	(blank)
Arthropoda	Insecta	Odonata	Gomphidae	Progomphus	(blank)
Arthropoda	Insecta	Odonata	Gomphidae	(blank)	(blank)
Arthropoda	Insecta	Odonata	Lestidae	Archilestes	(blank)
Arthropoda	Insecta	Odonata	Libellulidae	Brechmorhoga	mendax
Arthropoda	Insecta	Odonata	Libellulidae	(blank)	(blank)
Arthropoda	Insecta	Trichoptera	Glossosomatidae	Glossosoma	(blank)
Arthropoda	Insecta	Trichoptera	Helicopsychidae	Helicopsyche	(blank)
Arthropoda	Insecta	Trichoptera	Hydropsychidae	Cheumatopsyche	(blank)
Arthropoda	Insecta	Trichoptera	Hydropsychidae	Hydropsyche	(blank)
Arthropoda	Insecta	Trichoptera	Hydropsychidae	Smicridea	(blank)
Arthropoda	Insecta	Trichoptera	Hydropsychidae	(blank)	(blank)
Arthropoda	Insecta	Trichoptera	Hydroptilidae	Hydroptila	(blank)
Arthropoda	Insecta	Trichoptera	Hydroptilidae	Leucotrichia	(blank)
Arthropoda	Insecta	Trichoptera	Hydroptilidae	Ochrotrichia	(blank)
Arthropoda	Insecta	Trichoptera	Hydroptilidae	(blank)	(blank)
Arthropoda	Insecta	Trichoptera	Hydroptilidae	Ithytrichia	clavata
Arthropoda	Insecta	Trichoptera	Leptoceridae	Nectopsyche	(blank)

Table A-1. Macroinvertebrate taxa list, Tumacácori NHP, WY2018, cont.

Phylum	Class	Order	Family	Genus	Species
Arthropoda	Insecta	Trichoptera	Philopotamidae	Chimarra	(blank)
Arthropoda	Malacostraca	Amphipoda	Gammaridae	Gammarus	(blank)
Arthropoda	Malacostraca	Amphipoda	(blank)	(blank)	(blank)
Arthropoda	Malacostraca	Decapoda	Cambaridae	(blank)	(blank)
Arthropoda	Malacostraca	Decapoda	(blank)	(blank)	(blank)
Mollusca	Bivalvia	Veneroida	Corbiculidae	Corbicula	(blank)
Mollusca	Gastropoda	Basommatophora	Ancylidae	Ferrissia	rivularis
Mollusca	Gastropoda	Basommatophora	Physidae	Physa	(blank)
Platyhelminthes	Turbellaria	(blank)	(blank)	(blank)	(blank)

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