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Status of Climate and Water Resources at Tumacácori National Historical Park

Water Year 2015

Natural Resource Report NPS/SODN/NRR—2016/1293

ON THE COVER

Santa Cruz River, Tumacácori National Historical Park.
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Water Year 2015

Natural Resource Report NPS/SODN/NRR—2016/1293

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Acronyms

ADWR	Arizona Department of Water Resources
AGFD	Arizona Game and Fish Department
amsl	above mean sea level
bgs	below ground surface
cfs	cubic feet per second
COOP	Cooperative Observer Program
NHP	national historical park
NIWTP	Nogales International Wastewater Treatment Plant
NOAA	National Oceanic and Atmospheric Administration
NPS	National Park Service
QA/QC	quality assurance/quality control
RDI	Reconnaissance Drought Index
SC	specific conductivity
SE	standard error
SODN	Sonoran Desert Network
USFWS	U.S. Fish and Wildlife Service
USGS	U.S. Geological Survey
WY	water year

Executive Summary

Climate and hydrology are major drivers of ecosystems. They dramatically shape ecosystem structure and function, particularly in arid and semi-arid ecosystems. Understanding changes in climate, groundwater, streamflow, and water quality is central to assessing the condition of park biota and key cultural resources. This report combines data collected on climate, groundwater, and surface water at Tumacácori National Historical Park (NHP) to provide an integrated look at climate and water conditions during water year 2015 (October 2014–September 2015).

Globally, 2015 was the hottest year on record. By contrast, local conditions at Tumacácori NHP were mixed, with cool-season minimum and maximum air temperatures generally well above normal, followed by a relatively cool fore-summer (May–June), and monsoon maximum temperatures below normal. Annual precipitation was nearly 150% of normal, with the largest increases occurring in June—a month in which little to no rainfall typically occurs. Increased rainfall and mixed air temperatures reduced the reconnaissance drought index relative to recent years, indicating a degree of recovery from the drought of the early 2000s.

Water levels in the shallow aquifer at Tumacácori were at the lowest on record (June 2007–present) during the pre-monsoon period (May–early June) in WY2014. However, monsoon events near the end of WY2014, coupled with the above-average precipitation during the winter and late spring of WY2015, brought shallow-aquifer water levels back to near average.

Four sampling visits were made to the Santa Cruz River index site for water quality monitoring in WY2015, one during each quarter. There were 247 individual analyses of water samples, 88 of which were associated with Arizona state water quality standards. There were no exceedances observed. Nutrient concentrations remained low—a dramatic improvement over conditions at the park five years ago. In addition, more than 15,000 measurements were collected from a logging multiparameter probe, deployed for 2–3 weeks during each of three quarters of WY2015. These data showed that the median values of temperature and dissolved- oxygen concentration were within the expected range during all three deployments. The median values for pH and specific conductivity were outside the expected range during three quarters, for reasons that are uncertain. During WY2015, the amount of river flow was lower than the mean gage record in every month except September, likely due to reduced effluent contributions from the Nogales International Wastewater Treatment Plant. The native longfin dace (*Agosia chryogaster*) continues to be encountered in the river.

Acknowledgements

We thank Chief of Resource Management Adam Springer, Superintendent Bob Love, and the staff of Tumacácori National Historical Park for their support of this monitoring effort. Mark Hiller and Finnian Freeling assisted with data collection and processing, and Kristen Bonebrake led the management and posting of all data products. 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, groundwater, streamflow, and water quality is central to assessing the condition of park biota and key cultural resources.

This document summarizes climate and water resource conditions for water year (WY) 2015 (October 2014–September 2015) for Tumacácori National Historical Park (NHP), a small (144-ha) National Park Service unit in southern Arizona. 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 more instantaneous (minutes to days) conditions reflected by the term, "weather."

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

Tumacácori NHP has operated a National Oceanic and Atmospheric Administration (NOAA) Cooperative Observer Program (COOP) weather station (TUMACÁCORI NM, ID#0268865) since 1946 (Davey et al. 2007). The record from this station provides a reliable, long-term climate dataset used for the analyses in this report. In 2014, the National Park Service (NPS) Sonoran Desert Network (SODN) installed a Davis weather station (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 SODN 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 index seeks 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 found to be "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 National Historical Park. Data are available through www.climateanalyzer.org.

2.2 Results

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

2.2.1.1 Cool season (October–March)

Overall precipitation was slightly above normal (105%, 0.29") for the fall and winter of WY2015, with little to no rain in November and February (Figure 2-3). Maximum and minimum air temperatures were above normal (+2–4°F) throughout the cool season, except for a cold period in November and December (Figure 2-3), when minimum temperatures hovered around freezing (32°F).

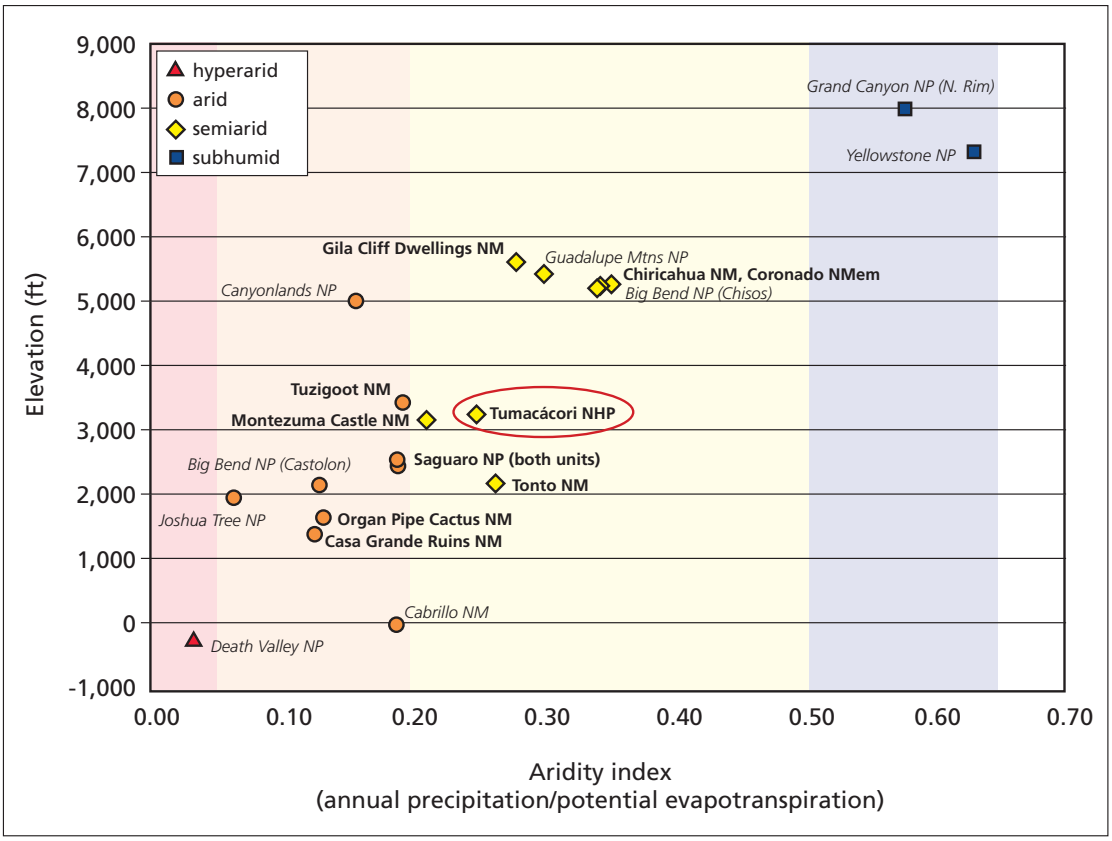

Figure 2-2. Aridity index vs. elevation of selected southwestern national parks, including Tumacácori National Historical Park. Figure from Hubbard and others (in prep).

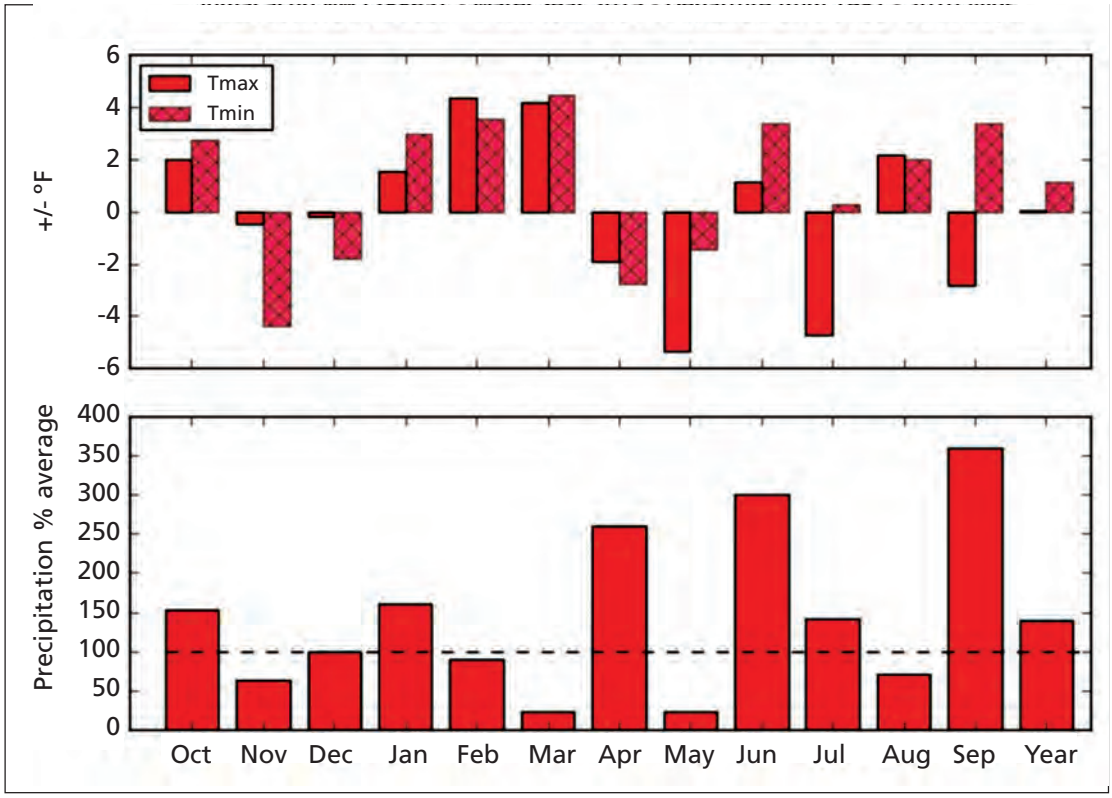

Figure 2-3. Departures from 30-year (1981–2010) normal minimum and maximum air temperature and precipitation, Tumacácori National Historical Park, WY2015. Graphics generated by climateanalyzer.org.

2.2.1.2 Warm season (April–September)

Warm-season maximum air temperatures were generally 2–4°F cooler than normal. Minimum air temperatures were consistently 1–3°F warmer than normal, except for a sustained cool snap in April and May. June—typically a month when little-to-no precipitation falls at Tumacácori NHP—was dramatically wetter than normal, with about 300% of the 1981–2010 normal levels. September had more than 350% of normal precipitation, with July and August closer to normal (see Figure 2-3). The result was an unusually early monsoon that was sustained through September, yielding warm-season precipitation that equaled annual totals for most years, and was 160% of (6.27" above) normal. Overall annual precipitation was 140% of normal for Tumacácori NHP (23.12 vs 16.56").

2.2.2 Reconnaissance drought index

Reconnaissance drought index (RDI; 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). RDI for Tumacácori NHP reflects the extended regional drought since 2000 (Figure 2-4). Conditions at the park became wetter in 2014, and 2015 was the fifth-wettest water year since 1981, from the perspective of both precipitation and evaporative demand. However, the five-year moving mean of total annual precipitation from water years 1981 to 2015 (Figure 2-5) suggests that the last two "wet" years have been insufficient to remedy the multi-year precipitation deficit.

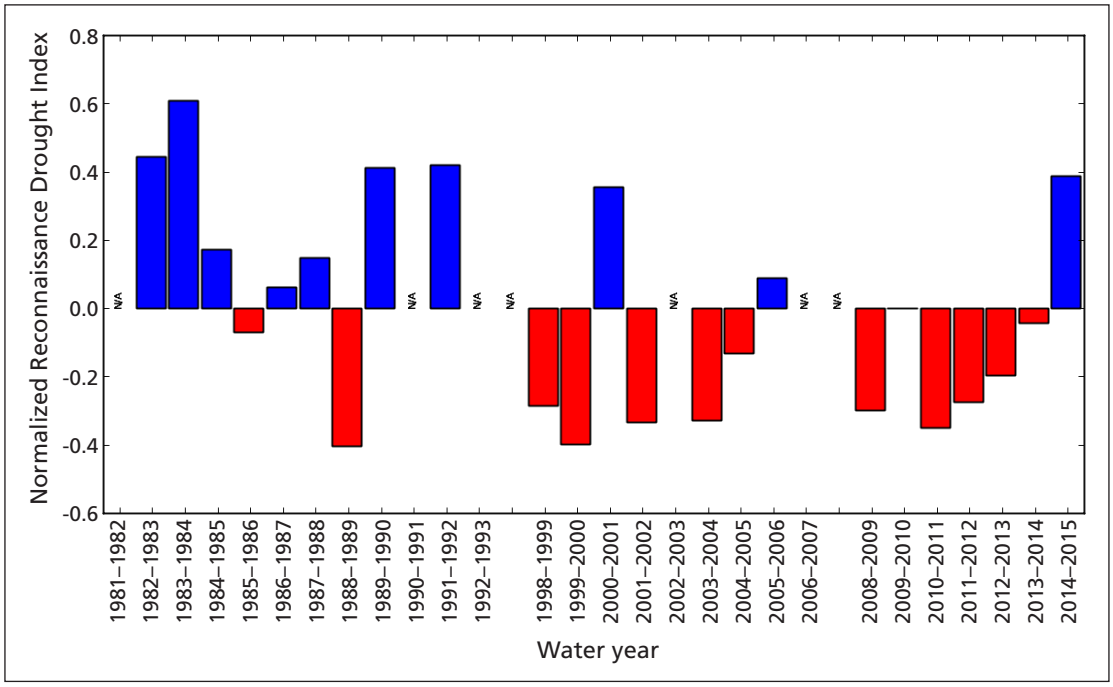

Figure 2-4. Reconnaissance drought index (RDI) for Tumacácori National Historical Park, water years 1981–2015. "n/a" = insufficient data to generate reliable RDI estimates. The station had an extended period without data collection from 1992 to 1997. Graphics generated by climateanalyzer.org.

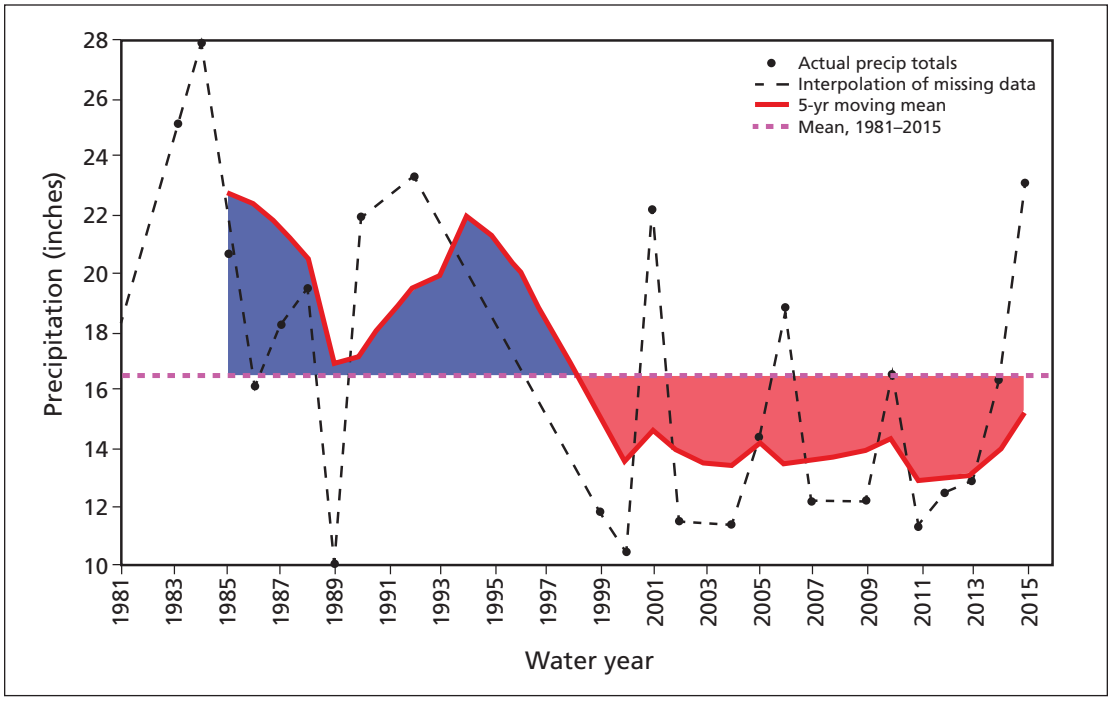

Figure 2-5. Five-year moving mean of annual precipitation, Tumacácori National Historical Park, 1981–2015. The moving mean (solid red line) is based on a timeseries with 28.6% (10 of 35) missing values, and includes the current year and previous four years. Missing years are linearly interpolated (dashed grey lines). Graphics generated by climateanalyzer.org.

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 like that at Tumacácori. For example, sustained low air temperatures can damage or even kill long-lived keystone plants, such as the velvet mesquite (*Prosopis velutina*; Glinski and Brown 1982) that dominates the bosque woodlands of the park, as well as the sensitive fruit trees of the Father Kino heritage orchard. Extreme precipitation events can also cause localized flooding (Figure 2-6) 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 30% more often than normal (31 days vs. 19.9 ± 5.4 days) in WY2015, and were of a slightly greater duration (2.58 consecutive days vs. 2.1 ± 0.1 days).

The number of days with extreme precipitation events (>1") in WY2015 was approximately normal (4 vs. 3.23 days for 1981–2010), with large events on July 19 (1.15"), July 29 (1.17"), August 10 (1.40"), and, particularly, September 22 (2.48").

Figure 2-6. Floodplain debris following a large flow event along the Santa Cruz River, Mission unit of Tumacácori National Historical Park.

3 Groundwater

3.1 Background and methods

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

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

3.1.1 Shallow and deep aquifers

Tumacácori NHP is situated above both shallow and deep aquifers. The deep aquifer lies beneath the shallow aquifer. The shallow, unconfined aquifer, along the Santa Cruz River, is influenced by infiltration from streamflow, groundwater subflow, regional pumping for potable water and irrigation, and transpiration by riparian trees and shrubs. As such, this aquifer exhibits relatively low-magnitude daily cycles (Figure 3-1). This shallow aquifer has the most direct connection to streamflow, and serves as the primary water source for riparian vegetation.

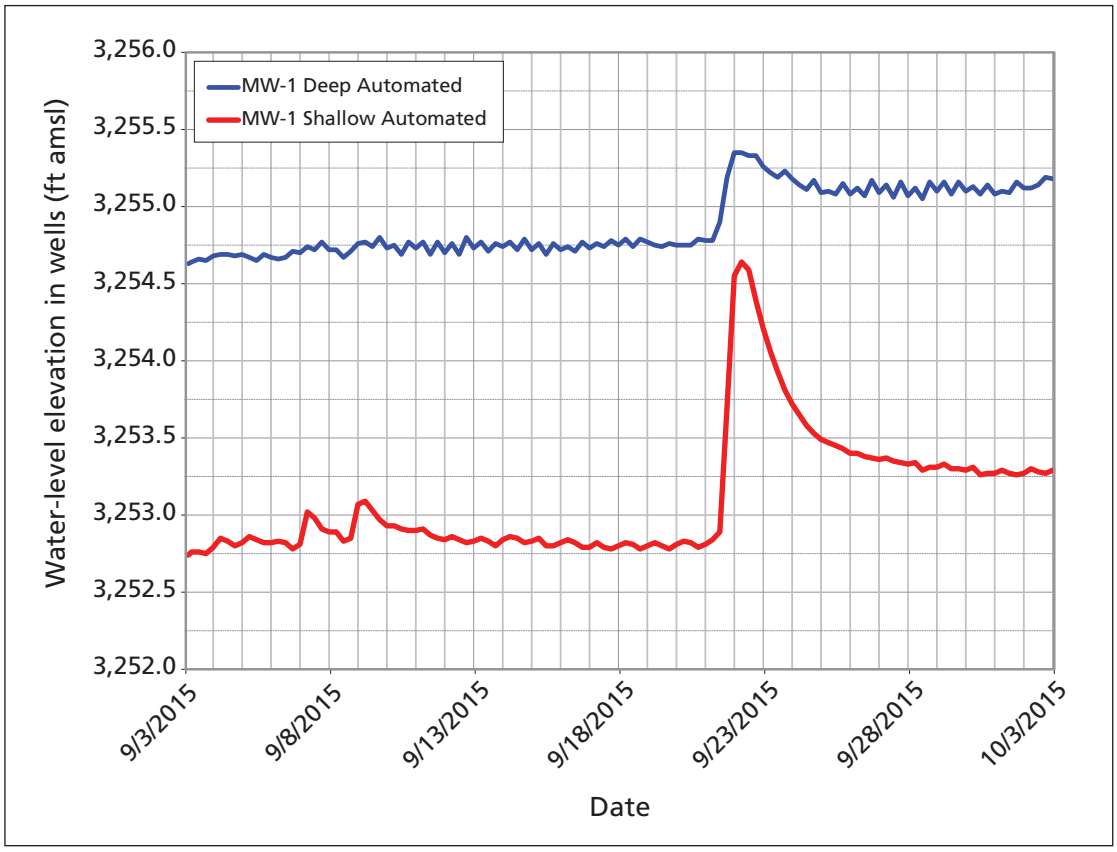

Figure 3-1. The shallow aquifer, along the river, is much more influenced by precipitation and subsequent infiltration than the deep aquifer. After a 2.48" rainstorm on September 22, 2015, the shallow aquifer rose almost four times as much as the deep aquifer. "amsl" = above mean sea level.

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 3-2). The University of Arizona installed two wells (MW-1 Shallow and MW-1 Deep; Figure 3-3) just north of Santa Gertrudis Lane in the Mission unit. Both wells are monitored continuously via pressure transducers operated by the Arizona Department of Water Resources (ADWR). MW-1 Shallow (ADWR 55-557439) is screened at a depth of between 30 and 60 feet. MW-1 Deep (ADWR 55-557438) is screened at 100–115 feet.

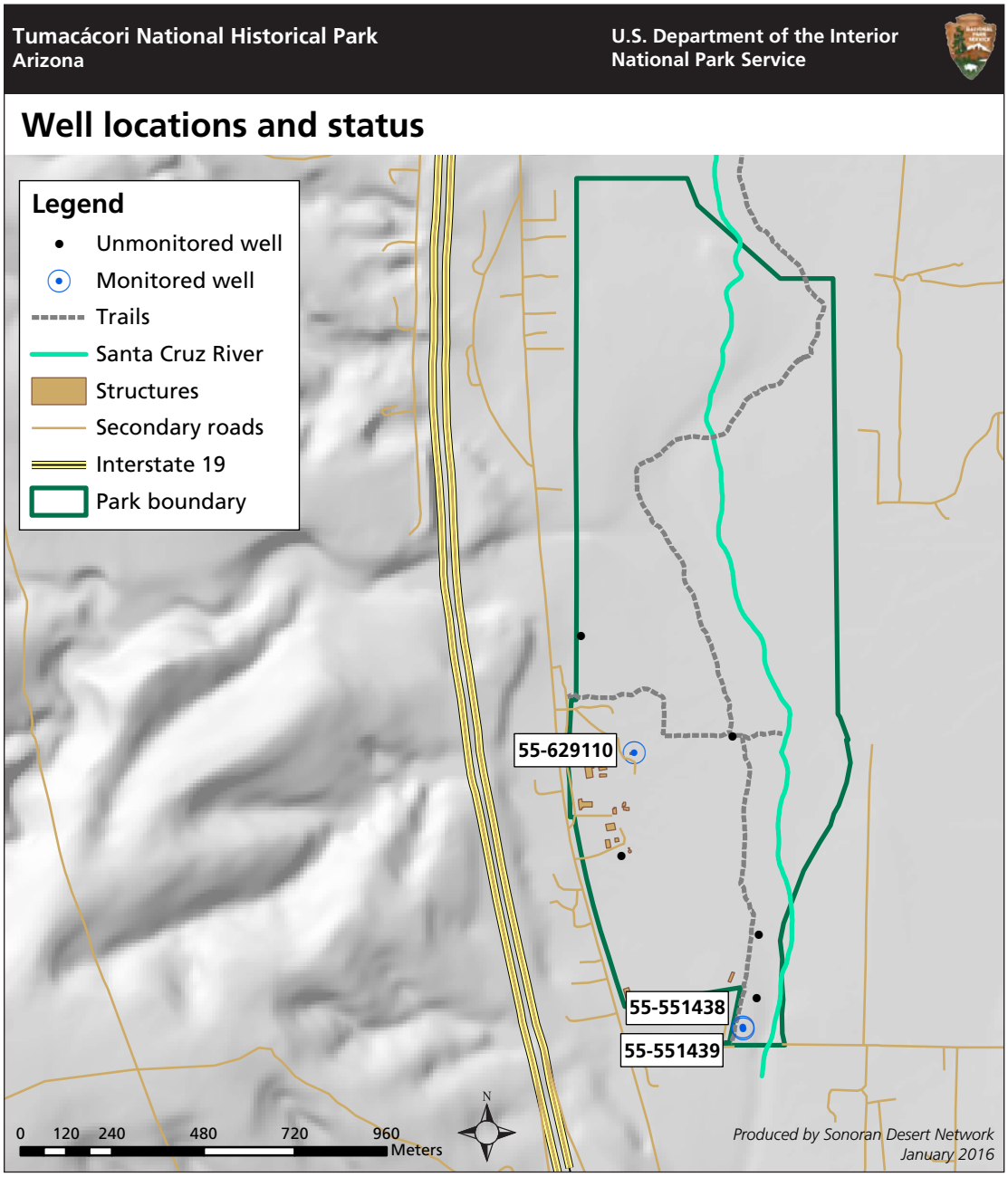

Figure 3-2 Monitoring well locations at Tumacácori National Historical Park.

Figure 3-3. Monitoring wells prior to installation (left; MW-1 Deep in the foreground, with MW-1 Shallow) and following instrumentation of real-time measurements (right; white box encloses MW-1 Deep), Tumacácori National Historical Park.

In addition to the Santa Gertrudis Lane wells, the Mission unit's water-supply well (ADWR 55-629110, marked as DC-21-13 30DCA on the well head; Figure 3-4), established in 1959 at a depth of 150' 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.

Figure 3-4. The Mission unit's water-supply well, monitored manually (via sounding tape) since 1960.

3.2 Results

3.2.1 Shallow aquifer (MW-1 Shallow)

The shallow aquifer (most closely linked with weather conditions and streamflow events) exhibits seasonal variability, with groundwater lows during the hot, dry, early summer months (Figure 3-5). In 2013 and especially 2014, the month of June was among the lowest periods on record for shallow groundwater at Tumacácori NHP. There are several potential explanations for the dramatic pre-monsoon lows in shallow groundwater. They include ecosystem changes associated with improved water quality since the 2009 upgrade of the Nogales International Wastewater Treatment Plant, increased pumping by high-volume irrigation wells installed upstream (between Peck and Josephine Canyons, AZ) in 2013, and extreme drought conditions in southern Arizona (see Chapter 2 of this report).

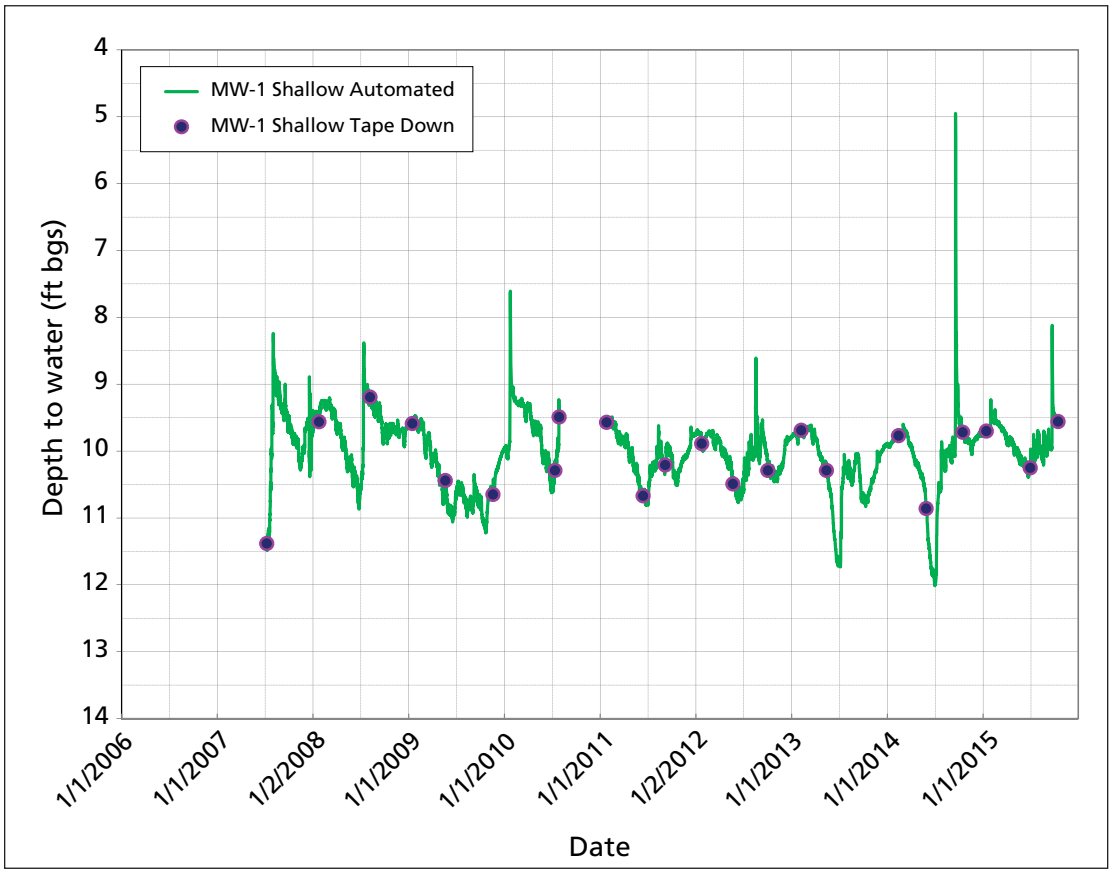

Figure 3-5. Depth-to-water at MW-1 Shallow, 2007–2015. "bgs" = below ground surface.

The shallow aquifer rebounded in 2015 (Figure 3-5).

3.2.2 Deep aquifer (MW-1 Deep)

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 (Figure 3-6). 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 3-6 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 3-7) illustrates that hydraulic head (shown here as water-level elevation) in the deep aquifer varies between about 1.5–2 feet more than in the shallow aquifer, except during flood periods. Over the relatively short distance between the monitoring intervals (about 40 feet), this constitutes

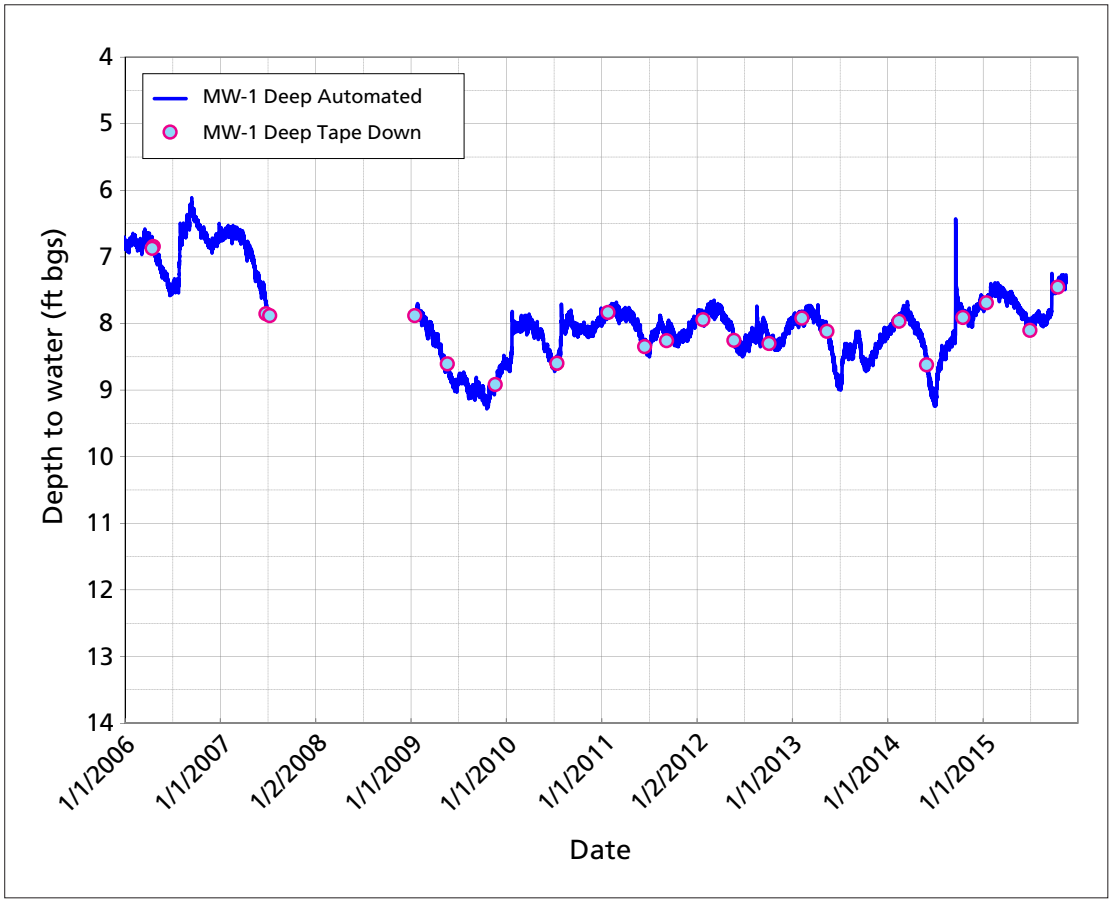

Figure 3-6. Depth-to-water at MW-1 Deep, 2006–2015. "bgs" = below ground surface.

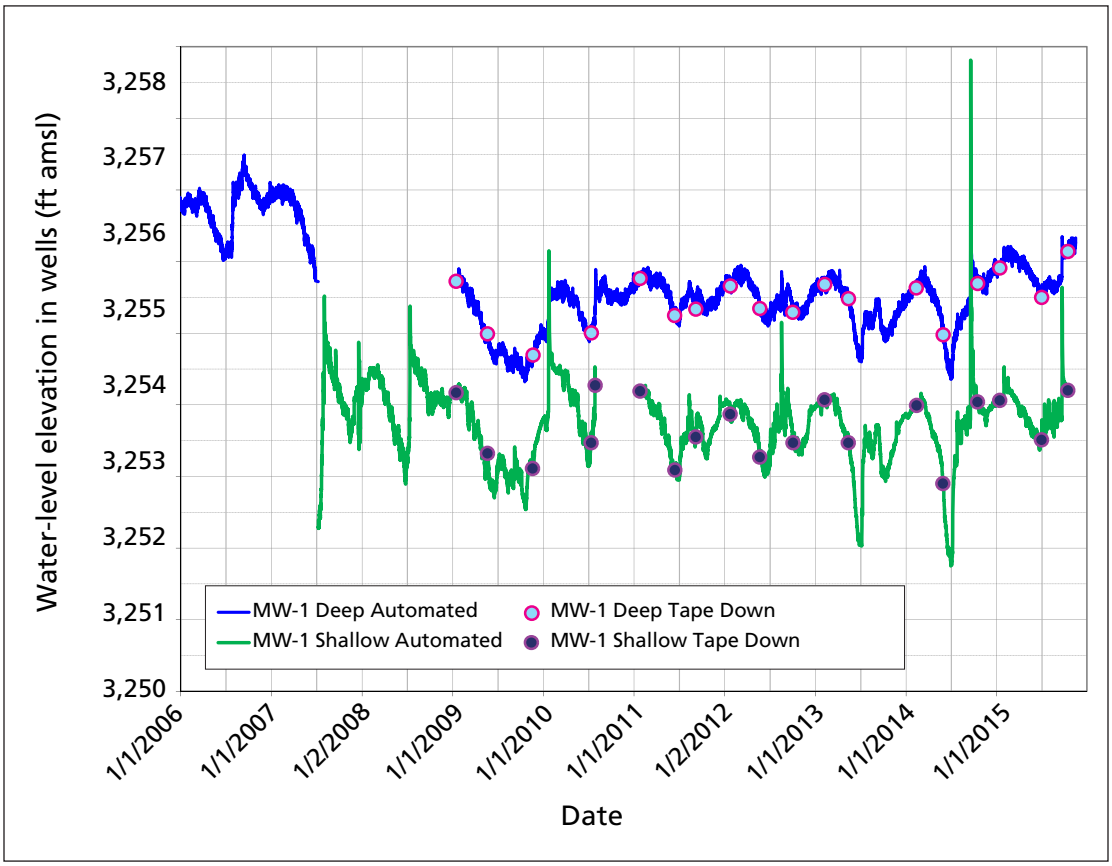

Figure 3-7. Water-level elevations at the deep and shallow monitoring wells north of Santa Gertrudis Lane, 2006–2015. "amsl" = above mean sea level.

a significant upward vertical gradient. The magnitude of vertical flow occurring as a result of this gradient depends on the hydraulic properties of the subsurface between the shallow- and deep-screened intervals.

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

3.2.3 Mission unit's water-supply well

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 3-8) 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.

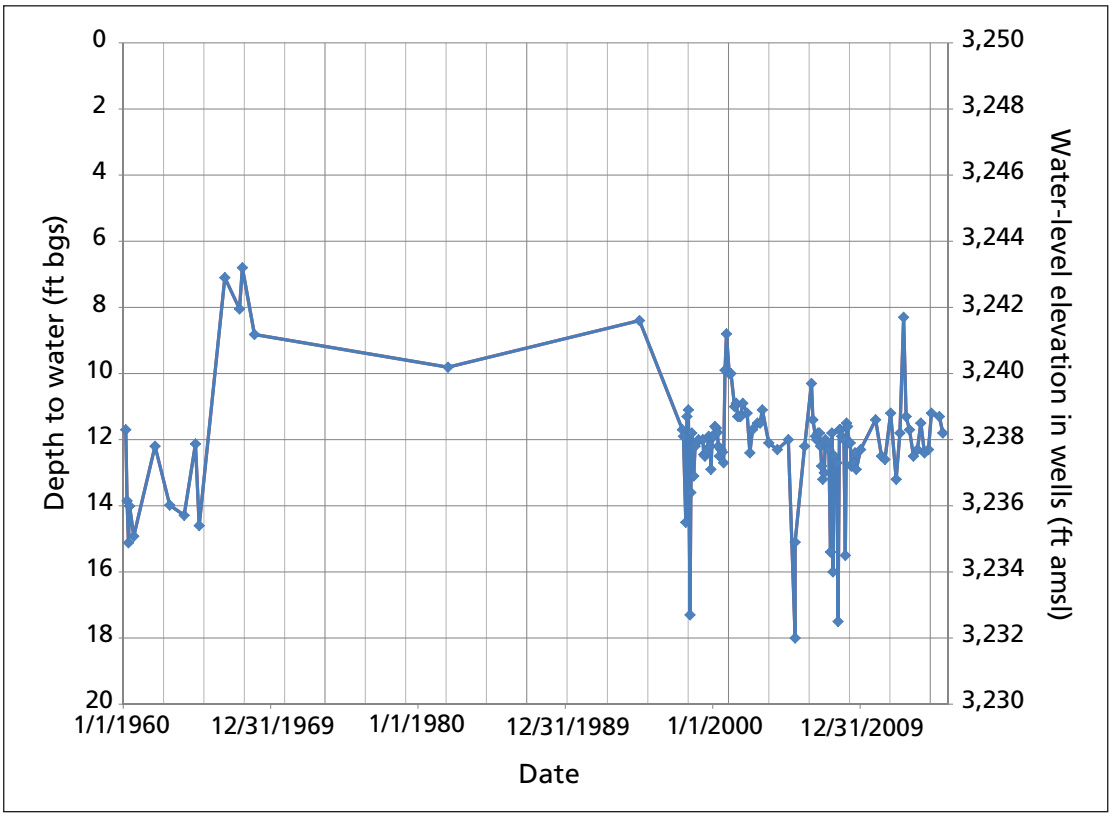

Figure 3-8. Depth-to-water and water-level elevation at the Mission unit's water-supply well, Tumacácori National Historical Park, 1960–2015. "bgs" = below ground surface. "amsl" = above mean sea level.

4 Surface Water

4.1 Background

Historically, the Santa Cruz River has been an intermittent stream (Norman et al. 2013). Today, however, the Santa Cruz River at Tumacácori NHP is an effluent-driven system, with most surface water provided by the Nogales International Wastewater Treatment Plant. The NIWTP has been discharging treated effluent into the Santa Cruz River since 1951, and from the current plant facility site since 1972. 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 water supply, allowing for the persistence of a diverse riparian habitat for wildlife within Tumacácori NHP (Norman et al. 2013).

There are several causes for concern 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 exceeded 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 in recent years 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).

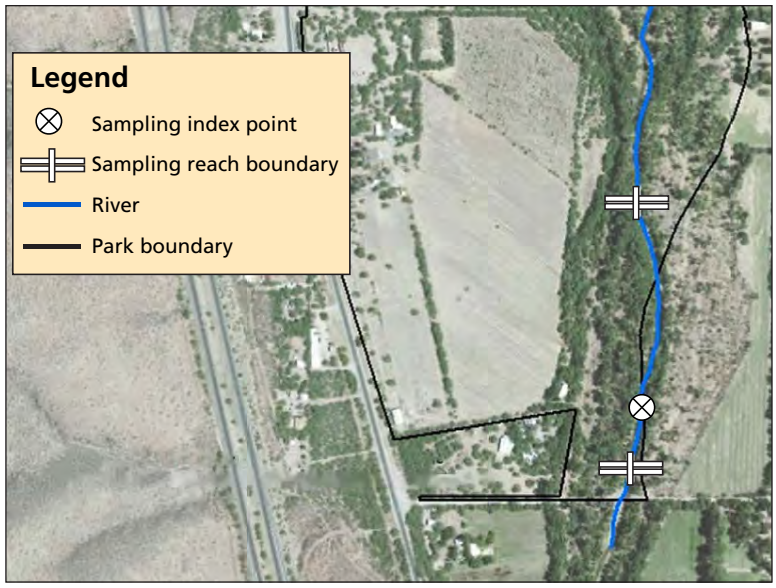

Figure 4-1. Sonoran Desert Network water quality sampling locations, Santa Cruz River, Tumacácori National Historical Park.

Water quality monitoring occurred ~150 m downstream from the southern boundary of the park at the Santa Gertrudis index site (Figure 4-1). Discrete and continuous water quality samples and measurements were collected at this location, 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.

4.2 Methods

A brief description of the data collection and processing methodologies followed by SODN staff at Tumacácori NHP during WY2015 is presented below. Detailed descriptions of these procedures will be available in SODN's water quality monitoring protocol (Gwilliam et al. in prep).

4.2.1 Water quality

4.2.1.1 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 (SC), 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 meter (YSI Professional Plus) was calibrated and deployed in a well-mixed part of the stream channel, logging temperature, pH, SC, 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, SC, and dissolved oxygen at 15-minute intervals for a minimum of two weeks every quarter, using a logging multi-parameter instrument (YSI XLM600 V2).

4.2.1.2 Samples

During each site visit, water samples were collected in a three-liter Nalgene sample collection bottle, following 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 dropped off at the contract laboratory. For WY2015, that lab was TestAmerica, in Phoenix, Arizona.

4.2.2 Water quantity

Streamflow data for this report were recorded at U.S. Geological Survey (USGS) gage 09481740 on the Santa Cruz River at Tubac, Arizona. This gage is located five kilometers downstream from our 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. The WY2015 annual summary for the USGS Tubac gage (USGS 2016) also provides data for this gage.

The USGS stream gage at Tubac is being used as a proxy for the stream discharge dynamics at the Santa Gertrudis stream monitoring index site at Tumacácori NHP. To determine acceptability of this proxy, SODN staff conducted an analysis comparing stream stage at the Tubac USGS gage to stream stage at the Santa Gertrudis index site during February–November 2015. The stream-gage data from the Santa Gertrudis index site were collected using a non-vented logging pressure transducer that was corrected by a co-located air-pressure logger.

A Kendall's Tau regression analysis conducted on the 15-minute stage data from both sites resulted in a strong and significant correlation ($R=0.55$; $p<0.0001$). Interpretation of a graph displaying the change in stage at both sites (Figure 4-2) also shows a clear connection between base flow and high flow events. These events occurred nearly simultaneously at both sites, with similar duration and intensity.

The analysis concluded that the USGS gage at Tubac serves as an acceptable proxy for stream stage and discharge for the Santa Gertrudis index site at Tumacácori NHP.

4.2.3 Aquatic macroinvertebrates and habitat

Macroinvertebrate sample collection by SODN coincides with the index period used by the Arizona Department of Environmental Quality to ensure compatibility of monitoring samples. The index period for warm water 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:

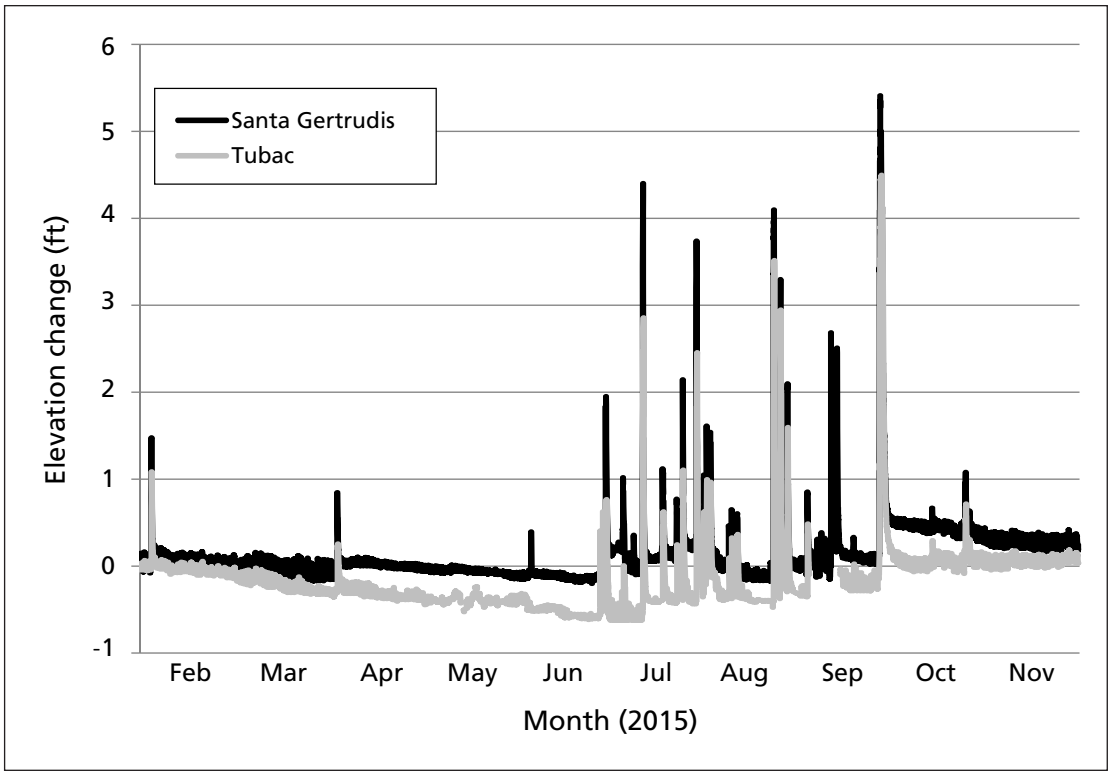

Figure 4-2. The close relationship between stream stage at the USGS Tubac stream gage and at the Santa Gertrudis index site at Tumacácori National Historical Park allows the former to be used as a proxy for the latter.

- 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 kicknet with a 0.3-m 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, with the goal of having a taxonomist, certified by the North American Benthological Society, identify all aquatic macroinvertebrates to the lowest taxonomic level possible.

4.2.4 Fish

Representatives from the Friends of the Santa Cruz River, the U.S. Fish and Wildlife Service (USFWS), the Arizona Game and Fish Department (AGFD), and the National Park Service used standardized methods to collect fish samples, including dip-netting, beach seining (6' × 10', 1/8" mesh); and a backpack electroshocker (Halltech). No reach was sampled more than once each year. Depth and substrate composition are generally consistent throughout the sampling reach.

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.

4.2.5 Data handling and analysis

All data on water quality and quantity are 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 against the State of Arizona's water quality standards (ADEQ 2009) and notes any exceedances.

4.3 Results

4.3.1 Water quality

In WY2015, SODN staff made a total of four sampling visits to the Santa Cruz River at Tumacácori NHP (Q1: 11/15/2014, Q2: 2/10/2015, Q3: 5/19/2015, Q4: 8/20/2015). Discrete samples were collected during each quarter.

Of 247 individual analyses of water samples collected at the Santa Gertrudis index site in WY2015, 88 were associated with Arizona surface-water criteria as designated according to beneficial use. Of those 88 samples, there were no exceedances; 100% of samples were compliant with Arizona state standards for surface water.

4.3.1.1 Core parameters

Discrete sampling. The discrete measurements made in the field (Table 4-1) represent conditions at the Tumacácori NHP index site during site visits in WY2015. 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 three quarters of WY2015 (Table 4-2) to collect data on temperature, specific conductivity, pH, and dissolved oxygen at 15-minute intervals. Figures 4-3 through 4-6 summarize the seasonal variability in those parameters. More than 15,000 measurements were collected.

The sonde was not deployed during the fourth quarter of WY2015 due to damage to the sonde mount, a gain in sediment elevation at the mount, and a change in the active river channel (Figure 4-7). These changes were due to the flow event in late September.

Table 4-1. Discrete data summary, Tumacácori National Historical Park, WY2015.

Parameter	Quarter				Arizona state standard	
	Q1	Q2	Q3	Q4	Measure	Beneficial use
Temperature (°C)	18.3	19.9	17	26.8	NS	
Specific conductivity (µS/cm)	808	707	764	785	NS	Park-specific
pH	7.57	7.89	7.6	7.52	6.5–9	Partial body contact, aquatic and wildlife (effluent-dependent), agricultural livestock watering
Oxygen concentration (mg/L)	7.64	6.59	10.9	6.54	3*	Aquatic and wildlife (effluent-dependent)
Turbidity (NTU)	1.3	4.35	4.16	5.29	NS	

*Dissolved oxygen concentration of 3.0 mg/L applies from three hours after sunrise to sunset, 1.0 mg/L applies from sunset to three hours after sunrise. NS = no standard.

Table 4-2. Summary table of continuous core parameter sampling metadata, Tumacácori National Historical Park, WY2015.

Quarter	Sample period	# samples	Discharge range (cfs)
Q1	10/23/2014–11/17/2014	2,401	2.2–7.3
Q2	2/25/2015–3/11/2015	1,338	6.5–14
Q3	4/30/2015–5/19/2015	1,801	1.1–3.7
Q4	NC	NC	NC

NC = not collected

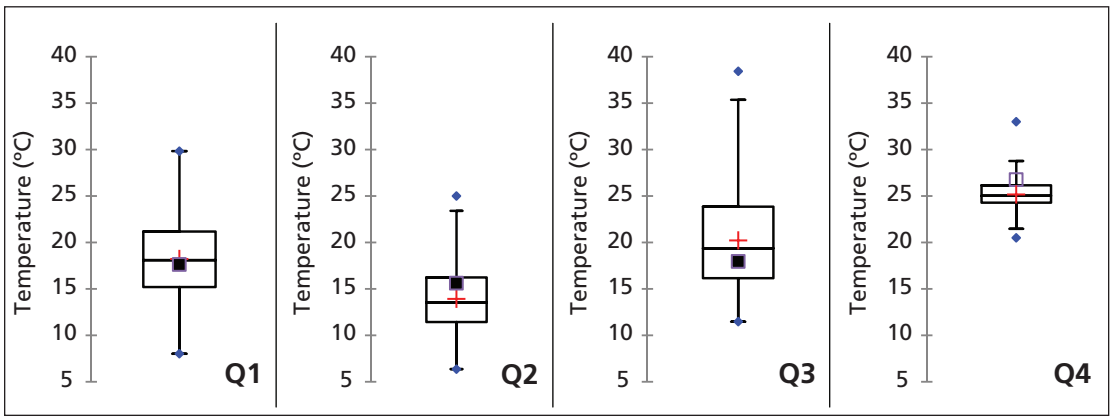

Figure 4-3. Water temperature data from the Santa Cruz River Santa Gertrudis index site at Tumacácori National Historical Park, 2011–2015.

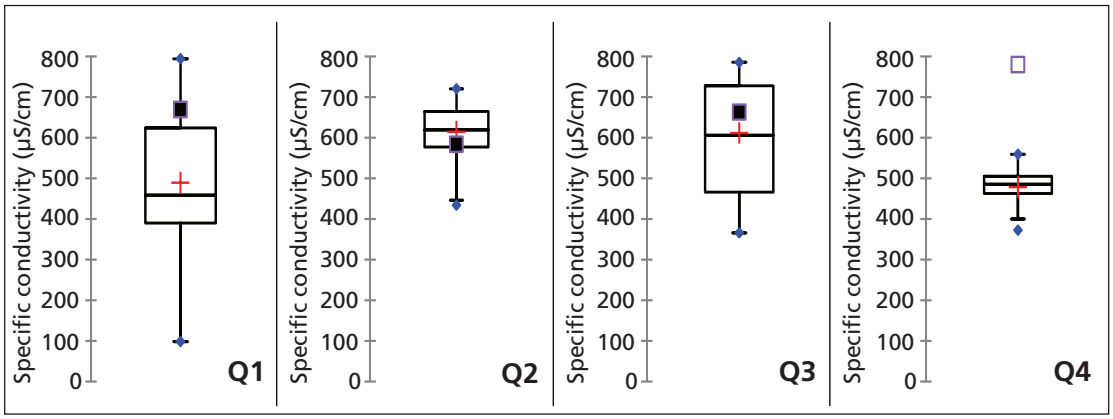

Figure 4-4. Specific conductivity data from the Santa Cruz River Santa Gertrudis index site at Tumacácori National Historical Park, 2011–2015.

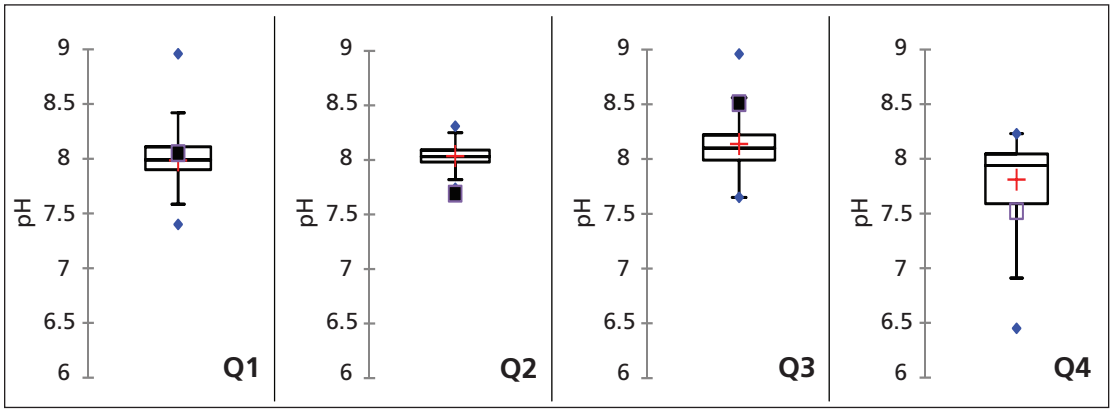

Figure 4-5. pH data from the Santa Cruz River Santa Gertrudis index site at Tumacácori National Historical Park, 2011–2015.

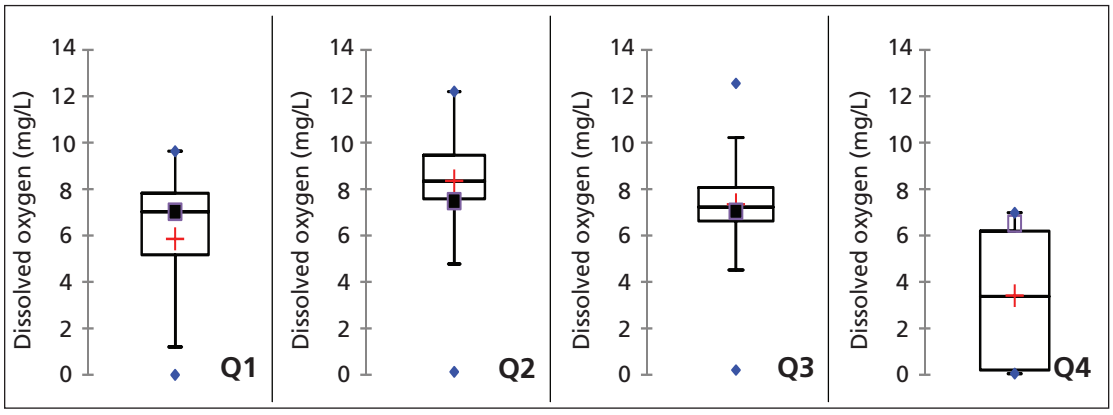

Figure 4-6. Dissolved oxygen concentration data from the Santa Gertrudis index site, Santa Cruz River, Tumacácori National Historical Park, 2011–2015.

Note: These figures include box-and-whisker plots displaying data from WY2011 to 2014 and boxes indicating median values for WY2015. The blue dots indicate maximum and minimum. Whiskers indicate limits. Boxes indicate the bounds of the first and third quartiles. The line in the box indicates the median; the red cross is the mean. The solid black block marks the median value from WY2015 sampling. The empty block for the Q4 sample indicates that the value was taken from discrete sampling due to loss of monitoring infrastructure during high flow in September 2015.

Figure 4-7. Sonde mount (a ~2-m steel beam driven into the sediment of the river bottom) at the Santa Gertrudis index site at Tumacácori National Historical Park. This mount was previously in the active channel, with the stream bottom approximately 0.75 meters below the elevation depicted in the photograph.

Because flow events can greatly influence the values recorded, and their high discharge rates can damage the sonde and other sampling infrastructure, they are avoided during sampling if possible. There were no significant flow events during the deployment periods in WY2015, as per data from USGS gage 09481740 on the Santa Cruz River at Tubac, Arizona, downstream from the index site.

The results from WY2015 were within what would be expected, with the following considerations.

The frequent high-flow events during the monsoon season limited the amount of data used for this statistical summary. For Q4, only the WY2011 data met QA/QC (quality assurance/quality control) requirements and were used for analysis.

The median specific conductivity during the Q1 sampling period was high—above the 75th percentile. The daily data showed that during the first several days of the deployment, SC was greater than 800 µS/cm, with a slow decrease until the middle of the deployment, when it stabilized at around 650 µS/cm. This caused the median value to be high. Sensor drift or fouling is possible, but comparison with QA/QC data collected during the deployment strongly indicates that this was not the case.

In all likelihood, SC was higher during the late summer due to warmer water temperature (especially at the beginning of the Q1 deployment), low flow rates, and the presence of unknown salts and other compounds. The concentrations of calcium, magnesium (see Table 4-5), sulfate (see Table 4-7), and the total dissolved solids and total suspended solids (see Table 4-6) indicate that the cause may have been dissolved sulfate salts (note the higher sulfate value) and/or other dissolved minerals, salts, or other compounds and substances. The observed SC concentration does not exceed any state or federal standards, or present an obvious hazard to human or wildlife health.

The median value of pH during Q2 was below the expected range of values. This may be the result of more precipitation during the winter months and a generally cooler winter.

The median value of pH during Q3 was high, approaching the upper limit (i.e., three standard deviations). This deployment included the beginning of May, when air and water temperature increase, along with water column and benthic productivity and changes in associated chemistry that may increase pH.

4.3.1.2 Nutrient dynamics

Nutrients sampled during WY2015 continued to be low, and represent a dramatic improvement over conditions at the park five years ago (Gwilliam et al. 2014). This is likely due to upgrades at the Nogales International Wastewater Treatment Plant (Norman et al. 2013). Instrumentation at the analytical laboratory SODN uses for nutrient analysis was upgraded this year, allowing for the reliable detection of nitrogen down to 0.10 mg/L. Nutrient concentrations were similar to or slightly lower than those observed in previous years (Table 4-3; Gwilliam et al. 2014).

4.3.1.3 Biological condition

E. coli results did not exceed the state standard for full or partial body contact during WY2015 (Table 4-4). However, it is likely that *E. coli* did exceed the state standards during and after precipitation events—times that SODN stream sampling attempts to avoid.

Table 4-3. Results of nutrient sampling, Tumacácori National Historical Park, WY2015.

Analyte	mg/L				Method	Arizona state standard	
	Q1	Q2	Q3	Q4		Measure (mg/L)	Beneficial use
Ammonia	<DL	0.11	<DL	<DL	EPA 350.1	1.97	Aquatic and Wildlife (effluent-dependent)[1,2]
Nitrate + Nitrite	3	2.8	3.7	3.9	EPA 300	3,730	Partial body contact
Nitrate-N	2.7	3.2	1.9	4.3	EPA 353.2	NS	--
Nitrogen, Total	3	3.2	1.9	4.3	Calculated	NS	--

[1]Chronic standard; [2]Calculated value using hardness

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

Table 4-4. Results of biological condition sampling, Tumacácori National Historical Park, WY2015.

Analyte	Quarter				Method	Arizona state standard	
	Q1	Q2	Q3	Q4		Measure	Beneficial use
Biochemical oxygen demand (mg/L)	ND	ND	2.7	ND	SM 5210B	NS	--
Total organic carbon (mg/L)	NC	NC	NC	2.8	SM 5752	NS	--
E. coli (MPN)	17.6	63.4	NC	217	SM 9293B	235–575 MPN/100 mL	Full/partial body contact

ND = not detected; NC = not collected; NS = no standard; SM = standard method (Eaton et al. 2005).

Past sampling at the Santa Gertrudis index site and other local sites has detected concentration estimates for *E. coli* that exceeded state standards (Gwillliam et al. 2014; Sanders et al. 2013). Caution should be exercised if any body contact with water from the Santa Cruz River is expected. 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. 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.

4.3.1.4 Metal and metalloids

During WY2015, metal concentrations were generally similar to those observed in previous years (Table 4-5; Gwilliam et al. 2014). Only parameters with results are reported. It should be noted that values for parameters not reported were not necessarily zero, but were below the detection limit of the analytical equipment, and may have been present in low concentrations.

4.3.1.5 Suspended and total sediment

During WY2015, sampling results for suspended and total sediments were in the range detected in previous years (Table 4-6; Gwilliam et al. 2014).

4.3.1.6 General water quality and inorganics

During WY2015, sampling results for general water quality and inorganics were in the range detected in previous years (Table 4-7; Gwilliam et al. 2014).

Table 4-5. Results of metal and metalloid sampling, Tumacácori National Historical Park, WY2015.

Analyte	mg/L				Method	Arizona state standard	
	Q1	Q2	Q3	Q4		Measure	Beneficial use
Dissolved metals							
Arsenic	<DL	<DL	<DL	0.0093	EPA 200.8	0.15	Aquatic and Wildlife (effluent-dependent)
Barium	NC	NC	NC	0.078	EPA 200.8	NS	
Boron	0.14	0.14	0.15	0.15	EPA 200.7	NS	
Calcium	85	70	75	81	EPA 200.7	NS	
Copper	<DL	<DL	<DL	0.0029	EPA 200.8	0.02	Aquatic and Wildlife (effluent-dependent)[1]
Iron	<DL	<DL	<DL	0.12	EPA 200.7	1	Aquatic and Wildlife (effluent-dependent)
Magnesium	14	12	13	14	EPA 200.7	NS	
Manganese	0.13	0.054	0.018	0.073	EPA 200.8	NS	
Molybdenum	<DL	<DL	<DL	0.0059	EPA 200.8	NS	
Nickel	<DL	<DL	<DL	0.011	EPA 200.8	0.11	Aquatic and Wildlife (effluent-dependent)[1]
Potassium	6.9	9	6.5	8.4	EPA 200.7	NS	
Silica	40	39	35	40	EPA 200.7	NS	
Sodium	71	68	76	74	EPA 200.7	NS	
Uranium	NC	NC	NC	0.0037	EPA 200.8	NS	
Total metals							
Aluminum	<DL	0.18	<DL	0.2	EPA 200.7	NS	
Arsenic	<DL	<DL	<DL	0.0088	EPA 200.8	0.2	Agricultural livestock watering
Barium	NC	NC	<DL	0.073	EPA 200.8	98	Partial body contact
Boron	0.16	0.14	0.14	0.16	EPA 200.7	1.9	Partial body contact
Calcium	88	73	79	80	EPA 200.7	NS	
Copper	<DL	<DL	<DL	0.0035	EPA 200.8	0.5	Agricultural livestock watering
Iron	0.1	0.17	<DL	0.2	EPA 200.7	NS	
Magnesium	14	12	13	13	EPA 200.7	NS	
Manganese	0.15	0.072	0.03	0.083	EPA 200.8	130	Partial body contact
Molybdenum	<DL	<DL	<DL	0.0055	EPA 200.8	NS	
Nickel	<DL	<DL	<DL	0.01	EPA 200.8	28	Partial body contact
Potassium	7.3	8.9	6.9	8.3	EPA 200.7	NS	
SiO2, Silica	42	40	37	41	EPA 200.7	NS	
Sodium	77	72	72	72	EPA 200.7	NS	
Uranium	NC	NC	NC	0.003	EPA 200.8	2.8	Partial body contact

[1]Calculated using hardness
DL = detection level
NS = no standard
Methods are from USEPA (1983).

Table 4-6. Results of suspended and total sediment sampling, Tumacácori National Historical Park, WY2015.

Analyte	mg/L				Methods	Arizona state standard	
	Q1	Q2	Q3	Q4		Measure	Beneficial use
Total dissolved solids	580	480	490	510	SM 2540C	NS	--
Total suspended solids	4.8	17	<DL	4.8	SM 2540D	NS	--

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

Table 4-7. Results of general and inorganic sampling, Tumacácori National Historical Park, WY2015.

Analyte	mg/L				Methods	Arizona state standard	
	Q1	Q2	Q3	Q4		Measure	Beneficial use
Alkalinity as CaCO3	210	200	190	190	SM 2320B	NS	--
Bicarbonate alkalinity as CaCO3	210	200	190	190	SM 2320B	NS	--
Chloride	57	50	55	57	EPA 300	NS	--
Fluoride	ND	0.53	0.52	ND	EPA 300	NS	--
Sulfate	120	94	110	110	EPA 300	NS	--
Total hardness	280	230	250	250	SM 2340B	NS	--

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

4.3.2 Water quantity

4.3.2.1 Mean daily discharge

A hydrograph, or a graphical representation of streamflow over time, displays the occurrence, length, and intensity of streamflow over a water year. Figure 4-8 displays the hydrograph on the Santa Cruz River at Tubac for WY2015. The largest individual flow events occurred during the monsoon season, in response to local and regional precipitation events. The large flow event on September 22, 2015, was in response to a precipitation event totaling 2.48".

Although precipitation in WY2015 was higher than in recent years (see Chapter 2), the mean daily discharge for WY2015 was 10.66 cfs (cubic feet per second), about half the gage-record average of 25.85 cfs (SE 5.58). The difference may be accounted for by the lower-than-average winter precipitation and a decrease in discharge from the NIWTP.

4.3.2.2 Seasonal proportional discharge

At Tumacácori NHP, the seasons for water quantity are defined as winter (October 11–December 7), spring (December 8–April 30), summer (May 1–July 4), and monsoon (July 5–October 10) (NPS 2003). In WY2015, the monsoon season contributed a greater proportion of annual streamflow than the seasonal annual mean; over half (55%) of the flow in the Santa Cruz River in WY2015 occurred during the monsoon season (Figure 4-9). This result was mainly in response to several intense precipitation events during July–October 2015 (see Chapter 2).

4.3.2.3 Mean monthly stream flow

The WY2015 data from the USGS gage on the Santa Cruz River at Tubac showed that flow was uniformly lower than the gage average for every month of WY2015, except September (Figure 4-10), likely due to reduced effluent discharge.

4.3.2.4 Peak flow events

The peak flow during WY2015 was 1,410 cfs, on September 22, 2015 (Figure 4-11). Peak flow typically occurs in July and August, making this one later than most.

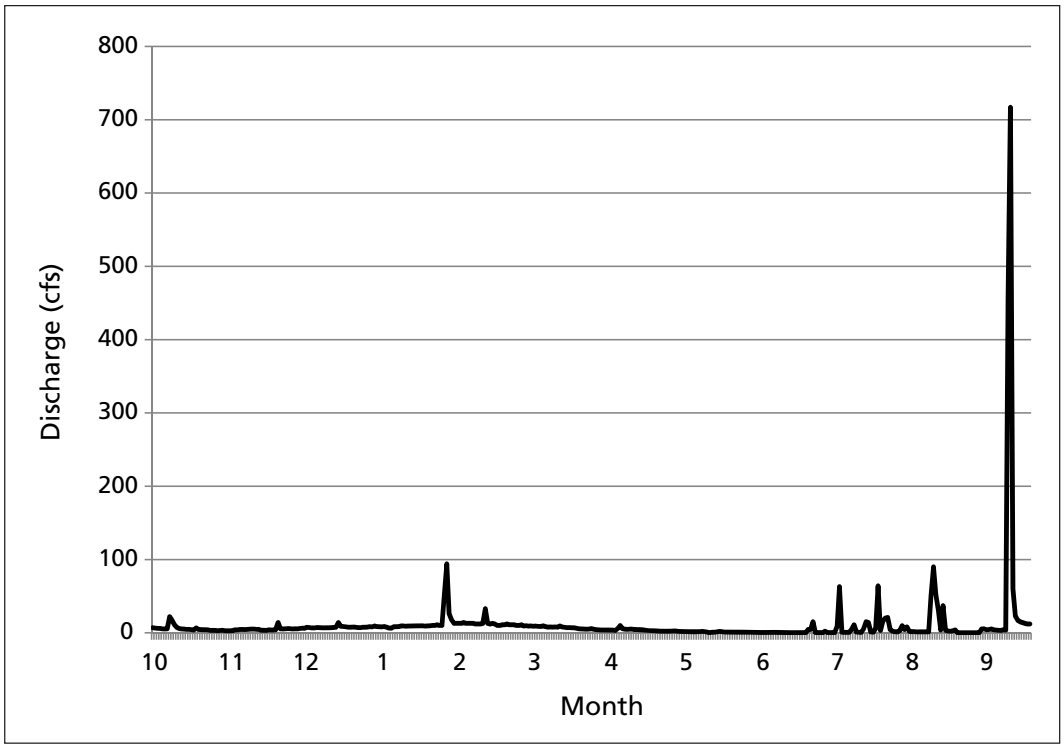

Figure 4-8. Hydrograph from USGS stream gage 09481740 at Tubac, Arizona, WY2015.

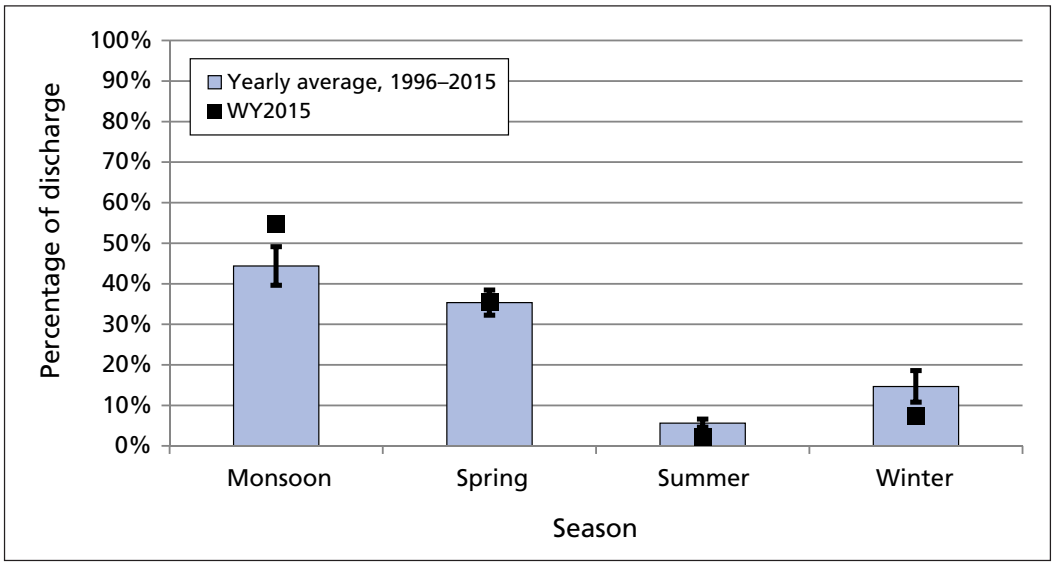

Figure 4-9. Seasonal proportion of discharge, Tumacácori National Historical Park, WY1996–2015. The source of these data is USGS stream gage 09481740 at Tubac, Arizona. The blue bars indicate the mean proportion of summed daily average discharge by season for the gage record (October 1995–present). Error bars indicate standard error. The black boxes indicate the mean proportion of summed daily average for WY2015.

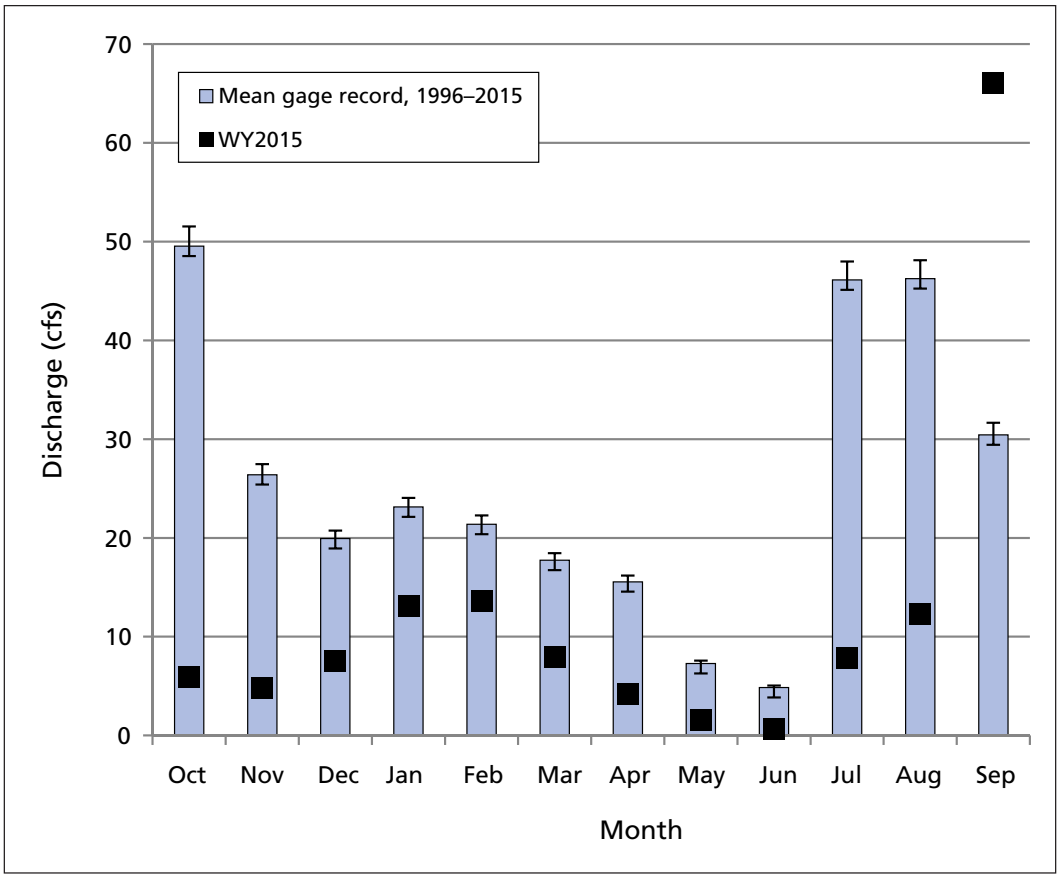

Figure 4-10. Monthly mean daily discharge, Tumacácori National Historical Park, WY1996–2015. The blue bars indicate the mean daily discharge (cubic feet per second) for the gage record (October 1995–present). Error bars indicate standard error. Black boxes indicate the monthly mean discharge for WY2015. Data are from USGS stream gage 09481740 at Tubac, Arizona.

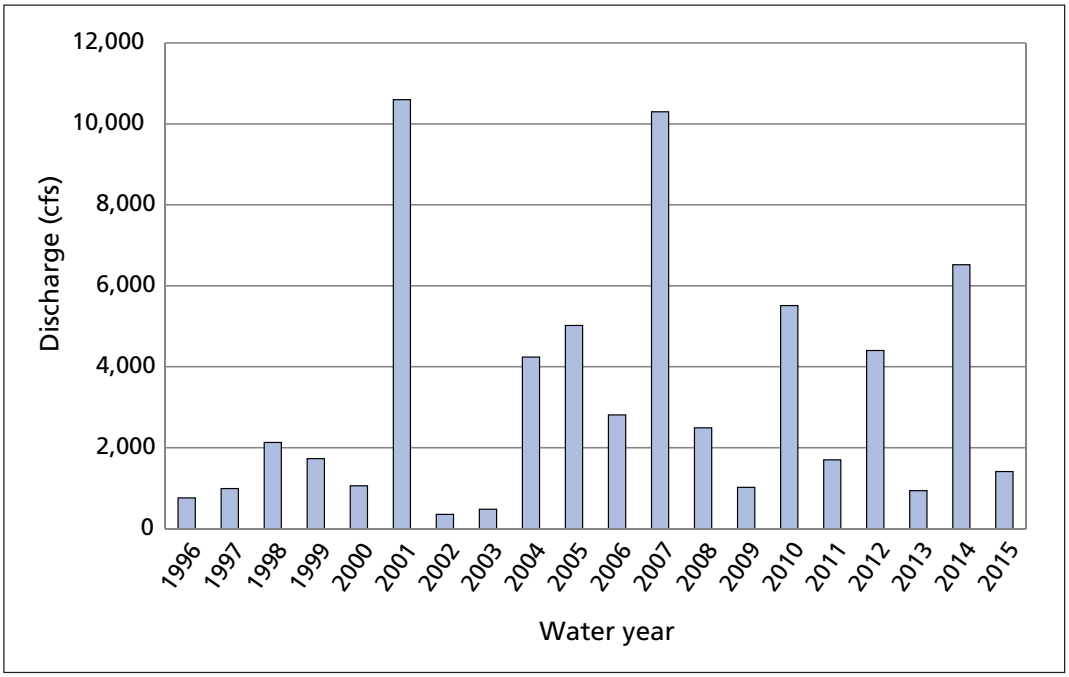

Figure 4-11. Annual peak flow, Tumacácori National Historical Park, WY1996–2015. The blue bars indicate the peak maximum recorded discharge by water year, 1996–2015. Data from 2002 and 2003 are estimated based upon the maximum daily average. Data from 2015 were provisional at time of publishing. Data are from USGS stream gage 09481740 at Tubac, Arizona.

4.3.3 Aquatic macroinvertebrates and habitat

The results from macroinvertebrate samples collected at Tumacácori NHP during early June 2015 were not available before publication of this report. When these data become available, they will be reported with the accompanying environmental data.

4.3.4 Fish

The collaborative fish-sampling project on the lower Santa Cruz River has been occurring since 2008, including sampling at the Santa Gertrudis index reach at Tumacácori NHP. In WY2015, surveys found 159 fish (8.49 fish/unit effort; Table 4-8). All fish sampled were longfin dace (*Agosia chryogaster*). This number indicates a continued presence of longfin dace at the Santa Gertrudis sample reach (see Figure 4-1), although in WY2015 the number was smaller than in recent years (AGFD 2014).

The reason for these lower numbers is likely the fish responding to a high flow event of approximately 5,000 cfs on September 19, 2014. Many of the fish sampled exhibited evidence of current or recent breeding status (AGFD 2014).

Table 4-8. Results of fish sampling at the Santa Gertrudis index reach, Tumacácori National Historical Park, WY2009–2015.

				Electrofishing			Seine		
		Total number		Effort	Catch per minute			Catch per m²	
Water year	Method*	AGCH	GAAF	(minutes)	AGCH	GAAF	Effort (m²)	AGCH	GAAF
2009	Electrofishing	0	0	7.80	0.00	0	--	--	--
2010	Seine	10	6	--	--	--	500	0.02	0.01
2011	Seine	43	0	--	--	--	520	0.08	0.00
2012	Electrofishing	510	11	14.47	35.25	0.76	--	--	--
2013	Seine	574	0	--	--	--	320	1.79	0.00
2014	Electrofishing	167	0	7.18	23.25	0	--	--	--
2015	Electrofishing	159	0	18.73	8.49	0	--	--	--

*Two different sampling methods were employed, depending on the status of the water depth. Sampling was conducted in November of each water year.

AGCH = longfin dace (*Agosia chryogaster*); GAAF = western mosquitofish (*Gambusia affinis*).

5 Conclusions

5.1 Climate

Globally, 2015 was the hottest year on record (NOAA 2016). By contrast, local conditions at Tumacácori NHP were mixed, with cool-season minimum and maximum air temperatures generally well above normal, followed by a relatively cool fore-summer (May–June), and monsoon maximum temperatures below normal. Annual precipitation was nearly 150% of normal (23.12 vs 16.56"), with the largest increases occurring in June—a month in which little to no rainfall typically occurs. Increased rainfall and mixed air temperatures reduced the reconnaissance drought index relative to recent years, indicating a degree of recovery from the drought of the early 2000s.

Long-term climate trends are important to the park ecosystem. However, stochastic events—such as large, monsoon-season rain events and the drying events seen in the Santa Cruz River in 2013 (SODN 2013)—are also important drivers of change.

5.2 Groundwater

The groundwater at Tumacácori NHP includes two major components, the shallow and deep aquifers. The shallow aquifer is unconfined and composed of the alluvium under the river and adjacent riparian area. The deep aquifer is below the shallow aquifer and is confined by a combination of permeable and impermeable layers of silt, sand, cobble, boulders, and caliche. These aquifers are responding both to the long-term drought conditions of the region and to large precipitation events during the water year.

The shallow aquifer typically varies approximately two feet annually, responding to variations in precipitation, streamflow, and evapotranspiration. Higher water levels are seen in the winter, and lower levels in the summer and monsoon seasons. The water levels in the shallow well were at the lowest on record (June 2007–present) during the pre-monsoon period (May–early June) in WY2014. However, monsoon events near the end of WY2014, coupled with the above-average precipitation during the winter and late spring of WY2015, brought shallow-aquifer water levels back to near average.

Because the deep well at Tumacácori NHP is thought to be damaged, analysis of the data from this well is pending an evaluation of the overall quality of data from this site. There are not enough data available from the drinking-water well to allow valid comparisons with data from the shallow well at this time.

5.3 Surface water

5.3.1 Water quality

Four sampling visits were made to the Santa Cruz River index site in WY2015, one during each quarter. There were 247 individual analyses of water samples, 88 of which were associated with Arizona state water quality standards. There were no exceedances observed.

Nutrient concentrations remained low, including ammonia, which had been an acute problem before the NIWTP was upgraded in 2009. Metals and other inorganic analytes were detected in similar concentrations to those of past sampling years.

A logging multiparameter water-quality instrument was deployed three times at Tumacácori NHP. Each deployment lasted 2–3 weeks. SODN typically attempts to deploy this instrument once each quarter. However, the mount to which the instrument is attached was damaged during a flow event. That, combined with sedimentation, prevented deployment during the fourth quarter. Despite only three deployments, over 15,000 measurements were collected.

The median value of temperature and dissolved oxygen concentration from the WY2015 deployments were within the expected range based on similar past deployments (WY2011–2014).

The median values for pH and specific conductivity were outside the expected range (percentiles 25–75) during the three deployment periods. Specific conductance was outside the expected range during the first-quarter deployment, which followed a high-flow event. (No high flow events occurred during the deployment.) Closer examination of the

discrete samples seems to indicate the possible presence of a dissolved sulfate salt or other unknown dissolved analyte during this deployment. The higher specific conductivity did not exceed any state or federal standards, nor do any other measurements.

During the second-quarter deployment, the pH median value was below the typical expected range. Lower stream flow and generally cooler atmospheric temperatures may have impacted water-column productivity and chemistry; however, definite reasons for this lower value—and the higher value in Q3—are unknown at this time. The pH observations may be indicative of a trend toward an increase in variability of the core water parameters, driven by the observed decreases in streamflow and increases in atmospheric temperatures. This possible increase in variability will be carefully considered in future reports as more data become available.

5.3.2 Water quantity

The main driver of the aquatic ecosystem at Tumacácori NHP is the consistent flow of 10–12 million gallons per day of treated effluent from the NIWTP, combined with stochastic, high-flow monsoon events. During WY2015, the amount of river flow was lower than the mean gage record (see Figure 4-10) in every month except September (due to the large, monsoon-related flow event). The curve generally follows the gage record mean, though at an overall lower level.

This pattern indicates that there is likely a systematic reason for the consistently lower flow. Over the last few years, the NIWTP has contributed less effluent into the Santa Cruz River because a new treatment plant, in Mexico, has begun treating and redirecting a portion of the Ciudad Nogales waste stream back into Mexico. This decrease of effluent, combined with increased temperatures, has led to an increase in direct evaporation from the surface water of the river, and in evapotranspiration for riparian vegetation that use groundwater contributed by the river.

5.3.3 Fish

WY2015 was the seventh year in which SODN worked with Arizona Game and Fish and other partners to sample fish on the Upper Santa Cruz River (i.e., Chavez Siding Crossing to Nogales Wash). One of the sample sites is a reach at the Santa Gertrudis Crossing that includes the Tumacácori NHP index site.

Since its return in 2009, following the upgrade to the NIWTP, the native longfin dace (*Agosia chryogaster*) continues to be encountered. The decrease in the metric (fish/min) seen in WY2015 may be related to the large flow event shortly before sampling occurred. The non-native western mosquitofish (*Gambusia affinis*), which was detected most recently at the Santa Gertrudis site in WY2012, has not been detected at any sample sites since that year. Apart from longfin dace and mosquitofish, no other fish taxa have been detected since 2009.

During the SODN fish inventory in 2001 and 2002 (Powell et al. 2005), nine fish taxa were detected at Tumacácori NHP. Four were natives, including the Gila topminnow, Sonora sucker, and desert sucker. Four were non-native, including the mosquitofish, and one was a hybrid. Longfin dace, adapted to exploit new habitat, are typically observed to follow the water as it advances up intermittent streams. It is suspected that the improvements of water quality since 2009, and subsequent changes to the chemistry (e.g., decrease in nutrients) and ecology (e.g., suspected decrease in organic layer on river bottom; Treese et al. 2009) of the Santa Cruz River may lead to an increase in native fish diversity in the near future.

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