National Park Service
U.S. Department of the Interior

Natural Resource Stewardship and Science

Status of Climate and Water Resources at Tumacácori National Historical Park

Water Year 2016

Natural Resource Report NPS/SODN/NRR—2017/1552

ON THE COVER

Discharge sampling along the Santa Cruz River, Tumacácori National Historical Park. NPS photo.

Status of Climate and Water Resources at Tumacácori National Historical Park

Water Year 2016

Natural Resource Report NPS/SODN/NRR—2017/1552

Prepared by
Evan L. Gwilliam
Laura Palacios
Sonoran Desert Network
National Park Service
12661 E. Broadway Blvd.
Tucson, AZ 85748

Kara Raymond
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

November 2017

U.S. Department of the Interior
National Park Service
Natural Resource Stewardship and Science
Fort Collins, Colorado

The National Park Service, Natural Resource Stewardship and Science office in Fort Collins, Colorado, publishes a range of reports that address natural resource topics. These reports are of interest and applicability to a broad audience in the National Park Service and others in natural resource management, including scientists, conservation and environmental constituencies, and the public.

The Natural Resource Report Series is used to disseminate comprehensive information and analysis about natural resources and related topics concerning lands managed by the National Park Service. The series supports the advancement of science, informed decision-making, and the achievement of the National Park Service mission. The series also provides a forum for presenting more lengthy results that may not be accepted by publications with page limitations.

All manuscripts in the series receive the appropriate level of peer review to ensure that the information is scientifically credible, technically accurate, appropriately written for the intended audience, and designed and published in a professional manner. This report received informal peer review by subject-matter experts who were not directly involved in the collection, analysis, or reporting of the data.

This report is available from the Sonoran Desert Network website, as well as at the Natural Resource Publications Management website. To receive this report in a format optimized for screen readers, please e-mail irma@nps.gov.

Please cite this publication as:

Gwilliam, E. L., L. Palacios, and K. Raymond. 2017. Status of climate and water resources at Tumacácori National Historical Park: Water year 2016. Natural Resource Report NPS/SODN/NRR—2017/1552. National Park Service, Fort Collins, Colorado.

NPS 311/140603, November 2017

Contents

Figures

Tables

Executive Summary

Climate and hydrology 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 to provide an integrated look at climate and water conditions during water year (WY) 2016. Overall annual precipitation was 108% of normal for the park. Overall precipitation was slightly below normal for the fall and winter, while the warm season was wetter than normal. Precipitation in September was 278% of normal, resulting in an extended monsoon season for the second year in a row. The reconnaissance drought index reflected the extended regional drought since 2000, but the five-year running mean of total annual precipitation suggested that the last three years have remedied the multi-year precipitation deficit. Extremely cold days occurred more often than normal in WY2016, and were of a slightly greater duration. The number of days with extreme precipitation events was approximately normal. Streamflow on the Santa Cruz River through the park was generally at or slightly below average in WY2016. Peak flow occurred on August 9. Water samples were collected from the Santa Cruz River at the Santa Gertrudis index site. Of 92 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). In WY2016, two taxa of fish were collected during collaborative sampling at the Santa Gertrudis index reach: longfin dace (*Agosia chryogaster*) and Gila topminnow (*Poeciliopsis occidentalis*). This was the first documentation of the federally endangered Gila topminnow in the index reach since 2002.

Acknowledgements

We thank Chief of Resource Management Adam Springer, Superintendent Bob Love, and the staff of Tumacácori National Historical Park for their onsite support of the monitoring effort. 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.

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 2016 (October 2015–September 2016). 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

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 National Historical Park 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 (Figure 2-1) 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 2-2). Used globally to classify 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.

Terms

Climate: meteorological conditions, such as temperature, humidity, atmospheric pressure, wind, and precipitation, that prevail in a region over long periods of time (seasons to years).

Weather: the present conditions of the atmosphere at a given time and place (minutes to days).

Potential evapotranspiration: the amount of water that would be lost to the atmosphere through evaporation and plant transpiration if water was unlimited.

Drought: a recurring, natural phenomenon associated with a deficit availability of water resources over a large geographic area and extending along a substantial period of time.

Figure 2-1. The Davis real-time weather station at Tumacácori NHP. Data are available through www.climateanalyzer.org.

2.2 Results and discussion

Data quality for the COOP station at Tumacácori NHP in water year (WY) 2016 was fair. Only two days were missing precipitation data, but 47 days were missing temperature data, primarily in August and September.

2.2.1 Departures from 30-year normals)

Overall annual precipitation was 108% of normal (1981–2010) for Tumacácori NHP (17.97" vs. 16.56").

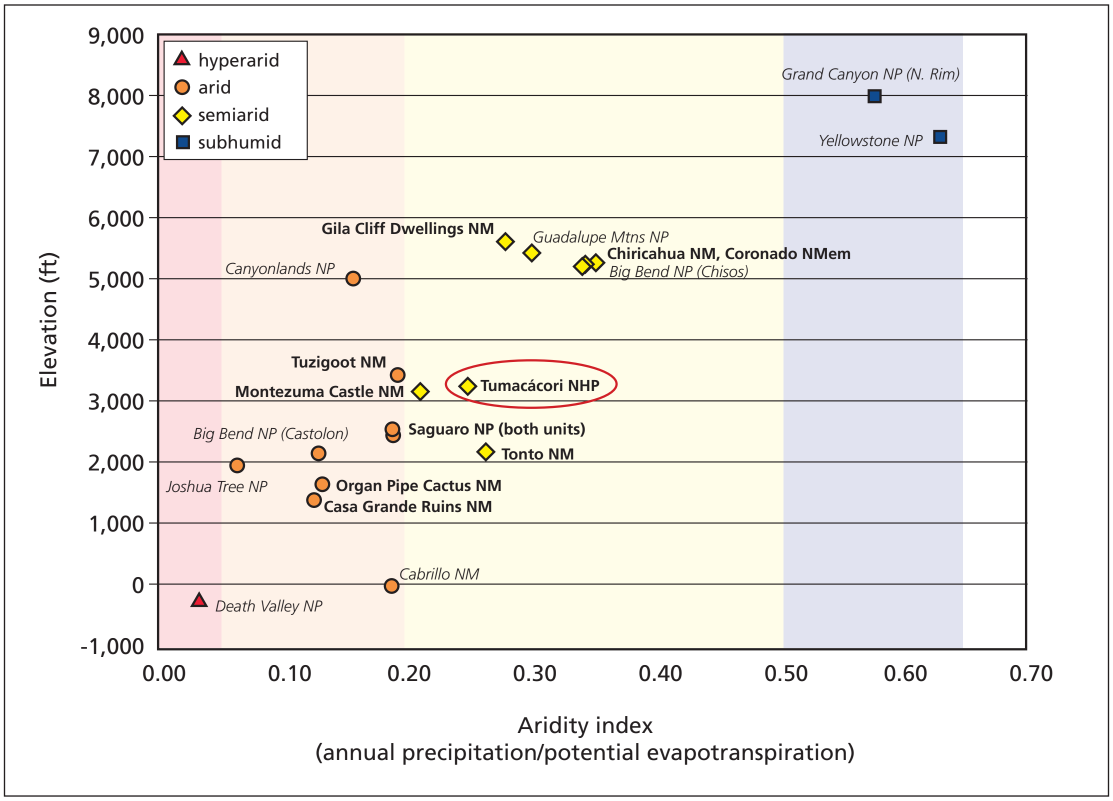

Figure 2-2. Aridity index vs. elevation of selected southwestern national parks, including Tumacácori NHP. Figure from Hubbard and others (in prep).

2.2.1.1 Cool season (October–March)

Overall precipitation was slightly below normal (87%, or -0.83") for the fall and winter of WY2016, with 0.51" of rain or less in November, December, February, and March (Figures 2-3 and 2-4). Maximum and minimum air temperatures were generally cooler than normal, except for a warm period in February and March (Figure 2-3).

2.2.1.2 Warm season (April–September)

Minimum and maximum air temperatures in April and May were 1–3°F cooler than normal, while June and July were 1–4°F warmer than normal. The warm season was wetter than normal (122%, +2.24"). Precipitation in September, a month when the monsoon season is normally on the decline, was 278% of normal, resulting in an extended monsoon season for the second year in a row.

2.2.2 Reconnaissance Drought Index

Reconnaissance Drought Index (RDI; Tsakiris and Vengelis 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). RDI for Tumacácori NHP reflected the extended regional drought since 2000 (Figure 2-5). The COOP station was insufficient to generate the RDI for WY2016. However, the Davis station RDI for WY2016 was -0.05, indicating a slightly dry year. The five-year running mean of total annual precipitation (water year) was equivalent to the long-term precipitation average from 1981 to 2016 (Figure 2-6), suggesting that the last three years have remedied the multi-year precipitation deficit.

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

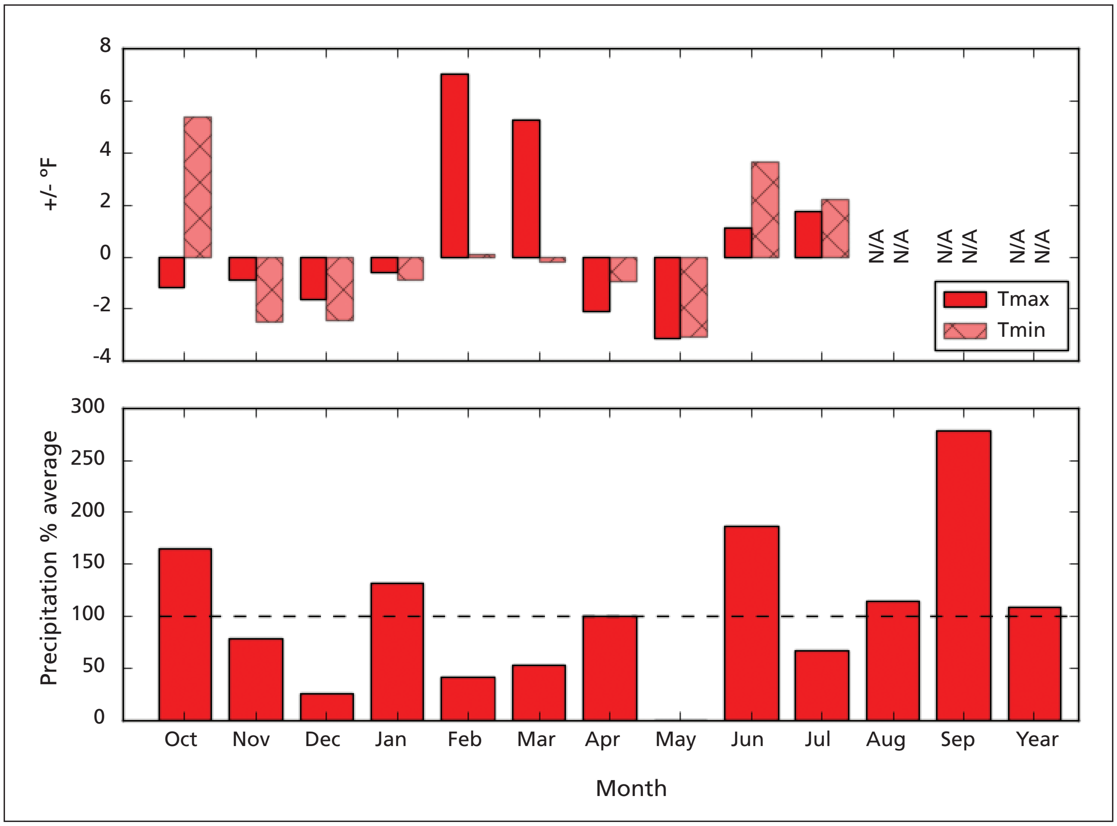

Figure 2-3. Departures from 30-year normal (1981–2010) -minimum and maximum air temperature and precipitation, Tumacácori NHP, WY2016. N/A = insufficient data to generate reliable averages. Graphics generated by climateanalyzer.org.

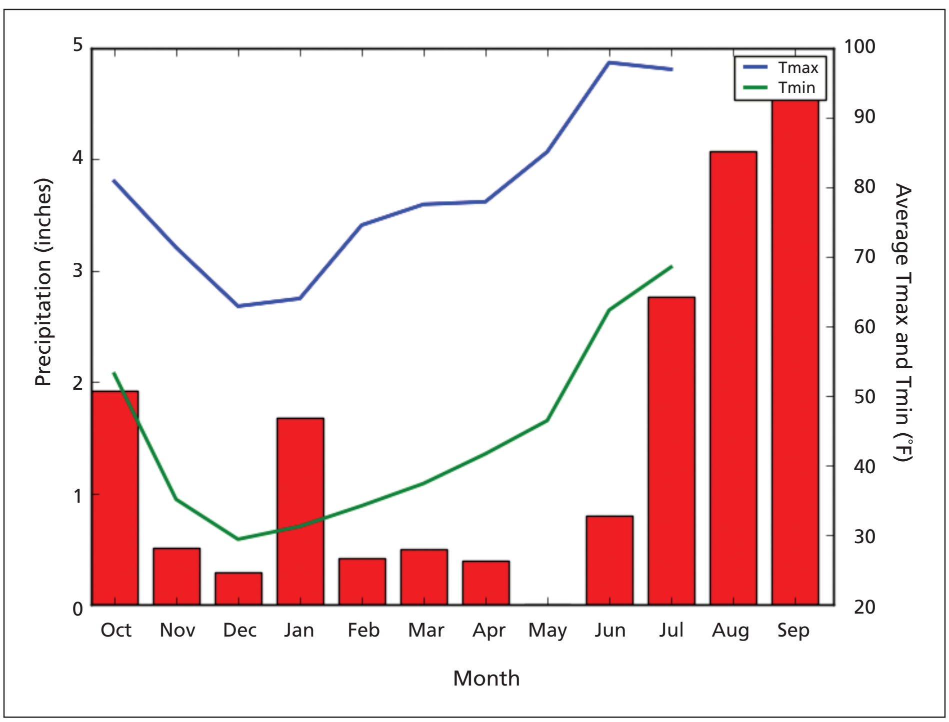

Figure 2-4. Average monthly maximum and minimum temperatures and monthly precipitation totals for Tumacácori NHP, WY2016. Graphics generated by climateanalyzer.org.

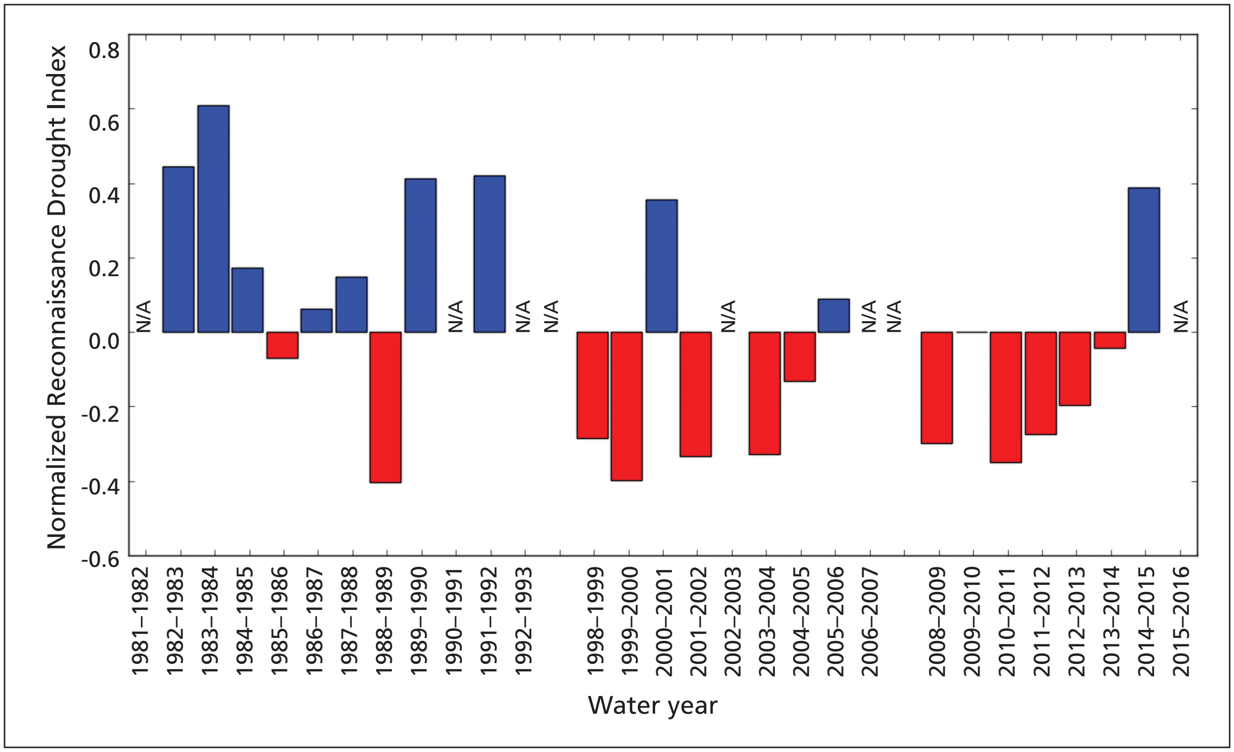

Figure 2-5. Reconnaissance Drought Index (RDI) for Tumacácori NHP, water years 1981–2016. N/A = insufficient data to generate reliable RDI estimates. The station had an extended period without data collection from 1992 to 1997. Drought index calculations are relative to the time period selected. Choosing a different set of start/end points may produce different results.Graphics generated by climateanalyzer.org.

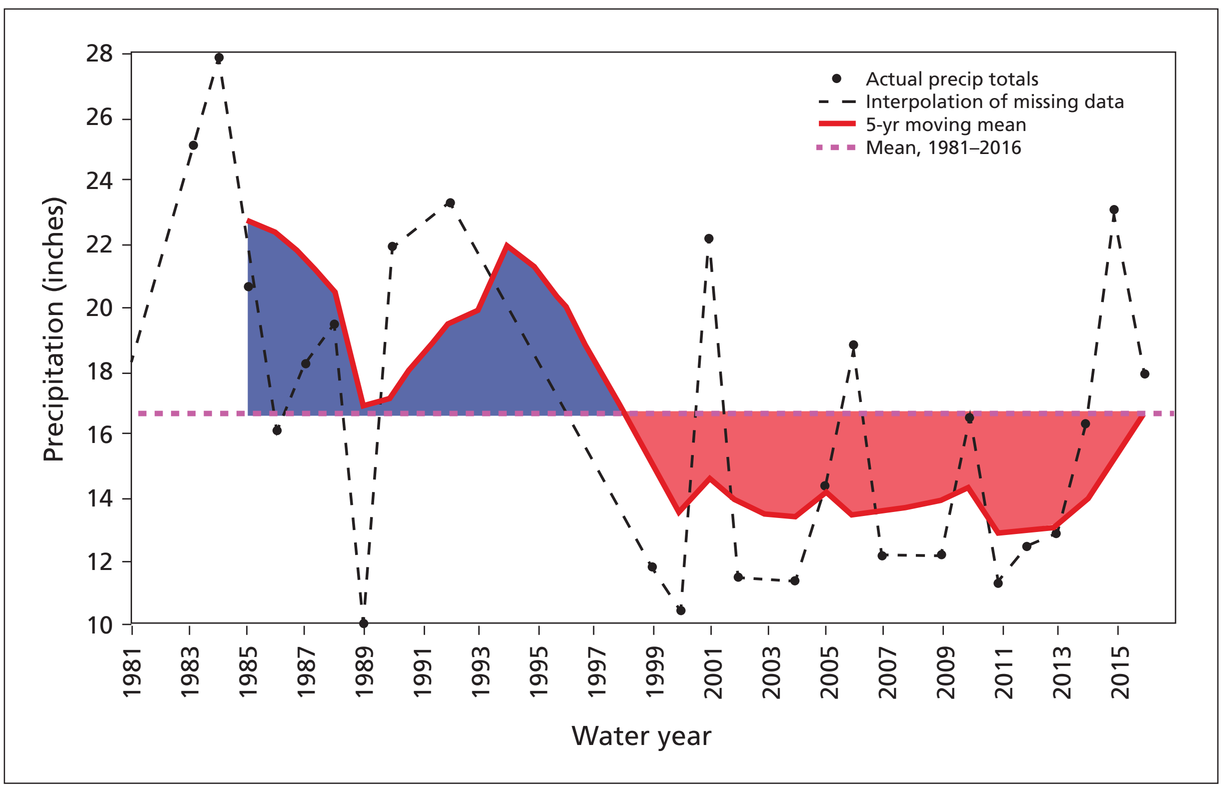

Figure 2-6. Five-year moving mean of annual precipitation, Tumacácori NHP, water years 1981–2016. The moving mean (solid red line) is based on a timeseries with 27.8% (10 of 36) missing values, and includes the current year and previous four years. Missing years are linearly interpolated (dashed gray lines). Graphics generated by climateanalyzer.org.

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 about 80% more often than normal (24 days vs. 13.3 ± 2.3 days) in WY2016, and were of a slightly greater duration (2.66 consecutive days vs. 2.1 ± 0.2 days).

The number of days with extreme precipitation events (>1") in WY2016 was approximately normal (4 vs. 3.23 days for 1981–2010) normal (3.23 days), with large events on August 1 (1.18"), August 9 (1.73"), September 1 (1.69"), and September 7 (2.88"). The rain event on September 7 was close to the 24-hour 10-year reoccurrence interval (2.91").

3 Surface Water

3.1 Background

Historically, the Santa Cruz River has been an intermittent stream (Norman et al. 2013). Today, however, the river as it flows through 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 about 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. In addition, 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).

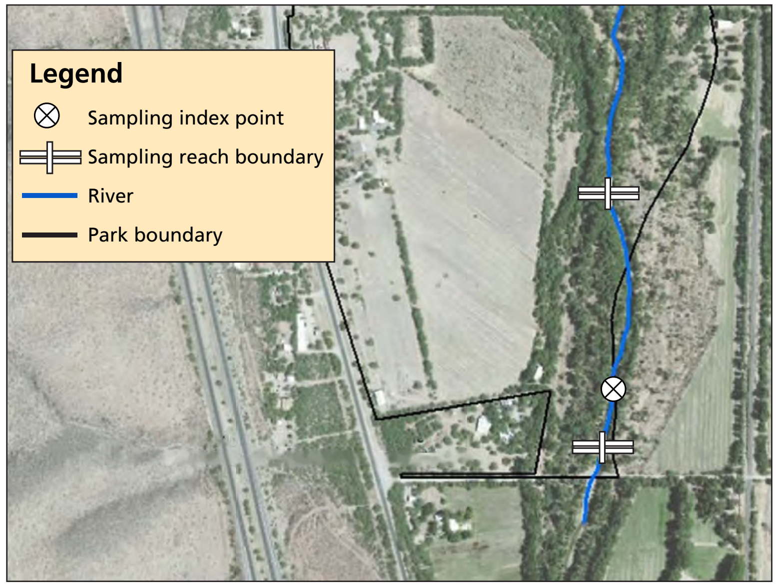

Figure 3-1. Map of the Santa Cruz River, Tumacácori NHP, with the Sonoran Desert Network water quality sampling locations.

3.2 Methods

Water quality monitoring occurred ~150 m downstream from the southern boundary of the park (Figure 3-1), at the Santa Gertrudis index site. This location 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 Sonoran Desert Network (SODN) staff at Tumacácori NHP during WY2016 is presented below. Detailed descriptions of these procedures will be available in the SODN water quality monitoring protocol (Gwilliam et al. in prep).

3.2.1 Water quantity

Streamflow data for this report were recorded at U.S. Geological Survey (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.

3.2.2 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 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).

3.2.3 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.

3.2.4 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 from April to 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.

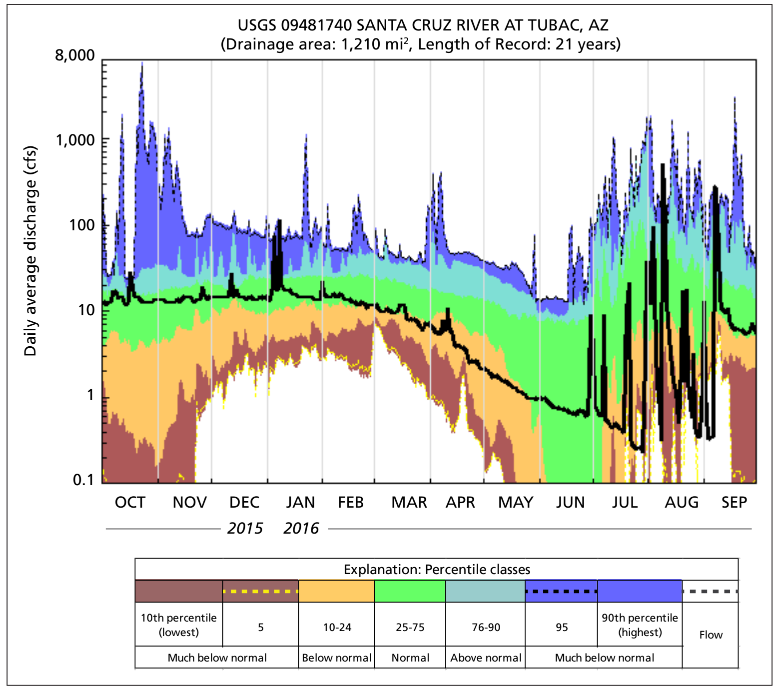

Figure 3-2. Hydrograph from USGS gauge 09481740, near Tubac, Arizona, WY2016.

3.2.5 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, 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.

3.2.6 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.

3.3 Results and discussion

3.3.1 Water quantity

USGS stream gauge 09481740, at Tubac, Arizona, was used as a proxy for stream discharge dynamics at the Santa Gertrudis index site at Tumacácori NHP (Gwilliam et al. 2016). The WY2016 annual summary for the USGS Tubac gauge provided data used in this report (USGS 2016).

Flow during WY2016 was generally at or slightly below average. Average annual flow was calculated to be 12.7 cubic feet per second (cfs), approximately half of the 21-year gauge mean of 25.5 cfs (StdErr +/- 5.6). Flow in fall, winter, and spring fell within the normal zone, briefly falling below normal during the late spring and early summer, then becoming variable as the stream reacted to monsoon precipitation (Figure 3-2). Peak flow during WY2016 occurred on August 9, during the monsoon, with a peak mean daily flow value of 520 cfs and a peak instantaneous flow of 1,170 cfs.

3.3.2 Water quality

In WY2016, 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 in each quarter (Table 3-1). After the sonde mount was damaged by flow events in late WY2015, sampling in Q1 and Q2 of WY2016 was precluded as a secondary sampling site was being established.

3.3.2.1 Core parameters

Discrete sampling—. Of 236 individual analyses of water samples collected from the Santa Cruz River at the Santa Gertrudis index site in WY2016, 92 were associated with Arizona surface-water criteria. Of those 92 samples, there was one exceedance (for *E.*

Table 3-1. Dates of discrete and continuous sampling, Santa Gertrudis index site, Tumacácori NHP, WY2016.

Quarter	Sampling date		Continuous samples collected	Discharge (cfs)
	Discrete	Continuous		
Q1	11/18/2015	Probe not deployed	0	11.6
Q2	02/09/16	Probe not deployed	0	12.5
Q3	05/17/2016	4/26/2016 –5/18/2016	3,291	3.6
Q4	08/22/16	8/22/2016–10/06/2016*	5,325**	10.53

*The retrieval of the sonde during Q4 was delayed because the instrument was buried by sediment in a flow event on 9/7/2016. The sonde was not located until 10/06/2016.

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

coli); that is, 99% of samples were compliant with state standards. The discrete measurements shown in Table 3-2, collected in the field, represent conditions at the Tumacácori NHP index site during site visits in WY2016. 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 to collect data on temperature, pH, specific conductivity, and dissolved oxygen at 15-minute intervals (Figure 3-3). During WY2016, more than 7,000 measurements were collected. No data were collected during Q1 and Q2 due to damage to the sonde mount, a gain in sediment elevation at the mount, and a change in the active river channel. These changes were due to a flow event in late September 2015 (Gwilliam et al. 2016).

To collect data during the second half of the year, a secondary sampling site was established at the Santa Gertrudis index site, attached to a cinderblock stabilized by three-quarter-inch rebar driven into the sediment. There were multiple flow events during the deployments in Q3 and Q4, finally resulting in the sonde being buried and lost for over a month. It was eventually retrieved in late October 2016.

The data from the WY2016 deployments were frequently being outside QA/QC limits, and heavily censored. The continuous data fromWY2016 are considered conditional and may not be used in future trend analyses.

The results from WY2016 were generally within what would be expected (Gwilliam et al. 2016), with several considerations.

Table 3-2. Discrete data summary, Santa Gertrudis index site, Tumacácori NHP, WY2016.

Parameter	Quarter				Arizona state standard measure
	Q1	Q2	Q3	Q4	
Temperature (°C)	13.1	12.6	19.4	24.5	NS[1]
Specific conductivity (µS/cm)	737	741	769	565	NS
pH	7.7	7.5	8.02	7.75	6.5–9.0
Oxygen concentration (mg/L)	8.77	8.06	10.24	5.92	>3*
Turbidity (NTU)	2.74	3.74	2.09	40.2	NS

NS = no standard.

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

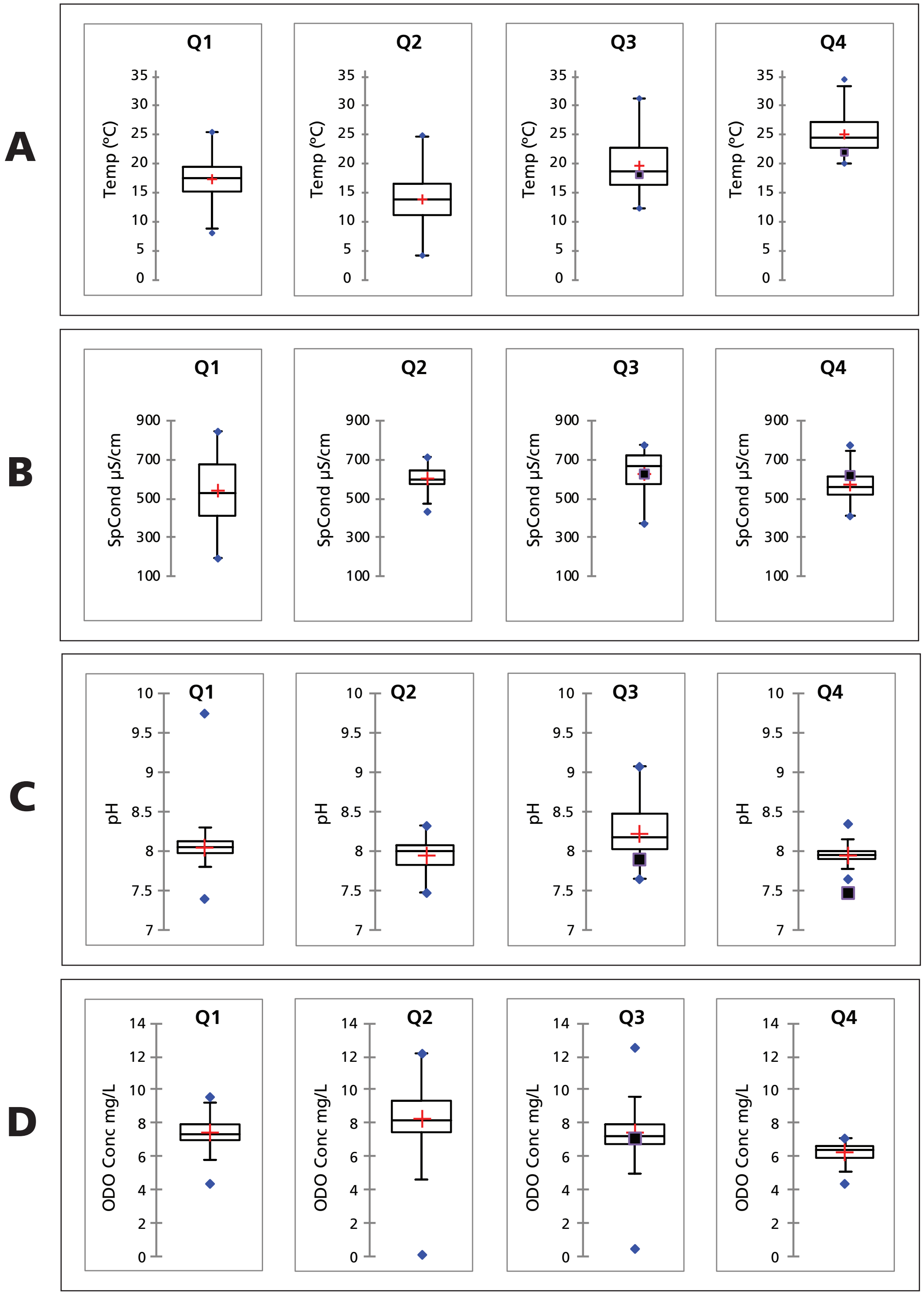

Figure 3-3. Data on (A) water temperature, (B) specific conductivity, (C) pH, and (D) dissolved oxygen concentration, from the Santa Cruz River, Santa Gertrudis index site, Tumacácori NHP, WY2016. The Q1 and Q2 samples present data for WY2011–2015. This figure summarizes the seasonal variability in water temperature, pH, specific conductivity, and dissolved oxygen. These figures include box-and-whisker plots displaying data from WY2011 to WY2015, and boxes indicating median values for WY2016. The blue dots indicate maximum and minimum. The whiskers indicate limits, and the box indicates the bounds of the first and third quartiles. The line in the box indicates the median, while the red cross is the mean. The solid black block marks the median value from WY2016 sampling.

- The median temperature value from the WY2016 Q4 deployment (see Figure 3-3) fell in the bottom 25th percentile of the record for the Santa Gertrudis site. This decrease in water temperature corresponded to a period of unusually cool air temperatures.
- During the Q4 deployment, there were several flow events associated with monsoon rains. These events ranged from 50 to 200 cfs, resulting in variable values for the parameters and a low median value for pH during this deployment. SODN QA/QC rated these pH values as poor, and they likely will not be considered for trend analysis.

3.3.2.2 Nutrient dynamics

Nutrient samples were collected during each sample period during WY2016. Only parameters with results are reported (Table 3-3). It should be noted that parameters not reported were not necessarily zero; they may have been present at values below the detection limit of the analytical equipment, in very low concentrations.

Nutrients sampled during WY2016 continued to be low due to upgrades at the NIWTP (Norman et al. 2013). Instrumentation at the analytical laboratory SODN used for nutrient analysis was upgraded in WY2015, allowing for the detection of nitrogen reliably down to 0.10 mg/L. Nutrient concentrations were similar to slightly lower than those observed in previous years (Gwilliam et al. 2014).

3.3.2.3 Biological condition

SODN's 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 (Table 3-4). 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.

E. coli results exceeded the state partial body contact standard during Q4 of WY2016 (see Table 3-4). It is likely that the *E. coli* estimates exceeded the state standards on more than this occasion, especially during and after precipitation events. However, when selecting sample dates, SODN avoids sampling during elevated flow events or just after precipitation events.

Table 3-3. Results of nutrient analysis, Santa Gertrudis index site, Tumacácori NHP, WY2016.

Analyte	mg/L				Method	Arizona state standard	
	Q1	Q2	Q3	Q4		Measure (mg/L)	Beneficial use
Ammonia	0.13	0.41	<DL	<DL	EPA 350.1	3.52	Aquatic and wildlife (effluent-dependent)[1,2]
Nitrate – Dissolved	5.9	3.6	3.3	3.2	EPA 300.0	3,730	Partial body contact
Nitrate + Nitrite	6.3	4.2	3.4	3.1	EPA 353.2	NS	
Total Nitrogen	6.3	4.2	3.4	3.1	Calculated	NS	

[1] Chronic standard; [2]Calculated value using temperature and pH

<DL=result was below the detection limit of the analytical equipment. NS = no standard. Methods are from USEPA (1983).

Table 3-4. Results of biological condition sampling, Santa Gertrudis index site, Tumacácori NHP, WY2016.

Analyte	mg/L				Method	Arizona state standard	
	Q1	Q2	Q3	Q4		Measure	Beneficial use
Total organic carbon	NC	NC	NC	3	SM 5130B	NS	
E. coli (MPN)	41.1	21.5	141	**>2,419.3**	SM 9223B	235–575 MPN/100 mL	Full/partial body contact

NC = not collected; NS = no standard; SM = standard method (Eaton et al. 2005).
Exceedances are indicated in bolded red.

Past sampling at the Santa Gertrudis index site and other local sites have detected concentration estimates for *E. coli* that exceeded state standards (Gwillliam et al. 2014; Sanders et al. 2013). Staff should exercise caution if body contact with water from the Santa Cruz River is expected, especially close to precipitation events.

3.3.2.4 Metal and metalloids

Only parameters with results are reported (Tables 3-5 and 3-6). It should be noted that parameters not reported were not necessarily zero; they may have been present at values below the detection limit of the analytical equipment, in very low concentrations. During WY2016, there were no exceedances of state or federal water quality standards from samples collected at the Santa Gertrudis index site. Concentrations were generally similar to those observed in previous years (Gwilliam et al. 2014; Gwilliam et al. 2016).

3.3.2.5 Suspended and total sediment

During WY2016, 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). Only parameters with results are reported (Table 3-7). It should be noted that parameters not reported were not necessarily zero; they may have been present at values below the detection limit of the analytical equipment, in very low concentrations.

3.3.2.6 General water quality & inorganics

During WY2016, samples for general water quality and inorganics were analyzed and results were in the range detected in previous years (Gwilliam et al. 2014; Gwilliam et al. 2016). Only parameters with results are reported (Table 3-8). It should be noted that parameters not reported were not necessarily zero; they may have been present at values below the detection limit of the analytical equipment, in very low concentrations.

3.3.3 Macroinvertebrates

Macroinvertebrate biological samples and associated habitat data were collected at the Santa Gertrudis index reach on May 17, 2016. The samples were received by the analytical lab in mid-June 2016, and the report from the lab was issued on June 20, 2017. A list of taxa collected from the index reach on the Santa Cruz River can be found in Appendix A.

Table 3-5. Results from dissolved metals sampling, Santa Gertrudis index site, Tumacácori NHP, WY2016.

Analyte	mg/L				Method	Arizona state standard	
	Q1	Q2	Q3	Q4		Measure (mg/L)	Beneficial use
Arsenic	0.017	<0.015	0.016	0.0072	EPA 200.7/200.8	0.15	Aquatic & Wildlife
Barium	NC	NC	NC	0.056	EPA 200.7/200.8	NS	
Boron	0.13	0.13	0.13	0.11	EPA 200.7	NS	
Calcium	68	73	76*	62	EPA 200.7	NS	
Copper	<0.015	<0.015	<0.015	0.0033	EPA 200.7/200.8	0.016	Aquatic & Wildlife[1]
Magnesium	12	12	12*	10	EPA 200.7	NS	
Manganese	0.12	0.69	0.025*	0.014	EPA 200.7/200.8	NS	
Molybdenum	NC	NC	NC	0.0049	EPA 200.7/200.8	NS	
Nickel	NC	NC	NC	0.0067	EPA 200.7/200.8	0.1	Aquatic & Wildlife[1]
Potassium	7.8	8.4	6.8	7.6	EPA 200.7	NS	
Silica	37	40	37*	32	EPA 200.7	NS	
Sodium	73	77	74	58	EPA 200.7	NS	
Uranium	NC	NC	NC	0.0027	EPA 200.7/200.8	NS	

[1]Calculated using hardness

*Matrix spike recovery was low, associated blank spike recovery was acceptable (Q3 samples) or matrix spike recovery was high, associated blank spike recovery was acceptable (Q4 samples).

Table 3-6. Results from total metals sampling, Santa Gertrudis index site, Tumacácori NHP, WY2016.

Analyte	mg/L				Method	Arizona state standard	
	Q1	Q2	Q3	Q4		Measure (mg/L)	Beneficial use
Aluminum	<0.10	0.14	<0.10	1.7*	EPA 200.7/200.7 Rev 4.4	NS	
Arsenic	0.015	<0.015	<0.015	0.0092	EPA 200.7/200.8	0.2	Agricultural livestock watering
Barium	NC	NC	NC	0.073	EPA 200.7/200.8	98	Partial body contact
Boron	0.12	0.13	0.12	0.11	EPA 200.7/200.7 Rev 4.4	186	Partial body contact
Calcium	67	73	77	62	EPA 200.7/200.7 Rev 4.4	NS	
Copper	<0.015	<0.015	<0.015	0.0064	EPA 200.7/200.8	0.5	Agricultural livestock watering
Iron	<0.10	0.16	<0.10	1.4*	EPA 200.7/200.7 Rev 4.4	NS	
Lead	<0.009	<0.009	<0.009	0.0028	EPA 200.7/200.8	0.015	Partial body contact
Magnesium	11	12	12	10	EPA 200.7/200.7 Rev 4.4	NS	
Manganese	0.12	0.086	0.032	0.077	EPA 200.7/200.8	130	Partial body contact
Molybdenum	NC	NC	NC	0.0048	EPA 200.7/200.8	NS	
Nickel	NC	NC	NC	0.0077	EPA 200.7/200.8	28	Partial body contact
Potassium	7.9	8.7	6.9	8.5*	EPA 200.7/200.7 Rev 4.4	NS	
SiO_2, Silica	38	43	39	38*	EPA 200.7/200.7 Rev 4.4	NS	
Sodium	74	76	73	59	EPA 200.7/200.7 Rev 4.4	NS	
Uranium	NC	NC	NC	0.0029	EPA 200.7/200.8	2.8	Partial body contact
Zinc	<0.020	<0.020	<0.020	0.014*	EPA 200.7/200.8	25	Agricultural watering

[1]Calculated using hardness
*Matrix spike recovery was low, associated blank spike recovery was acceptable (Q3 samples) or matrix spike recovery was high, associated blank spike recovery was acceptable (Q4 samples).
NC = Not collected; NS = no standard; Methods are from USEPA (1983).

Table 3-7. Results from suspended and total sediment sampling, Santa Gertrudis index site, Tumacácori NHP, WY2016.

Analyte	mg/L				Method	Arizona state standard measure
	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 3-8. Results from general and inorganic sampling, Santa Gertrudis index site, Tumacácori NHP, WY2016.

Analyte	mg/L				Method	Arizona state standard measure
	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).

The Santa Gertrudis index reach has been sampled since WY2012. Although there is not an established index threshold for effluent-dominated streams in Arizona (ADEQ 2009; ADEQ 2012), the Arizona Index of Biological Integrity (AZIBI) value has been at or below impaired status since WY2012 (Figure 3-4).

Riffle habitat, typically located at a spot in the river where there is a steep elevation gradient and larger particle size, is the optimal stream habitat type used for quantitative sampling (Lawson 2005). With few suitable riffle habitats, the bed material composition of the Santa Cruz River at the index site (and the rest of the Tumacácori NHP stream segment) is sub-optimal sampling habitat for developing an accurate macroinvertebrate AZIBI (Lawson 2005). In WY2016, only 16% of the Santa Gertrudis index reach was categorized as riffle (Figure 3-5). The distribution of particle sizes from the riffle habitat at the Santa Gertrudis index reach during WY2016 indicated the bias toward smaller particles, with most riffles containing gravel size particles or smaller (Figure 3-6). This corresponded to the generally overall sandy bed of the park segment of the Santa Cruz River (Figure 3-7).

The constant flow of water from the NIWTP since the 1950s (Norman et al. 2013), and the stochastic nature of large floods (mainly in response to localized monsoon precipitation), have led the river channel to be dominated by fine gravel and sand. These factors combine to bury places along the river where sharp decreases in elevation might otherwise develop.

Despite the effluent-driven system on the Santa Cruz, and sub-optimal habitat for calculating the AZIBI, the 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.

3.3.4 Fish

The current collaborative fish-sampling project on the lower Santa Cruz River has been occurring since 2008, including sampling at the Santa Gertrudis index reach. In WY2016, 209 fish were collected (23.96 fish/unit effort; Figure 3-8) (AGFD 2014). Two taxa of fish were collected: longfin dace (*Agosia chrysogaster*) and Gila topminnow (*Poeciliopsis occidentalis*).

The metric for longfin dace continued to hold at the Santa Gertrudis index reach, with a mean of 22.71 fish/unit effort for WY2012–2016. The continued presence of native longfin dace in the reach is encouraging.

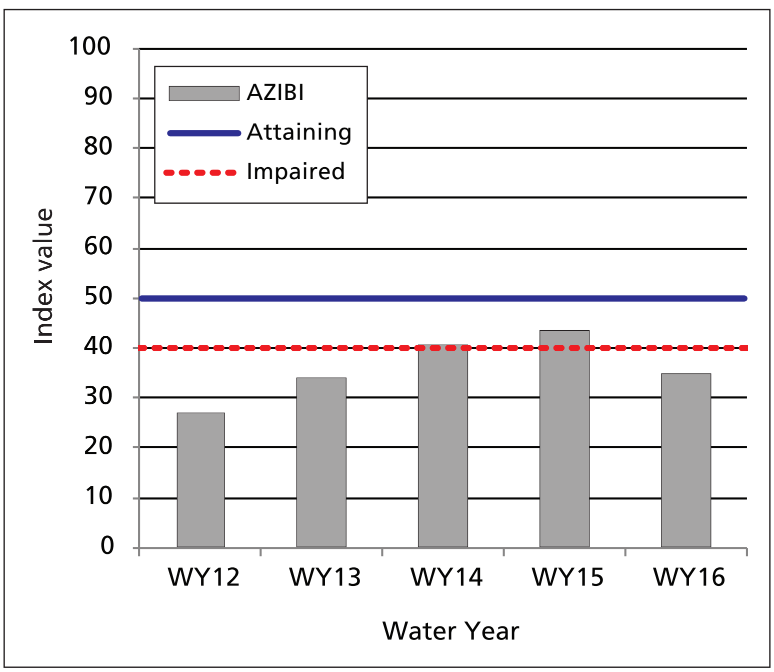

Figure 3-4. Arizona Index of Biological Integrity for the Santa Gertrudis index reach, Tumacácori NHP, water years 2012–2016.

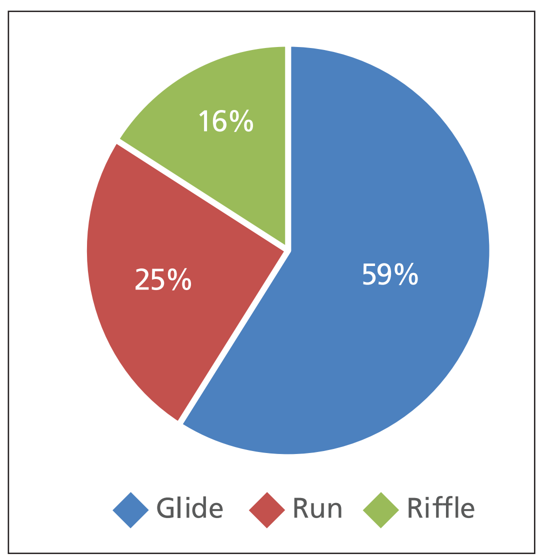

Figure 3-5. Percent of habitat type at the Santa Gertrudis index reach, Tumacácori NHP, WY2016.

The sampling also detected Gila topminnow, the first documentation of this federally endangered species (USFWS 1998) in the index reach since 2002 (Powell et al. 2005). The return of this rare species to park waters indicates a response to improved water quality and habitat features.

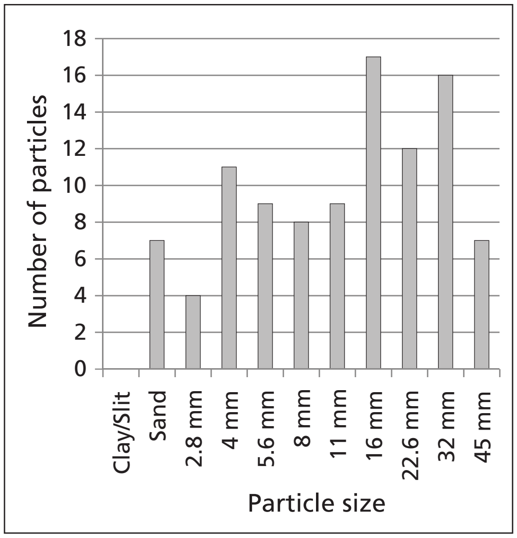

Figure 3-6. Histogram of particle sizes from riffle habitat at the Santa Gertrudis index reach, Tumacácori NHP, WY2016.

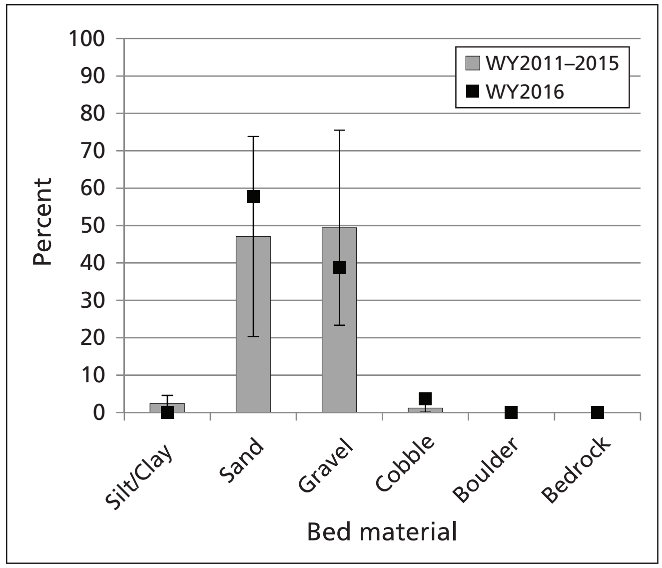

Figure 3-7. Composition of bed material size across the Santa Gertrudis index reach, comparing WY2016 to WY2011–2015. Error bars indicate one standard deviation.

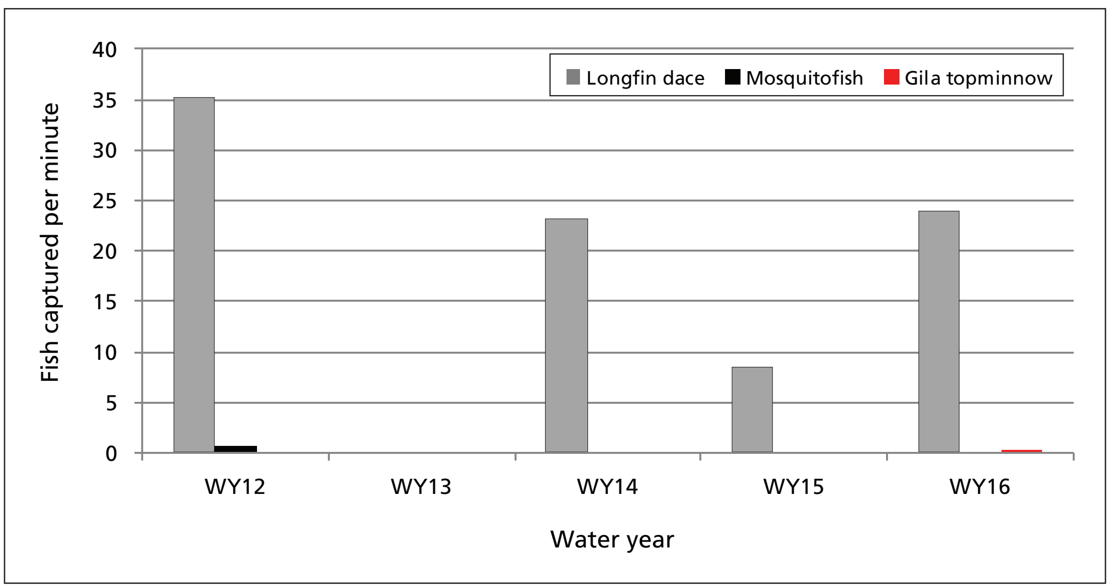

Figure 3-8. Fish per unit effort at Santa Gertrudis index reach, Tumacácori NHP, water years 2012–2016.

4 Literature Cited

Arizona Game and Fish Department (AGFD). 2014. Lower Santa Cruz fish survey 2014. Unpublished report.

Arizona Department of Environmental Quality (ADEQ). 2009. Unofficial copy of the 2009 surface water quality standards (18 A.A.C., Chapter 11, Article 1). http://legacy.azdeq.gov/environ/water/standards/download/SWQ_Standards-1-09-unofficial.pdf.

——. 2012. 2010 status of water quality: Arizona's integrated 305(b) assessment and 303(d) listing report. http://www.resolutionmineeis.us/sites/default/files/references/adeq-water-quality-status-2012.pdf.

Blunden, J., and D. S. Arndt, eds., 2013. State of the climate in 2012. Bulletin of the American Meteorological Society, 94(8):S1–S238.

Davey, C. A., K. T. Redmond, and D. B. Simeral. 2007. Weather and climate inventory, National Park Service, Sonoran Desert Network. Natural Resource Technical Report NPS/SODN/NRTR—2007/044. National Park Service, Fort Collins, Colorado.

Glinski, R. L., and D. E. Brown. 1982. Mesquite (*Prosopis juliflora*) response to severe freezing in southeastern Arizona. Journal of the Arizona-Nevada Academy of Science 17(1):15–18.

Gwilliam, E. L., C. Filippone, and J. A. Hubbard. 2016. Status of climate and water resources at Tumacácori National Historical Park: Water year 2015. Natural Resource Report NPS/ SODN/NRR—2016/1293. National Park Service, Fort Collins, Colorado.

Gwilliam, E. L., K. L. Raymond, and L. Palacios. 2014. Streams monitoring at Tumacácori National Historical Park: 2011 summary report. Natural Resource Data Series NPS/SODN/ NRDS—2014/743. National Park Service, Fort Collins, Colorado.

Gwilliam E. L., K. L. Raymond, S. Buckley, C. L. Fillippone, J. A. Hubbard, C. McIntyre, and S. Studd. In prep. Streams monitoring protocol for the Sonoran Desert Network. National Park Service, Fort Collins, Colorado.

Hubbard, J. A., K. Raymond, E. Gwilliam, and M. Tercek. in prep. Climate monitoring protocol for the Sonoran, Chihuahuan, and Southern Plains national parks.

Irwin, R. J. 2008. Draft part B lite QA/QC review checklist for aquatic vital sign monitoring protocols and SOPs, National Park Service, Water Resources Division. Fort Collins, Colorado.

Lawson, L. L., ed. 2005. Macroinvertebrate sampling and analysis procedures, section 3, part A, *in* A manual of procedures for the sampling of surface waters. Report TM05-01, Arizona Department of Environmental Quality, Phoenix.

Norman, L. M., M. L. Villarreal, R. Niraula, T. Meixner, G. Frisvold, and W. Labiosa. 2013. Framing scenarios of binational water policy with a tool to visualize, quantify and valuate changes in ecosystem services. Water 5(3):852–874. Available online at http://www.mdpi.com/2073-4441/5/3/852.

Powell, B. F., E. W. Albrecht, W. L. Halvorson, C. A. Schmidt, P. Anning, and K. Docherty. 2005. Vascular plant and vertebrate inventory of Tumacácori National Historical Park. U.S. Geological Survey Open File Report 2005–1142. 126 p. http://pubs. usgs.gov/of/2005/1142/.

Sanders, E. C., Y. Yongping, and A. Pitchford. 2013. Fecal coliform and *E. coli* concentrations in effluent-dominated streams of the Upper Santa Cruz River. Water 5:243–261.

Strahler, A.H. 2013. Introducing physical geography. 6th edition. Hoboken, N.J.: Wiley.

Tsakiris, G., and H. Vangelis. 2005. Establishing a drought index incorporating evapotranspiration. European Water 9/10:3–11.

United Nations Environment Programme (UNEP). 1992. World atlas of desertification. London: Edward Arnold.

U.S. Fish and Wildlife Service (USFWS). 1998. Gila topminnow, *Poeciliopsis occidentalis occidentalis*, revised recovery plan. U.S. Fish and Wildlife Service, Albuquerque, New Mexico.

U.S. Geological Survey (USGS). 2006. National field manual for the collection of water-quality data: U.S. Geological survey techniques of water-resources investigations, book 9, chapters A1–A9. http://pubs.water. usgs.gov/twri9A.

——. 2016. Unpublished data on stream stage at Santa Gertrudis index site.

Appendix A. Macroinvertebrate Taxa List, Santa Gertrudis Index Site, Tumacácori NHP, WY2016

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	Neoelmis	caesa
Arthropoda	Insecta	Coleoptera	Elmidae	Optioservus	
Arthropoda	Insecta	Coleoptera	Elmidae	Stenelmis	
Arthropoda	Insecta	Coleoptera	Elmidae		
Arthropoda	Insecta	Coleoptera	Elmidae		
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. Macroinvertebrate Taxa List, Santa Gertrudis Index Site, Tumacácori NHP, WY2016, 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	Thienemannimyia 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		
Arthropoda	Insecta	Diptera	Muscidae		
Arthropoda	Insecta	Diptera	Psychodidae	Maruina	

Appendix A. Macroinvertebrate Taxa List, Santa Gertrudis Index Site, Tumacácori NHP, WY2016, cont.

Phylum	Class	Order	Family	Genus	Species
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	Allognosta	
Arthropoda	Insecta	Diptera	Stratiomyidae	Caloparyphus	
Arthropoda	Insecta	Diptera	Stratiomyidae	Euparyphus	
Arthropoda	Insecta	Diptera	Stratiomyidae	Stratiomys	
Arthropoda	Insecta	Diptera	Stratiomyidae		
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	Homoleptohyphes	
Arthropoda	Insecta	Ephemeroptera	Leptohyphidae	Leptohyphes	
Arthropoda	Insecta	Ephemeroptera	Leptohyphidae	Tricorythodes	
Arthropoda	Insecta	Ephemeroptera	Leptohyphidae		
Arthropoda	Insecta	Ephemeroptera	Leptophlebiidae	Traverella	albertana
Arthropoda	Insecta	Ephemeroptera	Leptophlebiidae		
Arthropoda	Insecta	Ephemeroptera			
Arthropoda	Insecta	Hemiptera	Belostomatidae		

Appendix A. Macroinvertebrate Taxa List, Santa Gertrudis Index Site, Tumacácori NHP, WY2016, cont.

Phylum	Class	Order	Family	Genus	Species
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	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	lampropeltis
Arthropoda	Insecta	Odonata	Gomphidae	Erpetogomphus	
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	Paltothemis	lineatipes
Arthropoda	Insecta	Odonata	Libellulidae		
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	
Arthropoda	Insecta	Trichoptera	Hydropsychidae	Smicridea	
Arthropoda	Insecta	Trichoptera	Hydropsychidae		
Arthropoda	Insecta	Trichoptera	Hydroptilidae	Hydroptila	
Arthropoda	Insecta	Trichoptera	Hydroptilidae	Leucotrichia	
Arthropoda	Insecta	Trichoptera	Hydroptilidae	Mayatrichia	

Appendix A. Macroinvertebrate Taxa List, Santa Gertrudis Index Site, Tumacácori NHP, WY2016, cont.

Phylum	Class	Order	Family	Genus	Species
Arthropoda	Insecta	Trichoptera	Hydroptilidae	Ochrotrichia	
Arthropoda	Insecta	Trichoptera	Hydroptilidae	Oxyethira	
Arthropoda	Insecta	Trichoptera	Hydroptilidae		
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				

NPS 311/140603, November 2017

National Park Service
U.S. Department of the Interior

Natural Resource Stewardship and Science
1201 Oak Ridge Drive, Suite 150
Fort Collins, Colorado 80525

www.nature.nps.gov

EXPERIENCE YOUR AMERICA™