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Natural Resource Stewardship and Science

Status of Climate and Water Resources at Tumacácori National Historical Park

Water Year 2017

Natural Resource Report NPS/SODN/NRR—2018/1671

ON THE COVER

Aquatic macroinvertebrate sampling on the Santa Cruz River, Tumacácori National Historical Park. NPS photo.

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Contents

Figures

Tables

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 to provide an integrated look at climate and water conditions during water year 2017 (October 2016–September 2017).

Overall annual precipitation was 126% of normal. A wet winter and strong monsoon season made up for below normal rainfall in the early fall and early spring. Temperatures at Tumacácori NHP tended to be warmer than normal and there were substantially fewer extremely cold days. The reconnaissance drought index indicated that the regional drought that began in 2000 continued through WY2017.

The three monitored wells at Tumacácori NHP indicated that mean groundwater levels in WY2017 were higher than the mean of the data record for each well (0.18–0.48 ft). Water levels in both the shallow and deep aquifer wells dropped in response to dry spring conditions, and then quickly increased with monsoon precipitation and flow events. However, 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. Streamflow on the Santa Cruz River through the park was below average in WY2017. In fact, discharge in the Santa Cruz was slightly above the 25th percentile for a majority of the water year. Spring and early summer discharge was below normal, with drying/no flow events likely occurring during the end of June and early July. The WY2017 monsoon was generally above average, providing average flow into the fall. Peak flow occurred on July 23, followed by a flow event of nearly the same magnitude on August 1. This gauge is located five kilometers downstream from the index sampling site in Tumacácori NHP. Water samples were collected from the Santa Cruz River at the Santa Gertrudis index site. Of 85 individual analyses associated with Arizona surface-water criteria, there was one exceedance (for *E. coli*); that is, 99% 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). Given the circumstances, the stability of diversity and abundance of mayflies (Ephemeroptera) and caddisflies (Trichoptera)—and low abundance of indicators of poor water quality, such as midge larvae (Chironomidae)—indicated that the habitat and water quality at the index reach were generally positive. Three taxa of fish were collected during collaborative sampling at the Santa Gertrudis index reach: longfin dace (*Agosia chryogaster*), Gila topminnow (*Poeciliopsis occidentalis*), and western mosquitofish (*Gambusia affinis*). This was the second documentation of the federally endangered Gila topminnow in the index reach since 2002. The continued presence of longfin dace and an increase in Gila topminnow are positive indicators of the animals' response to improved water quality and habitat features on this reach.

Acknowledgements

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. Colombe Lefort 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. 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, streamflow, and water quality is central to assessing the condition of park biota and key cultural resources. This report combines data collected on climate and surface water at Tumacácori National Historical Park (NHP) to provide an integrated look at climate and water conditions during water year (WY) 2017 (October 2016–September 2017). Detailed analyses of trends will follow in subsequent reports as the period of record warrants such assessments. For details on the monitoring protocols, park setting, and resources, and information on other resources of management focus, please see http://science.nature.nps.gov/im/units/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 the National Park Service manages and protects. Freeze-thaw cycles also impact vulnerable cultural resources. Cooler temperatures result in condensation and moisture imbibition to earthen materials, which will expand and weaken the matrix if it freezes.

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 the long-term average annual precipitation relative to the average annual potential evapotranspiration, can be a useful tool for contrasting the local climate of national parks (Figure 2-1). Used globally to classify

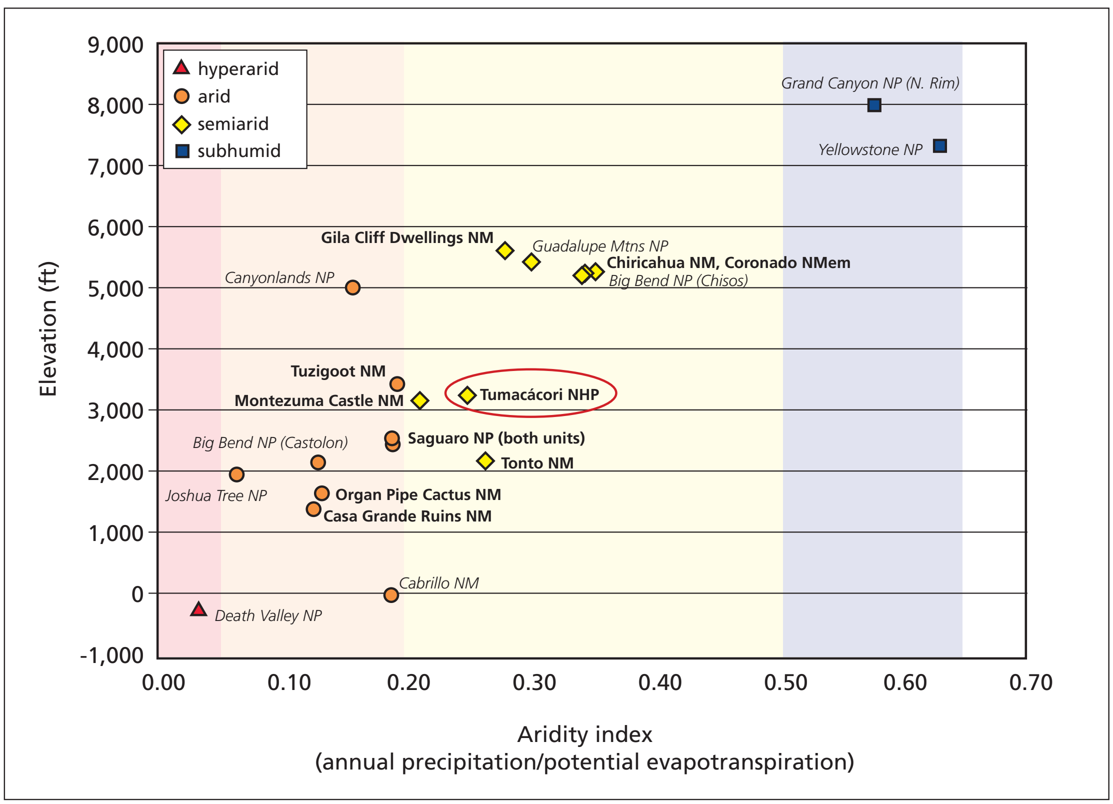

Figure 2-1. Aridity index vs. elevation of selected southwestern national parks, including Tumacácori National Historical Park. Figure from Hubbard and others (in prep).

climate zones, aridity indices seek to answer the question, "How dry is dry?" (Tsakiris and Vengelis 2005). Using the period of record (1946–present), the climate of Tumacácori NHP is categorized as semi-arid.

2.2 Results and discussion

Data quality during WY2017 was excellent. Only five days were missing temperature data, and the precipitation record was complete.

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

Overall annual precipitation was 68% of normal for Tumacácori NHP (11.26" vs 16.56").

2.2.1.1 Cool season (October–March)

Overall precipitation was below normal (63% or -2.26") for fall and winter WY2017. Precipitation in December and January was greater than normal. October, November, February, and March were extremely dry, each with ≤0.31" precipitation (Figures 2-2 and 2-3). Air temperatures were generally 2–8°F warmer than normal, with the exception of the mean maximum temperature in January, which was 2.8°F below normal (Figure 2-3).

2.2.1.2 Warm season (April–September)

Maximum and minimum air temperatures in the spring and summer months were near normal (within -2.5 and 3.9°F of normal). The warm season was drier than normal (71%, -3.04" precipitation). The monsoon was strong for three weeks in July, but tapered off quickly, a pattern seen throughout the Sonoran Desert. Precipitation in July was 4.81", representing 43% of the WY2017 total annual rainfall. Precipitation in May was 175% of normal, owing to a single 0.4" storm event. Rainfall in all other spring and summer months was less than normal (5–51% of normal).

2.2.2 Reconnaissance Drought Index

Reconnaissance drought index (Tsakiris and Vengelis 2005) provides a measure of drought severity and extent relative to the 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 reflected the extended regional drought since 2000, which continued through WY2017 (Figure 2-4). However, the five-year running mean of total annual precipitation was only slightly below the long-term precipitation average from 1981 to 2017 (Figure 2-5), suggesting that the drought has been less severe during the last five years.

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 for Apache Highlands ecosystems. 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 also 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% more often than normal (15 days vs. 13.3 ± 1.4 days) in WY2017, and were of a greater duration (3.75 consecutive days vs. 2.1 ± 0.1 days).

There were no extreme precipitation events (>1") in WY2017, compared to an average 3.23 days per year in 1981–2010. The largest storm event occurred on December 25 (0.87").

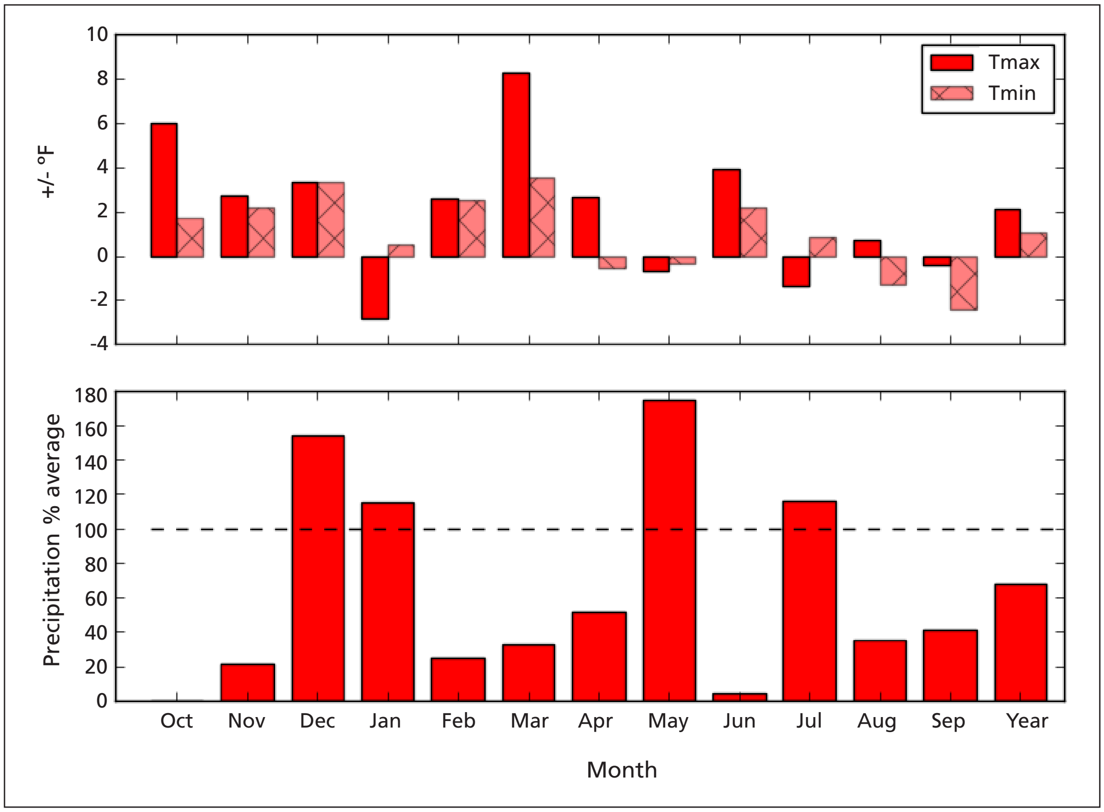

Figure 2-2. Departures from 30-year (1981–2010) normal minimum and maximum air temperature and precipitation, Tumacácori National Historical Park, WY 2017. Graphics generated by climateanalyzer. org.

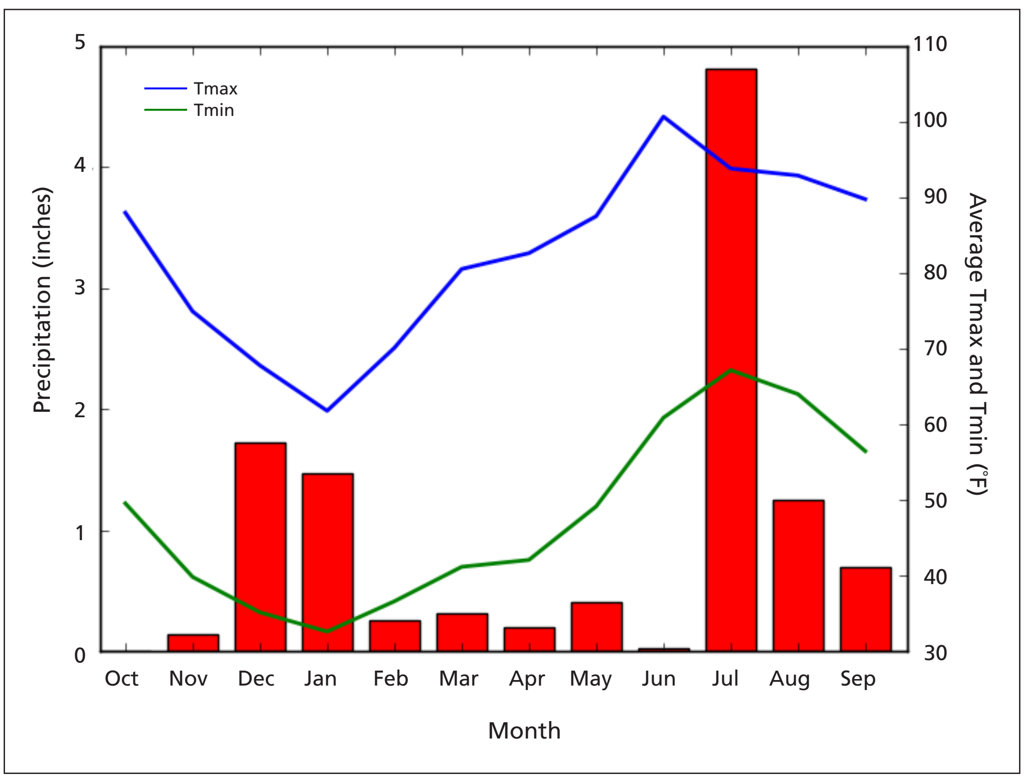

Figure 2-3. Climogram for water year 2017, Tumacácori National Historical Park. Graphics generated by climateanalyzer. org

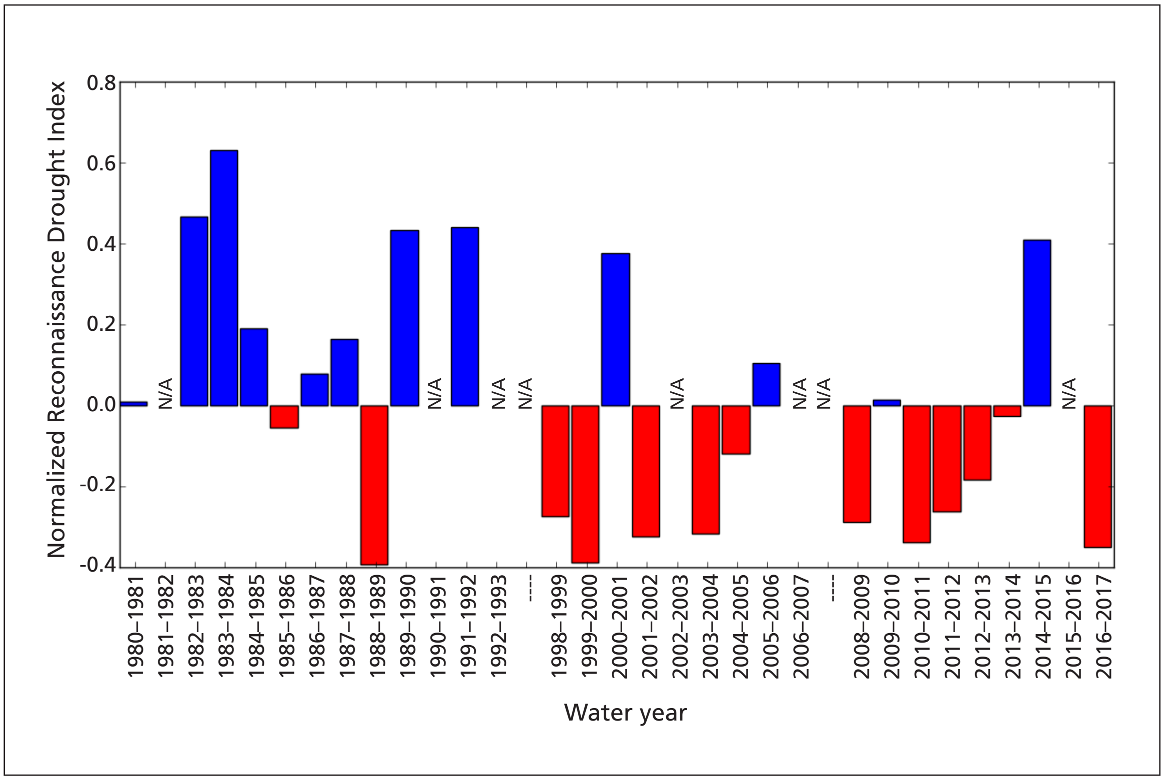

Figure 2-4. Reconnaissance drought index (RDI), Tumacácori National Historical Park, water years 1981–2017. “N/A” = insufficient data to generate reliable RDI estimates. The station had an extended period without data collection from 1992 to 1997. Drought index calculations are relative to the time period selected. Graphics generated by climateanalyzer.org.

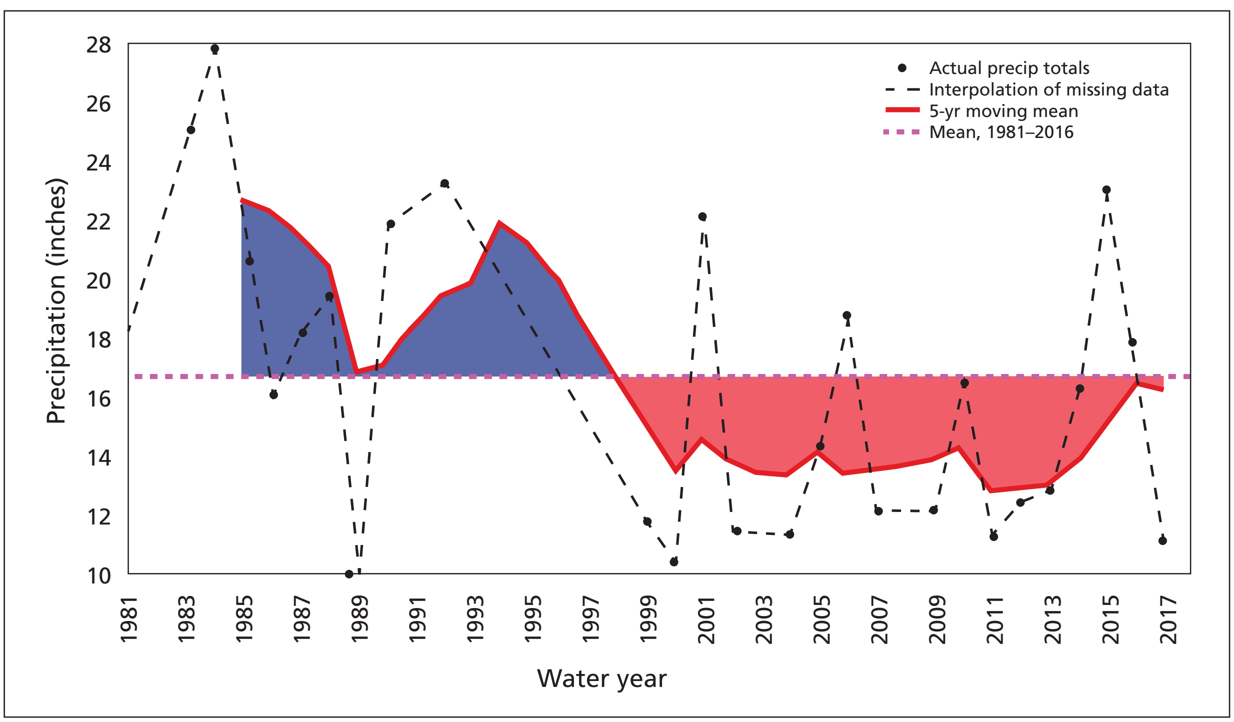

Figure 2-5. Five-year moving mean of annual precipitation, Tumacácori National Historical Park, water years 1981–2017. The moving mean (solid red line) is based on a timeseries with 27.0% (10 of 37) missing values, and includes the current year and previous four years. Missing years are linearly interpolated (dashed 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 springs, 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).

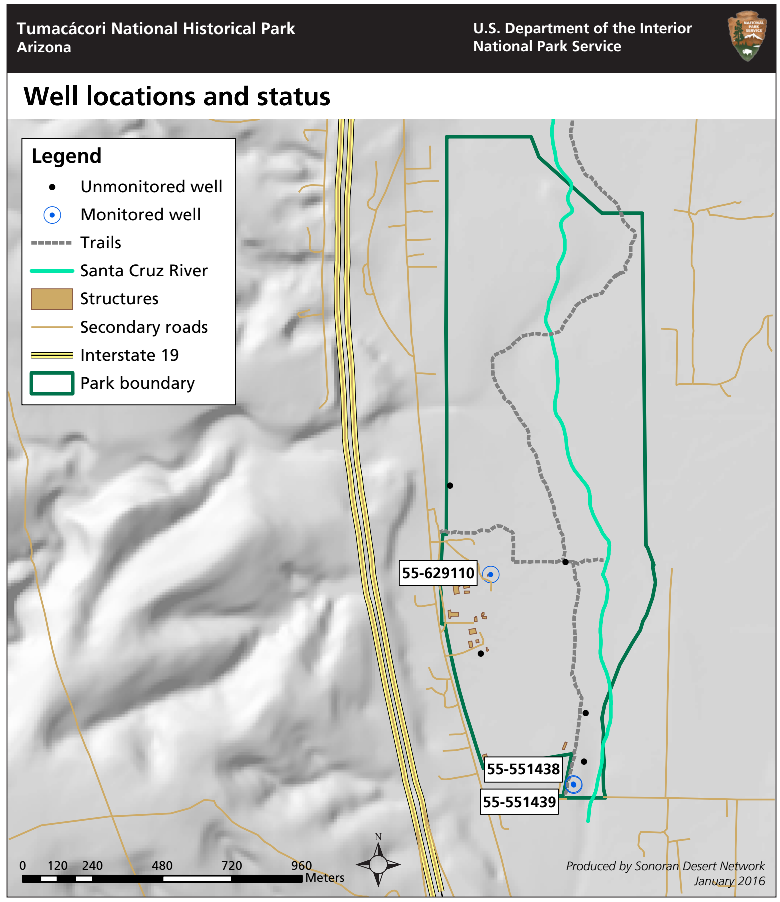

Figure 3-1. Monitoring well locations at Tumacácori National Historical Park.

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.

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. The Sonoran Desert Network began monitoring water levels at this well in 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). Data are available at https://gisweb.azwater.gov/waterresourcedata/wellregistry.aspx.

In addition to the Santa Gertrudis Lane wells, the Mission unit's water-supply well, 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 of the ADWR data reported in this document may be retrieved by entering well identification information at https://gisweb.azwater. gov/waterresourcedata/GWSI.aspx.

3.2 Results

3.2.1 Shallow aquifer (MW-1 Shallow)

The mean depth-to-water (DTW) at the shallow aquifer well in WY2017 was 9.83 feet bgs (below ground surface), which was 0.18 feet higher than the annual mean for WY2008–2016 (Figure 3-2). However, data were missing between May 16 and June 28, which is generally a dry time of year. Therefore, the mean water level for WY2017 may actually be lower. In WY2017, the lowest water level recorded (10.86 ft bgs) occurred on July 6, prior to the onset of the monsoon season (Figure 3-2). The highest water level in WY2017 (7.15 ft bgs) occurred on August 1, the same day as the largest flow event (3,150 cfs) at the U.S. Geological Survey (USGS) gauge on the Santa Cruz River at Tubac (USGS 09481740). 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. The range between the minimum and maximum water levels was 3.71 feet, demonstrating an annual variation 1.10 feet greater than the mean annual range for WY2008–2016.

3.2.2 Deep aquifer (MW-1 Deep)

The mean DTW at the deep aquifer well in WY2017 was 7.55 feet bgs, which was 0.48 feet higher than the annual mean for WY2010–2016 (Figure 3-3). Similar to the shallow aquifer well, the lowest water level reading at the deep aquifer well in WY2017 (8.24 ft bgs) occurred on July 6, while the

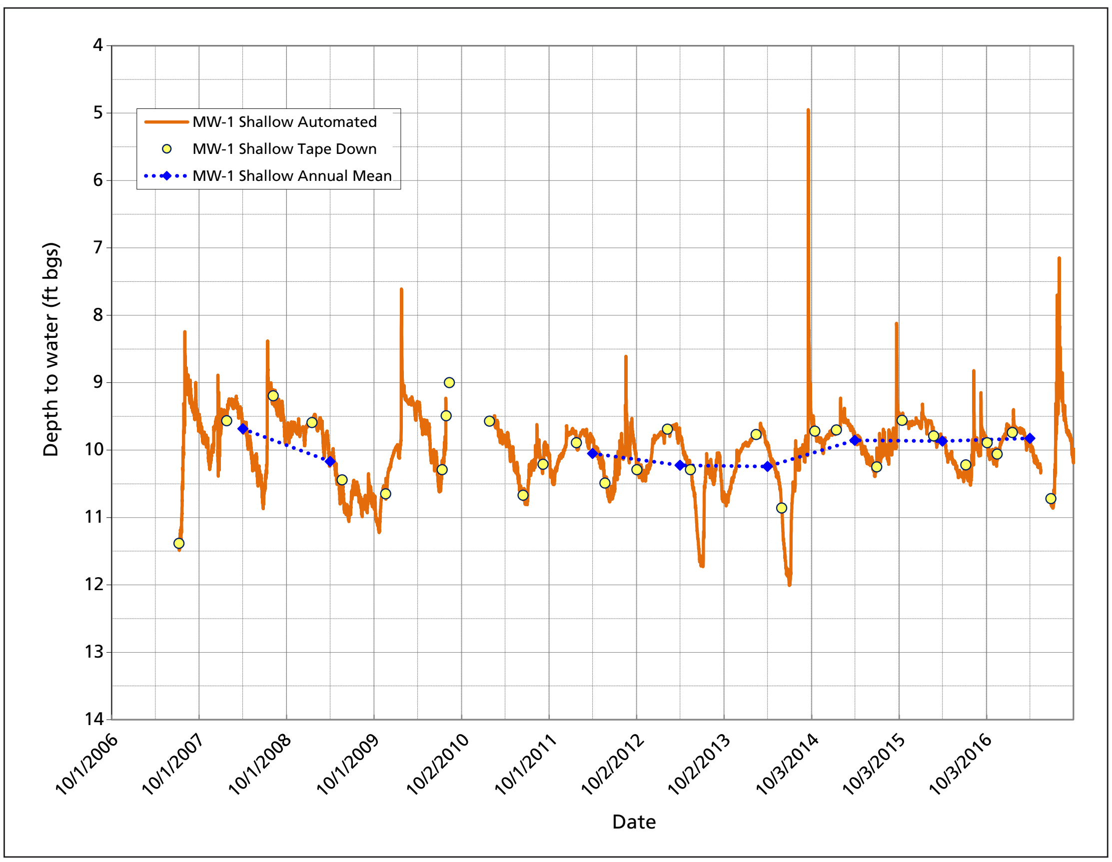

Figure 3-2. Depth-to-water at MW-1 Shallow (ADWR 55-551439), water years 2007–2017. Annual mean depth-to-water was not calculated for WY2007, 2010, and 2011 due to gaps in the data record. "bgs" = below ground surface.

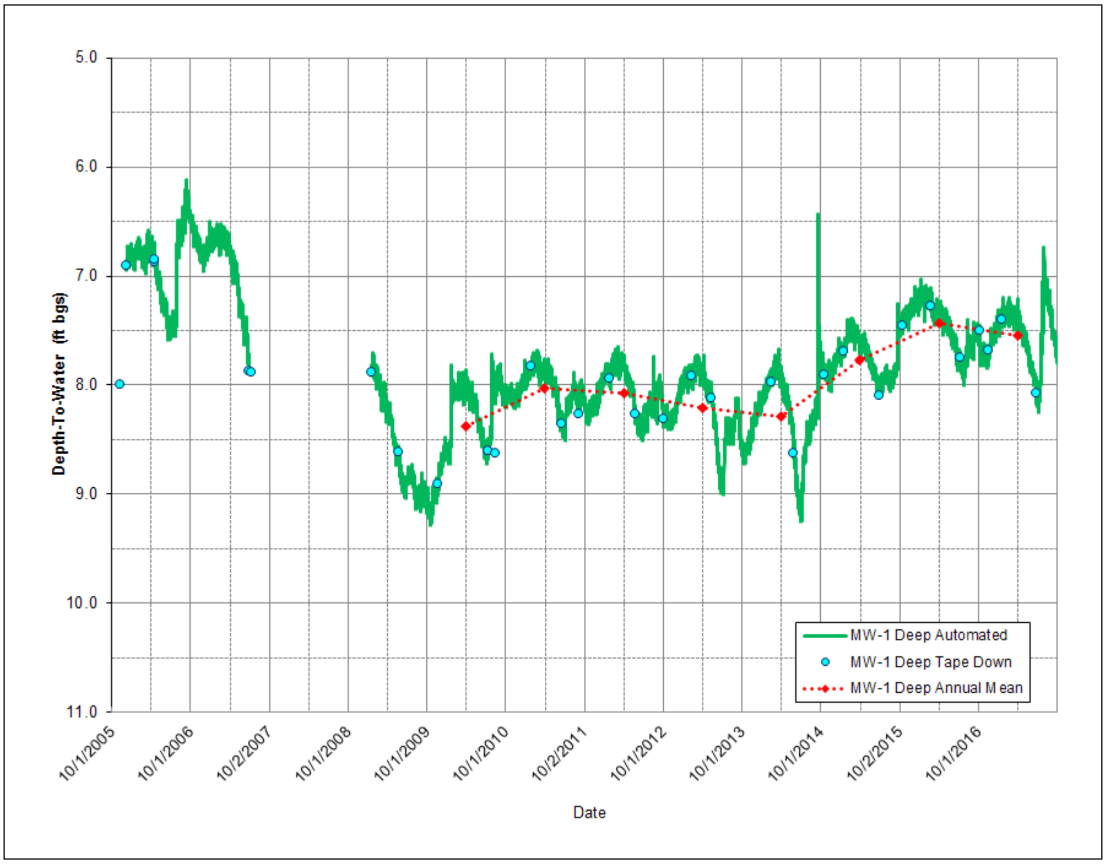

Figure 3-3. Depth-to-water at MW-1 Deep (ADWR 55-551438), water years 2006–2017. Annual mean depth-to-water was not calculated for WY2006–2009 due to gaps in the data record. "bgs" = below ground surface.

highest (6.73 ft bgs) occurred on August 1 (Figure 3-3). The range between the minimum and maximum water levels was 1.51 feet, demonstrating an annual variation 0.20 feet greater than the mean annual range for WY2010–2016. 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. Seasonal fluctuations are present, with maximum water-level elevations occurring in the winter–spring season and annual minimum water levels occurring in June of each year.

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 below land surface (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 3-3 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 (Figure 3-4) 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 periods. 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 re-

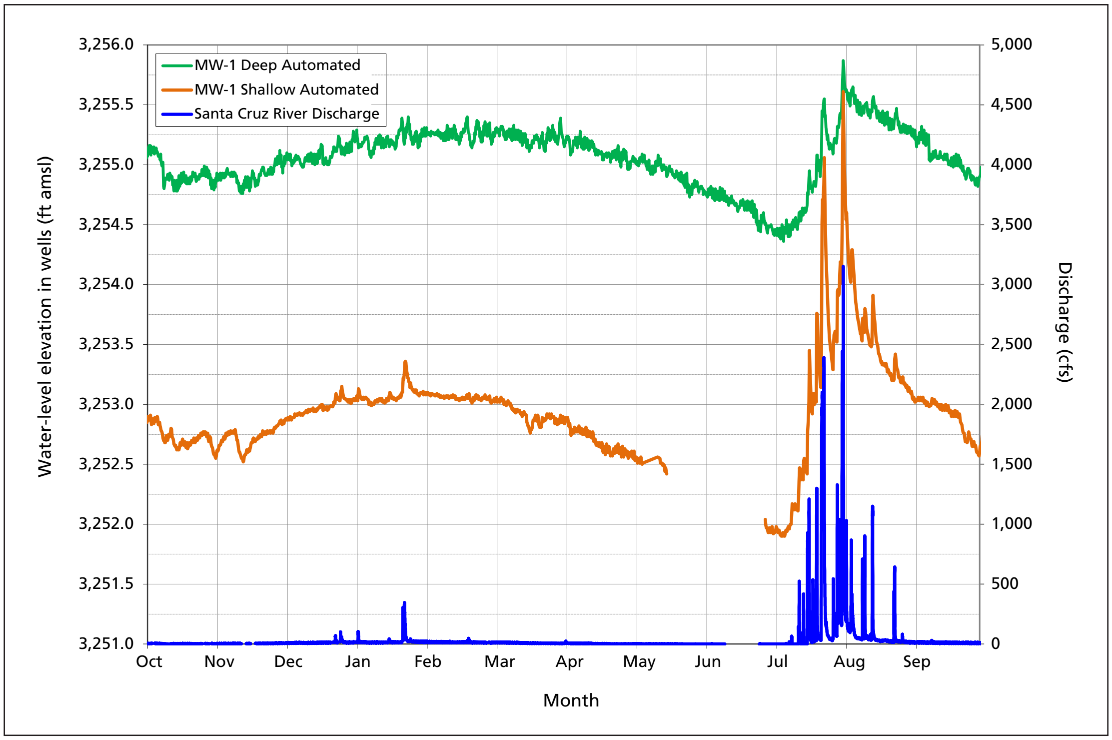

Figure 3-4. Water-level elevations at the deep and shallow monitoring wells at Tumacácori National Historical Park and discharge at the USGS gauge on the Santa Cruz River at Tubac, Arizona, WY2017. "amsl" = above mean sea level.

sult 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 WY2017 (Figure 3-5). The mean was 11.3 ft below ground surface, suggesting that mean water level for WY2017 was above the mean for the historic record (12.03 below ground surface). Intermittent manual (sounding-tape) measurements at the Mission unit's water-supply well provide the longest period of record (1960–present), although the paucity of measurements before 1998 (when ADWR instituted annual monitoring) limits our ability to interpret earlier conditions. The measurement data (Figure 3-5) span the period prior to and following the introduction of effluent from the Nogales International Wastewater Treatment Plant (NIWTP), which began at its current location in 1972. Following the introduction of groundwater pumping from the shallow aquifer in the 1920s and 1930s, the river had become ephemeral to intermittent and the riparian gallery along the river was lost. By 1977, effluent releases from the NIWTP provided the needed baseflow for the Santa Cruz River to become perennial at Tumacácori once again. The early data from this well are insufficient to determine how water status in the deeper, Old Alluvium aquifer was affected by these changes in the river over the period of record.

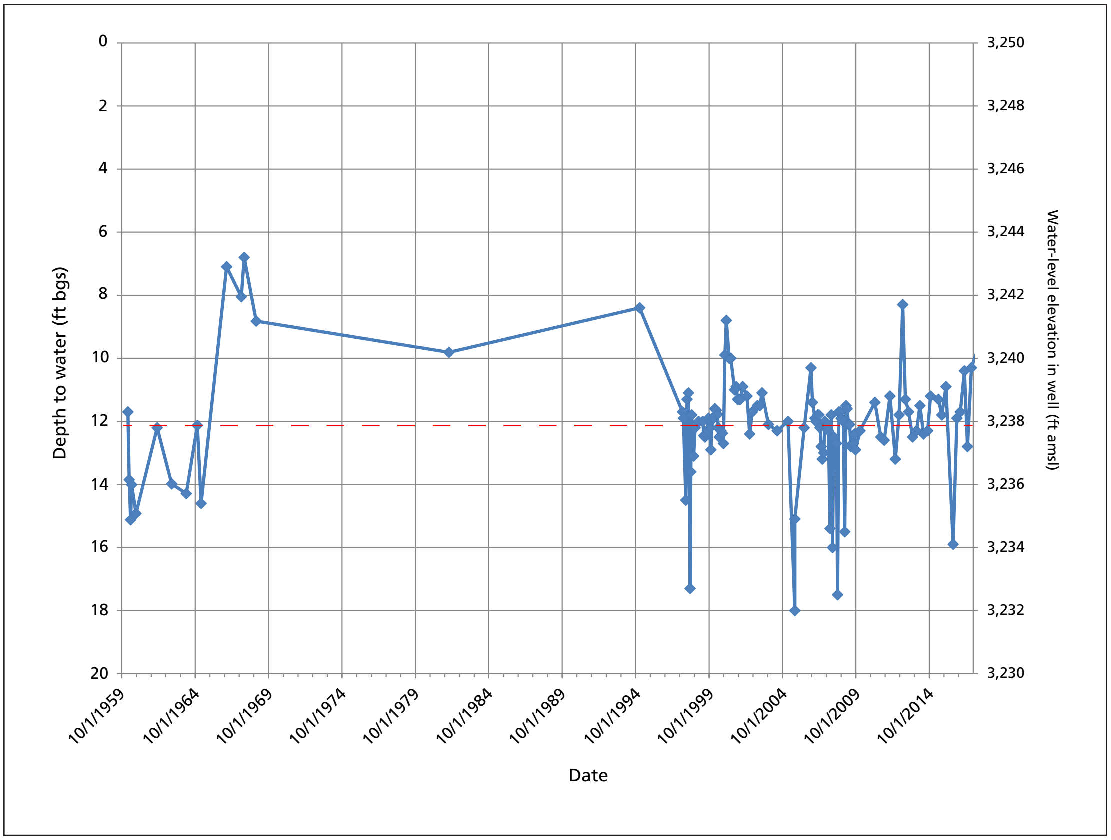

Figure 3-5. Depth-to-water and water-level elevation at the Mission unit's water-supply well, WY1960–2017, Tumacácori National Historical Park. "bgs" = below ground surface. "amsl" = above mean sea level. Dashed red line represents mean bgs at 12.03 feet.

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. 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 in turn 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 the springtime. The amount of discharge from the NIWTP has decreased due to the construction of the Los Alisos wastewater treatment plant in Mexico, which has reduced the flow of the Santa Cruz through Tumacácori NHP (Norman et al. 2013).

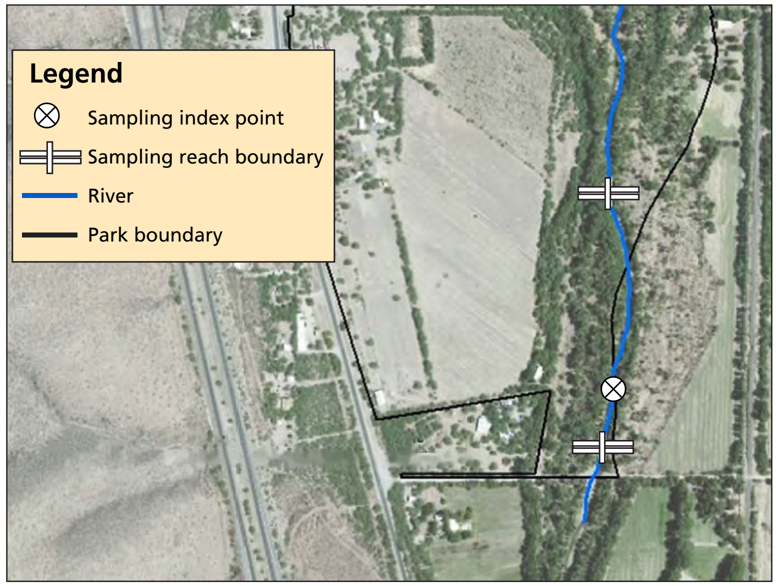

Figure 4-1. Map of the Santa Cruz River, Tumacácori NHP, with the SODN water quality sampling locations.

4.2 Methods

Water quality monitoring occurred ~150 m downstream from the park's southern boundary (Figure 4-1), at the Santa Gertrudis index site. 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 main unit at Tumacácori NHP.

A brief description of the data collection and processing methodologies followed by SODN staff at Tumacácori NHP during WY2017 is presented below. Detailed descriptions of these procedures will be available in the SODN water quality monitoring protocol (Gwilliam et al. in prep).

4.2.1 Water quantity

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. Data on daily mean discharge and annual peak discharge 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 the core parameters. 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). We transferred the sample water to bottles 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 WY2016, 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, using dipnets, beach seine (6' x 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 water quality and quantity data 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 provided by the manufacturer (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 gauge at Tubac, Arizona (09481740), is being used as a proxy for the stream discharge dynamics at the Santa Gertrudis stream monitoring index site at Tumacácori NHP (Gwilliam et al. 2016) The WY2017 annual summary for the USGS Tubac gauge provides data for this gauge (USGS 2017). Figure 4-2 shows the mean daily discharge for WY2017 in comparison to the mean daily flows for the gauge record.

The discharge in the Santa Cruz was slightly above the 25th percentile for a majority of WY2017. As seen in Figure 4-2, the black line (WY2017 mean daily discharge) hugs the transition between the green area (data within the 25th and 75th percentile of data from the gauge record) and the light brown area (the data falling below the 25th percentile

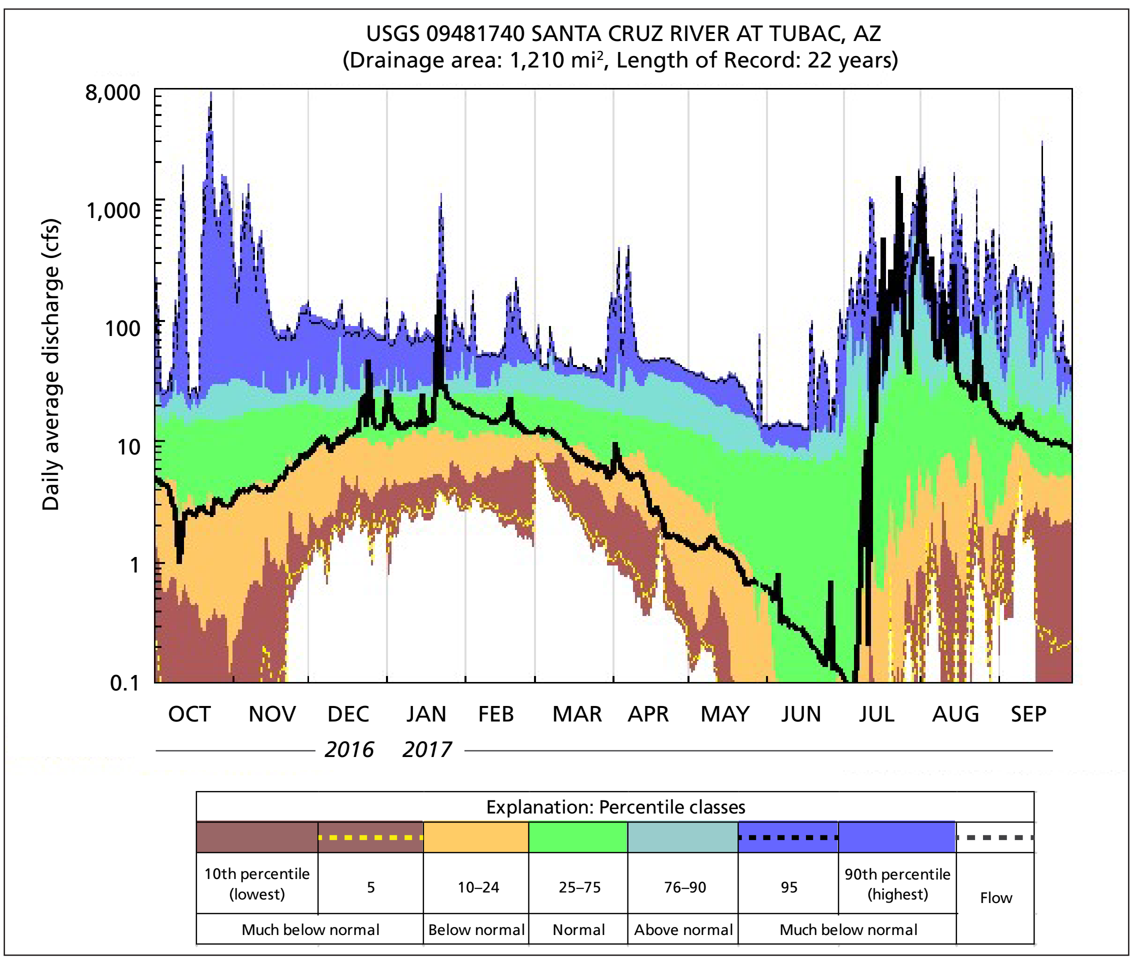

Figure 4-2. Hydrograph from USGS gauge 09481740, near Tubac, Arizona, water year 2017.

of all data for the gauge record). Spring and early summer discharge was below normal, with drying/no flow events likely occurring during the end of June and early July. The WY2017 monsoon was generally above average, providing average flow into the fall.

The peak mean daily flow of 1,520 cfs occurred on July 23, 2017, followed by a flow event of nearly the same magnitude (1,480 cfs) on August 1. The mean annual flow in WY2017 was 32.6 cfs (SD 129.8), compared to the gauge record of 25.1 cfs (SD 128.5). The sustained period of above-average flow during the monsoon caused the WY2017 mean discharge value to be higher than the gauge record mean. The lower flow during the rest of the year is reflected in the median values for the annual discharge: WY2017 median was 8.6 cfs compared to the gauge record of 11.7 cfs.

The difference between these statistics illustrates the importance of the higher flows during the monsoon season. A majority of the annual amount of water flowing into the Santa Cruz River system is from monsoon storms (illustrated by the elevated annual mean value). These flow events are vitally important for groundwater recharge and provide ecosystem services for the aquatic and riparian zones of the Santa Cruz River (Norman et al. 2013).

The monsoon storms can also impact regional water resources and park management. On July 25, 2017, there was a breach in the sewer pipe bringing raw sewage to the NIWTP (see Trevizo 2017). This spill occurred in Portero Creek, a tributary of the Santa Cruz River 16 kilometers upstream of the park. This pipe conveys 10–13 million of gallons of untreated waste from the cities and surrounding areas of Nogales, Sonora, and Nogales, Arizona. Intense flow events from monsoon storms dislodged debris that damaged the pipe and caused the leak. Repair began on October 9 and concluded on October 27 (IBWC 2017).

The discharge of raw sewage into the Santa Cruz River occurred during late July and early August. Sampling by SODN occurred on August 28, 2017 did not detect abnormal concentrations of nutrients or other parameters commonly associated with raw sewage. Despite the high levels of *E. coli* and elevated concentrations of total suspended solids collected by SODN during the Q4 sample in August, there was no clear evidence of the leak in samples from the Santa Cruz River at the park.

4.3.2 Water quality

In WY2017, SODN staff made a total of four sampling visits to the Santa Cruz River at Tumacácori NHP. Discrete samples were collected in each quarter. Continuous sampling occurred during deployment periods during each quarter (Table 4-1).

Of 240 discrete water quality samples collected, 85 had associated state standards. There was one exceedance during WY2017, for *E. coli* (see Table 4-4) during the fourth quarter (summer) sample, resulting in 98.8% compliance with state standards.

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

Table 4-1. Dates of discrete sampling and continuous measurements at Tumacácori NHP, WY2017.

Quarter	Discrete sampling	Continuous measurements	Continuous measurements collected*
Q1	11/17/2016	11/17/2016–12/1/2016	1,330
Q2	2/13/2017	2/13/2017–3/2/2017	1,624
Q3	5/16/2017	4/25/2017–5/16/2017	2,011
Q4	8/28/2017	Not sampled	0

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

4.3.2.1 Core parameters

Discrete sampling—. The discrete measurements shown in Table 4-2, collected in the field, represent conditions at the Tumacácori NHP index site during site visits in WY2017. 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 temperature, specific conductivity, pH, and dissolved-oxygen data at 15-minute intervals. During WY2017, more than 4,900 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. During second-quarter sampling (see Table 4-1), there was slightly elevated discharge (10.3 cfs vs. 8.6 cfs gauge record), and a small flow event on February 19. This led to lower-than-expected specific-conductivity values throughout the deployment. (Increased flow can dilute the concentration of analytes in the water, decreasing specific-conductivity measurements.) The median value of specific conductivity in WY2017 was in the lower 25% of values for Q2 deployments (Figure 4-3B), likely due to the elevated discharge rates during the deployment.

The WY2017 spring samples (Q3, see Table 4-1) had an elevated median pH value of 8.61, which was in the top 75% of gauge record results (Figure 4-3C). Flow was low during this deployment period (3.56 cfs; see Table 4-2). The specific conductivity median value for Q3 (717 µS/cm) was also elevated, approaching the 75% percentile of gauge records. Other elevated parameters during the Q3 sample, including total calcium and sulfate, are shown in Tables 4-5 and 4-6, below. This may be the result of low flow, but the reason is uncertain.

Table 4-2. Discrete data summary for core water quality parameters, Santa Cruz River, Tumacácori NHP, WY2017.

Parameter	Quarter				Arizona state standard
	Q1	Q2	Q3	Q4	
Temperature (°C)	17.3	17.5	19.3	23.2	NS[a]
Specific Conductivity (µS/cm)	735	737	760	686	NS
pH	7.57	7.84	7.97	7.68	6.5–9.0
Oxygen concentration (mg/L)	7.82	7.68	8.18	6.73	>3[b]
Turbidity (NTU)	2.14	4.67	1.61	21.9	NS
Discharge (cfs)	8.01	10.3	3.56	22	–

[a] Maximum allowable increase in ambient water due to a thermal discharge is 3.0°C.
b Dissolved oxygen concentration of 3.0 mg/L applies from three hours after sunrise to sunset, 1.0 mg/L applies sunset to three hours after sunrise.
NS = no standard.

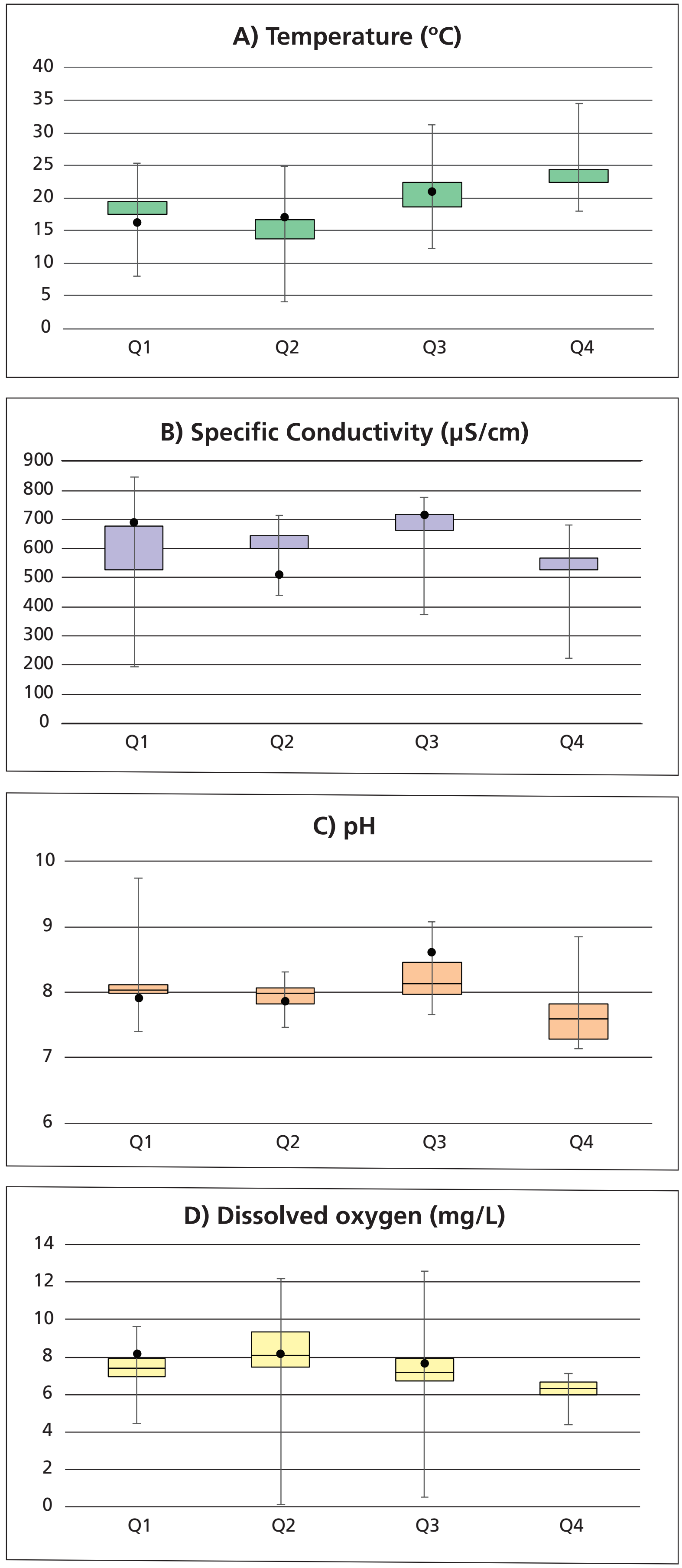

Figure 4-3. Data on (A) water temperature, (B) specific conductivity, (C) pH, and (D) dissolved oxygen concentration, from the Santa Cruz River, Santa Gertrudis index site, Tumacácori NHP, WY2017.

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 solid black dots mark the median value from WY2017 sampling for each parameter.

Please note no data were collected during Q4 in WY2017, because the flow exceeded safety protocols during the Q4 deployment date. Box plots are presented for Q4 for WY2011–2016 to provide reference to the range of data from this site.

4.3.2.2 Nutrient dynamics

Nutrient samples were collected during each sample period during WY2017 (Table 4-3). Dissolved nitrate has been regularly detected at this sample site since WY2008. Initial analysis indicates that concentrations of dissolved nitrate have increased in the Q4 (August) sample from WY2008 to WY2017 (Pearson's Correlation test; two tail p=0.029; alpha=0.05). Further analysis is being conducted to understand this pattern, which will be addressed in a future report. Only parameters with results are reported. It should be noted that measurements for parameters not reported were not necessarily zero. Rather, they were below the detection limit of the analytical equipment and may be present in very low concentrations.

4.3.2.3 Biological condition

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 state standard for a single sample of *E. coli* is 575 cfu/100 mL.

The state standard for *E. coli* was exceeded during Q4 (summer) in WY2017 (Table 4-4). These exceedances are frequent at the sample site. The bacterium, *Escherichia coli*, is used as an indicator of human fecal contamination. However, it is relatively ubiquitous in the environment, found in decaying material, soil, and in the guts of mammals, including humans (Paretti et al. 2017). Exceedances typically occur during and after flow events resulting from precipitation events that wash soil and other material into the Santa Cruz River.

4.3.2.4 Metal and metalloids

During WY2017, there were no exceedances of state or federal water quality standards from metal and metalloid 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).

Table 4-3. Results of nutrient sampling, Santa Cruz River, Tumacácori NHP, WY2017.

Analyte	mg/L				Method	Arizona state standard (mg/L)	Beneficial use
	Q1	Q2	Q3	Q4			
Nitrate - Dissolved	4.5	3.1	2.7	3.3	EPA 300.0	3,733	Partial body contact
Nitrate + Nitrite	4.7	3.3	2.9	3.5	EPA 353.2	NS	–
Total Nitrogen	4.7	3.3	2.9	3.5	Calculated	NS	–

NS = no standard. Methods are from Eaton and others (2005).
*Exceedance noted.

Table 4-4. Results of biological condition sampling, Santa Cruz River, Tumacácori NHP, WY2017.

Analyte	Measurement				Method	Arizona state standard (mg/L)	Beneficial use
Total Organic Carbon (mg/L)	NC	NC	NC	3.2	SM 5130B	NS	–
E. coli (MPN)	43.4	12.8	104.9	>2,419.6*	SM 9223B	575 MPN/100 mL	Full/partial body contact

NC = not collected; NS = no standard; SM = standard method (Eaton et al. 2005).
*Exceedance noted.

Table 4-5. Results from metal and metalloids (dissolved) sampling, Santa Cruz River, Tumacácori NHP, WY2017.

Analyte	mg/L				Method	Arizona state standard (mg/L)	Beneficial use
	Q1	Q2	Q3	Q4			
Arsenic	<0.015	<0.015	<0.015	0.0073	EPA 200.7/200.8	0.15	Aquatic & Wildlife
Barium	NC	NC	NC	0.061	200.8	NS	–
Boron	0.13	0.14	0.12	0.11	EPA 200.7	NS	–
Calcium	69	65	79	58	EPA 200.7	NS	–
Copper	<0.015	<0.015	<0.015	0.0031	EPA 200.7/200.8	0.015	Aquatic & Wildlife[1]
Magnesium	11	11	13	9.3	EPA 200.7	NS	–
Manganese	0.018	0.028	0.025	0.015	EPA 200.7/200.8	NS	–
Molybdenum	<0.20	<0.20	<0.20	0.0042	EPA 200.7/200.8	NS	–
Nickel	NC	NC	NC	0.0067	200.8	0.0895	Aquatic & Wildlife[1]
Potassium	<3.0	6.8	6	8.5	EPA 200.7	NS	–
Silica	10	39	39	34	EPA 200.7	NS	–
Sodium	75	65	67	64	EPA 200.7	NS	–
Uranium	NC	NC	NC	0.0027	200.8	NS	–

[1]Calculated using hardness
NC = Not collected; NS = no standard; Methods are from USEPA (1983).

Table 4-6. Results from metal and metalloids (total) sampling, Santa Cruz River, Tumacácori NHP, WY2017.

Analyte	mg/L				Method	Arizona state standard (mg/L)	Beneficial use
	Q1	Q2	Q3	Q4			
Aluminum	<0.10	0.15	<0.10	1.3	EPA 200.7/200.7 Rev 4.4	NS	–
Arsenic	<0.015	<0.015	<0.015	0.0076	EPA 200.7/200.8	0.2	Agricultural livestock watering
Barium	NC	NC	NC	0.074	200.8	98	Partial body contact
Boron	0.13	0.14	0.13	0.11	EPA 200.7/200.7 Rev 4.4	187	Partial body contact
Calcium	67	64	83	58	EPA 200.7/200.7 Rev 4.4	NS	–
Copper	<0.015	<0.015	<0.015	0.008	EPA 200.7/200.8	0.5	Agricultural livestock watering
Iron	<0.10	0.12	<0.10	1	EPA 200.7/200.7 Rev 4.4	NS	–
Lead	<0.0090	<0.0090	<0.0090	0.002	EPA 200.7/200.8	0.015	Partial body contact
Magnesium	12	10	13	9.7	EPA 200.7/200.7 Rev 4.4	NS	–
Manganese	0.039	0.038	0.029	0.066	EPA 200.7/200.8	131	Partial body contact
Molybdenum	<0.020	<0.020	<0.020	0.0042	EPA 200.7/200.8	NS	–
Nickel	NC	NC	NC	0.008	200.8	28	Partial body contact
Potassium	8	8.1	6.3	8.7	EPA 200.7/200.7 Rev 4.4	NS	–
SiO_2, Silica	39	35	40	40	EPA 200.7/200.7 Rev 4.4	NS	–
Sodium	79	72	70	64	200.7 Rev 4.4	NS	–
Uranium	NC	NC	NC	0.0028	EPA 200.7/200.8	2.8	Partial body contact
Zinc	<0.020	<0.020	<0.020	0.012	EPA 200.7/200.8	25	Agricultural watering

NC = Not collected; NS = no standard
Methods are from USEPA (1983).

Only parameters with results are reported. It should be noted that measurements for parameters not reported were not necessarily zero. Rather, they were below the detection limit of the analytical equipment and may be present in very low concentrations.

4.3.2.5 Suspended and total sediment

During WY2017, samples for suspended and total sediment were analyzed and results were in the range detected in previous years (Gwilliam et al. 2014; Gwilliam et al. 2016) (Table 4-7). Only parameters with results are reported. It should be noted that measurements for parameters not reported were not necessarily zero. Rather, they were below the detection limit of the analytical equipment and may be present in very low concentrations.

4.3.2.6 General water quality and inorganics

During WY2017, samples in the general water quality and inorganics group were analyzed and results were in the range detected in previous years (Gwilliam et al. 2014; Gwilliam et al. 2016) (Table 4-8). Only parameters with results are reported. It should be noted that measurements for parameters not reported were not necessarily zero. Rather, they were below the detection limit of the analytical equipment and may be present in very low concentrations.

Table 4-7. Results from suspended and total sediment sampling, Santa Cruz River, Tumacácori NHP, WY2017.

Analyte	mg/L				Method	Arizona state standard
	Q1	Q2	Q3	Q4		
Total Dissolved Solids	470	480	510	410	SM 2540C	NS
Total Suspended Solids	<4.0	5.6	<4.0	56	SM 2540D	NS

NS = no standard; SM = standard method (Eaton et al. 2005).

Table 4-8. Results from general and inorganic sampling, Santa Cruz River, Tumacácori NHP, WY2017.

Analyte	mg/L				Method	Arizona state standard
	Q1	Q2	Q3	Q4		
Alkalinity as $CaCO_3$	180	200	230	170	SM 2320B	NS
Bicarbonate Alkalinity as $CaCO_3$	180	200	230	170	SM 2320B	NS
Chloride	51	50	55	43	EPA 300.0	NS
Sulfate	91	93	100	79	EPA 300.0	NS
Total Hardness	210	230	240	200	SM 2340B	NS
Anion/Cation balance	2.50%	3.60%	-2.10%	3.60%	SM 1030E	NS

NS = no standard; SM = standard method (Eaton et al. 2005); other methods are from USEPA (1983).

4.3.3 Macroinvertebrates

Macroinvertebrate biological samples and associated habitat data were collected at the Santa Gertrudis index reach on May 17, 2017. The samples were received by the analytical lab on June 19, 2017, and the report from the lab was issued on February 12, 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). However, despite the effluent-driven system, and sub-optimal habitat for calculating the AZIBI (Gwilliam et al. 2017), the stability of diversity and abundance of mayflies (Ephemeroptera) and caddisflies (Trichoptera)—and low abundance of indicators of poor water quality, such as midge larvae (Chironomidae)—indicated that the habitat and water quality at the index reach were generally positive in WY2017 (Figure 4-5).

4.3.4 Fish

A 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. In WY2017, 302 fish were collected (69.43 fish/unit effort), of three taxa: longfin dace (*Agosia chryogaster*), western mosquitofish (*Gambusia affinis*), and Gila topminnow (*Poeciliopsis occidentalis*).

The metric for longfin dace increased in WY2017 (42.76 fish/minute), as did the metric for the federally endangered Gila topminnow (25.97 fish/minute). The non-native western mosquitofish was also measured (0.69 fish/minute) (Figure 4-6). The continued presence of longfin dace and the increase in Gila topminnow are positive indicators of the animals' response to improved water quality and habitat features on this reach.

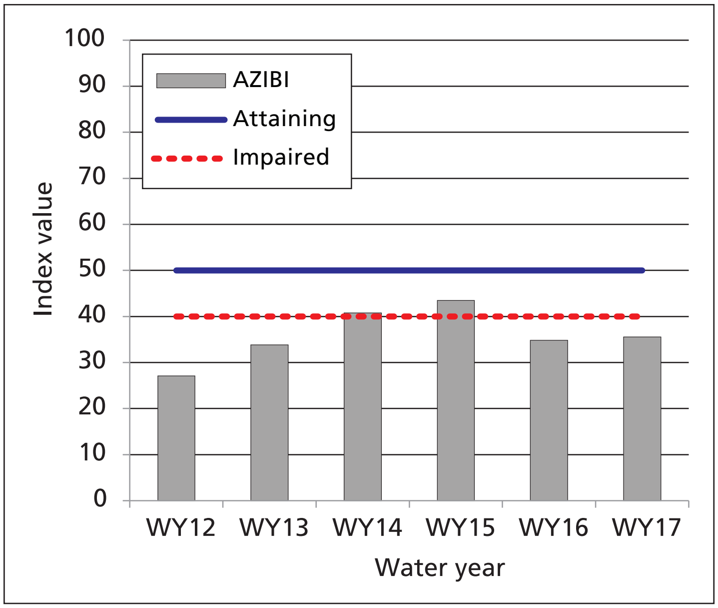

Figure 4-4. Arizona Index of Biological Integrity for the Santa Gertrudis sample reach at Tumacácori NHP, 2012–2017.

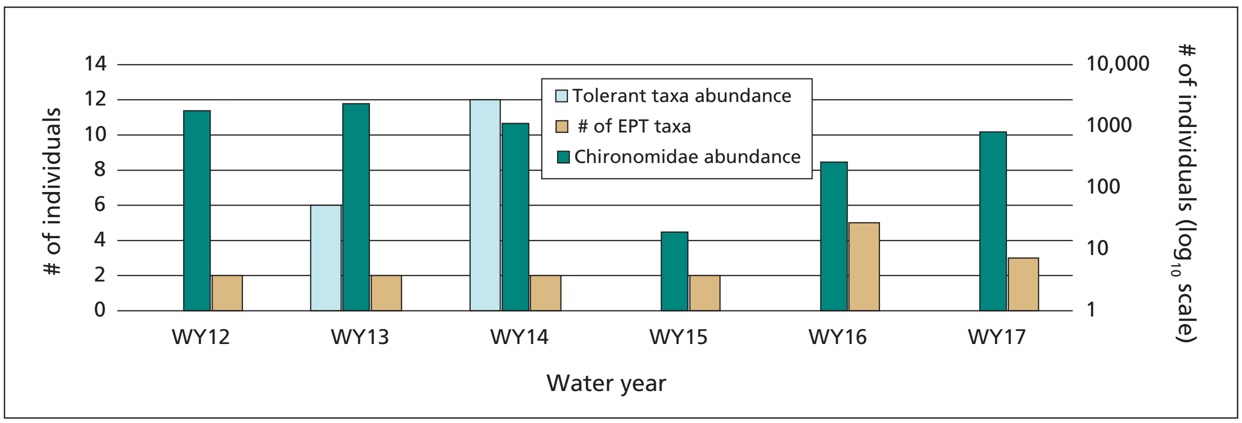

Figure 4-5. Selected macroinvertebrate metrics, WY2012–2017. Tolerant taxa=those commonly found in sites with poor water quality. # of EPT taxa=the number of taxa in the mayfly, caddisfly and stonefly orders (indicators of excellent water quality). Chironomidae abundance=the total number of individuals in the midge order counted during each sample.

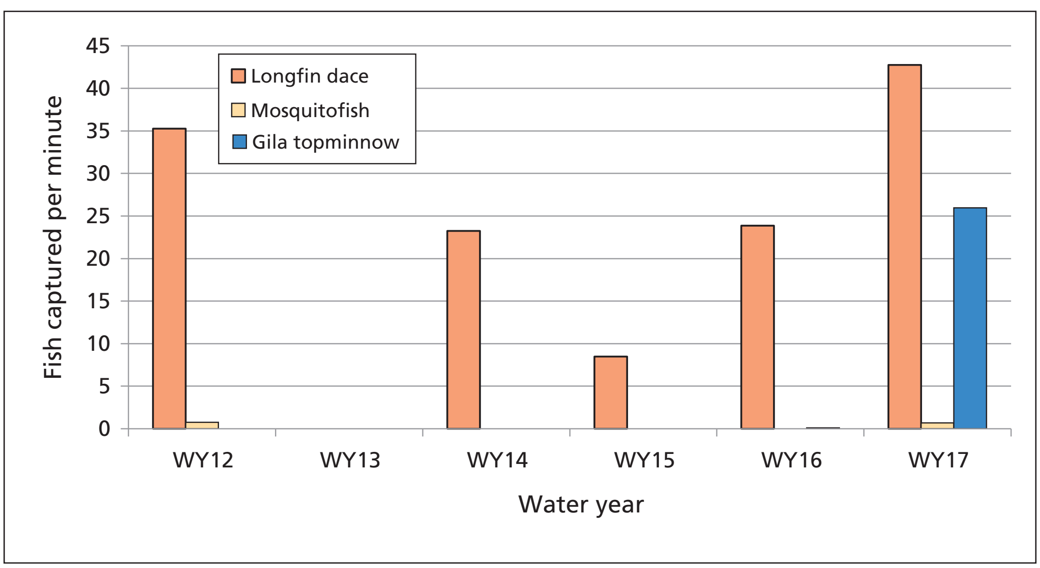

Figure 4-6. Fish per unit effort at Santa Gertrudis index reach, Tumacácori NHP, WY2012–2017.

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Appendix A. Taxa Collected from the Index Reach on the Santa Cruz River, Tumacácori NHP, WY2017

Phylum	Class	Order	Family	Genus	Species
Annelida	Clitellata	–	–	–	–
Arthropoda	Arachnida	Trombidiformes	Arrenuridae	Arrenurus	–
Arthropoda	Arachnida	Trombidiformes	Hydryphantidae	Protzia	–
Arthropoda	Arachnida	Trombidiformes	Hygrobatidae	–	–
Arthropoda	Arachnida	Trombidiformes	Lebertiidae	Lebertia	–
Arthropoda	Arachnida	Trombidiformes	Sperchonidae	Sperchon	–
Arthropoda	Arachnida	Trombidiformes	Sperchonidae	Sperchonopsis	–
Arthropoda	Arachnida	Trombidiformes	Sperchonidae		–
Arthropoda	Arachnida	Trombidiformes	Torrenticolidae	Testudacarus	–
Arthropoda	Arachnida	Trombidiformes	Torrenticolidae	Torrenticola	–
Arthropoda	Arachnida	Trombidiformes	–	–	–
Arthropoda	Entognatha	Collembola	–	–	–
Arthropoda	Insecta	Coleoptera	Curculionidae	–	–
Arthropoda	Insecta	Coleoptera	Dryopidae	Helichus	–
Arthropoda	Insecta	Coleoptera	Dryopidae	Postelichus	–
Arthropoda	Insecta	Coleoptera	Dytiscidae	Agabus	–
Arthropoda	Insecta	Coleoptera	Dytiscidae	Laccophilus	maculosus
Arthropoda	Insecta	Coleoptera	Dytiscidae	Stictotarsus	–
Arthropoda	Insecta	Coleoptera	Dytiscidae	–	–
Arthropoda	Insecta	Coleoptera	Elmidae	Cleptelmis	addenda
Arthropoda	Insecta	Coleoptera	Elmidae	Dubiraphia	–
Arthropoda	Insecta	Coleoptera	Elmidae	Heterelmis	–
Arthropoda	Insecta	Coleoptera	Elmidae	Microcylloepus	pusillus
Arthropoda	Insecta	Coleoptera	Elmidae	Microcylloepus	–
Arthropoda	Insecta	Coleoptera	Elmidae	Neocylloepus	–
Arthropoda	Insecta	Coleoptera	Elmidae	Optioservus	–
Arthropoda	Insecta	Coleoptera	Elmidae	Stenelmis	–
Arthropoda	Insecta	Coleoptera	Elmidae	–	–
Arthropoda	Insecta	Coleoptera	Elmidae	Neoelmis	caesa
Arthropoda	Insecta	Coleoptera	Gyrinidae	Dineutus	–
Arthropoda	Insecta	Coleoptera	Gyrinidae	Gyretes	–
Arthropoda	Insecta	Coleoptera	Gyrinidae	–	–
Arthropoda	Insecta	Coleoptera	Haliplidae	Peltodytes	–
Arthropoda	Insecta	Coleoptera	Hydraenidae	Gymnochthebius	–
Arthropoda	Insecta	Coleoptera	Hydraenidae	Ochthebius	–
Arthropoda	Insecta	Coleoptera	Hydrophilidae	Berosus	–
Arthropoda	Insecta	Coleoptera	Hydrophilidae	Helochares	–
Arthropoda	Insecta	Coleoptera	Hydrophilidae	Tropisternus	–
Arthropoda	Insecta	Coleoptera	Hydrophilidae	–	–
Arthropoda	Insecta	Coleoptera	Psephenidae	Eubrianax	edwardsii

Appendix A. Taxa Collected from the Index Reach on the Santa Cruz River, Tumacácori NHP, WY2017, cont.

Phylum	Class	Order	Family	Genus	Species
Arthropoda	Insecta	Coleoptera	Psephenidae	Psephenus	–
Arthropoda	Insecta	Diptera	Ceratopogonidae	Atrichopogon	–
Arthropoda	Insecta	Diptera	Ceratopogonidae	Bezzia	–
Arthropoda	Insecta	Diptera	Ceratopogonidae	Culicoides	–
Arthropoda	Insecta	Diptera	Ceratopogonidae	Dasyhelea	–
Arthropoda	Insecta	Diptera	Ceratopogonidae	Forcipomyia	–
Arthropoda	Insecta	Diptera	Ceratopogonidae	Probezzia	–
Arthropoda	Insecta	Diptera	Ceratopogonidae	–	–
Arthropoda	Insecta	Diptera	Chironomidae	Apedilum	–
Arthropoda	Insecta	Diptera	Chironomidae	Boreoheptagyia	–
Arthropoda	Insecta	Diptera	Chironomidae	Cladotanytarsus	–
Arthropoda	Insecta	Diptera	Chironomidae	Cricotopus	–
Arthropoda	Insecta	Diptera	Chironomidae	Dicrotendipes	–
Arthropoda	Insecta	Diptera	Chironomidae	Lopescladius	–
Arthropoda	Insecta	Diptera	Chironomidae	Micropsectra	–
Arthropoda	Insecta	Diptera	Chironomidae	Nanocladius	–
Arthropoda	Insecta	Diptera	Chironomidae	Orthocladius	–
Arthropoda	Insecta	Diptera	Chironomidae	Paracladopelma	–
Arthropoda	Insecta	Diptera	Chironomidae	Polypedilum	–
Arthropoda	Insecta	Diptera	Chironomidae	Pseudosmittia	–
Arthropoda	Insecta	Diptera	Chironomidae	Rheosmittia	–
Arthropoda	Insecta	Diptera	Chironomidae	Rheotanytarsus	–
Arthropoda	Insecta	Diptera	Chironomidae	Robackia	demeijerei
Arthropoda	Insecta	Diptera	Chironomidae	Saetheria	tylus
Arthropoda	Insecta	Diptera	Chironomidae	Saetheria	–
Arthropoda	Insecta	Diptera	Chironomidae	Thienemanniella	–
Arthropoda	Insecta	Diptera	Chironomidae	Thienemanni-myia group	–
Arthropoda	Insecta	Diptera	Chironomidae	–	–
Arthropoda	Insecta	Diptera	Culicidae	Anopheles	–
Arthropoda	Insecta	Diptera	Dixidae	Dixa	–
Arthropoda	Insecta	Diptera	Dixidae	Dixella	–
Arthropoda	Insecta	Diptera	Dixidae	–	–
Arthropoda	Insecta	Diptera	Dolichopodidae	–	–
Arthropoda	Insecta	Diptera	Empididae	Chelifera	–
Arthropoda	Insecta	Diptera	Empididae	Hemerodromia	–
Arthropoda	Insecta	Diptera	Empididae	Neoplasta	–
Arthropoda	Insecta	Diptera	Empididae	Wiedemannia	–
Arthropoda	Insecta	Diptera	Empididae	–	–
Arthropoda	Insecta	Diptera	Ephydridae	Ephydra	–
Arthropoda	Insecta	Diptera	Ephydridae	–	–

Appendix A. Taxa Collected from the Index Reach on the Santa Cruz River, Tumacácori NHP, WY2017, cont.

Phylum	Class	Order	Family	Genus	Species
Arthropoda	Insecta	Diptera	Muscidae	–	–
Arthropoda	Insecta	Diptera	Psychodidae	Maruina	–
Arthropoda	Insecta	Diptera	Psychodidae	Pericoma	–
Arthropoda	Insecta	Diptera	Psychodidae	–	–
Arthropoda	Insecta	Diptera	Sciomyzidae	–	–
Arthropoda	Insecta	Diptera	Simuliidae	Simulium	–
Arthropoda	Insecta	Diptera	Simuliidae	–	–
Arthropoda	Insecta	Diptera	Stratiomyidae	Caloparyphus	–
Arthropoda	Insecta	Diptera	Stratiomyidae	Euparyphus	–
Arthropoda	Insecta	Diptera	Stratiomyidae	–	–
Arthropoda	Insecta	Diptera	Stratiomyidae	Allognosta	–
Arthropoda	Insecta	Diptera	Stratiomyidae	Stratiomys	–
Arthropoda	Insecta	Diptera	Tabanidae	Tabanus	–
Arthropoda	Insecta	Diptera	Tabanidae	–	–
Arthropoda	Insecta	Diptera	Tipulidae	Limnophila	–
Arthropoda	Insecta	Diptera	Tipulidae	Limonia	–
Arthropoda	Insecta	Diptera	Tipulidae	Tipula	–
Arthropoda	Insecta	Diptera	Tipulidae	–	–
Arthropoda	Insecta	Diptera	–	–	–
Arthropoda	Insecta	Ephemeroptera	Baetidae	Acentrella	–
Arthropoda	Insecta	Ephemeroptera	Baetidae	Baetis	–
Arthropoda	Insecta	Ephemeroptera	Baetidae	Baetodes	–
Arthropoda	Insecta	Ephemeroptera	Baetidae	Callibaetis	–
Arthropoda	Insecta	Ephemeroptera	Baetidae	Camelobaetidius	–
Arthropoda	Insecta	Ephemeroptera	Baetidae	Centroptilum	–
Arthropoda	Insecta	Ephemeroptera	Baetidae	Fallceon	quilleri
Arthropoda	Insecta	Ephemeroptera	Baetidae	Fallceon	–
Arthropoda	Insecta	Ephemeroptera	Baetidae	Paracloeodes	minutus
Arthropoda	Insecta	Ephemeroptera	Baetidae	Pseudocloeon	–
Arthropoda	Insecta	Ephemeroptera	Baetidae	–	–
Arthropoda	Insecta	Ephemeroptera	Caenidae	Caenis	–
Arthropoda	Insecta	Ephemeroptera	Ephemerellidae	Serratella	–
Arthropoda	Insecta	Ephemeroptera	Heptageniidae	Epeorus	–
Arthropoda	Insecta	Ephemeroptera	Heptageniidae	Heptagenia	–
Arthropoda	Insecta	Ephemeroptera	Heptageniidae	–	–
Arthropoda	Insecta	Ephemeroptera	Isonychiidae	Isonychia	–
Arthropoda	Insecta	Ephemeroptera	Leptohyphidae	Homoleptohy-phes	–
Arthropoda	Insecta	Ephemeroptera	Leptohyphidae	Leptohyphes	–
Arthropoda	Insecta	Ephemeroptera	Leptohyphidae	Tricorythodes	–
Arthropoda	Insecta	Ephemeroptera	Leptohyphidae	–	–

Appendix A. Taxa Collected from the Index Reach on the Santa Cruz River, Tumacácori NHP, WY2017, cont.

Phylum	Class	Order	Family	Genus	Species
Arthropoda	Insecta	Ephemeroptera	Leptophlebiidae	Traverella	albertana
Arthropoda	Insecta	Ephemeroptera	Leptophlebiidae	–	–
Arthropoda	Insecta	Ephemeroptera	–	–	–
Arthropoda	Insecta	Hemiptera	Belostomatidae	–	–
Arthropoda	Insecta	Hemiptera	Corixidae	Trichocorixa	–
Arthropoda	Insecta	Hemiptera	Corixidae	–	–
Arthropoda	Insecta	Hemiptera	Gerridae	–	–
Arthropoda	Insecta	Hemiptera	Naucoridae	Ambrysus	–
Arthropoda	Insecta	Hemiptera	Naucoridae	–	–
Arthropoda	Insecta	Hemiptera	Notonectidae	–	–
Arthropoda	Insecta	Hemiptera	Veliidae	Microvelia	–
Arthropoda	Insecta	Hemiptera	Veliidae	Rhagovelia	–
Arthropoda	Insecta	Hemiptera	Veliidae	–	–
Arthropoda	Insecta	Lepidoptera	Crambidae	Petrophila	–
Arthropoda	Insecta	Lepidoptera	Noctuidae	–	–
Arthropoda	Insecta	Megaloptera	Corydalidae	Corydalus	cornutus
Arthropoda	Insecta	Odonata	Calopterygidae	Hetaerina	americana
Arthropoda	Insecta	Odonata	Calopterygidae	Hetaerina	–
Arthropoda	Insecta	Odonata	Calopterygidae	–	–
Arthropoda	Insecta	Odonata	Coenagrionidae	Argia	–
Arthropoda	Insecta	Odonata	Coenagrionidae	Enallagma	–
Arthropoda	Insecta	Odonata	Coenagrionidae	–	–
Arthropoda	Insecta	Odonata	Gomphidae	Erpetogomphus	–
Arthropoda	Insecta	Odonata	Gomphidae	Erpetogomphus	lampro-peltis
Arthropoda	Insecta	Odonata	Gomphidae	Progomphus	borealis
Arthropoda	Insecta	Odonata	Gomphidae	Progomphus	–
Arthropoda	Insecta	Odonata	Gomphidae	–	–
Arthropoda	Insecta	Odonata	Lestidae	Archilestes	–
Arthropoda	Insecta	Odonata	Libellulidae	Brechmorhoga	mendax
Arthropoda	Insecta	Odonata	Libellulidae	Brechmorhoga	–
Arthropoda	Insecta	Odonata	Libellulidae	–	–
Arthropoda	Insecta	Odonata	Libellulidae	Paltothemis	lineatipes
Arthropoda	Insecta	Plecoptera	Perlodidae	Isoperla	–
Arthropoda	Insecta	Plecoptera	–	–	–
Arthropoda	Insecta	Trichoptera	Brachycentridae	Micrasema	–
Arthropoda	Insecta	Trichoptera	Calamoceratidae	Phylloicus	aeneus
Arthropoda	Insecta	Trichoptera	Glossosomatidae	–	–
Arthropoda	Insecta	Trichoptera	Helicopsychidae	Helicopsyche	–
Arthropoda	Insecta	Trichoptera	Hydropsychidae	Cheumatopsyche	–
Arthropoda	Insecta	Trichoptera	Hydropsychidae	Hydropsyche	–

Appendix A. Taxa Collected from the Index Reach on the Santa Cruz River, Tumacácori NHP, WY2017, cont.

Phylum	Class	Order	Family	Genus	Species
Arthropoda	Insecta	Trichoptera	Hydropsychidae	Smicridea	–
Arthropoda	Insecta	Trichoptera	Hydropsychidae	–	–
Arthropoda	Insecta	Trichoptera	Hydroptilidae	Hydroptila	–
Arthropoda	Insecta	Trichoptera	Hydroptilidae	Leucotrichia	–
Arthropoda	Insecta	Trichoptera	Hydroptilidae	Ochrotrichia	–
Arthropoda	Insecta	Trichoptera	Hydroptilidae	Oxyethira	–
Arthropoda	Insecta	Trichoptera	Hydroptilidae	–	–
Arthropoda	Insecta	Trichoptera	Hydroptilidae	Mayatrichia	–
Arthropoda	Insecta	Trichoptera	Leptoceridae	Nectopsyche	–
Arthropoda	Insecta	Trichoptera	Leptoceridae	Oecetis	–
Arthropoda	Insecta	Trichoptera	Leptoceridae	–	–
Arthropoda	Insecta	Trichoptera	Philopotamidae	Chimarra	–
Arthropoda	Insecta	Trichoptera	Philopotamidae	–	–
Arthropoda	Insecta	Trichoptera	Polycentropodidae	Polycentropus	–
Arthropoda	Insecta	Trichoptera	Polycentropodidae	–	–
Arthropoda	Insecta	Trichoptera	Rhyacophilidae	Rhyacophila	brunnea/ vemna group
Arthropoda	Insecta	Trichoptera	–	–	–
Arthropoda	Malacostraca	Amphipoda	Gammaridae	Gammarus	–
Arthropoda	Malacostraca	Amphipoda	Hyalellidae	Hyalella	–
Arthropoda	Malacostraca	Amphipoda	–	–	–
Arthropoda	Malacostraca	Decapoda	Cambaridae	–	–
Arthropoda	Malacostraca	Decapoda	–	–	–
Chordata	Actinopterygii	–	–	–	–
Chordata	Amphibia	Anura	–	–	–
Mollusca	Bivalvia	Veneroida	Corbiculidae	Corbicula	fluminea
Mollusca	Bivalvia	Veneroida	Corbiculidae	Corbicula	–
Mollusca	Bivalvia	Veneroida	Pisidiidae	Pisidium	–
Mollusca	Bivalvia	Veneroida	Pisidiidae	Sphaerium	–
Mollusca	Bivalvia	Veneroida	Pisidiidae	–	–
Mollusca	Bivalvia	–	–	–	–
Mollusca	Gastropoda	Basommatophora	Ancylidae	Ferrissia	rivularis
Mollusca	Gastropoda	Basommatophora	Lymnaeidae	Lymnaea	–
Mollusca	Gastropoda	Basommatophora	Physidae	Physa	–
Mollusca	Gastropoda	Basommatophora	Planorbidae	Gyraulus	–
Mollusca	Gastropoda	Basommatophora	Planorbidae	–	–
Mollusca	Gastropoda	–	–	–	–
Nemata	–	–	–	–	–
Platyhelminthes	Turbellaria	–	–	–	–

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