



Status of Climate and Water Resources at Montezuma Castle and Tuzigoot National Monuments

Water Year 2016

Natural Resource Report NPS/SODN/NRR—2017/1551



ON THE COVER

Wet Beaver Creek, Montezuma Castle National Monument (Well unit). NPS/A.W. Biel

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Executive Summary

Climate and hydrology dramatically shape ecosystem structure and function, particularly in arid and semi-arid ecosystems. Understanding changes in climate and water resources is central to assessing the condition of park biota as well as key cultural resources. This document summarizes climate and water resource conditions for water year (WY) 2016 for Montezuma Castle and Tuzigoot national monuments, two small National Park Service units in central Arizona. Overall annual precipitation was 92% of normal for Montezuma Castle National Monument (NM) and 107% of normal for Tuzigoot NM. Precipitation at both parks was below normal for the fall and winter of WY2016, while for the spring and summer it was close to average at Montezuma Castle and greater than normal at Tuzigoot. The reconnaissance drought index for both parks reflected the extended regional drought that began in 2000 and has continued through WY2016. Both parks experienced higher numbers of extremely cold days than normal in WY2016. Extremely warm days were also more plentiful at Tuzigoot NM. Streams data are collected at Beaver Creek (Montezuma Castle NM, Castle unit), Wet Beaver Creek (Montezuma Castle NM, Well unit), and the Verde River (Tuzigoot NM). At Wet Beaver Creek, mean daily discharge during WY2016 was well below the gauge record mean. Recorded flow at the Verde River gauge at Tuzigoot NM was either at or below historic lows in WY2016—well below the 5th percentile for a majority of the year. Flow data for Beaver Creek were provisional. There were four exceedances of state water quality standards for *E. coli* and arsenic during WY2016, resulting in an average of 98.4% compliance with standards across the three units. Macroinvertebrate values from the Beaver Creek and Verde River index sites both scored in the “attaining” category for the Arizona Index of Biological Integrity (AZIBI) for warmwater streams. Data from the Wet Beaver Creek index reach fell in the “inconclusive” range, though there was no obvious observed decrease in water quality at the Wet Beaver Creek site.

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We thank Chief of Resource Management Matt Guebard, biologists Tina Greenawalt and Fraser Watson, Superintendent Dorothy FireCloud, and the staff of Montezuma Castle and Tuzigoot national monuments for their on-site support of this 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 and groundwater is central to assessing the condition of park biota as well as key cultural resources.

This document summarizes climate and water resource conditions for water year (WY)

2016 (October 2015–September 2016) for Montezuma Castle and Tuzigoot national monuments, both small National Park Service units (341 and 329 ha, respectively) in central 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

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 NPS (National Park Service) manages and protects.

2.2 Methods

Montezuma Castle National Monument (NM) has operated a National Oceanic and Atmospheric Administration (NOAA) Cooperative Observer Program (COOP) weather station (MONTEZUMA CASTLE NM, ID#25635) since 1938. Tuzigoot NM has operated a similar station (TUZIGOOT, ID#028904) since 1911. The record from these stations provides a reliable, long-term climate dataset used for the analyses in this report.

In 2014, the Sonoran Desert Network (SODN) established Davis weather stations at both units of Montezuma Castle NM, and at Tuzigoot NM to provide real-time weather conditions (Figure 2-1). All three stations are linked to the NOAA Citizen Weather Observer Program (CWOP) and accessible through www.climateanalyzer.org. See the SODN climate monitoring protocol (Hubbard et al. in prep) for details on methods and data handling.

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

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 stations at Montezuma Castle (left) and Tuzigoot (right) national monuments. Data are available through www.climateanalyzer.org.

the question, “How dry is dry?” (Tsakiris and Vengelis 2005). Using the period of record (1957–present), the climate of Montezuma Castle NM is semi-arid. The climate of Tuzigoot NM (1946–present) is arid, though near the threshold of semi-arid (see Figure 2-2).

2.2.1 Results and discussion

Data quality from the COOP stations in WY2016 was excellent. Data were missing from only seven days at Montezuma Castle NM and six days at Tuzigoot NM.

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

Overall annual precipitation was 92% of normal for Montezuma Castle NM (13.2" vs. 14.4"). Overall annual precipitation was 107% of normal for Tuzigoot NM (13.58" vs. 12.71").

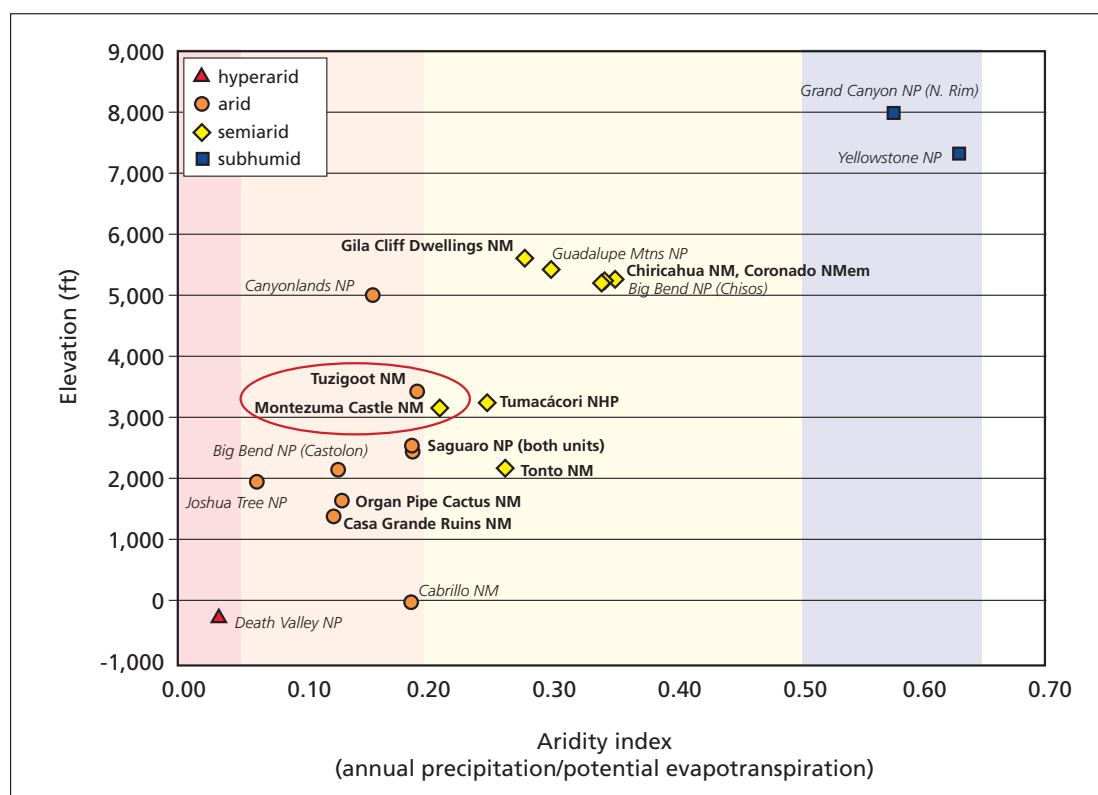


Figure 2-2. Aridity index vs. elevation of selected southwestern national parks, including Montezuma Castle and Tuzigoot national monuments. Figure from Hubbard and others (in prep).

2.2.1.2 Cool season (October–March)

At Montezuma Castle NM, overall precipitation was below normal (75% or -1.8") for the fall and winter of WY2016. December, February, and March were extremely dry (0–0.21") (Figures 2-3 and 2-4). Maximum and minimum temperatures were cooler than normal in November–January, while maximum temperatures in February and March were greatly above normal. As is usually the case, mean monthly low temperatures were below freezing from November to February.

At Tuzigoot NM, precipitation was below normal (63% or -2.35") for the fall and winter of WY2016. December, February, and March were extremely dry, each with 0.07" or less of precipitation (Figures 2-5 and 2-6). Maximum air temperatures for February and March were warmer than normal (+10.7°F and +7.0°F, respectively). Maximum and minimum air temperatures for the other cool-season months were generally close to normal (within -2 to 4°F of normal).

2.2.1.3 Warm season (April–September)

At Montezuma Castle NM, overall precipita-

tion was close to average (109%, +0.65") for the spring and summer months in WY2016. Only September rainfall was below the historic normal. Mean maximum high temperatures were generally lower than normal in the early part of the warm season (except for a period of above-average temperatures in June), then became closer to normal in July.

At Tuzigoot NM, the spring and summer of WY2016 were wetter than normal (150%, +3.22"). Both May and August precipitation were about 300% above normal, while July was unusually dry (32% of normal). Rainfall in August was 6.24", accounting for 46% of the total annual rainfall for WY2016. This led to an overall annual precipitation that was close to normal for Tuzigoot NM, despite the low rainfall in the cool season. Warm-season maximum and minimum temperatures were variable. The mean maximum air temperature in June was 6.5°F warmer than usual, while the other months were generally close to normal (within -2 to 4°F of normal).

2.2.1.4 Reconnaissance Drought Index

Reconnaissance Drought Index (RDI; Tsai-

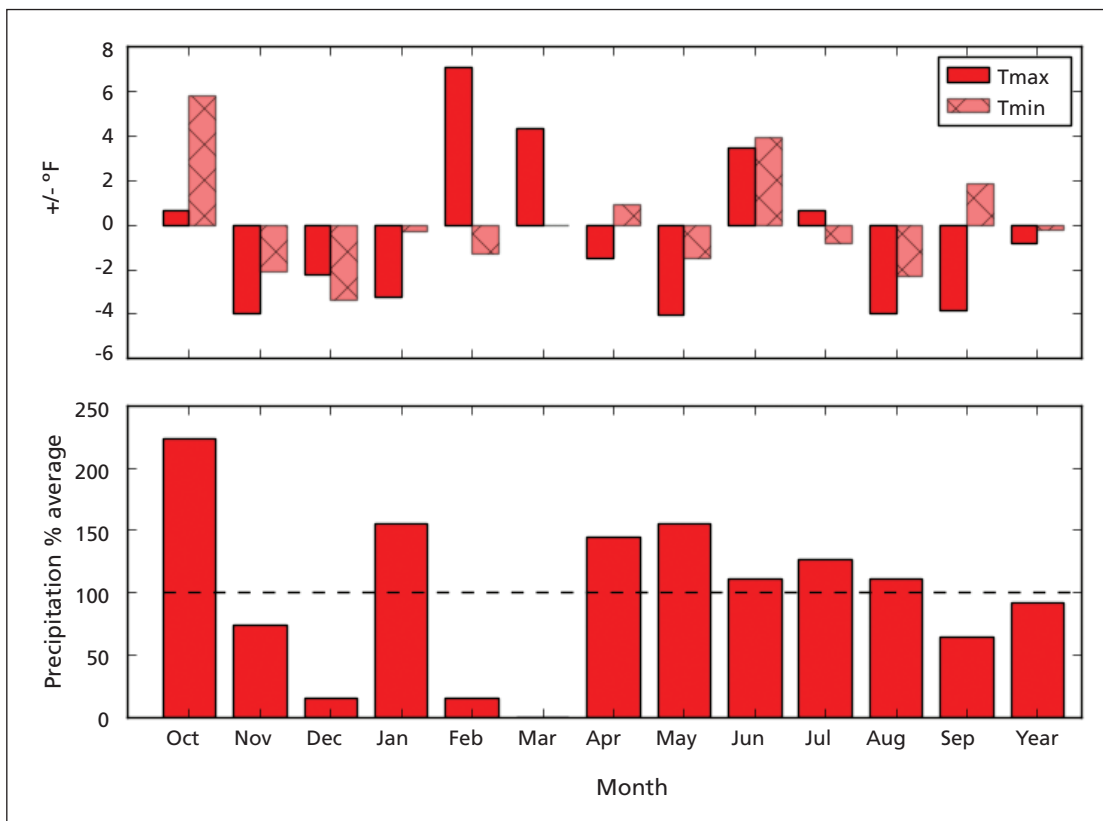


Figure 2-3. Departures from 30-year (1981–2010) normal minimum and maximum air temperature and precipitation, Montezuma Castle NM, WY2016. Graphics generated by climateanalyzer.org.

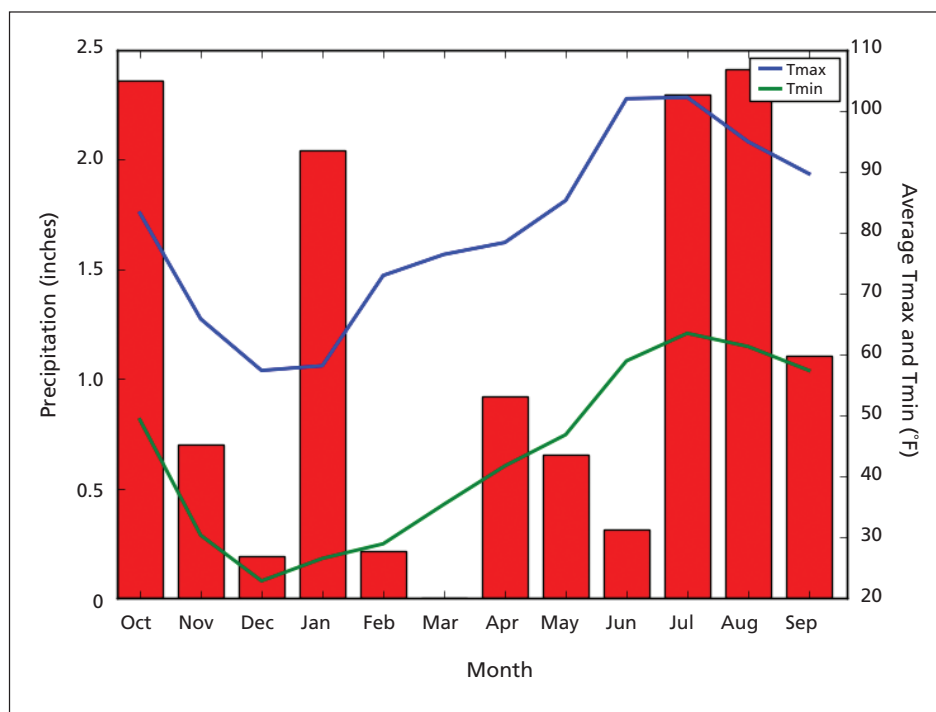


Figure 2-4. Average monthly maximum and minimum temperatures and monthly precipitation totals for Montezuma Castle NM, WY2016. Graphics generated by climateanalyzer.org.

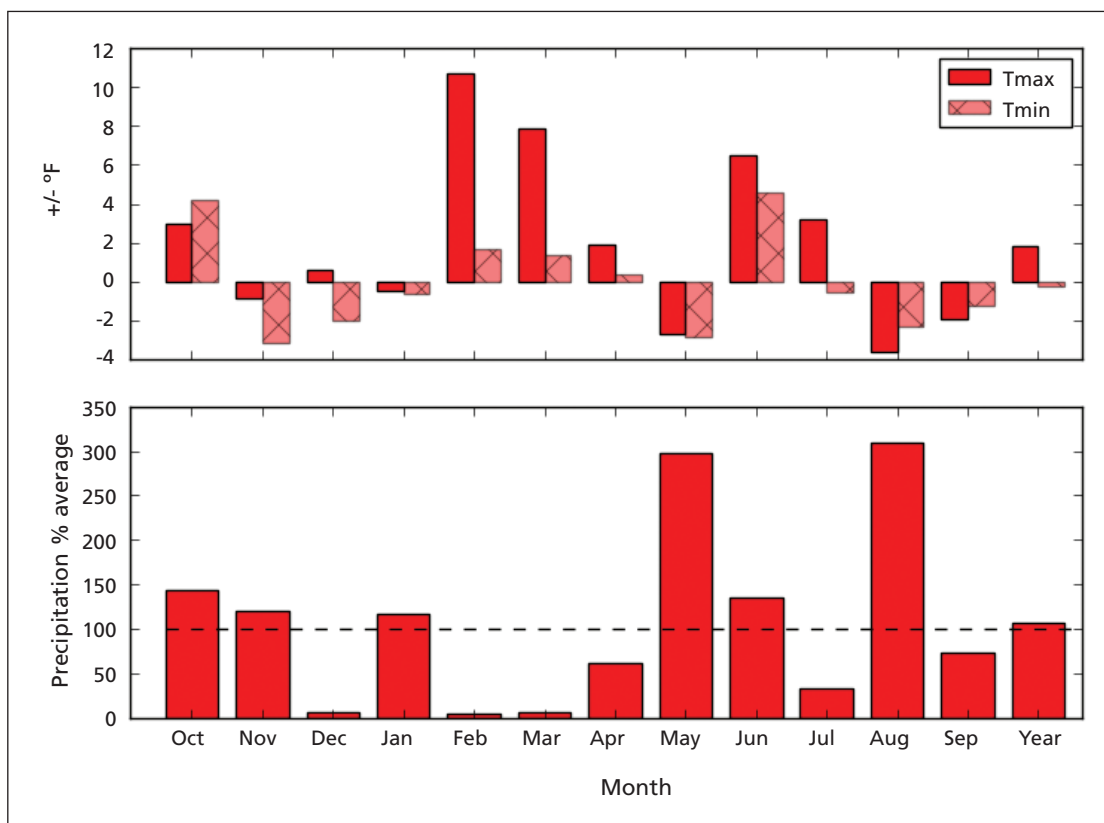


Figure 2-5. Departures from 30-year (1981–2010) normal minimum and maximum air temperature and precipitation, Tuzigoot NM, WY2016. Graphics generated by climateanalyzer.org.

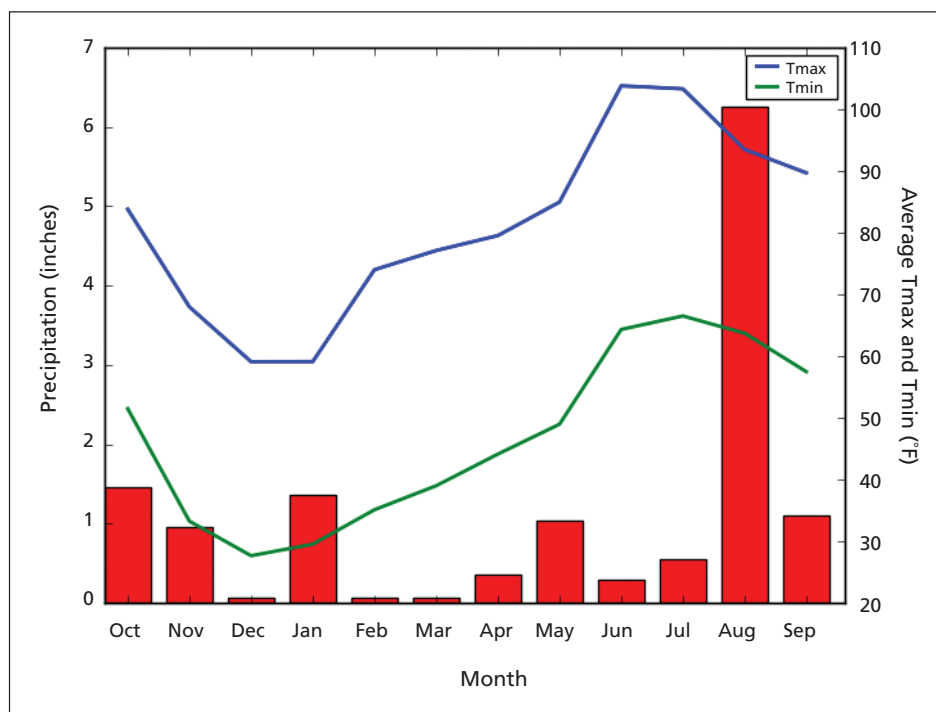


Figure 2-6. Average monthly maximum and minimum temperatures and monthly precipitation totals for Tuzigoot NM, WY2016. Graphics generated by climateanalyzer.org.

kiris and Vengelis 2005) provides a measure of drought severity and extent relative to the long-term climate based on the ratio of average precipitation to average potential evapotranspiration over shorter periods of time (seasons to years).

The reconnaissance drought index for Montezuma Castle NM reflected the extended regional drought that began in 2000 and has continued through WY2016, although the evaporative demand was somewhat balanced with precipitation (Figure 2-7). The five-year moving mean of total annual precipitation for 1981–2016 (Figure 2-8) demonstrated the continued, multi-year precipitation deficit.

RDI for Tuzigoot NM also reflected the extended regional drought since 2000 (Figure 2-9), although conditions did begin a limited recovery in WY2015 that continued in 2016, from the perspective of both precipitation and evaporative demand. The five-year running mean of total annual precipitation for water years 1981–2016 (Figure 2-10) suggested that these recent “wet” years have started to remedy the multi-year precipitation deficit.

2.2.1.5 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. Although high air temperatures are a defining feature of warm deserts, extreme frost events also have important consequences for the Arizona–New Mexico Mountains ecosystems. In particular, sustained low air temperatures can damage or even kill long-lived keystone plants, such as the large deciduous-tree species (Turner et al. 2003) that dominate the riparian wood-

lands of Montezuma Castle NM, the mesquite and cold deciduous trees (Turner et al. 2003) that dominate the bosque and riparian woodlands of Tuzigoot NM, and the aquatic organisms that live in river environments. Extreme precipitation events can also cause localized flooding and erosion (Figure 2-11), spur or inhibit plant productivity and reproduction, and modify animal behavior.

At Montezuma Castle NM, extremely cold days ($<22^{\circ}\text{F}$, 5th percentile of 1981–2010 data) occurred slightly more often than normal (24 vs. 22.3 ± 1.4 days) in WY2016, and were of longer duration than normal (4 consecutive days vs. 2.5 ± 0.1 days). No days were below 32°F all day. The number of extreme precipitation events ($>1''$) in WY2016 was approximately normal (2 vs. 2.2 days for 1981–2010). Large events occurred on October 20 (1.03") and January 6 (1.04").

In terms of both low and high temperatures, Tuzigoot NM experienced more extreme days than normal in WY2016. Extremely cold days ($<26^{\circ}\text{F}$, 5th percentile of 1981–2010 data) were more plentiful (23 days vs. 14.6 ± 1.1 days), and were of slightly greater duration (2.3 consecutive days vs. 2.1 ± 0.1 days). No day remained below 32°F all day. Extremely warm days ($>103^{\circ}\text{F}$, 95th percentile) were also more plentiful (36 days vs. $16.6 \text{ days} \pm 1.6$). The number of extreme precipitation events ($>1''$) in WY2016 was somewhat below normal (1 vs. 1.8 days for 1981–2010) normal, with one large event on August 1 (1.2"). There was precipitation on 14 days in August, and the rainfall amount for that month (6.4") exceeded the 10-year return frequency. This means the high August rainfall total was unusual but not extremely rare; an event expected to occur once every 10 years, based on the historic record.

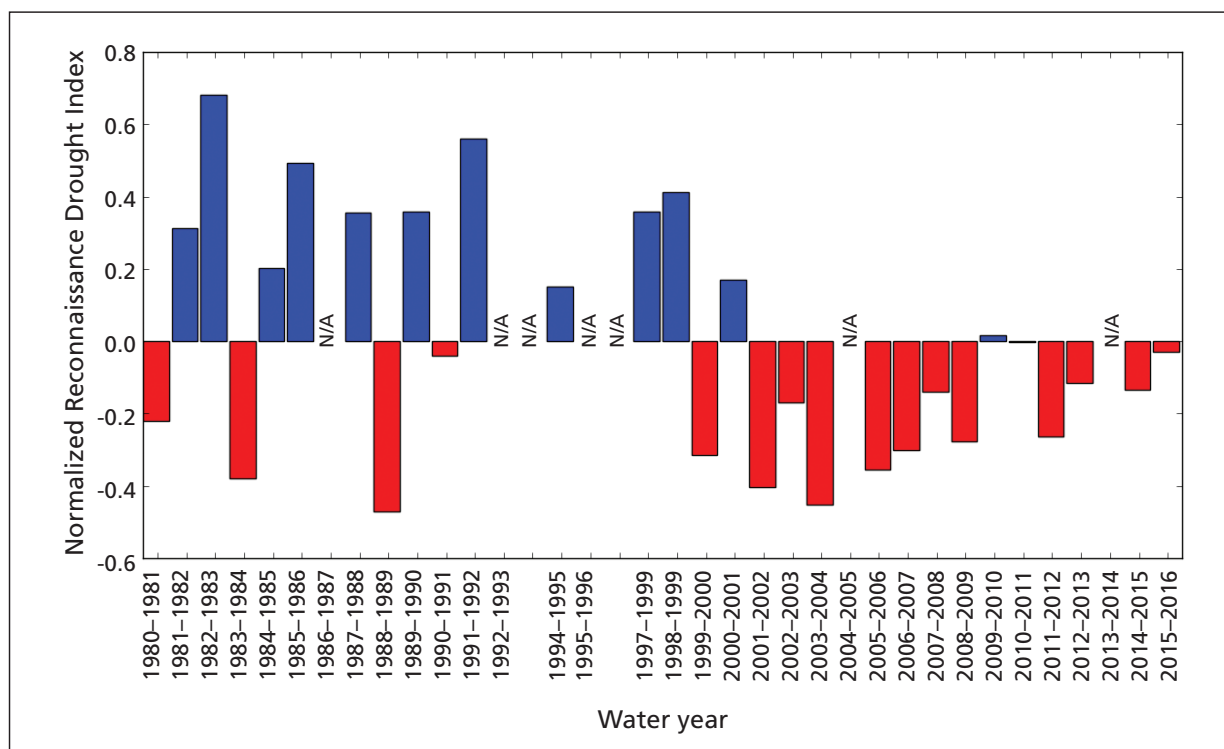


Figure 2-7. Reconnaissance Drought Index (RDI) for Montezuma Castle NM, water years 1981–2016. N/A = insufficient data to generate reliable RDI estimates. Graphics generated by climateanalyzer.org.

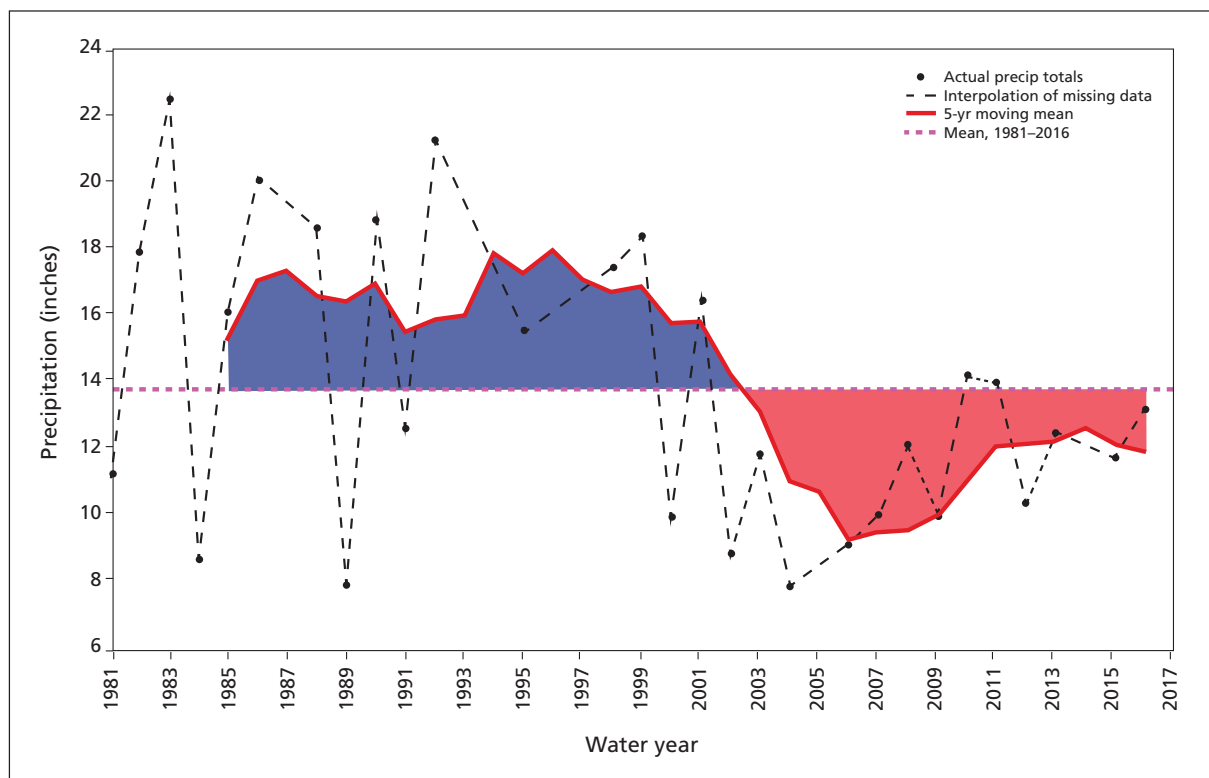


Figure 2-8. Five-year moving mean of annual precipitation, Montezuma Castle NM, 1981–2016. The moving mean (solid red line) is based on a timeseries with 19.4% (7 of 36) missing values, and includes the current year and previous four years. Missing years are linearly interpolated (dashed grey lines). Graphics generated by climateanalyzer.org.

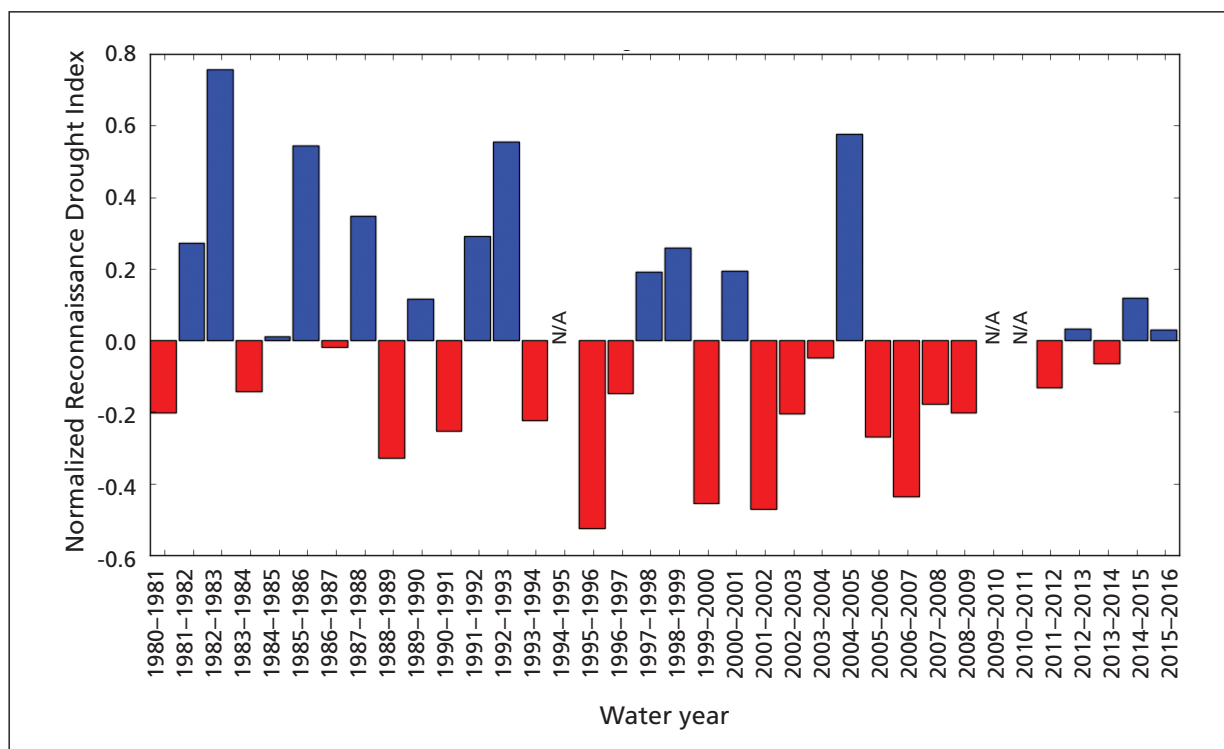


Figure 2-9. Reconnaissance Drought Index (RDI) for Tuzigoot NM, water years 1981–2016. N/A = insufficient data to generate reliable RDI estimates. Graphics generated by climateanalyzer.org.

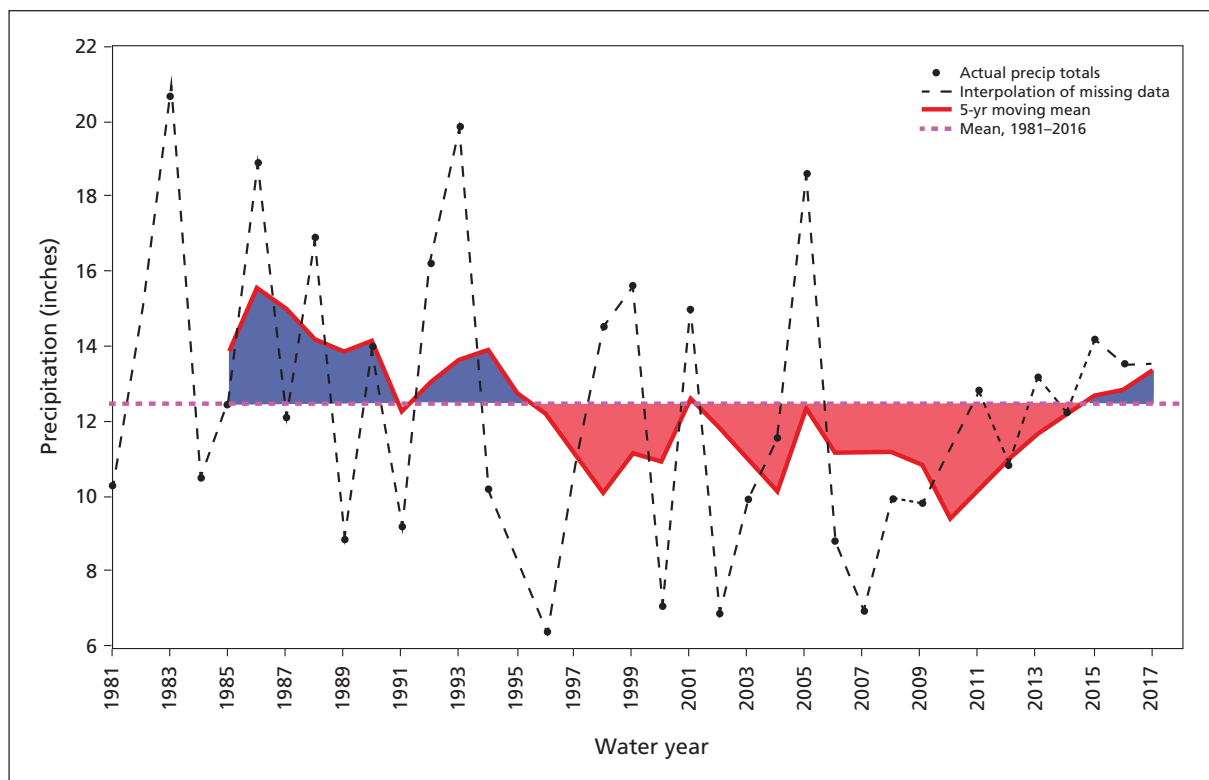


Figure 2-10. Five-year moving mean of annual precipitation, Tuzigoot NM, 1981–2015. The moving mean (solid red line) is based on a timeseries with 8.3% (3 of 36) missing values, and includes the current year and previous four years. Missing years are linearly interpolated (dashed grey lines). Graphics generated by climateanalyzer.org.



Figure 2-11. Channel cutting along the Tavasci outflow ditch following heavy rain, Tuzigoot NM. NPS photo.

3 Surface Water

3.1 Background

The Verde River and two of its tributaries flow through Montezuma Castle and Tuzigoot national monuments. The Verde River flows through Tuzigoot NM, Beaver Creek flows through the Castle unit of Montezuma Castle NM, and Wet Beaver Creek flows through the Well unit of Montezuma Castle NM. These streams are part of a large hydrologic drainage basin that directs surface and ground-water flow from the upper and lower Verde River watersheds, part of the Transition Zone between the Colorado Plateau Structural Province and the Basin and Range Structural Province in Arizona (Blasch et al. 2006). They are an important part of the cultural and ecological resources of both monuments. SODN has systematically collected surface-water data at Montezuma Castle and Tuzigoot national monuments since WY2011.

3.2 Methods

A brief description of the data collection and processing methodologies followed by SODN staff at Montezuma Castle NM and Tuzigoot NM 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).

All samples and field data in WY2016 were collected at the index reach on Beaver Creek (Figure 3-1), Wet Beaver Creek (Figure 3-2), or the Verde River (Figure 3-3). These figures indicate the location where water quantity and water quality samples are collected (index point), where macroinvertebrates are collected (index reach), and show the boundaries of the overall sampling unit (stream segment).

3.2.1 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,

Terms

The **stream segment** is a relatively homogenous (physically, chemically, and biologically), >150-meter length of stream bounded by a tributary, administrative boundary, or other geographic feature (Fitzpatrick et al. 1998).

Within each stream segment is one **index reach**, generally a 100–300-meter stretch of stream.

Also within each stream segment—preferably, within the index reach—is an **index site** where water quantity and water quality data are collected.

we noted hydrologic conditions and sampled core parameters using the following methods:

- On arrival at the site, a multi-parameter water quality meter (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 duration of the 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 used a logging multi-parameter instrument (YSI XLM600 V2) to collect data on temperature, pH, specific conductivity, and dissolved oxygen at 15-minute intervals for a minimum of two weeks every quarter.

3.2.2 Water quality 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 U.S. Geological Survey's 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 WY2016, that lab was TestAmerica, in Phoenix, Arizona.



Sampling Sites, Beaver Creek

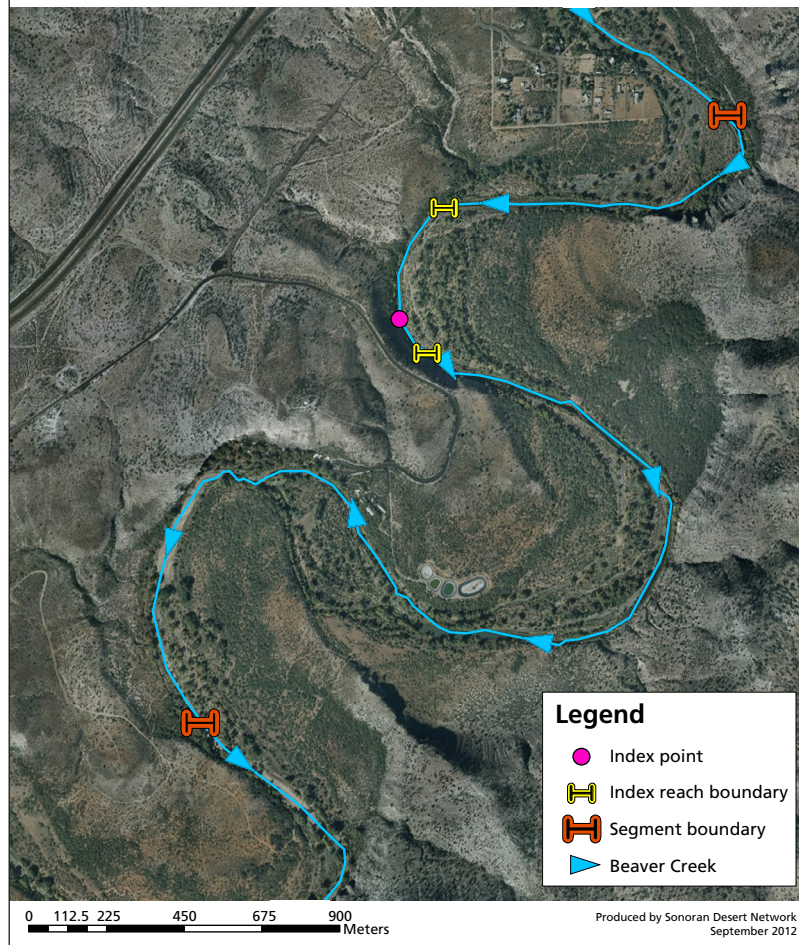


Figure 3-1. Sampling sites on Beaver Creek, Montezuma Castle NM (Castle unit).

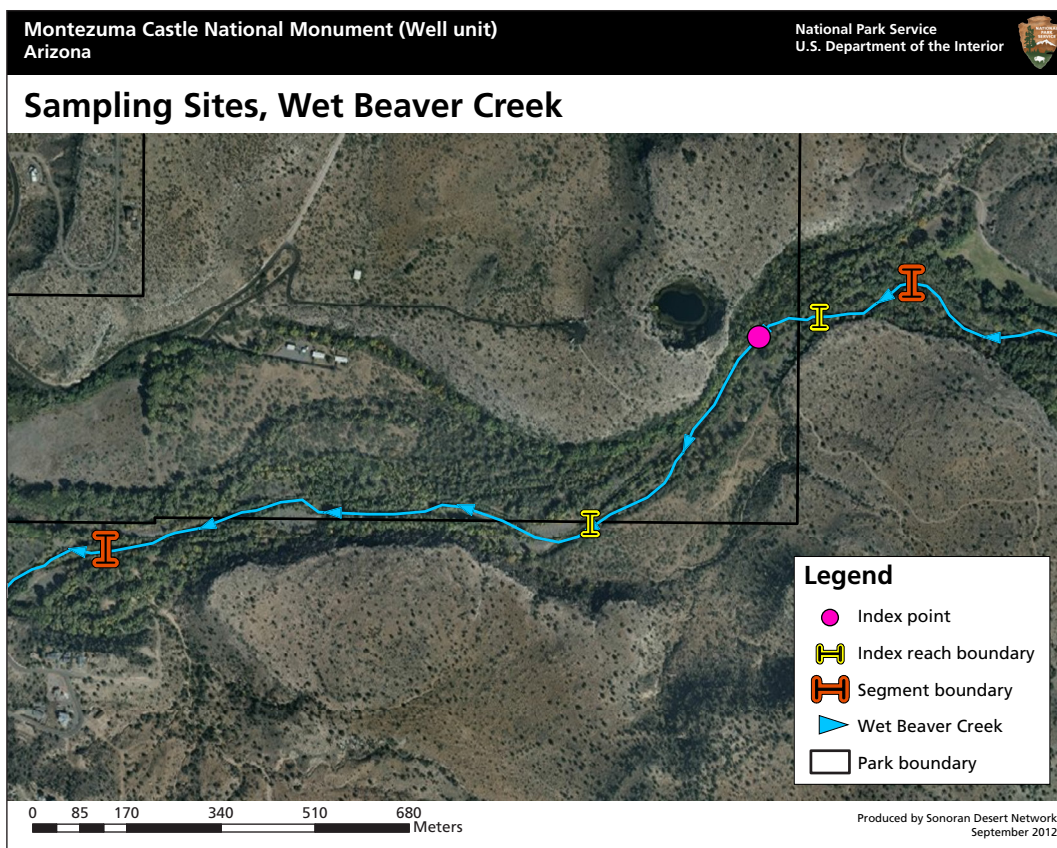


Figure 3-2. Sampling sites on Wet Beaver Creek, Montezuma Castle NM (Well unit).

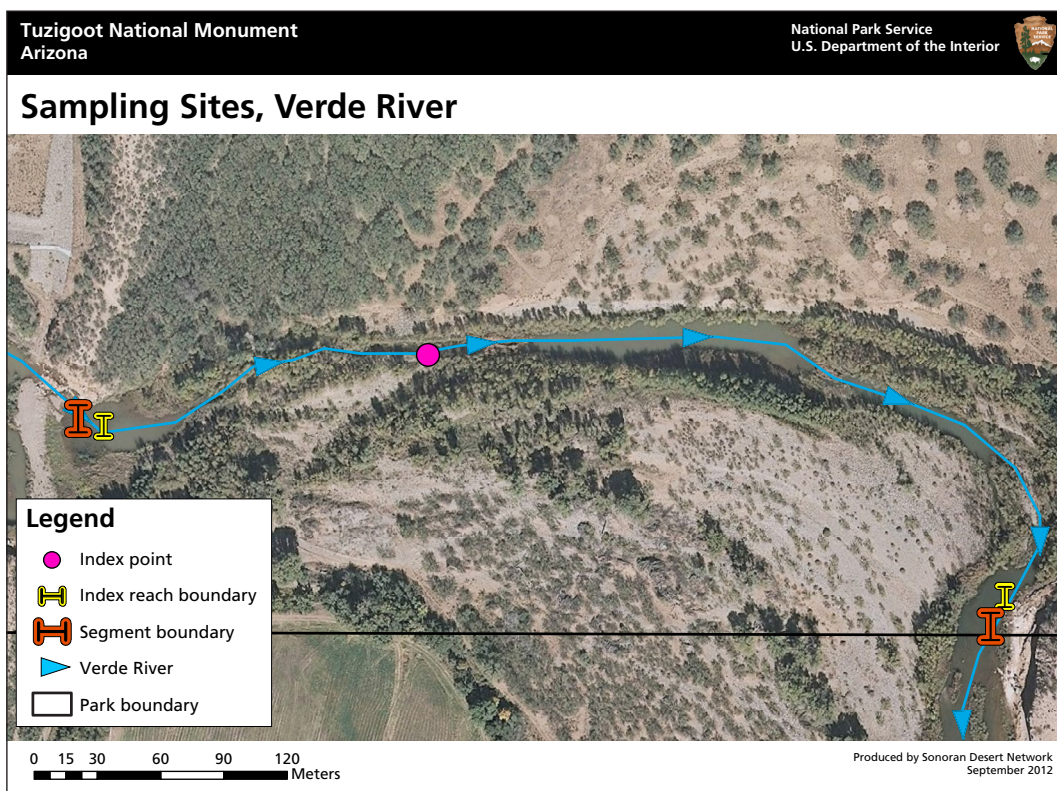


Figure 3-3. Sampling sites on the Verde River, Tuzigoot NM.

3.2.3 Water quantity data

Streamflow data for this report were gathered from several sources, including discharge measurements collected by SODN, park staff, and three U.S. Geological Survey (USGS) gauges: 09505200, on Beaver Creek, near Lake Montezuma, Arizona; 09505400, on Wet Beaver Creek, near Rimrock Arizona; and 09504000, on the Verde River, near Clarkdale, Arizona (Figure 3-4).

3.2.3.1 Beaver Creek

Data from the gauge on Beaver Creek for WY2016 were used to generate a provisional rating curve for the site.

3.2.3.2 Wet Beaver Creek

The Wet Beaver Creek gauge is 4.6 kilometers upstream from the index site on Wet Beaver Creek. Several ephemeral streams and intermittent springs flow into Wet Beaver Creek between the USGS gauge and the Wet Beaver Creek index site. A simple regression analysis of concurrent stage data during baseflow from the USGS gauge and a logging pressure

transducer at the Wet Beaver Creek index site indicates that the discharge recorded at the USGS site is very similar ($r^2=0.635$; $p<0.0001$). During precipitation events this similarity decreases, especially if the ephemeral streams between the two sites are flowing. Overall, however, the hydrograph from the USGS site provides an accurate year-round representation of flow in at the Wet Beaver Creek index site (Gwilliam et al. 2013).

3.2.3.3 Verde River

Data for the Verde River index site were taken from hand measurements of flow velocity at the index site, and from the Clarkdale USGS gauge, located upstream from the Verde River index site. The presence of an agricultural diversion dam between the gauge and the index site has a major impact on flow in the index segment, reducing baseflow by ~86% (Gwilliam et al. 2013). The seasonal and monthly discharge data, especially for large events that overtop the dam, are vitally important to the ecology of the Tuzigoot NM stream segment, as this flow allows

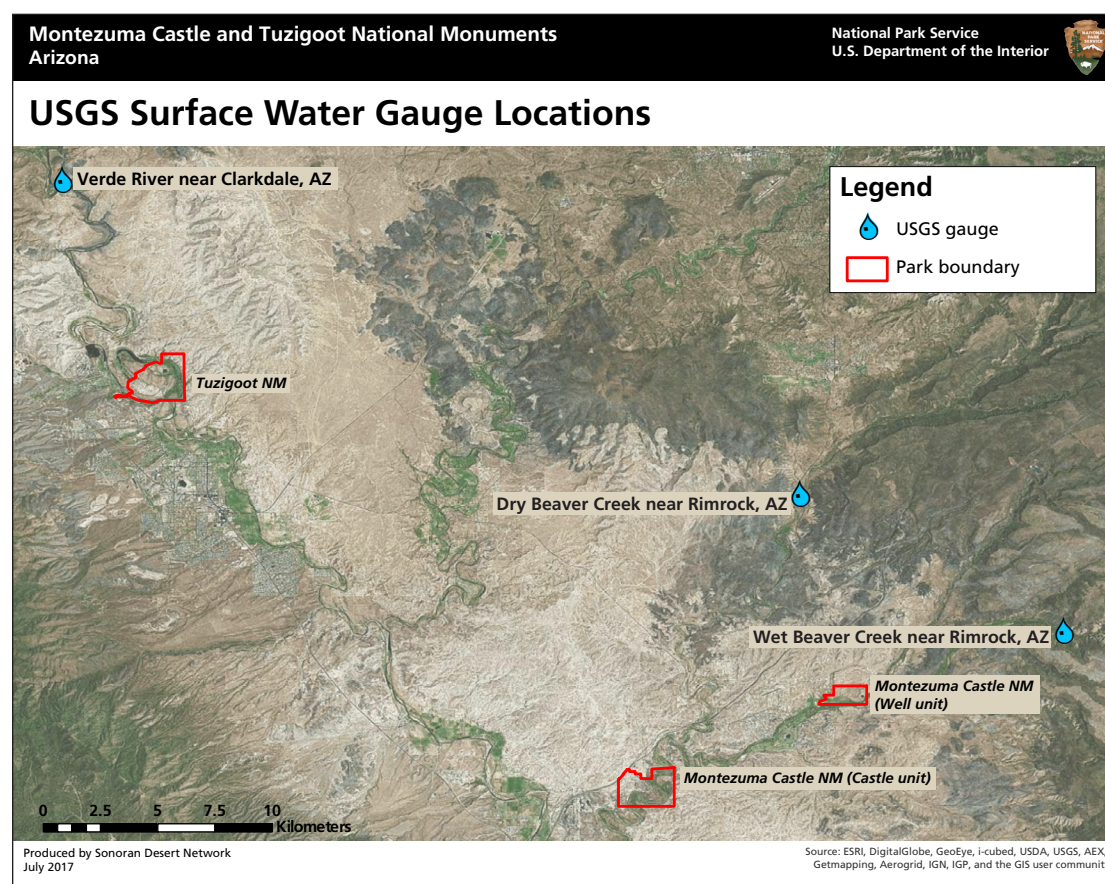


Figure 3-4. Locations of USGS stream gauges near Montezuma Castle and Tuzigoot national monuments.

river-based hydrologic and morphologic processes to drive ecological function in the stream segment (Gwilliam et al. 2013).

3.2.4 Aquatic macroinvertebrates and habitat

SODN macroinvertebrate sample collection uses methods proscribed by the State of Arizona for calculating TMDL (total maximum daily load) indices for warmwater streams at elevations below 5,000 feet. It also coincides with the index period (April–May) used by the Arizona Department of Environmental Quality (ADEQ) to ensure compatibility of monitoring samples (Lawson 2005).

SODN sampling typically occurs in late May, to accommodate the ADEQ QA/QC (quality assurance/quality control) rule of requiring four weeks to pass between a bankfull flow event and a sampling event (ADEQ 2015). At Beaver and Wet Beaver creeks, experience has shown that there is a high likelihood of flow events (approaching or exceeding bankfull) during late April.

The index reach at each stream is at least 150 meters long; exact lengths are shown in Table 3-1. Each 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 m² 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.

3.2.5 Data handling and analysis

All water quality and quantity data 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 2016) and notes any exceedances.

Table 3-1. Sampling dates and index reach lengths at Montezuma Castle and Tuzigoot national monuments during WY2016.

Unit	Stream	Sample date	Index reach length (m)
Montezuma Castle NM (Castle unit)	Beaver Creek	6/3/2015	423
Montezuma Castle NM (Well unit)	Wet Beaver Creek	6/2/2016	567
Tuzigoot NM	Verde River	6/4/2015	311

Table 3-2. Dates of sampling visits to index sites at Montezuma Castle and Tuzigoot national monuments in WY2016.

Unit	Site	Quarter			
		Q1	Q2	Q3	Q4
Montezuma Castle NM (Castle unit)	Beaver Creek	10/13/2015	2/11/2016	5/25/2016	8/25/2016
Montezuma Castle NM (Well unit)	Wet Beaver Creek	10/13/2015	2/11/2016	5/25/2016	8/25/2016
Tuzigoot NM	Verde River	10/12/2015	2/10/2016	5/24/2016	8/24/2016

3.3 Results and discussion

SODN staff sampled each index site quarterly during WY2016 (Table 3-2). We collected data on water quantity, water quality, and macroinvertebrates.

3.3.1 Water quantity

Water quantity data were collected at all three index sites. Stage data were collected before and after each discharge measurement at the Montezuma Castle sites; a discharge measurement was collected during each visit. Monument staff collected similar discharge measurements monthly.

Continuous discharge data were also collected. Products derived from available gauge data were downloaded for use in this document.

3.3.1.1 Beaver Creek

SODN has generated a provisional rating curve for the WY2016 Beaver Creek gauge

(USGS 09505200). A lack of discharge measurements at flow rates higher than 35 cubic feet per second (cfs) severely limited the accuracy of the rating at levels higher than 35 cfs. Any discharge estimates from this calculation should be considered provisional and any estimate above 35 cfs should be considered very carefully (Figure 3-5).

According to the available data, the mean daily discharge on Beaver Creek was 19 cfs—approximately one-third of the mean value from WY2005 to 2008 (69 cfs).

The Beaver Creek gauge, a cooperative project between Montezuma Castle NM, the Sonoran Desert Network, and the USGS, was upgraded in WY2015. Provisional raw-stage data are available in near real-time from the Climate Analyzer at http://www.climateanalyzer.org/sonoran_desert/HADS/bcma3/.

As noted above, the WY2016 rating curve for

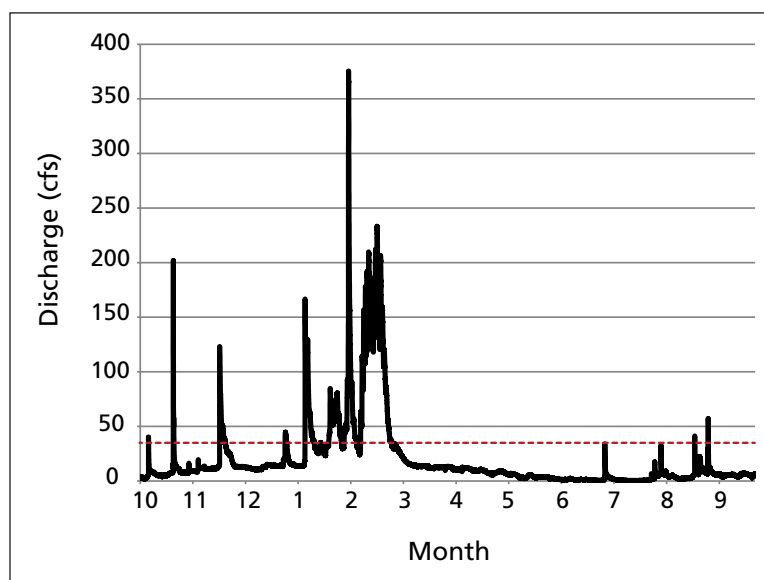


Figure 3-5. Hydrograph from Beaver Creek, Montezuma Castle National Monument (Castle unit), WY2016. The black line indicates the mean daily flow in cubic feet per second (cfs). The red dotted line indicates 35 cfs.

Beaver Creek gauge data is provisional, especially for results above 35 cfs. To ascertain if this provisional hydrograph (Figure 3-6) accurately represented flow events above 35 cfs, SODN compared hydrographs from the two creeks that contribute most of the flow to Beaver Creek: Dry Beaver Creek, in Yavapai County, Arizona (<https://waterdata.usgs.gov/usa/nwis/uv?09505200>; Figure 3-7) and Wet Beaver Creek (https://waterdata.usgs.gov/usa/nwis/uv?site_no=09505350; Figure 3-8). Results indicated that the Beaver Creek gauge accurately captures the occurrence and duration of flow events, but not their magnitude.

The hydrograph for Beaver Creek captured a flow event in mid-November, identified by the green dashed-line oval in Figure 3-6. The green dashed-line oval in the Dry Beaver Creek hydrograph (Figure 3-7) indicates the same flow event of approximately 450 cfs. In the Beaver Creek hydrograph, this event was measured at approximately 125 cfs, lower than the Dry Beaver Creek value.

A similar situation occurred at the beginning of February, when an event that caused flow of over 500 cfs on both Wet and Dry Beaver creeks was estimated by the rating curve to be approximately 375 cfs at Beaver Creek (see red dotted ovals in all three figures). Because Wet and Dry Beaver creeks both flow into Beaver Creek, the value on Beaver Creek would be expected to be much higher than 375 cfs.

The rating curve developed for Beaver Creek in WY2016 adequately identified when events occurred. However, it was not a reliable measure of the intensity of events. SODN will explore ways to improve the rating for the Beaver Creek gauge.

3.3.1.2 Wet Beaver Creek

At Wet Beaver Creek, the mean daily discharge during WY2016 was 12.2 cfs, well below the gauge record mean of 30.3 cfs. The mean daily discharge at Wet Beaver Creek deviated from the expected range during the latter half of the year (Figure 3-9). The flow from the end of February through the end of the water year was at or near the lowest 25th percentile. This low flow was especially evident during the latter half of the spring

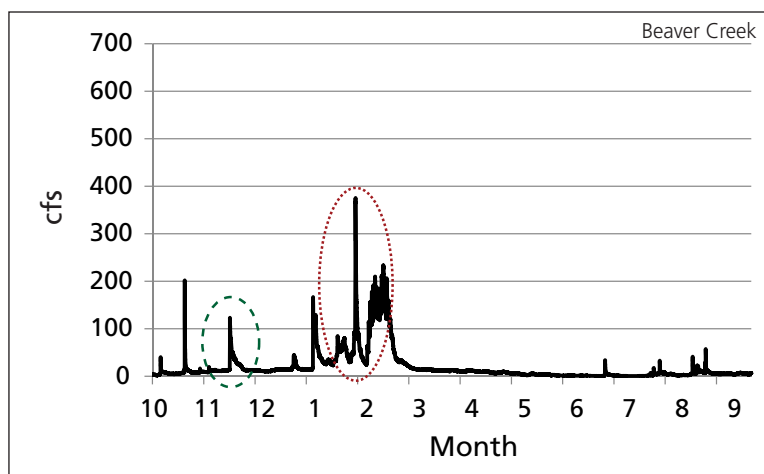


Figure 3-6. Hydrograph from Beaver Creek, Montezuma Castle National Monument (Castle unit), WY2016. The ovals identify localized flow events that occurred on Dry Beaver Creek (green dashed) and Wet and Dry Beaver creeks (red dotted).

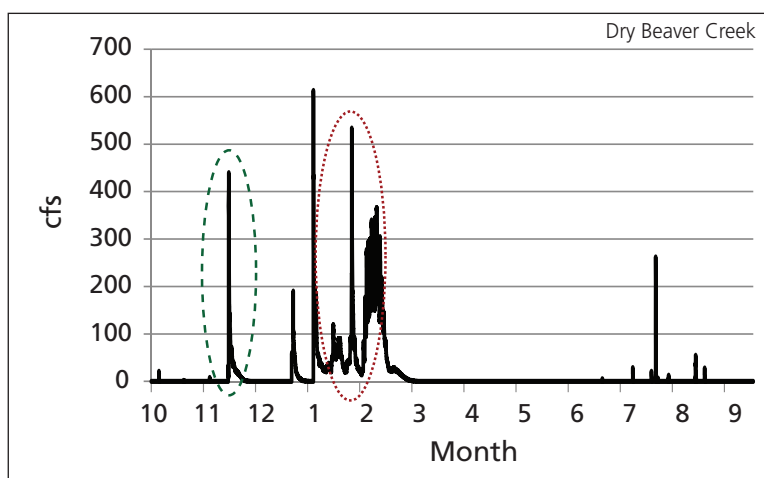


Figure 3-7. Hydrograph from Dry Beaver Creek, Yavapai County, Arizona, WY2016. The ovals identify localized flow events that occurred on Dry Beaver Creek (green dashed) and Wet and Dry Beaver creeks (red dotted).

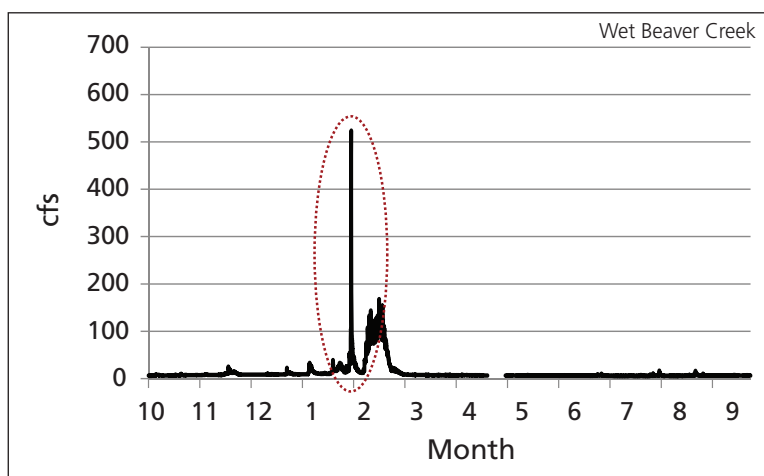


Figure 3-8. Hydrograph from Wet Beaver Creek, Montezuma Castle National Monument (Well unit), WY2016. The red dotted oval identifies a localized flow event that occurred on Wet and Dry Beaver creeks.

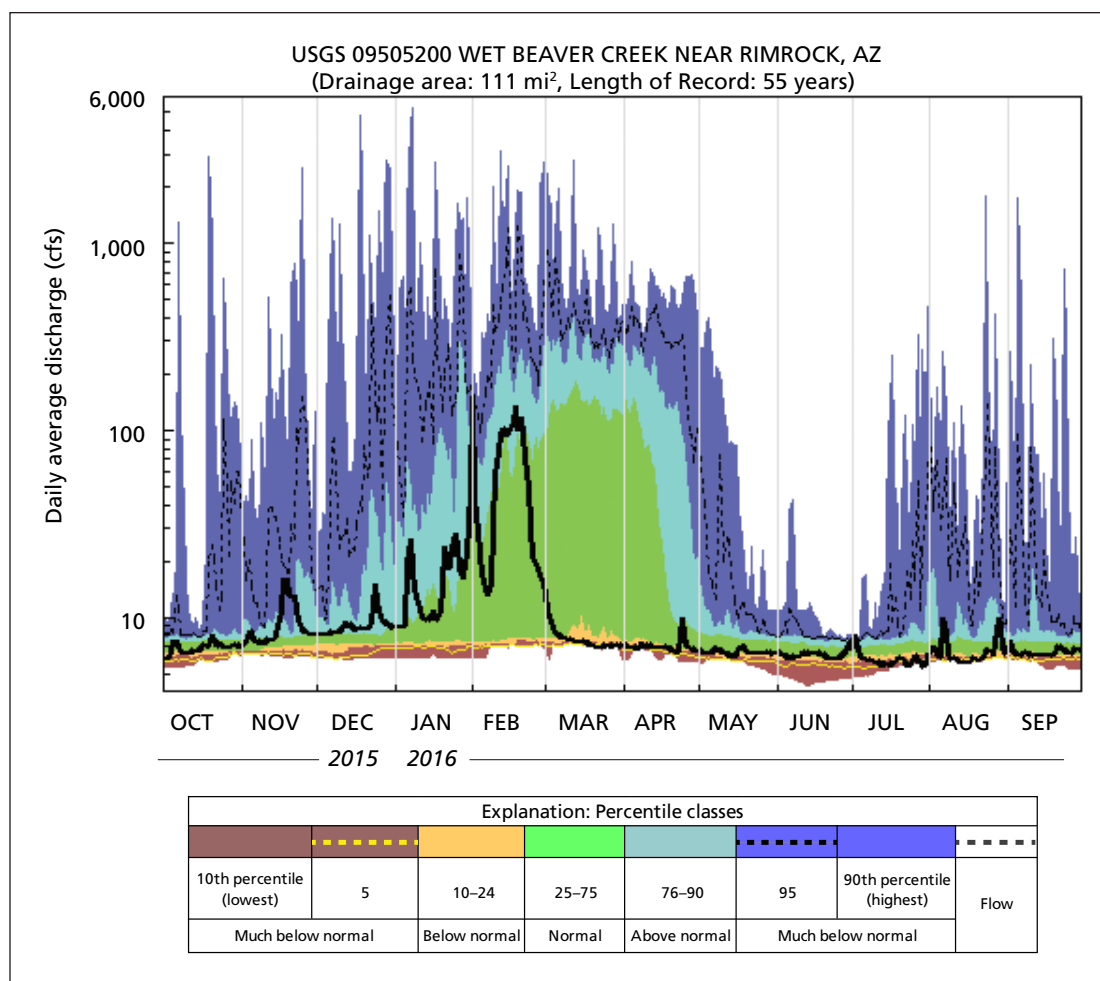


Figure 3-9. Mean daily discharge, Wet Beaver Creek, Montezuma Castle NM (Well unit), WY2016 (cfs). The solid black line represents mean daily discharge. The various colors represent the range of data, coded by percentile range (USGS 2017).

snowmelt period, typically occurring mid-January to mid-May. During that important ecological period for flow, the mean daily discharge was below or approaching the lower 5th percentile.

These low-flow periods at the Wet Beaver and Beaver Creek stations were likely expressed as no-flow events in the areas of the stream segments where the loss of elevation is the least (e.g., glides). Such events can lead to stream discontinuity and to drying events in pools.

The USGS gauge on Wet Beaver Creek has a 55-year record. Using this dataset, we can examine difference of the centroid of flow on Wet Beaver Creek between the gauge record and WY2016. The centroid is the temporal middle of the large pulse of water that moves through the watershed as water from snow-

melt on the Mogollon Rim flows through the system. At Wet Beaver Creek, the centroid for WY2016 was approximately one month earlier in the year than the centroid for the 55-year gauge record (Figure 3-10). Earlier peak runoff may impact plants and animals that depend on the timing of the spring melt pulse for successful recruitment (Bunn and Arthington 2002; Stromberg 1998).

3.3.1.3 Verde River

The Verde River stream segment at Tuzigoot NM (including the index site and reach where all SODN stream sampling takes place; see Figure 3-3), lies below an agricultural dam. Due to this diversion, only about 14% of the flow on the Verde River flows through the Verde River segment in the park (Gwilliam et al. 2013), and most of that flow occurs when the dam is leaking or has failed. This flow value varied from 0.20 to 25.3 cfs dur-

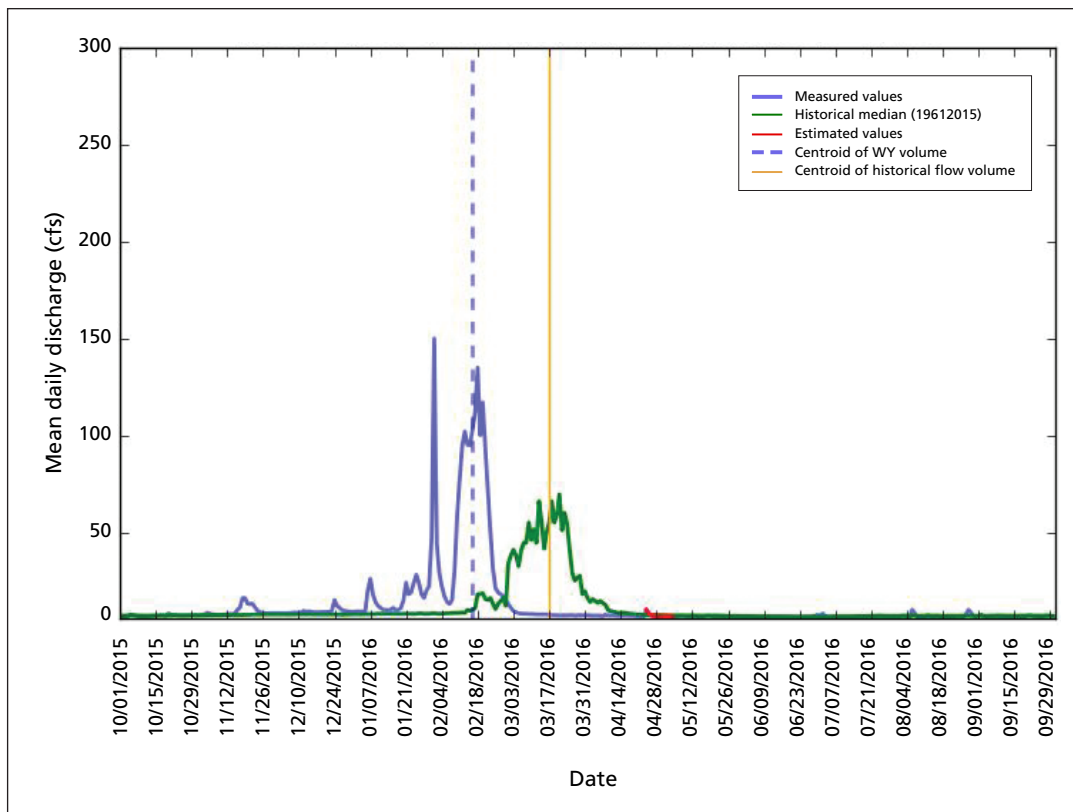


Figure 3-10. Centroid of flow volume, Wet Beaver Creek, Montezuma Castle NM (Well unit), WY2016 vs. gauge record (55 years). The dotted blue line indicates the WY2016 flow centroid. The orange line indicates the gauge-record centroid. Peak flow has moved nearly a month earlier. Graphic from Climate Analyzer.

ing WY2016 (see Table 3-5, below), and varied depending on the integrity of the dam—that is, how much water leaked through the earthen structure.

The most important hydrologic events that occur on the Tuzigoot NM stream segment are flow events that exceed the elevation or degrade the integrity of the diversion dam (estimated to be ~4,000 cfs; see red dotted line on Figure 3-11, below), causing a high-flow event in the stream segment. No such event occurred in WY2016, although the flow events in August may have weakened the dam structure and led to greater flow during the late summer and fall.

The recorded flow at this gauge during WY2016 was either at or below historic lows. For a majority of the year, flow was well below the 5th percentile (Figure 3-11). The mean daily flow recorded at this gauge (65.5 cfs) was the lowest in the gauge record (since 1965). Eight months during WY2016 were record lows for mean daily flow.

The agricultural diversion may act as a buffer to the impacts of low flow; the difference

between 100% vs. %5 of mean daily flow on a non-diverted segment of the Verde River during WY2016 is much greater than the difference between 14% vs. 5% on the river segment below the diversion. The low flow experienced on the Verde River above the diversion in WY2016 (~5% of the gauge record mean) did not impact the flow experienced by the segment of the Verde River managed by the NPS.

3.3.2 Water quality

In WY2016, SODN visited each index site on Beaver Creek, Wet Beaver Creek, and the Verde River four times, roughly once during each quarter of the water year (Table 3-3). Samples were collected for analysis by a contracted laboratory (TestAmerica in WY2016) or analyzed by SODN staff on site. A multi-parameter water quality logger was deployed for 2–3 weeks each quarter at the Wet Beaver Creek index site. A total of 719 discrete analyses were performed at the three index site locations. Of those 719 discrete analyses, 264 analyses had associated state standards.

There were four exceedances of state stan-

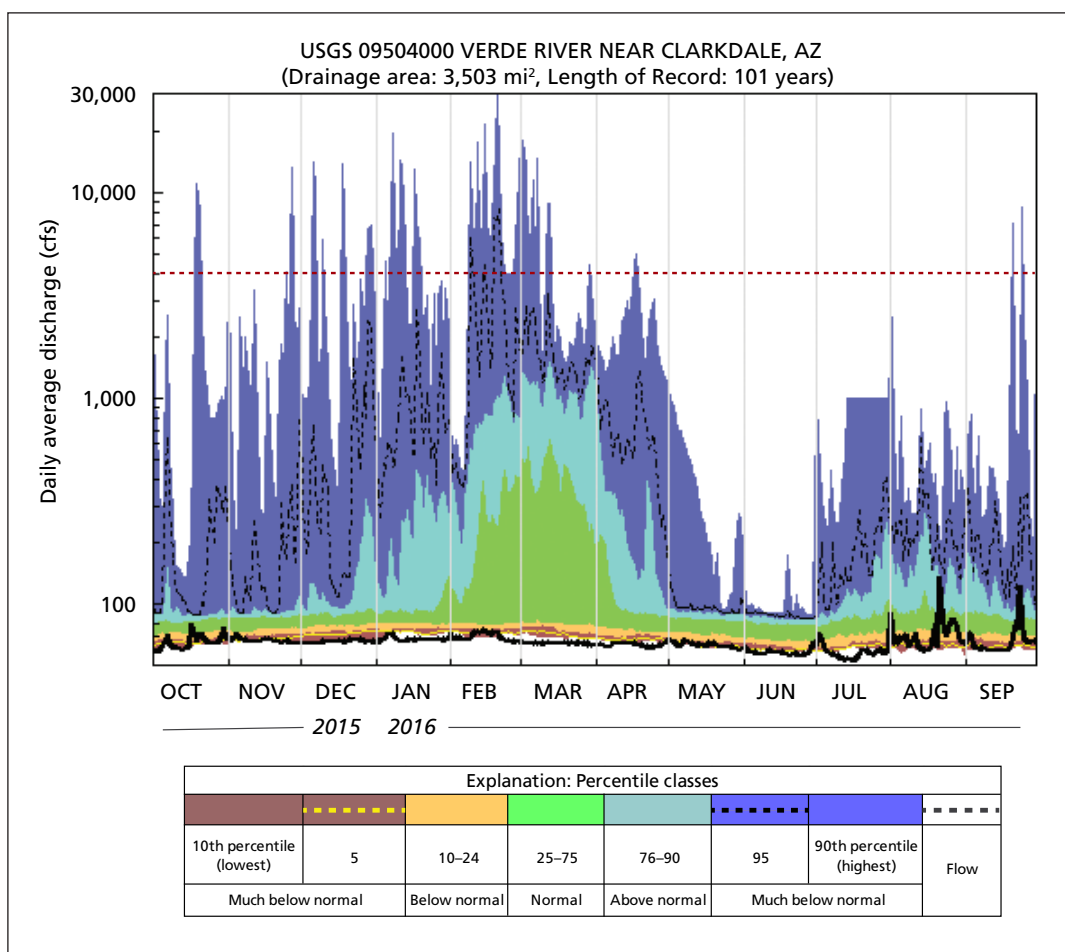


Figure 3-11. Mean daily discharge at the USGS gauge near Clarkdale, Arizona. The solid black line represents mean daily discharge. The various colors represent the range of data, coded by percentile range (USGS 2017). The red dotted line indicates the discharge value that is estimated to cause the diversion dam upstream of the Tuzigoot NM stream segment to breach (Gwilliam et al. 2013).

Table 3-3. Discrete sampling summary for Beaver Creek, Wet Beaver Creek, and the Verde River, WY2016.

Site	Beaver Creek	Wet Beaver Creek	Verde River	Total
Total analyses	240	240	239	719
Analytes with standards	88	88	88	264
Analytes that exceeded standards	3	0	1	4
Parameters in exceedance	<i>E. coli</i> (spring, summer), arsenic (summer)	No exceedances	<i>E. coli</i> (summer)	
% compliance (# analytes that met standards)	96% (85)	100% (88)	99% (87)	98.4% (260)

PLEASE NOTE: Care should be taking when handling water from Beaver Creek, Wet Beaver Creek, and the Verde River in Tuzigoot NM to limit chronic and acute exposure. There has been a reoccurring exceedance of the arsenic standard due to mineral arsenic in the rocks and other materials that compose the geology of the region (Blasch et al. 2006). Additionally, exceedances for *E. coli* have occurred in these streams, typically associated with precipitation runoff carrying material bearing the bacterium from the ground surface into the stream.

Table 3-4. Results of discrete core water quality sampling parameters on Beaver Creek, Wet Beaver Creek, and the Verde River during WY2016.

Parameter	Stream	Quarter				AZ state standard	Beneficial use ^a
		Q1	Q2	Q3	Q4		
Temperature (°C)	Beaver Creek	19.6	5.0	17.0	21.5	NS	
	Wet Beaver Creek	16.7	4.4	15.6	20.8		
	Verde River	21.2	9.7	23.8	22.6		
Specific conductivity (µS/cm)	Beaver Creek	502.0	143.7	498.0	480.0	NS	
	Wet Beaver Creek	459.0	123.4	432.0	423.0		
	Verde River	500.0	535.0	522.0	477.0		
pH	Beaver Creek	7.97	7.63	7.96	8.03	6.5–9.0	Aquatic and Wildlife - Warmwater, Full Body Contact, Agricultural Livestock
	Wet Beaver Creek	7.83	6.79	8.04	8.16		
	Verde River	7.97	NC	8.11	8.04		
Dissolved oxygen concentration (mg/L)	Beaver Creek	10.80	11.50	6.61	6.06	>6	Aquatic and Wildlife - Warmwater
	Wet Beaver Creek	9.34	12.10	8.71	8.20		
	Verde River	8.22	11.10	8.62	8.72		
Turbidity (NTU)	Beaver Creek	3.49	53.40	9.48	84.60	NS	
	Wet Beaver Creek	6.21	21.40	1.85	4.41		
	Verde River	15.10	2.140	3.69	393.00		
Discharge (cfs)	Beaver Creek	3.5	NC	2.8	5.4	NS	
	Wet Beaver Creek	7.9	^b 86.0	7.0	8.8		
	Verde River	7.2	25.3	0.2	15.2		

^aBeneficial use(s) with the most stringent standard are shown.

^bDischarge from Wet Beaver Creek was estimated from the USGS gauge 09505200 Wet Beaver Creek during Q2 due to high flow conditions.

NC = not collected; NS = no standard

dards for *E. coli* and arsenic during WY2016, resulting in an average of 98.4% compliance with state water quality standards across the three units (Table 3-3).

3.3.2.1 Core parameters

Discrete measurements collected in the field represent conditions at each index site during site visits in WY2016 (Table 3-4). Results were all within the range for a warmwater stream. There were no significant flow events during the WY2016 deployment periods.

Continuous core water quality results—

A logging multi-parameter sonde was deployed at the Wet Beaver Creek index site for approximately two weeks during each quarter to collect data on temperature, pH, specific conductivity, and dissolved oxygen at 15-minute intervals (Table 3-5). More than 30,000 distinct measurements were collected

Table 3-5. Sonde deployment periods and number of samples collected during each deployment, Wet Beaver Creek index site at Montezuma Castle NM (Well unit), WY2016.

Quarter	Sample period	# samples
Q1	10/13/2015–10/17/2015	1,656
Q2	2/11/2016–3/8/2016	9,988
Q3	5/26/2016–7/5/2016	15,768
Q4	8/25/2016–9/13/2016	7,308

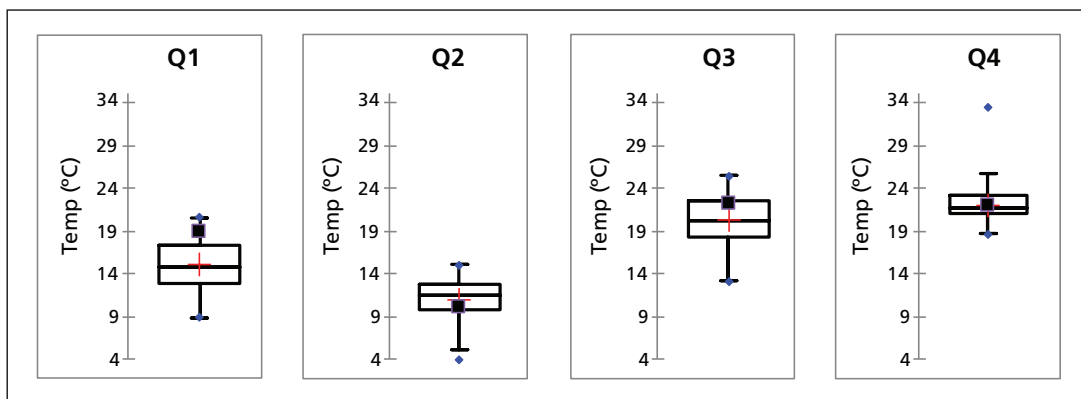
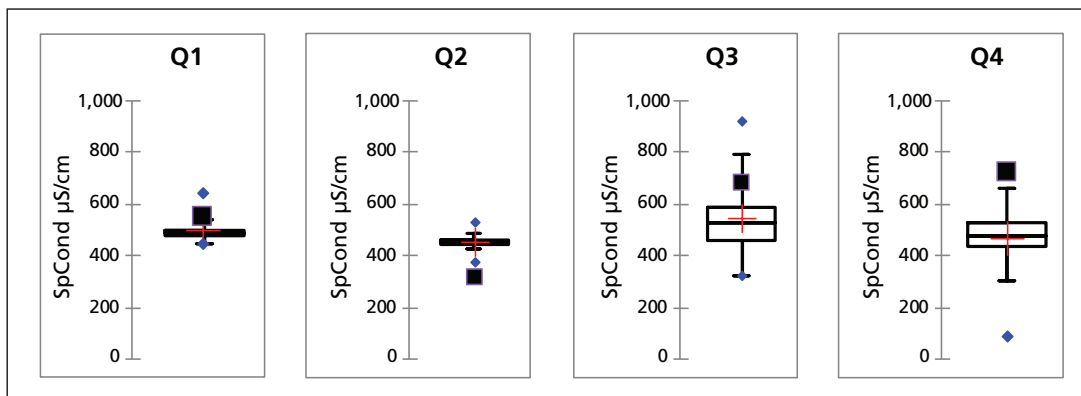
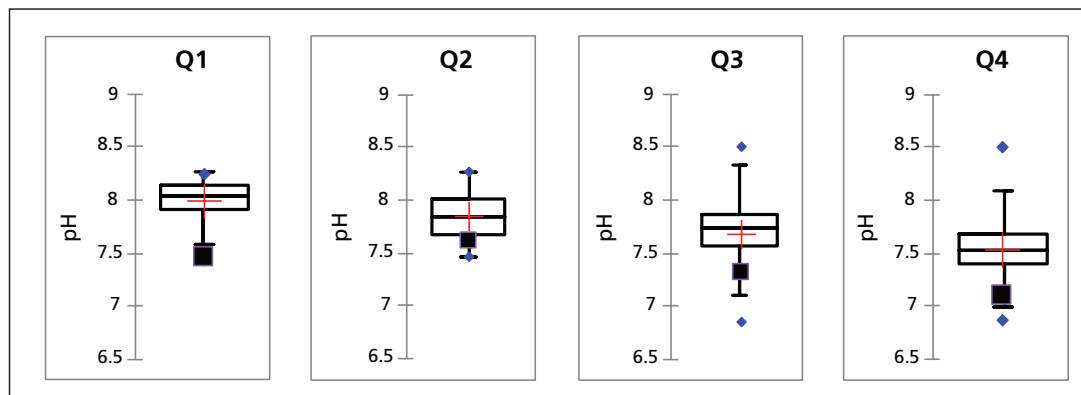
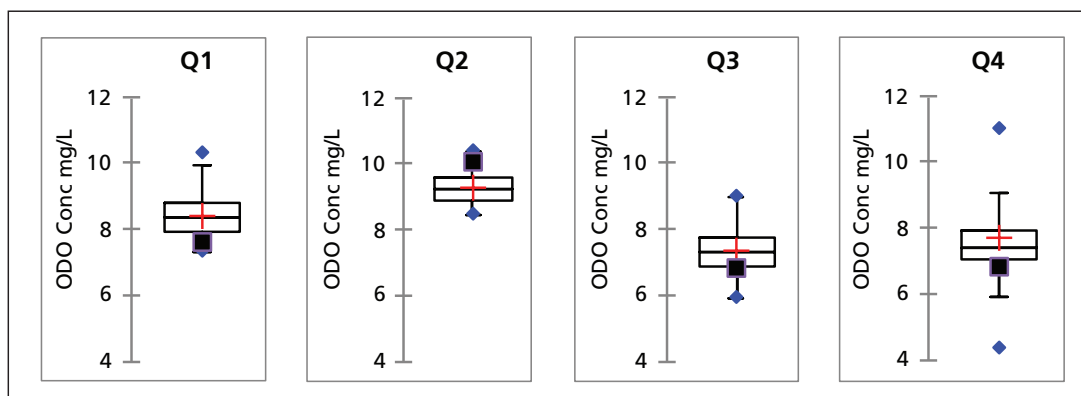
A**B****C****D**

Figure 3-12. Data on (A) water temperature, (B) specific conductivity, (C) pH, and (D) dissolved oxygen concentration, Wet Beaver Creek index site, Montezuma Castle NM (Well unit), WY2016. This figure summarizes the seasonal variability in these parameters. These figures include box-and-whisker plots displaying data from water year 2011 to water year 2015 and grey square markers indicating median values for WY2016. The blue dots indicate maximum and minimum, the whiskers indicate limits and the box indicates the bounds of the 1st and 3rd quartiles, the line in the box indicates the median, while the red cross is the mean.

during WY2016. The results from this sampling (Figure 3-12) were within the expected range for each site (Gwilliam et al. 2013), with two exceptions: pH and specific conductivity.

The sample pH median value was in the lower 25% of sample record values during every quarter. The reason for these low values is currently unexplained. There may have been sensor degradation or other quality-control issues. SODN is currently exploring possible pH probe failure and drift errors at this and other sites.

Specific conductivity was outside the expected range for all four quarters during WY2016. During the Q2 deployment, the median value for specific conductivity was very low, falling outside the previous range of data. There was a flow event just prior to this deployment, depressing specific conductivity for the first half of the deployment. The impact of this event can be seen in the discrete water quality values collected at the beginning of the Q2 deployment, with values for total dissolved solids (TDS) and total suspended sediments (TSS) (see Table 3-10, below) down to 95 mg/L from typical ~250 mg/L. During the second half of the deployment, specific conductivity averages were around 450 μ S/cm, approximating the median for the Q2 sample

record. Water temperature followed a similar pattern, with the first half of the deployment averaging about 8°C, with a return during the latter half to the median value of ~12°C. This anomalous result appears to be a result of sampling during the tail-end of a small flow event, and a subsequent rapid increase in water temperature.

Specific conductivity was high during quarters 1, 3, and 4. During quarters 1 and 3, the median value was in the upper 75% of the sample record. The Q1 sample was close to the median. The difference is likely a statistical anomaly, with greater variance in the Q1 sample. The Q3 sample is likely explained by the lack of precipitation and higher temperatures preceding and continuing through the Q3 sonde deployment. The Q4 median value was at the upper bounds of the range of data, perhaps because of the low flow conditions that persisted at the Wet Beaver Creek index site from the start of March until the deployment date in late August 2016.

3.3.2.2 Nutrients

Nutrients were sampled at each index site during each quarter of WY2016 (Table 3-6). Dissolved nitrate was detected at the Wet Beaver Creek index site. This parameter has been detected at that index site in the past

Table 3-6. Results of nutrient sampling, Beaver Creek Wet Beaver Creek, and Verde River, WY2016.

Analytes	Stream	Quarter				Method	Arizona state standard	Beneficial use ¹
		Q1	Q2	Q3	Q4			
Ammonia (mg/L)	Beaver Creek	<0.01	<0.01	<0.01	<0.01	350.1	1.4	Aquatic and Wildlife - Warmwater
	Wet Beaver Creek	<0.01	<0.01	<0.01	<0.01			
	Verde River	<0.01	<0.01	<0.01	0.13			
Dissolved nitrate (mg/L)	Beaver Creek	<0.5	<0.5	<0.5	<0.5	300	3,730	Full Body Contact
	Wet Beaver Creek	<0.5	<0.5	1.8	<0.5			
	Verde River	<0.5	<0.5	<0.5	<0.5			
Nitrate + Nitrite (mg/L)	Beaver Creek	<0.01	<0.01	<0.01	<0.01	353.2	NS	
	Wet Beaver Creek	<0.01	<0.01	<0.01	<0.01			
	Verde River	<0.01	<0.01	<0.01	0.33			
Nitrogen, Total (mg/L)	Beaver Creek	<0.01	<0.01	<0.10	<0.01	Calc. ²	3	Park-specific Standard
	Wet Beaver Creek	<0.01	<0.01	1.80	<0.01			
	Verde River	<0.01	<0.01	<0.10	0.33			

¹Beneficial use(s) with the most stringent standard are shown.

²Calculated using a hardness of 290 mg/L, temperature of 22.6°C, and pH of 8.04

NS = no standard

(2012, 2011, 2008, 2007), but never in concentrations approaching state or federal standards. This value may indicate a source of nutrients, either human (e.g., septic system) or natural (e.g., beaver dam). Ammonia was detected during the Q4 sample at the Verde River index site. This can be the result of human activity (e.g., agriculture/fertilizer) or natural processes (e.g., mobilization of nutrients impounded by the diversion dam).

3.3.2.3 Biological condition

Analytes of biological condition were sampled at each index site during each quarter of WY2016 (Table 3-7). *E. coli* exceeded Arizona state water quality standards at the Beaver Creek index site during quarters 3 and 4, and at the Verde River site during Q4. All of these exceedances were above the full body contact (“swimming” standard). The Q4 sample at Beaver Creek was also above the partial body contact standard (“wading” standard)—and above the detection limit of the test (>2,417 cfu).*

E. coli is a ubiquitous environmental bacterium that specializes in the gut environment of mammals. It has been used as an indicator of fecal contamination of surface waters (ADEQ 2015b). *E. coli* itself is a possible pathogen, and is an indicator of other microbiological pathogens. SODN urges park

managers to continue to limit public access to the streams and waterbodies, and to provide guidance and personal protective equipment to employees who need to come in contact with the water. No one should ever drink untreated stream water.

There have been past exceedances of *E. coli* standards on these streams (Gwilliam et al. 2013). Those past exceedances, and the ones in WY2016, have been associated with precipitation events in the watershed. There were precipitation events a week before the Q3 sampling event at Beaver Creek, and on the day of sampling and also on four of the five preceding days of the Q4 sampling on all three streams (precipitation data can be accessed at http://www.climateanalyzer.org/sonoran_desert). Precipitation washes material (including wild and domestic animal waste) from the surface into adjoining streams.

3.3.2.4 Metals

Analytes of the metals group were sampled at each index site during each quarter of WY2016 (Tables 3-8 and 3-9). Only parameters with results are reported. Please note that parameters not reported are not assumed to be zero, but rather below the detection limit of the analytical equipment. They may have been present in very low concentrations.

*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 235 cfu/100 mL.

Table 3-7. Results of biological condition sampling, Beaver Creek, Wet Beaver Creek, and Verde River, WY2016.

Analyte	Stream	Quarter				Method	Arizona state standard	Beneficial use ^a
		Q1	Q2	Q3	Q4			
Total organic carbon (mg/L)	Beaver Creek	NC	NC	NC	2.2	SM5130B	NS	
	Wet Beaver Creek	NC	NC	NC	1.1			
	Verde River	NC	NC	NC	3.4			
<i>E. coli</i> (MPN/100mL)	Beaver Creek	5.29	48.20	551.00	>2,417.00	SM 9223B	<235 ^b	Full Body Contact
	Wet Beaver Creek	63.60	11.70	29.40	153.00			
	Verde River	14.30	7.13	58.20	354.00			

^aBeneficial use(s) with the most stringent standard are shown.

^bCalculated with single sample method

MPN = most probable number; NC = not collected; NS = no standard; SM = standard method (Eaton et al. 2005).

Red bold indicates exceedance of state water quality standard

Table 3-8. Sampling results for dissolved metals, Beaver Creek, Wet Beaver Creek, and Verde River, WY2016.

Analyte	Stream	Quarter				Method	Arizona state standard	Beneficial use ^a
		Q1	Q2	Q3	Q4			
Arsenic (mg/L)	Beaver Creek	0.036	<0.015	0.032	0.030	EPA 200.7/200.8	0.15	Aquatic and Wildlife - Warmwater Chronic
	Wet Beaver Creek	0.027	<0.015	0.023	0.022			
	Verde River	0.027	0.022	0.024	0.014			
Barium (mg/L)	Beaver Creek	NC	NC	NC	0.19	EPA 200.7/200.8	NS	
	Wet Beaver Creek	NC	NC	NC	^b 0.28			
	Verde River	NC	NC	NC	0.14			
Boron (mg/L)	Beaver Creek	0.34	<0.10	0.28	0.31	EPA 200.7	NS	
	Wet Beaver Creek	0.18	<0.10	0.17	0.15			
	Verde River	0.19	0.17	0.17	0.14			
Calcium (mg/L)	Beaver Creek	46	17	43	42	EPA 200.7	NS	
	Wet Beaver Creek	47	14	50	47			
	Verde River	47	53	49	53			
Magnesium (mg/L)	Beaver Creek	28.0	6.8	27.0	25.0	EPA 200.7	NS	
	Wet Beaver Creek	23.0	6.9	23.0	22.0			
	Verde River	25.0	28.0	34.0	21.0			
Manganese (mg/L)	Beaver Creek	0.017	<0.010	0.019	0.0100	EPA 200.7/200.8	NS	
	Wet Beaver Creek	0.032	<0.010	0.011	0.0150			
	Verde River	<0.010	<0.010	0.090	0.0088			
Potassium (mg/L)	Beaver Creek	3.6	<3.0	<3.0	3.6	EPA 200.7	NS	
	Wet Beaver Creek	<3.0	<3.0	<3.0	<3.0			
	Verde River	<3.0	<3.0	<3.0	<3.0			
Silica (mg/L)	Beaver Creek	21	14	18	21	EPA 200.7	NS	
	Wet Beaver Creek	23	17	22	23			
	Verde River	19	17	19	18			
Sodium (mg/L)	Beaver Creek	29.0	5.5	18.0	26.0	EPA 200.7	NS	
	Wet Beaver Creek	18.0	<5.0	17.0	16.0			
	Verde River	27.0	28.0	26.0	22.0			

^aBeneficial use(s) with the most stringent standard are shown.

^bThe spike recovery value was unusable because the analyte concentration in the sample was disproportionate to the spike level. The associated blank spike was acceptable.

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

Table 3-9. Sampling results for total metals, Beaver Creek, Wet Beaver Creek, and Verde River, WY2016.

Analyte	Stream	Quarter				Method	Arizona state standard	Beneficial use ^a
		Q1	Q2	Q3	Q4			
Aluminum (mg/L)	Beaver Creek	0.24	3.60	0.35	2.00	EPA 200.7/200.7 r 4.4	NS	
	Wet Beaver Creek	0.16	2.50	<0.10	<0.10			
	Verde River	0.42	<0.10	<0.10	8.30			
Arsenic (mg/L)	Beaver Creek	0.028	<0.015	0.028	0.034	EPA 200.7/200.8	0.03	Full Body Contact
	Wet Beaver Creek	0.020	<0.015	0.021	0.024			
	Verde River	0.016	0.023	0.023	0.018			
Barium (mg/L)	Beaver Creek	NC	NC	NC	0.22	EPA 200.7/200.8	98	Full Body Contact
	Wet Beaver Creek	NC	NC	NC	0.24			
	Verde River	NC	NC	NC	0.22			
Boron (mg/L)	Beaver Creek	0.29	<0.10	0.27	0.33	EPA 200.7/200.7 r 4.4	1, 186	Agricultural Irrigation ^c , Full Body Contact
	Wet Beaver Creek	0.16	<0.10	0.15	0.16			
	Verde River	0.17	0.16	0.17	0.16			
Calcium (mg/L)	Beaver Creek	47	21	44	54	EPA 200.7/200.7 r 4.4	NS	
	Wet Beaver Creek	51	14	48	47			
	Verde River	51	52	51	74			
Chromium (mg/L)	Beaver Creek	NC	NC	NC	<0.0030	EPA 200.7/200.8	1	Agricultural Irrigation ^c
	Wet Beaver Creek	NC	NC	NC	<0.0030			
	Verde River	NC	NC	NC	0.0075			
Copper (mg/L)	Beaver Creek	<0.0150	<0.0150	<0.0150	0.0021	EPA 200.7/200.8	0.5	
	Wet Beaver Creek	<0.0150	<0.0150	<0.0150	<0.0020			
	Verde River	<0.0150	<0.0150	<0.0150	0.0200			
Iron (mg/L)	Beaver Creek	0.22	2.70	0.30	1.60	EPA 200.7/200.7 r 4.4	NS	
	Wet Beaver Creek	0.26	1.70	<0.10	0.19			
	Verde River	0.26	<0.10	<0.10	5.90			
Lead (mg/L)	Beaver Creek	<0.009	<0.009	<0.009	0.0011	EPA 200.7/200.8	0.015	Full Body Contact
	Wet Beaver Creek	<0.009	<0.009	<0.009	<0.0010			
	Verde River	<0.009	<0.009	<0.009	0.0120			
Magnesium (mg/L)	Beaver Creek	26.0	7.6	27.0	28.0	EPA 200.7/200.7 r 4.4	NS	
	Wet Beaver Creek	23.0	6.8	21.0	23.0			
	Verde River	26.0	27.0	35.0	25.0			
Manganese (mg/L)	Beaver Creek	0.023	0.050	0.030	0.050	EPA 200.7/200.8	10, 131	Agricultural Irrigation ^c , Full Body Contact
	Wet Beaver Creek	0.050	0.018	0.014	0.024			
	Verde River	0.024	<0.010	0.084	0.140			
Nickel (mg/L)	Beaver Creek	NC	NC	NC	0.004	EPA 200.7/200.8	0.51	Fish Consumption
	Wet Beaver Creek	NC	NC	NC	<0.002			
	Verde River	NC	NC	NC	0.013			
Potassium (mg/L)	Beaver Creek	3.3	<3.0	<3.0	3.9	EPA 200.7/200.7 r 4.4	NS	
	Wet Beaver Creek	<3.0	<3.0	<3.0	<3.0			
	Verde River	<3.0	<3.0	<3.0	4.2			

Table 3-9. Sampling results for total metals, Beaver Creek, Wet Beaver Creek, and Verde River, WY2016, cont.

Analyte	Stream	Quarter				Method	Arizona state standard	Beneficial use ^a
		Q1	Q2	Q3	Q4			
Silica (mg/L)	Beaver Creek	21	29	20	35	EPA	NS	
	Wet Beaver Creek	23	24	21	24	200.7/200.7		
	Verde River	20	17	19	60	r 4.4		
Sodium (mg/L)	Beaver Creek	26	5.6	26	26	EPA	NS	
	Wet Beaver Creek	17	<5.0	16	15	200.7/200.7		
	Verde River	26	28	26	21	r 4.4		
Uranium (mg/L)	Beaver Creek	NC	NC	NC	<0.0010	EPA	2.8	Full Body Contact
	Wet Beaver Creek	NC	NC	NC	<0.0010	200.7/200.8		
	Verde River	NC	NC	NC	0.0011			
Zinc (mg/L)	Beaver Creek	<0.02	<0.02	<0.02	<0.01	EPA	5.1	Fish Consumption
	Wet Beaver Creek	<0.02	<0.02	<0.02	<0.01	200.7/200.8		
	Verde River	<0.02	<0.02	<0.02	0.03			

^aBeneficial use(s) with the most stringent standard are shown.

^bThe spike recovery value was unusable because the analyte concentration in the sample was disproportionate to the spike level. The associated blank spike was acceptable.

^cWet Beaver Creek and Verde River only.

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

Results in red bold indicate exceedance of state water quality standard.

Only one exceedance was recorded during WY2016, at the Beaver Creek index site during Q4. However, arsenic concentrations approached the state standard for full body contact at most sites during most sampling visits. These WY2016 concentrations are typical for the region. Arsenic concentrations have occasionally exceeded state standards in the past (e.g., total arsenic 0.11 mg/L on August 18, 2010). Historically, arsenic has been regularly detected in samples from all three streams in and around the administered stream segments at Montezuma and Tuzigoot national monuments (NPS 1995).

A background concentration of arsenic is considered to be the result of natural wearing processes in the Verde River watershed, primarily from oxidized sulfides of the Verde Formation and Tertiary volcanic deposits (Blasch et al. 2006). These elevated levels of arsenic have the potential to decrease the resilience of plant and animal populations to other stresses and make them more susceptible to disruptions in ecological function (e.g., low flow).

It is recommended that park managers limit staff contact with stream water without proper personal protective equipment (e.g., waders), especially during low-flow periods, when arsenic concentrations are typically higher.

3.3.2.5 Total suspended sediments and dissolved solids

Total suspended sediments and total dissolved solids were sampled at each index site during each quarter of WY2016 (Table 3-10). Total suspended sediments were high at the Verde River index site during Q4 sampling. The reasons are unknown, but there may have been increased leaking through the diversion dam during this period, combined with summer conditions (increased evaporation).

3.3.2.6 General water quality and inorganics

Analytes of this group were sampled at each index site during each quarter of WY2016 (Table 3-11). Results remained within the range of expected values (Gwilliam et al. 2013). Values for hardness and alkalinity were low at the

Table 3-10. Results of TSS and TDS sampling, Beaver Creek, Wet Beaver Creek, and Verde River, WY2016.

Analyte	Stream	Quarter				Method
		Q1	Q2	Q3	Q4	
Total dissolved solids (mg/L)	Beaver Creek	290	110	280	270	SM 2540C
	Wet Beaver Creek	250	95	250	240	
	Verde River	290	300	350	270	
Total suspended sediments (mg/L)	Beaver Creek	4.8	45.0	8.4	56.0	SM 2540D
	Wet Beaver Creek	4.0	<4.0	<4.0	<4.0	
	Verde River	20.0	<4.0	<4.0	210.0	

SM = standard method (Eaton et al. 2005)

There are not state standards for these parameters.

Table 3-11. Results of general and inorganic sampling, Beaver Creek, Wet Beaver Creek, and Verde River, WY2016.

Analyte (mg/L)	Stream	Quarter				Method
		Q1	Q2	Q3	Q4	
Alkalinity as CaCO ₃ (mg/L)	Beaver Creek	270	67	250	230	SM 2320B
	Wet Beaver Creek	240	60	230	220	
	Verde River	260	240	250	230	
Bicarbonate alkalinity as CaCO ₃ (mg/L)	Beaver Creek	270	67	250	230	SM 2320B
	Wet Beaver Creek	240	60	230	220	
	Verde River	250	220	250	230	
Carbonate alkalinity as CaCO ₃ (mg/L)	Beaver Creek	<5.0	<5.0	<5.0	<5.0	SM 2320B
	Wet Beaver Creek	<5.0	<5.0	<5.0	<5.0	
	Verde River	11.0	21.0	<5.0	<5.0	
Chloride (mg/L)	Beaver Creek	17.0	4.6	18.0	17.0	EPA 300.0
	Wet Beaver Creek	10.0	<3.0	9.8	9.2	
	Verde River	14.0	13.0	15.0	13.0	
Sulfate (mg/L)	Beaver Creek	<5	<5	<5	5	EPA 300.0
	Wet Beaver Creek	<5	<5	<5	<5	
	Verde River	17	17	<5	17	
Total hardness (mg/L)	Beaver Creek	220	85	220	250	SM 2340B
	Wet Beaver Creek	220	63	210	210	
	Verde River	230	240	270	290	
Anion/Cation balance (%)	Beaver Creek	0.01%	0.06%	0.00%	0.02%	SM 1030E
	Wet Beaver Creek	0.00%	0.03%	0.01%	0.02%	
	Verde River	-0.03%	0.06%	-0.02%	0.08%	

SM = standard method (Eaton et al. 2005); other methods are from USEPA (1983).

There are not state standards for these parameters.

Beaver Creek and Wet Beaver Creek index sites during Q2 due to elevated flow.

3.3.3 Macroinvertebrates

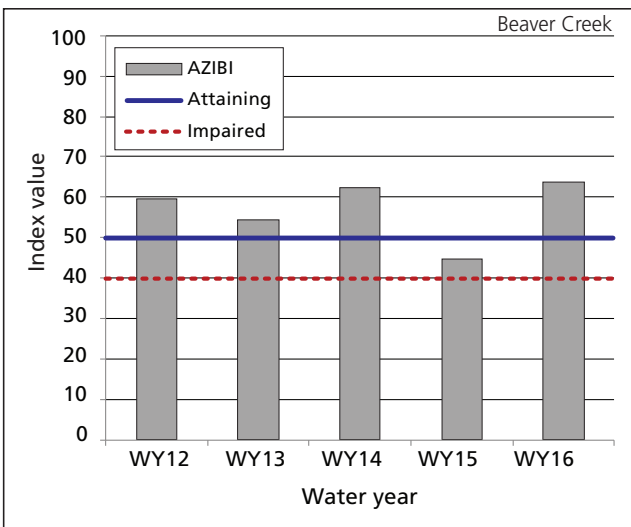
Macroinvertebrate biological samples and associated habitat data were collected at the three index reaches on May 20–22, 2016. The analytical lab received the samples in mid-June 2016, and issued the report on June 20, 2017.

The Arizona Index of Biological Integrity (AZIBI) for warmwater streams was calculated from WY2016 samples following methods proscribed by the ADEQ (2015b). The State of Arizona has determined that index values above a score of 49 indicate that the stream is attaining the state standard, with the index value falling above the 25th percentile of reference scores (ADEQ 2015b). The WY2016 values from the Beaver Creek index site (63.6), and the Verde River site (49.1), both scored in the “attaining” category (Figure 3-13a and 3-13b, respectively).

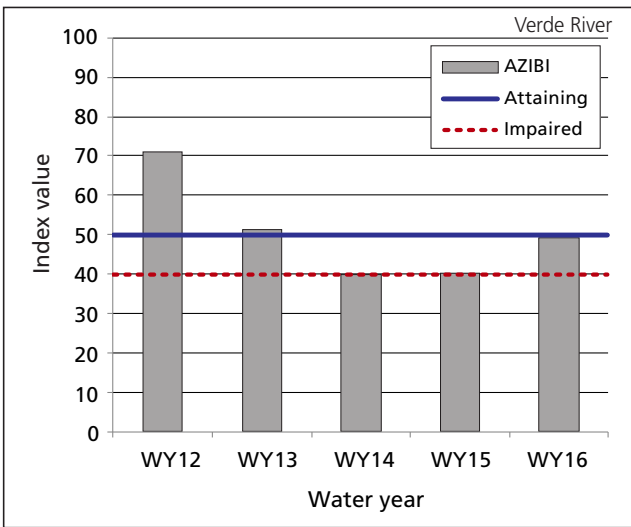
In WY2016, the data from the Wet Beaver Creek index reach scored a 46.6, falling in the “inconclusive” range, or between percentiles 10–25 of reference scores (Figure 3-13c). For a conclusive outcome, the ADEQ requires a second sample during the same index period (ADEQ 2015b). This second visit was not conducted in WY2016 (or in preceding years) because the lab SODN uses to sort and identify the macroinvertebrate samples does not generate the results for at least six months. This delay precludes a return visit.

To attempt to accommodate this delay when “inconclusive” ratings occur, the SODN program estimates whether the current WY value was attaining by comparing values for the current WY to the mean of the site-record index results. The Wet Beaver Creek AZIBI for WY2016 was lower than the mean value for water years 2012–2015, falling just outside one standard deviation of the mean. This indicated that the WY2016 value was uncommonly low, and likely not attaining the state standard.

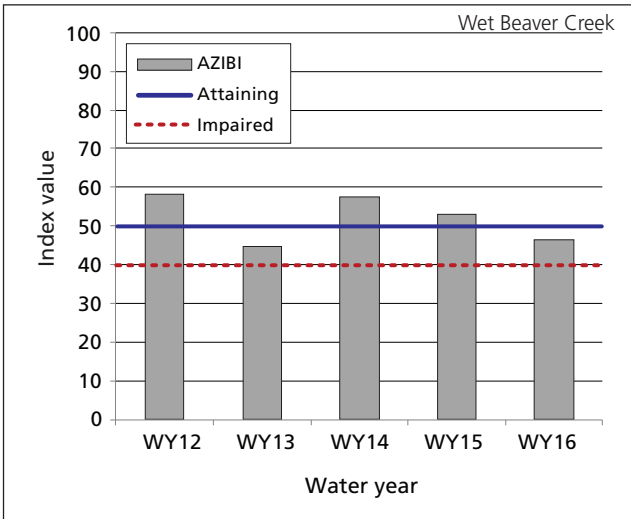
The low AZIBI score at Wet Beaver Creek in WY2016 resulted primarily from a change in the abundance of the dominant family metric (in this case, *Orthocladiinae*, a subfamily



A



B



C

Figure 3-13. Arizona Index of Biotic Integrity values for the (A) Beaver Creek, (B) Verde River, and (C) Wet Beaver Creek index reaches, WY2012–2016. Any values falling between the “impaired” and “attaining” lines are considered “inconclusive” relative to the state standard.

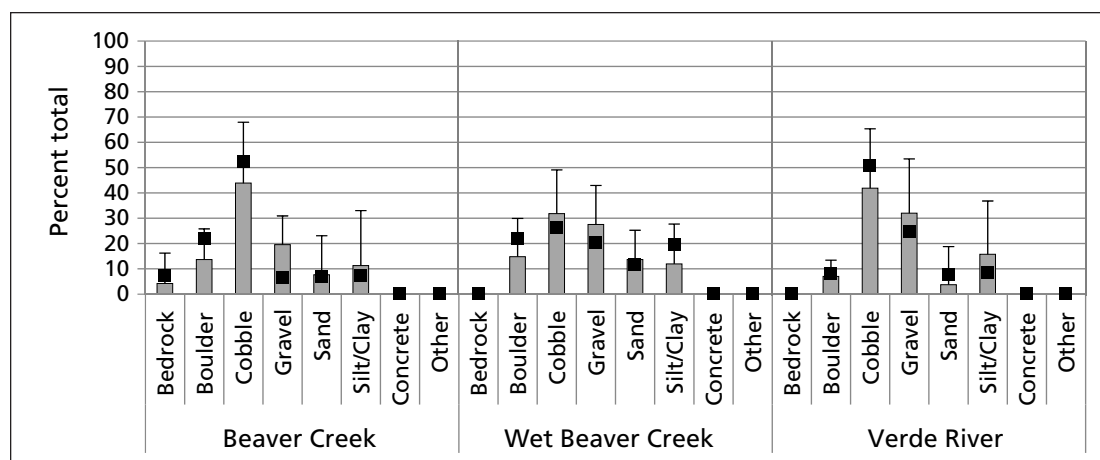


Figure 3-14. Substrate classification for index reaches at Beaver Creek, Wet Beaver Creek, and the Verde River, water years 2011–2016. Grey bars indicate the mean value (%) for water years 2011–2015. The error bars are one standard deviation. The black square is the WY2016 result.

of the non-biting midge family, *Chironomidae*). Midge larvae are typically considered an indicator of poor water quality (Merritt and Cummins 1996). Thus, the weight of this metric lowered the score. All other macroinvertebrate metrics used to calculate the AZIBI were similar to those of years when the AZIBI was attaining for all three streams.

The reason for the increase in midge larvae abundance may lie with physical processes. Since WY2011, measurements have shown a subtle shift in particle size, from a system dominated by gravel and cobble to increased frequency of boulders and sand/silt. In WY2016, values for silt/clay and boulders were higher

than the mean values for those parameters in water years WY2011–2015 (Figure 3-14).

These results indicate that there has been deposition of fine particulates around the boulders and large cobble that compose the bottom of Wet Beaver Creek, a subtle increase in embeddedness. The increase of this microhabitat—the small spaces between the larger particles filled with fine material—may favor the Chironomid midges, and lead to their higher abundance.

The reason for this increase in smaller particles may lie with the dearth of spring-season flow events in WY2016. There were virtually no flow events from the end of February until the macroinvertebrate sampling occurred at the end of May (see Figure 3-9). This unusual lack of flow events may have allowed for the deposition of fine material, leading to the increase in abundance of these particular taxa in the expanded microhabitat.

Finally, there was no obvious observed decrease in water quality at the Wet Beaver Creek site. Dissolved oxygen concentration was lower during the WY2016 Q3 deployment, but not abnormal. Dissolved nitrate was detected at 1.8 mg/L in the WY2016 Q3 sample—an elevated reading, but not alarmingly high, and the only detection for nutrients at Wet Beaver Creek during WY2016.

The mean values for the entire site record (WY2012–2016) met the state standard of “attaining” for all three index reaches (Figure 3-15).

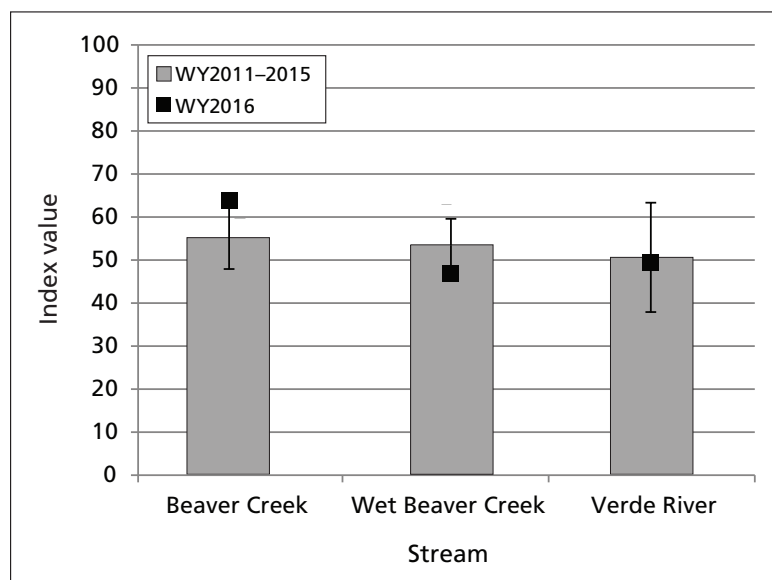


Figure 3-15. Macroinvertebrate Arizona Index of Biotic Integrity scores from water years 2012–2016. Grey bars indicate the mean value for water years 2012–2015. The black solid square indicates the AZIBI score for WY2016. Error bars indicate one standard deviation.

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