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

Water Year 2018

Natural Resource Report NPS/SODN/NRR—2019/1985



ON THE COVER

Springs monitoring, Montezuma Castle National Monument. NPS photo.

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

Water Year 2018

Natural Resource Report NPS/SODN/NRR—2019/1985

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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) 2018 for Montezuma Castle and Tuzigoot national monuments, two small National Park Service units in central Arizona.

Overall annual precipitation was 49% of normal for Montezuma Castle National Monument (NM) and 76% of normal for Tuzigoot NM, with extremely low rainfalls in the fall and winter months. Mean monthly maximum temperatures at both parks were above normal for all months except one at Montezuma Castle. Mean monthly minimum temperatures were more variable and there were approximately the same number of extremely cold days as normal. The reconnaissance drought index was negative for Tuzigoot NM—showing a return to drought conditions following recent wetter years—and likely negative for Montezuma Castle NM.

Groundwater levels at the Montezuma Castle and Montezuma Well water-supply wells in WY2018 both declined from WY2017, by 24.20 and 8.10 feet, respectively. However, both wells had been recently pumped, so those values may not represent actual conditions. Over the monitoring record, water levels at the Castle unit have been variable with no discernible trend, while water levels at the Well unit have generally declined. In WY2018, groundwater levels in the three monitoring wells near Tuzigoot NM showed variable changes from the previous year. The Kauzlarich index well increased 1.60 feet, the Centerville USGS well decreased 0.45 feet, and the City of Cottonwood index well #1 decreased 3.70 feet. All three wells have shown relatively stable groundwater levels since 1999.

Expansion Spring (Montezuma Castle NM Castle unit) and Shea Spring (Tuzigoot NM) were both classified as "undisturbed," despite some evidence of beaver activity at Shea Spring. Sensors indicated that both springs were likely wetted throughout the sampling period. We are currently establishing the range of natural variation for water-quality results.

Mean daily discharge from the Beaver Creek station was 7.13 cubic feet per second (cfs), approximately one-tenth of the mean value from WY2005 to 2008. At Wet Beaver Creek, mean daily discharge during WY2018 was 7.05 cfs, well below the gage record mean of 30.2 cfs. There was a striking lack of flow events, including from snowmelt and monsoon events. Recorded flow at the Verde River gage was either at or below the 25th percentile for most of the year. The hydrograph at this gage showed patterns similar to those at the Wet Beaver Creek gage—there was no snowmelt pulse observed this year.

There were 10 exceedances of water-quality standards during WY2018: seven on Beaver Creek (one *E. coli,* three dissolved oxygen, and three total arsenic), one on Wet Beaver Creek (total arsenic), and two on the Verde River (one *E. coli* and one total lead). This was a 94% compliance rate across the three units. Macroinvertebrate index values for warmwater streams were likely attaining at all sample sites. The values for Beaver and Wet Beaver Creek were the highest recorded by SODN. This was good news after several years of either not attaining or scoring in the inconclusive category.

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We thank Chief of Natural Resources Tina Greenawalt, Superintendent Dorothy Firecloud, and the staff of Montezuma Castle and Tuzigoot national monuments for their onsite support of the monitoring effort. Alex Buckish, Gregory Goodrum, Misa Kupkova, Colombe Lefort, Terezia Machová, David Máck, Jessica McGarey, and Kate McNicholas assisted with data collection and processing. Kristen Bonebrake led the management and posting of all data products. Macroinvertebrate identifications were determined by the Utah State University BugLab, and TestAmerica (Arizona) processed the water chemistry samples. Andy Hubbard and Greg Goodrum contributed to this report.

1 Introduction

Climate and hydrology are major drivers of ecosystems. They dramatically shape ecosystem structure and function, particularly in arid and semi-arid ecosystems. Understanding changes in climate, groundwater, streamflow, and water quality is central to assessing the condition of park biota and key cultural resources. This document summarizes climate and water resource conditions for water year (WY) 2018 (October 2017–September 2018) 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 other resources of management focus, please see the Sonoran Desert Network website.

2 Climate

2.1 Background and methods

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

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

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 a Davis weather station at each unit of Montezuma Castle NM (Castle unit and Well unit), and at Tuzigoot NM to record real-time weather conditions. All three stations are linked to the NOAA Citizen Weather Observer Program 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 2-1). Used globally to classify climate zones, aridity indices seek to answer the question, "How dry is dry?" (Tsakiris and Vangelis 2005). Using the period of record (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 (Figure 2-1).

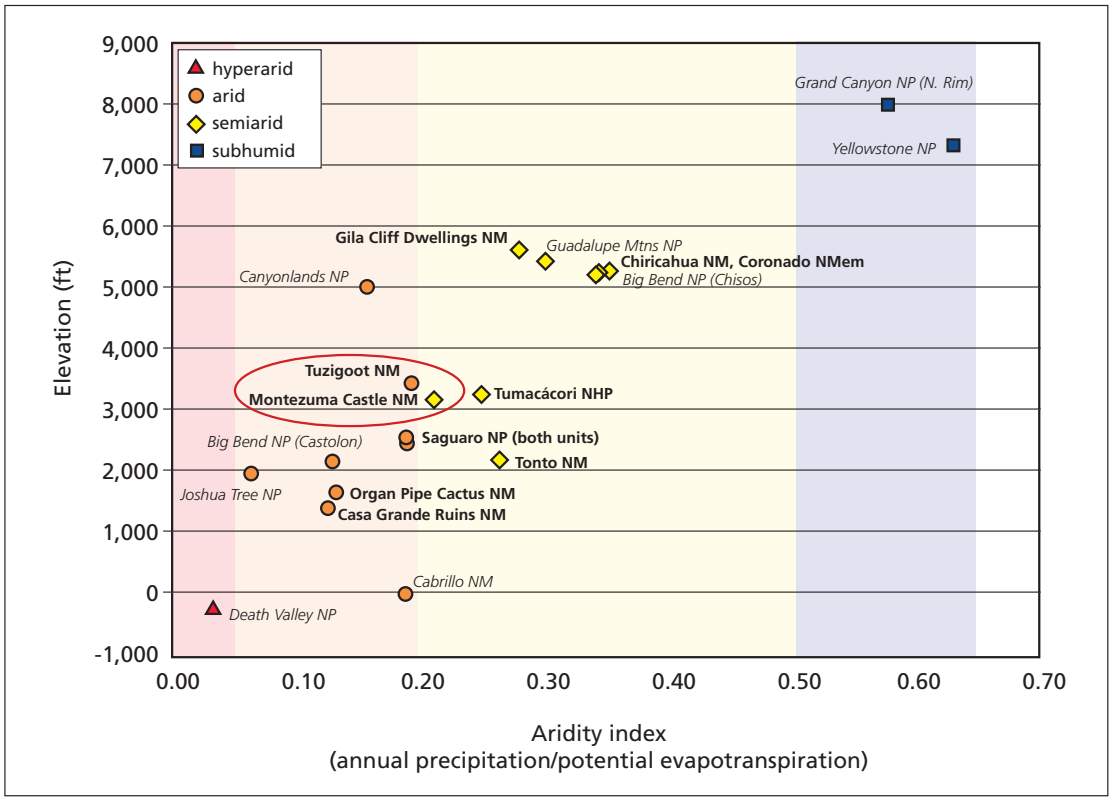


Figure 2-1. Aridity index vs. elevation of selected southwestern national parks, including Montezuma Castle and Tuzigoot national monuments. Figure from Hubbard and others (in prep).

2.2 Results and discussion

Data quality was fair from the COOP stations at Montezuma Castle NM and Tuzigoot NM in WY2018. The station at Montezuma Castle was missing precipitation data on two days and temperature data on 20 days. The station at Tuzigoot was missing precipitation data on four days and temperature data on 14 days.

Overall annual precipitation was below normal for both parks: 49% of normal for Montezuma Castle NM (7.1" vs 14.4"), and 76% of normal for Tuzigoot NM (9.7" versus 12.7"). Rainfall at Montezuma Castle in WY2018 was the second-lowest in the 80-year record.

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

2.2.1.1 Cool season (October–March)

At Montezuma Castle NM, precipitation was a fraction of normal (22%, or -5.66") for the fall and winter of WY2018. No rain fell in October through December, and rain during the other months was ≤53% of normal (Figures 2-2 and 2-3). These drought conditions were intensified by mean monthly maximum air temperatures that were above normal (+1–6°F). Mean monthly minimum air temperatures were generally cooler than normal, up to -3°F, except in November.

Precipitation at Tuzigoot NM was also well below normal (22%, or -4.94") for the fall and winter of WY2018. No rain fell in October through December, and rain during the other months was ≤56% of normal (Figures 2-4 and 2-5). Mean maximum air temperatures were extremely high in October through January, peaking with a mean temperature 10.5°F above normal in December. February and March were only moderately warmer than normal (≤+3°F). Mean minimum temperatures were generally near normal, except in November (+4.3°F).

2.2.1.2 Warm season (April–September)

At Montezuma Castle NM, overall precipitation was below normal (77%, or -1.63") for the spring and summer of WY2018 (see Figures 2-2 and 2-3). The monsoon started strong in July but tapered off early, resulting in a total accumulation of 0.16" in September. Spring rainfall was lower than normal, but the monsoon in July and August was stronger than normal. Maximum air temperatures were generally above normal (up to +4.6°F). Minimum air temperatures were closer to normal (within -0.4 and 2.2°F of normal).

Unlike Montezuma Castle NM, Tuzigoot NM was wetter than normal (131%, or +1.95") in the spring and summer of WY2018 (see Figures 2-4 and 2-5). The monsoon also started strong in July, tapering to a low rainfall amount in September. However, Tuzigoot NM also experienced unseasonal rain in May and June (0.95" and 2.03", respectively). Maximum mean air temperatures were warmer than normal (+1.1–7.6°F). Mean minimum air temperatures were generally closer to normal, within 1.5°F, except April (+4.1°F).

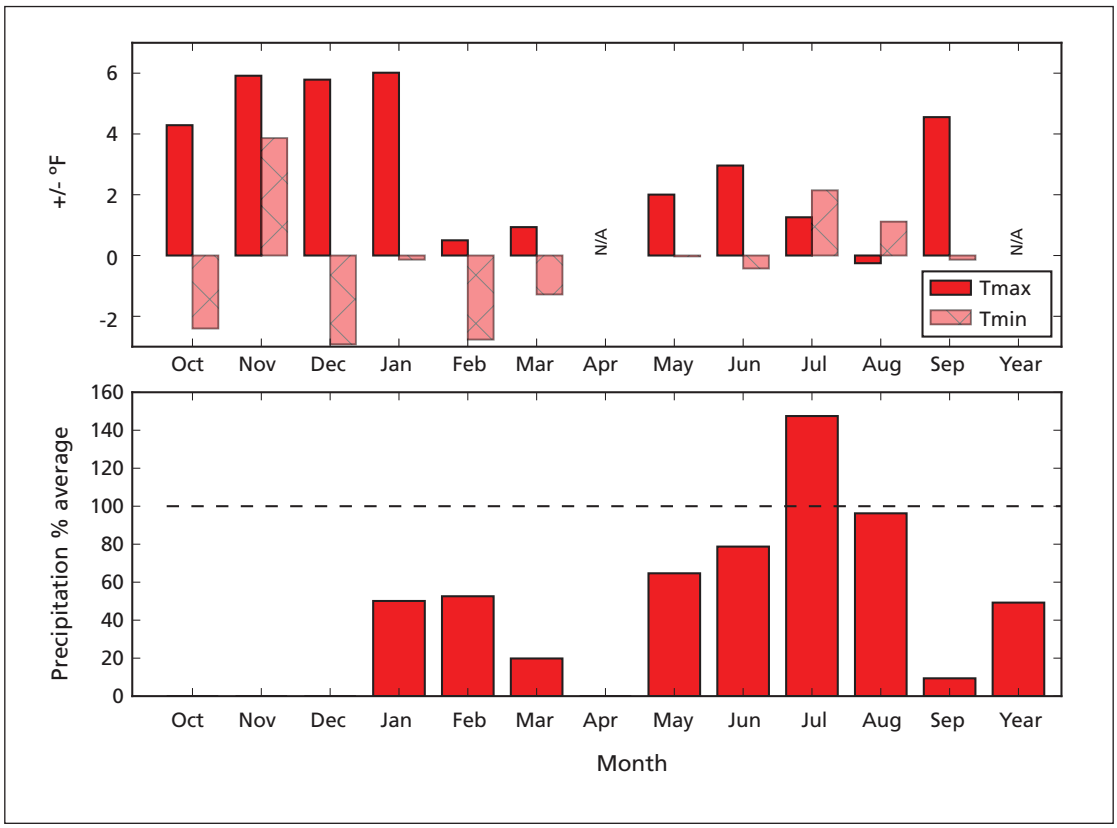


Figure 2-2. Departures from 30-year (1981–2010) normal minimum and maximum air temperature and precipitation, Montezuma Castle National Monument, WY2018. "N/A" = insufficient data to generate reliable data. Graphics generated by climateanalyzer.org.

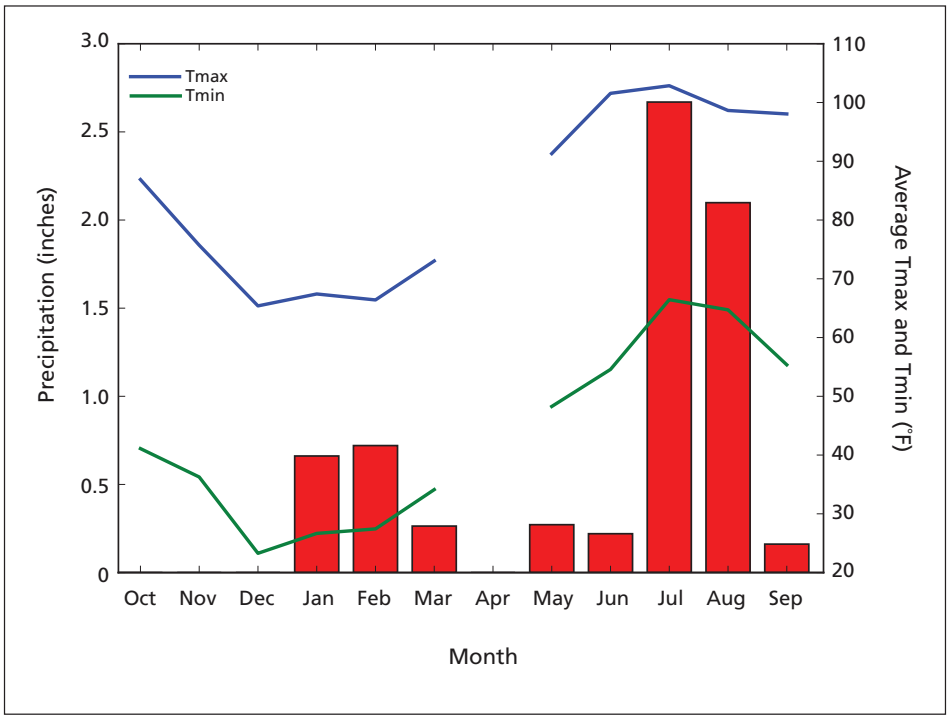


Figure 2-3. Climogram for Montezuma Castle National Monument, WY2018. Graphics generated by climateanalyzer.org.

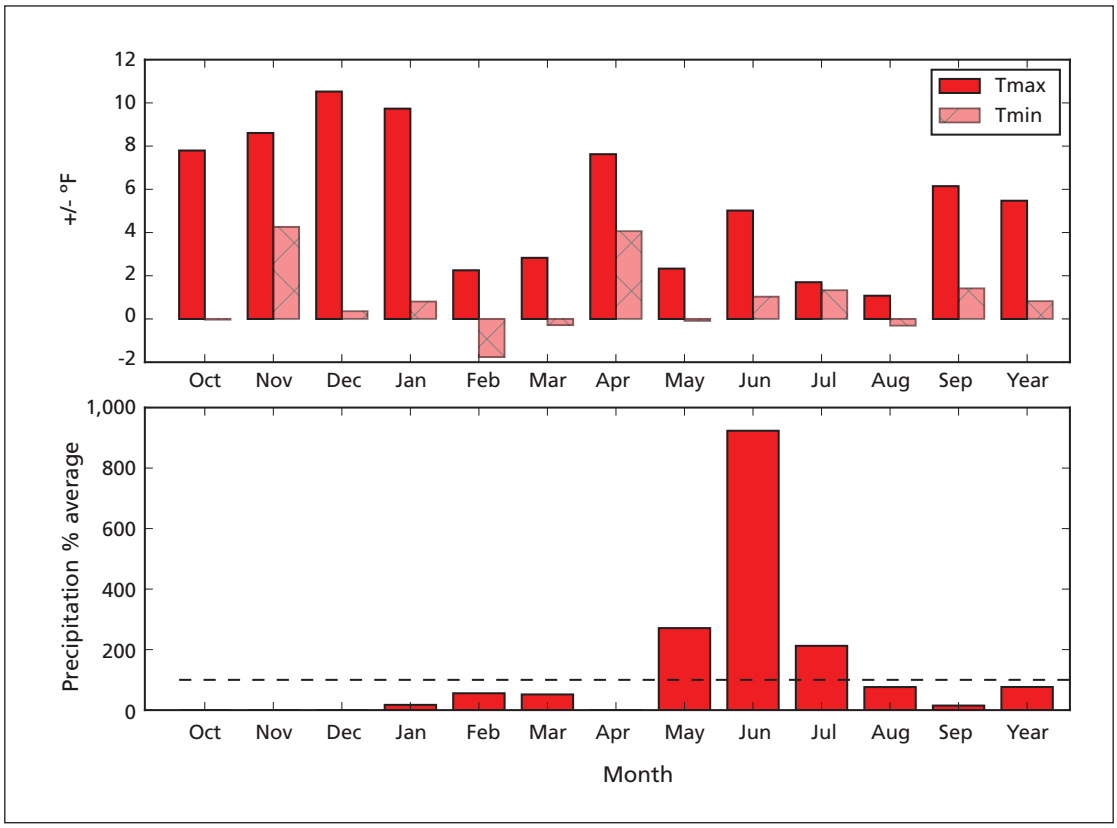


Figure 2-4. Departures from 30-year (1981–2010) normal minimum and maximum air temperature and precipitation, Tuzigoot National Monument, WY2018. Graphics generated by climateanalyzer.org.

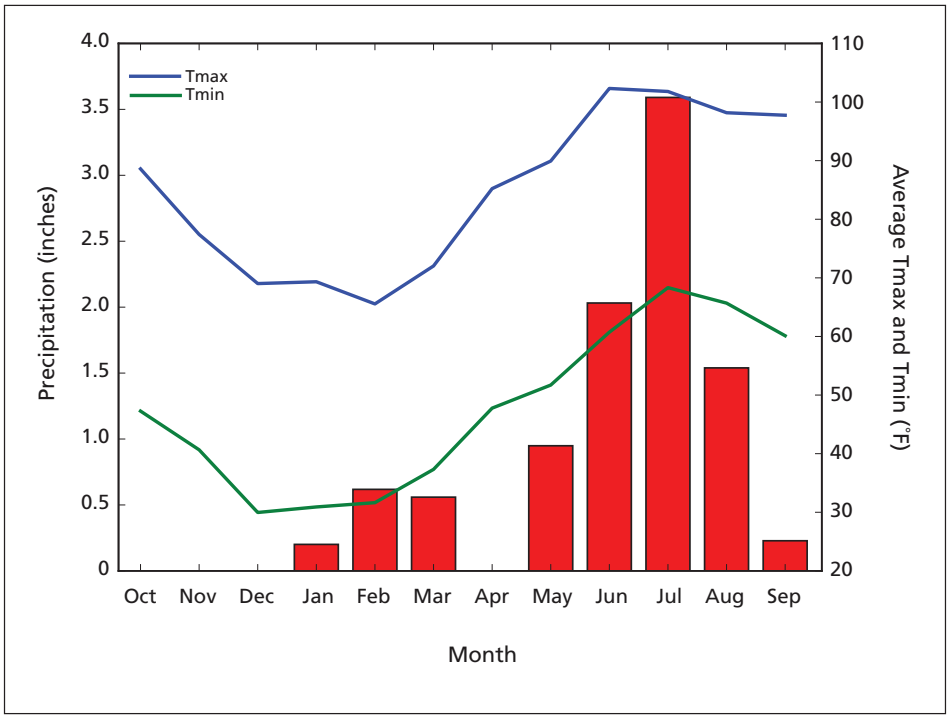


Figure 2-5. Climogram for Tuzigoot National Monument, WY2018. Graphics generated by climateanalyzer.org.

2.2.2 Reconnaissance Drought Index

Reconnaissance drought index (Tsakiris and Vangelis 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 RDI for Montezuma Castle NM could not be calculated for WY2018, but the low precipitation likely resulted in a negative value, reflecting the continuation of regional drought that began in 2000 (Figure 2-6). The five-year moving mean of total annual precipitation from years 1981–2018 (Figure 2-7) demonstrates the continued multi-year precipitation deficit.

The RDI for Tuzigoot NM showed a return to drought conditions in WY2018, following recent wetter years (Figure 2-8). The five-year running mean of total precipitation for water years 1981–2018 indicated a continued water surplus, despite lower rainfall in WY2018 (Figure 2-9).

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 Arizona–New Mexico Mountains ecosystems. In particular, sustained low air temperatures can damage or even kill long-lived keystone plants (including the large deciduous trees that dominate the riparian woodlands of the park) (Turner et al. 2003), and the aquatic organisms that live in the river environment. Extreme precipitation events can also cause localized flooding and erosion events, spur or inhibit plant productivity and reproduction, and modify animal behavior.

At Montezuma Castle NM, extremely cold days (<22°F, 5th percentile of 1981–2010 data) occurred slightly more often than normal (25 vs. 22.3 ±1.4 days) in WY2018, and were of a longer duration than normal (3.6 consecutive days vs. 2.5 ± 0.1 days). There were no extreme precipitation events (>1") in WY2018, compared to a mean of 2.2 days for 1981–2010. The largest event occurred on August 13, with 0.84".

Tuzigoot NM experienced as many extremely cold days (<26°F, 5th percentile of 1981–2010 data) as normal (15 days vs. 14.6± 1.1 days), and they were of a similar duration (2.5 consecutive days vs. 2.1 ± 0.1 days). The number of extreme precipitation events (>1") in WY2018 was normal (2 vs. 1.8 days for 1981–2010) normal. Large events occurred on June 13 (1.31") and July 13 (1.31").

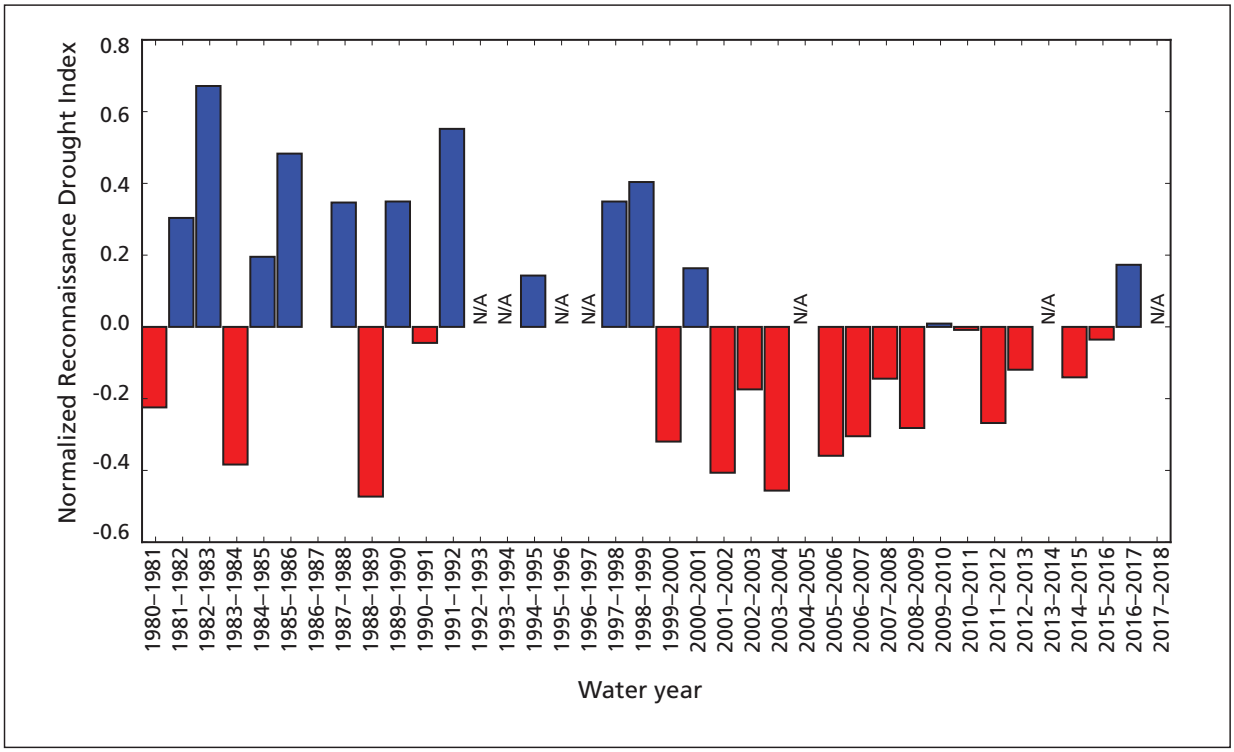


Figure 2-6. Reconnaissance drought index (RDI), Montezuma Castle National Monument, water years 1981–2018. "N/A" = insufficient data to generate reliable RDI estimates. Graphics generated by climateanalyzer.org.

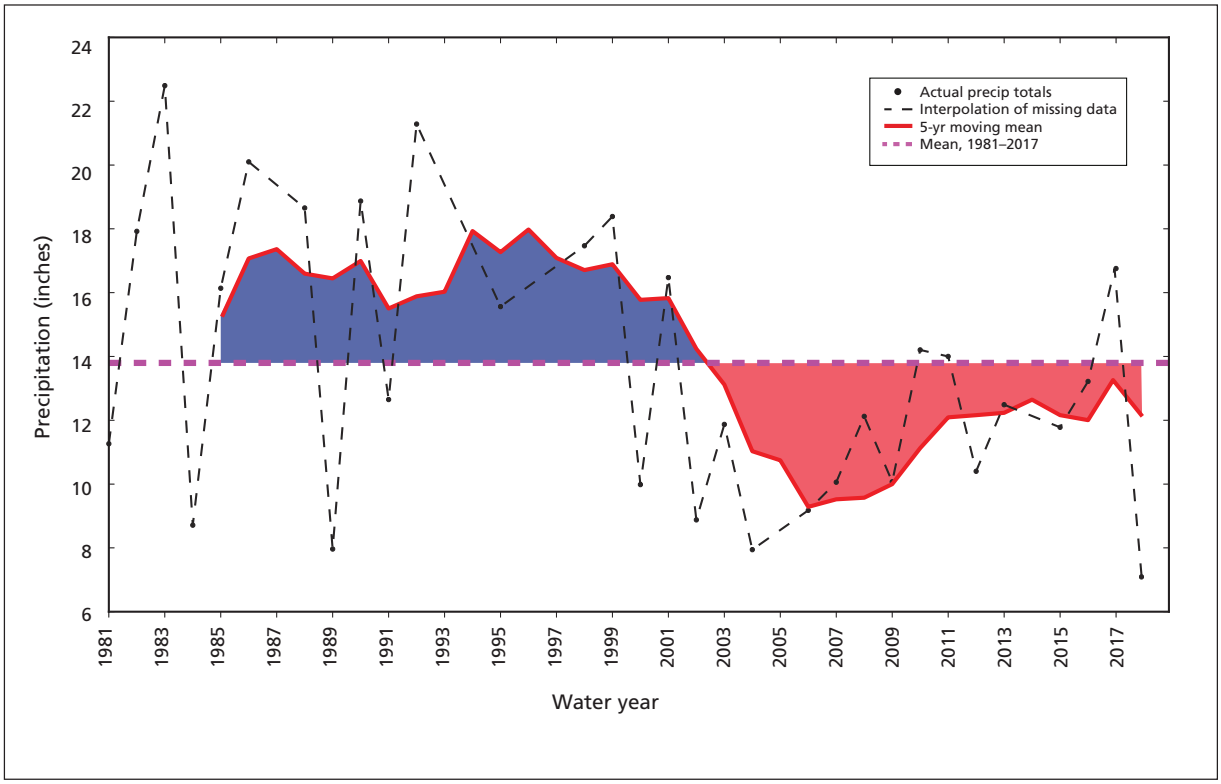


Figure 2-7. Five-year moving mean of annual precipitation, Montezuma Castle National Monument, 1981–2018. The moving mean (solid red line) is based on a timeseries with 18.9% (7 of 37) missing values, and includes the current year and previous four years. Blue and red fields represent water surplus and deficit. Missing years are linearly interpolated (dashed grey lines). Graphics generated by climateanalyzer.org.

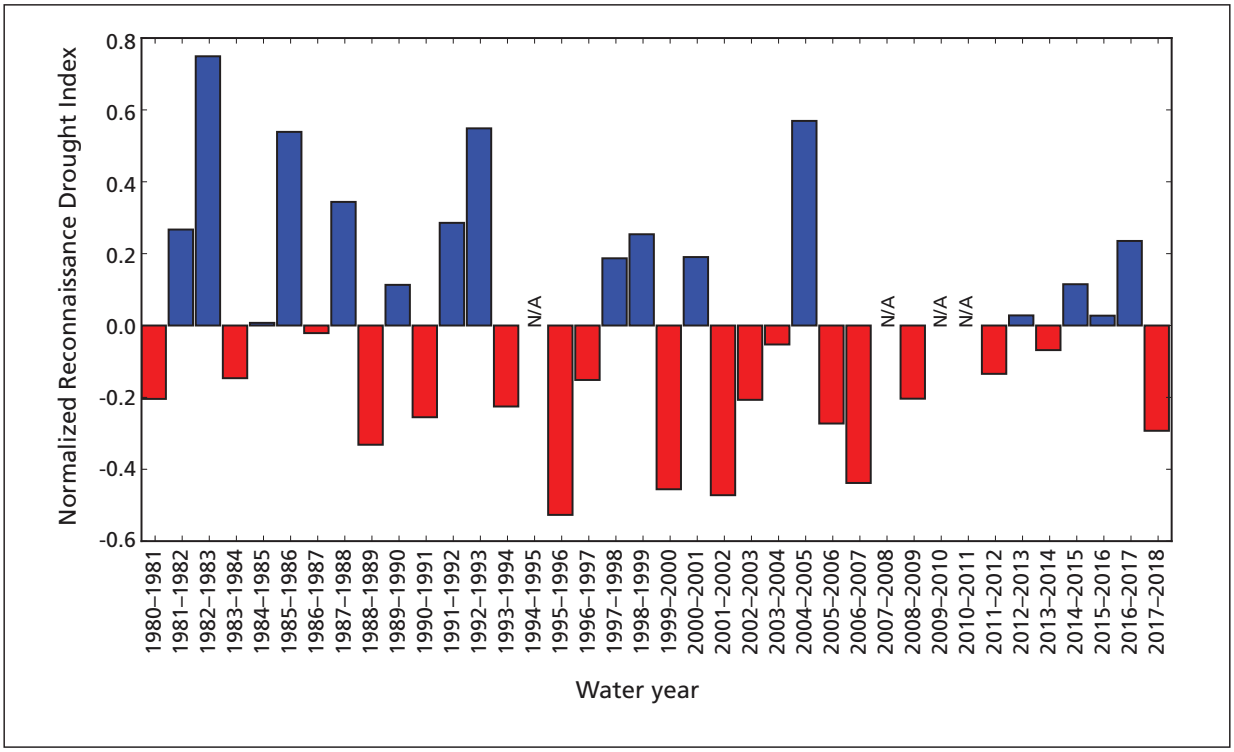


Figure 2-8. Reconnaissance drought index (RDI), Tuzigoot National Monument, water years 1981– 2018. "N/A" = insufficient data to generate reliable RDI estimates. Graphics generated by climateanalyzer.org.

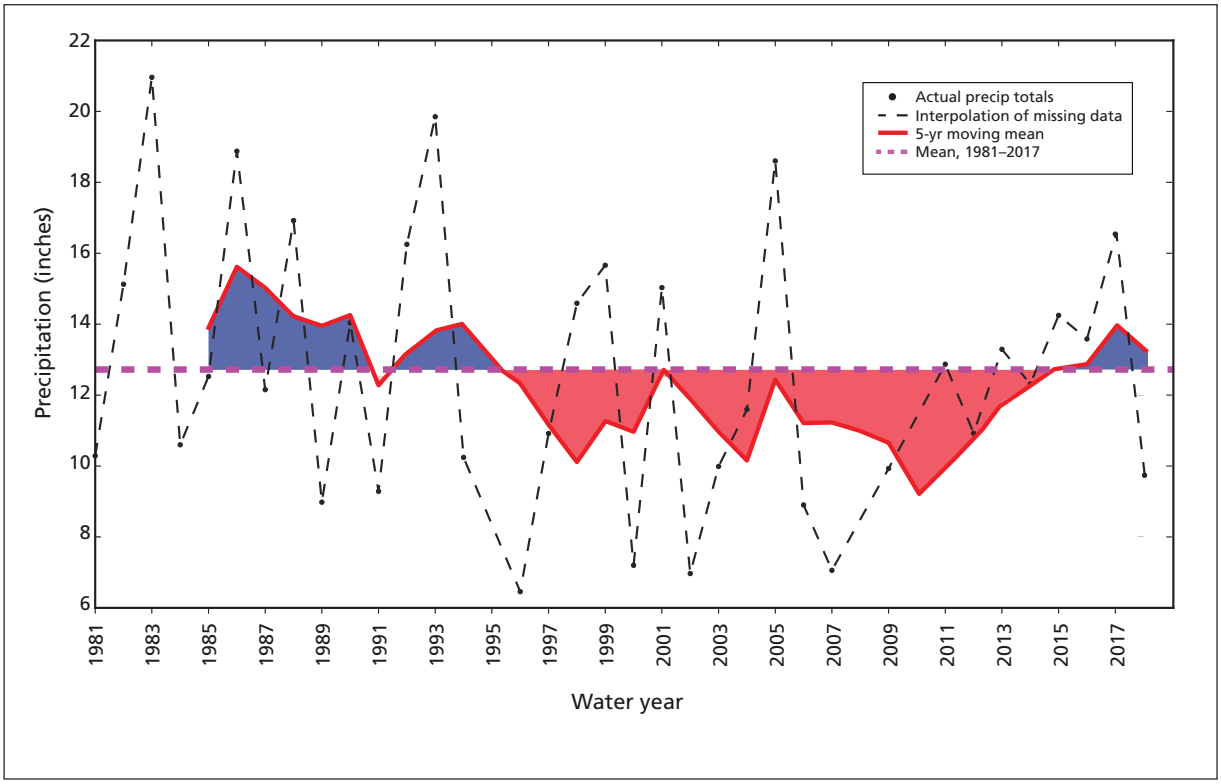


Figure 2-9. Five-year moving mean of annual precipitation, Tuzigoot National Monument, 1981–2018. The moving mean (solid red line) is based on a timeseries with 5.4% (2 of 37) missing values, and includes the current year and previous four years. Blue and red fields represent water surplus and deficit. Missing years are linearly interpolated (dashed grey lines). Graphics generated by climateanalyzer.org.

3 Groundwater

3.1 Background

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.

Montezuma Castle and Tuzigoot national monuments are in the Verde Valley sub-basin that spans from the Black Hills of Yavapai County to the Mogollon Rim. Groundwater recharge to the sub-basin primarily originates from high-elevation winter precipitation northeast of the sub-basin, along the Mogollon Rim and Coconino Plateau. Stream infiltration also recharges the Verde Valley sub-basin in some areas. Groundwater in the Verde Valley sub-basin generally flows north to south, following the Verde River, and leaves the sub-basin through streamflow and evapotranspiration (Blasch et al. 2006).

The Coconino multiple aquifer system (C-aquifer) occurs north of the Verde River along the Mogollon Rim. The aquifer infiltrates precipitation and discharges groundwater to springs and streams as base flow, including Montezuma Well and Wet Beaver Creek (Hart et al. 2002). The C-aquifer also transmits groundwater to the Verde Formation aquifer. The Verde Formation occurs throughout most of the Verde Valley sub-basin, and is the primary water-bearing unit. The Verde Formation is 1,600–4,000 feet thick, characterized by permeable limestone facies separated by mudstone and sandstone facies. Groundwater in the Verde Formation occurs mainly under unconfined conditions, but locally confined conditions exist (Blasch et al. 2006).

At Tuzigoot NM, an unnaturally elevated groundwater table exists in areas immediately adjacent to Peck's Lake and Tavasci Marsh due to the current and historic management of both water bodies. Diversions from the Verde River, inflows from Peck's Lake to Tavasci Marsh, and impoundments within the marsh have increased the hydraulic pressure gradient, maintaining high surface-water levels (Ryan and Parsons 2009). In recent years, surface-water inflows from Peck's Lake to the marsh have been limited, but groundwater inflows are still occurring. The groundwater table likely experiences a steep decrease as groundwater flows down-gradient from Peck's Lake and Tavasci Marsh.

3.2 Methods and monitoring wells

Six wells are monitored in Montezuma Castle and Tuzigoot national monuments. All wells are manually monitored annually by the Arizona Department of Water Resources (ADWR), unless noted otherwise. All ADWR data reported in this document may be retrieved by entering well-identification information at the department's website. More detailed information on monitoring methods may be found in the SODN groundwater monitoring protocol (Filippone et al. 2014).

3.2.1 Montezuma Castle National Monument wells

Three wells are monitored at Montezuma Castle NM (Figure 3-1): one at the Castle unit and two at the Well unit. Established in 1958, the park's water-supply well (WSW) (629124) is a 160-foot-deep well in the Verde Formation limestone. Of the two wells at the Well unit, one is in the park and the other is outside the park boundary. The Montezuma Well WSW (629125) was established in 1970 to a depth of 140 feet. ADWR has manually monitored the well since 2012. Prior to that, the well was infrequently monitored. The ADWR index well (514006) is located outside the park, 0.56 miles from the Montezuma Well WSW. The well was es-

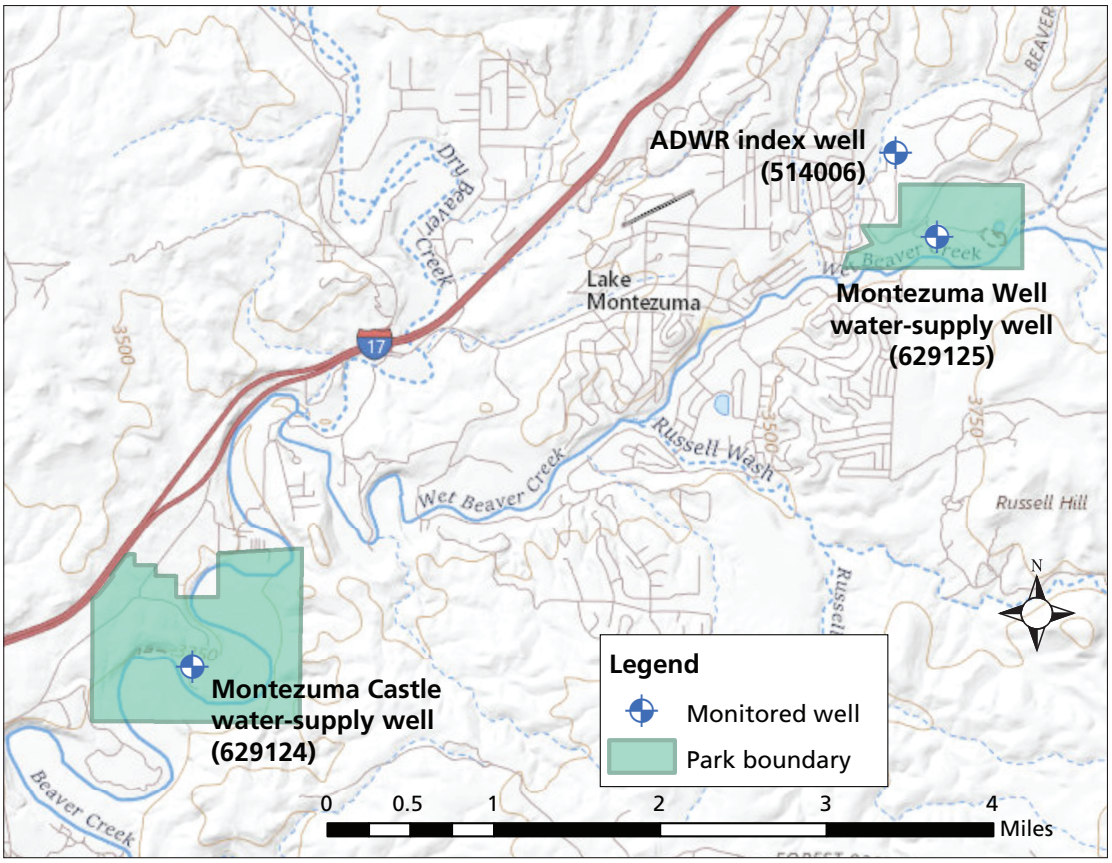


Figure 3-1. Monitoring wells at Montezuma Castle National Monument.

tablished in 1986 to a depth of 300 feet. Both wells at the Well unit are likely completed in the C-aquifer.

3.2.2 Tuzigoot National Monument wells

All Tuzigoot NM monitoring wells (Figure 3-2) are within the Verde Formation. The Tuzigoot NM WSW (629092) was constructed in 1952 to a depth of 313 feet. It is infrequently monitored, most recently in 1994. The three wells used to monitor groundwater at Tuzigoot NM are all outside the park boundary. The Kauzlarich ADWR index well (629211) is located at Dead Horse Ranch State Park, 0.81 miles from the Tuzigoot WSW. The well was established in 1958 to a depth of 1,400 feet. The City of Cottonwood ADWR index well #1 (609076), located 1.98 miles from the Tuzigoot WSW, was established in 1920 to a depth of 300 feet. The Centerville USGS well 344544112025001 (642366) was established in 1977 to a depth of 365 feet. The well is 1.42 miles from the Tuzigoot WSW. This well is monitored at least annually by the U.S. Geological Survey and ADWR. The USGS data can be accessed from the National Water Information System website.

3.3 Results

Water-level measurements were collected at five of six wells in WY2018. ADWR recorded an attempt to measure the water level at the ADWR index well (514006) near the Well unit, but a measurement was not made, for undefined reasons. Data for the WSWs at the Castle and Well units were collected after the wells were recently pumped and may not represent actual groundwater-level conditions.

3.3.1 Montezuma Castle National Monument wells

Groundwater level at the Castle-unit WSW was 63.00 feet below ground surface (bgs) in WY2018, a decrease of 24.20 feet from WY2017 (Figure 3-3). However, pumping prior to measurement in WY2018 likely

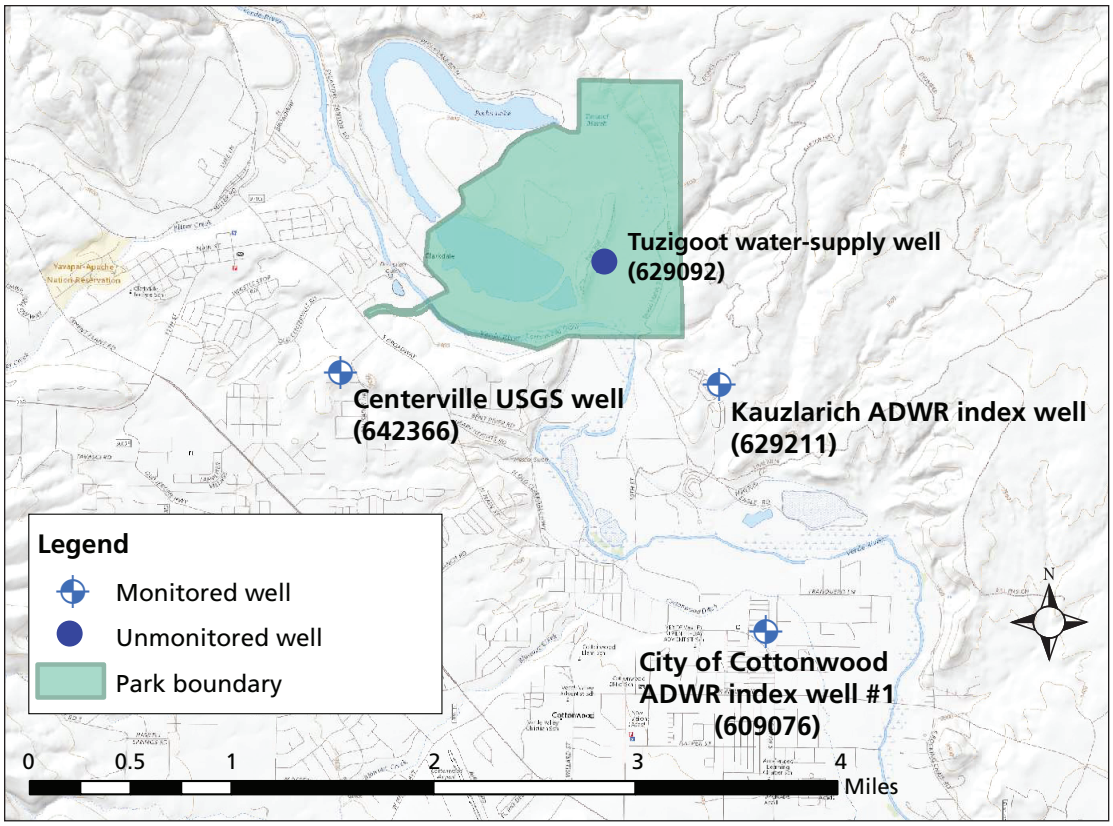


Figure 3-2. Monitoring wells at Tuzigoot National Monument.

contributed to part of the drop. The water level has been variable over the monitoring period, with a range of 29.06–70.26 feet bgs since 1958, and a mean of 45.61 feet bgs.

Water level at the Well-unit WSW was 144.0 feet bgs in WY2018 (Figure 3-3), the lowest recorded. The water level was 8.10 feet lower than in WY2017. However, pumping prior to measurement in WY2018 likely contributed to part of the drop. Since the well was established in 1970, the water level has declined 118 feet. This same downward trend is seen in the ADWR index well (514006) near the Well unit, which declined 73.10 feet since 1991. Figure 3-4 shows that that ADWR index well is upgradient of the Well-unit WSW, and tends to be 24–32 feet higher in elevation than the Well-unit WSW.

Though variable, winter precipitation at the Happy Jack COOP station (23828), on the Mogollon Rim, has exhibited a general downward trend during the period of record (see Figure 3-3). Decreasing winter rains at high elevations are likely reducing groundwater recharge to the Verde Valley sub-basin, which is especially noticeable at the Well unit, where wells are completed in the C-aquifer.

3.3.2 Tuzigoot National Monument wells

The City of Cottonwood index well #1 was 40.5 feet bgs in WY2018—a decrease of 3.70 feet from WY2017, and a net decrease of 9.50 feet from WY1977, when the well was installed (Figure 3-5). The City of Cottonwood index well #1 is relatively representative of the Tuzigoot WSW. Both wells are shallow and likely accessing the same local aquifer within the Verde Formation. Figure 3-6 shows similar water-level elevations at the Tuzigoot WSW and City of Cottonwood index well #1 in 1977 and 1978.

The Centerville USGS well was 274.55 feet bgs in WY2018, a decrease 0.45 feet from WY2018, and a net decline of 5.25 feet since the well was established in 1978. This well has been relatively stable over the entire monitoring record, with a range of 267.42–276.71 feet bgs. The hydraulic head of the Centerville USGS well is also approximately 100 feet higher than the City of Cottonwood

index well #1, likely indicating a steep hydraulic gradient between the two wells.

The Kauzlarich ADWR index well was 40.20 feet bgs in WY2018, an increase of 1.60 feet from WY2017. The well has experienced a net decline of 24.7 feet since the well was established in 1959. However, routine monitoring since 1999 has shown relatively stable water levels, varying between 39.20 and 44.40 feet bgs. The Kauzlarich ADWR index well is a deep well with a hydraulic head approximate 120 feet higher in elevation than the City of Cottonwood index well #1. This suggests that the well is accessing a confined or semi-confined aquifer within the Verde Formation.

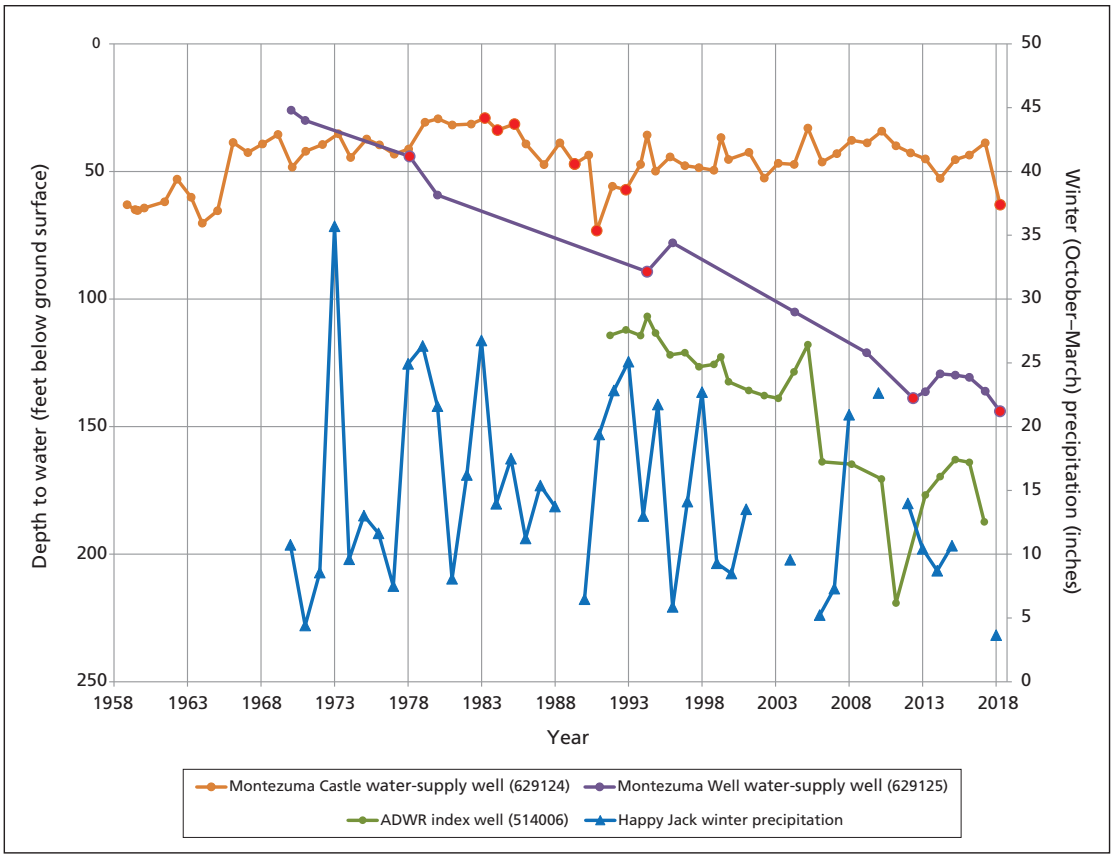


Figure 3-3. Depth-to-water measurements at three wells at Montezuma Castle National Monument and annual winter precipitation (October–March) at the Happy Jack COOP station. Measurements taken while or soon after groundwater pumping indicated in red.

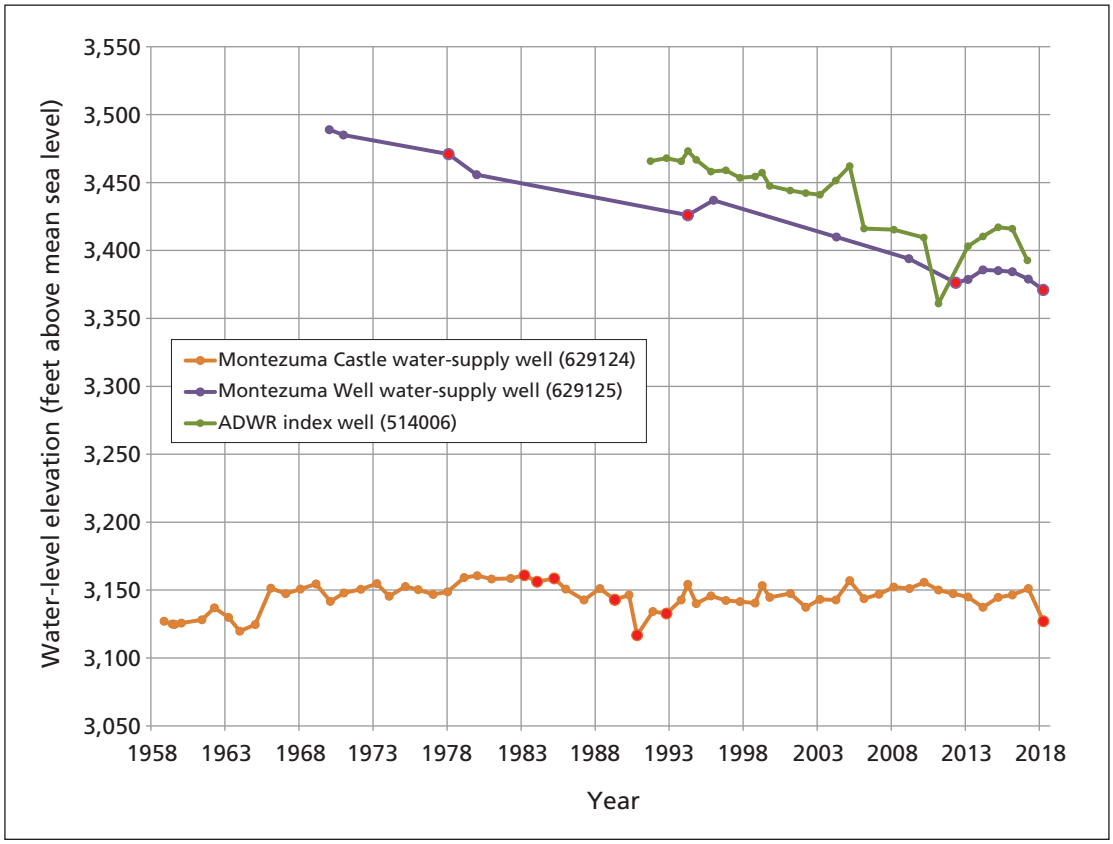


Figure 3-4. Water elevation measurements at three wells at Montezuma Castle National Monument. Measurements taken during or soon after pumping groundwater indicated in red.

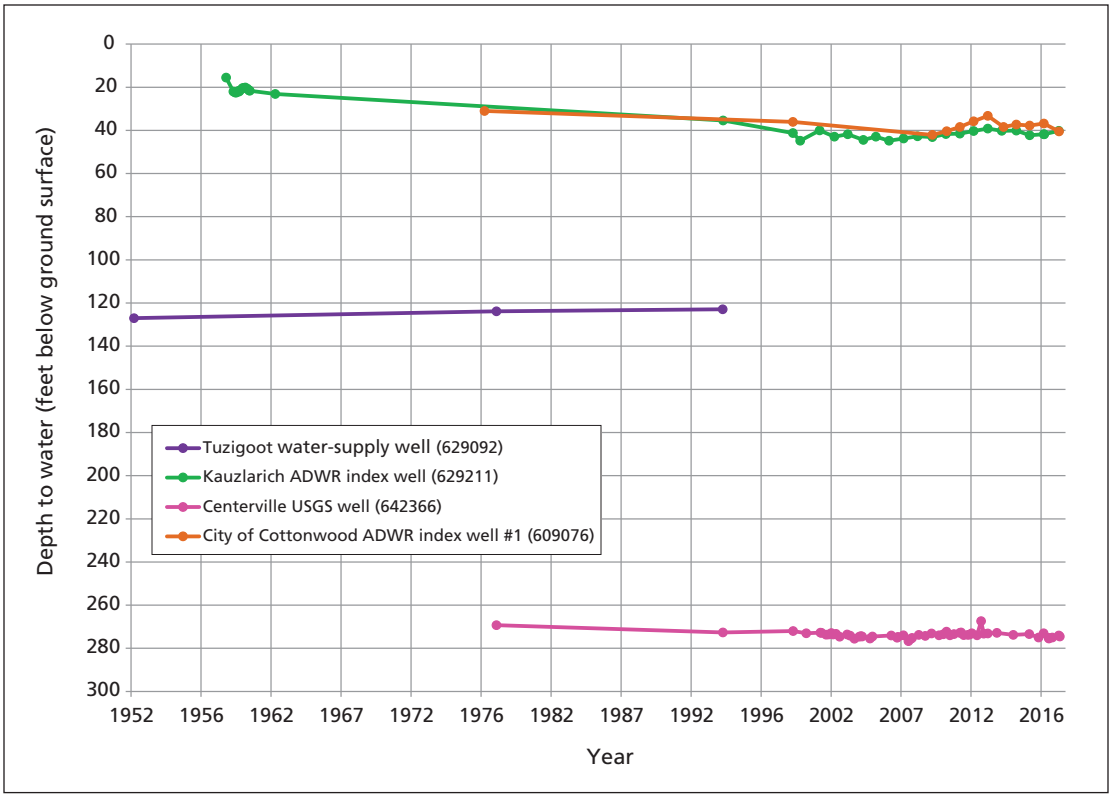


Figure 3-5. Depth-to-water measurements at four wells at Tuzigoot National Monument.

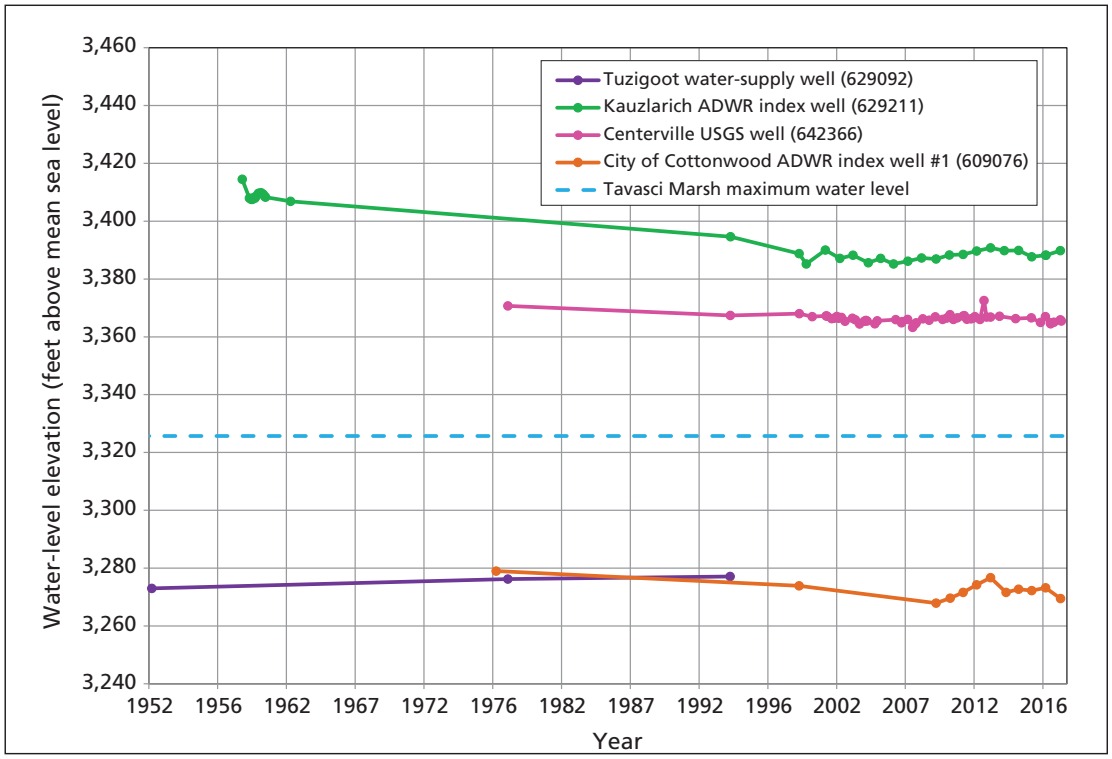


Figure 3-6. Water-elevation measurements at four wells at Tuzigoot National Monument.

4 Springs

4.1 Background

Spring, seep, and tinaja (hereafter "springs") ecosystems are small, relatively rare biodiversity hotspots in arid lands. Associated aquatic organisms, riparian vegetation, and fauna can vary greatly by spring type (Sada et al. 2005).

Common stressors to springs biota include reduced water availability (drying), water temperature extremes (freezing, high temperatures), reduced light penetration (due to turbidity) and biochemical conditions outside the usual "environmental envelope" for a given site (Sada 2013a, 2013b). Climate change is an emerging impact on springs in the American Southwest. Expected changes include increased air temperatures, reduced precipitation, increased evaporation rates, increased drought frequency, and increased frequency and magnitude of extreme weather events (Garfin et al. 2013). These changes may cause springs to go dry (Comer et al. 2012, Dekker and Hughson 2014) or experience reduced flow (Grimm et al. 1997, Weissinger et al. 2016), which may result in disruption of ecological functions and loss of species diversity (Garfin et al. 2013).

4.2 Methods

At Montezuma Castle and Tuzigoot national monuments, Sonoran Desert Network springs monitoring focuses on two sentinel sites: Expansion Spring (Montezuma Castle NM) and Shea Spring (Tuzigoot NM). The statistical inference provided by this design is limited to each individual spring monitored over time.

SODN monitors a suite of vital signs and parameters organized into four modules: site characterization, site condition, water quantity, and water quality. A brief description of the data-collection methodologies followed during WY2018 is presented below. See McIntyre and others (2018) for additional details.

4.2.1 Site characterization

The site-characterization module is a modification of the inventory methods developed for the Mojave Desert Network (Sada and Pohlmann 2006). This module is completed once every five years, or after significant events, and provides context for interpreting change in the other modules. The module includes spring type and characterization, GPS locations, site diagram and site description, and vegetation community description. See the springs monitoring protocol for details (McIntyre et al. 2018). This module was completed at both monuments in 2017 and will be recollected in 2022.

4.2.2 Site condition

The site-condition module is based on inventory methods developed for the Mojave Desert Network (Sada and Pohlmann 2006). It contains four subsections: disturbance, photopoints, obligate/facultative wetland plants, and invasive plants and wildlife. The disturbance assessment is a categorical measure of natural and anthropogenic disturbance and the level of stress on vegetation and soils in springs ecosystems (Sada and Pohlmann 2006). The magnitude of each disturbance is classified on a scale of 1–4, where 1 = undisturbed, 2 = slightly disturbed, 3 = moderately disturbed, and 4 = highly disturbed (Sada and Pohlmann 2006). Photographs are taken from designated photopoints to show the spring and its landscape context. The presence of a suite of obligate or facultative wetland plants is noted during each visit using a checklist. The presence and density of invasive non-native plants, by species, are recorded during each visit. The presence of invasive non-native aquatic wildlife species is also recorded.

4.2.3 Water quantity

The water-quantity module provides information on the persistence of surface water, spring discharge, and wetted extent. The persistence of surface water at springs is estimated by analyzing the variance of temperature measurements between paired sensors deployed in each spring near the primary orifice (point of groundwater emergence) and in a nearby tree or shrub (McIntyre et al. 2018). When the variance from the two

sensors becomes statistically indistinguishable, the spring is likely dry. (Work continues to refine methods to reduce the occurrence of false-positive and false-negative results.) A timed sample of water volume measures the system's surface discharge. Wetted extent measures the physical length (up to 100 m), width, and depth of present surface water.

4.2.4 Water quality

Water-quality monitoring measures core water-quality parameters and water chemistry. Core parameters sampled by SODN include water temperature, pH, specific conductivity, dissolved oxygen, and total dissolved solids. Discrete samples of these parameters are collected with a multiparameter meter (YSI Professional Plus) deployed on-site. Water chemistry is assessed by collecting a surface-water sample and estimating the concentration of major ions with a photometer (YSI 9500)



Figure 4-1. Expansion Spring orifice A, Montezuma Castle National Monument, March 2018.

4.3 Results and discussion

4.3.1 Site characterization

Expansion Spring (Figure 4-1) is a rheocrene spring. The spring emerges in the bed of a small, muddy channel as a diffuse, muddy springbrook that flows intermittently for approximately 10 meters before disappearing within one meter of Beaver Creek. The warm, turbid water flows over a silt substrate that is easily agitated. The broader channel is consistently approximately one meter wide, though the springbrook within is much more narrow and its flow is often diffuse. The crew estimated that water present on March 14, 2018, was dominated by spring discharge.

Shea Spring is a limnocrene spring associated with Tavasci Marsh. A single, small orifice feeds into a large (5 × 6 × 1-m) pool. The initial orifice (Figure 4-2) creates a small (400 × 100 × 1-cm) pool that flows through vegetation to a large pool (Figure 4-3) reinforced on the west. This is considered a secondary orifice that collects the clear, cool flow and contains an additional few bubbling limnocrene orifices in its sandy center. Shea Spring was considered wetted during sampling on March 13, 2018.

4.3.2 Site condition

At ***Expansion Spring***, disturbance surveys in WY2018 resulted in a median value of 1 = undisturbed for both anthropogenic and natural disturbance. There was minimal evidence of recent flooding due to scouring of the stream channel near the orifice and widening of the pool slightly downstream. This channel change prevented the surface flow from reaching Beaver Creek (Figure 4-4). The crew observed two obligate/facultative wetland plant genera: horsetail (*Equisetum* sp.), and sycamore (*Platanus* sp.). No invasive plant or animal species were noted by staff.

At ***Shea Spring***, disturbance surveys resulted in a median value of 1 = undisturbed for both anthropogenic and natural disturbance. There was minimal evidence of recent flooding and beaver activity on the tree on the pool's western edge. The attached water sensors were moved, and the tree bark had been ripped off and/or chewed (Figure 4-5).



Figure 4-2. Shea Spring orifice A, Tuzigoot National Monument, March 2018.



Figure 4-3. Shea Spring orifice B, Tuzigoot National Monument, March 2018.



Figure 4-4. Expansion Spring pool near Beaver Creek, Montezuma Castle National Monument, March 2018.



Figure 4-5. Evidence of beaver activity near Shea Spring, Tuzigoot National Monument, March 2018.

The crew observed two obligate/facultative wetland plant genera: horsetail (*Equisetum* sp.) and cattail (*Typha* sp.). No invasive plants or animals were noted during WY2018.

4.3.3 Water quantity

At ***Expansion Spring***, temperature sensors were deployed from October 2017 to October 2018. Sensors indicated that the spring was wetted throughout the sampled extent (Figure 4-6). Discharge from Orifice A was estimated at 8.3 ± 0.16 liters per second. Expansion Spring was assessed as a rheocrene system with a channel length of 11 meters. Width and depth averaged 61.5 and 13.2 centimeters, respectively.

At ***Shea Spring***, temperature sensors were deployed October 2017–March 2018 and March 2018–October 2018. During the first deployment, the sensor was displaced from its initial location and found hanging above the surface water. These data will be censored in future analysis. It is likely that the spring was wetted during this deployment. During the second deployment, sensors indicated the spring was wetted for the entirety of the sample (Figure 4-7). Discharge and wetted extent were not assessed due to the extended, marshy structure of the limnocrene system.

4.3.4 Water quality

At ***Expansion Spring***, a single sample was measured for core water quality (Table 4-1) and water chemistry (Table 4-2) at the spring orifice in WY2018. At ***Shea Spring***, core water quality (Table 4-1) and water chemistry (Table 4-2) were measured at each of two orifices. We are currently establishing the range of natural variation for these results.

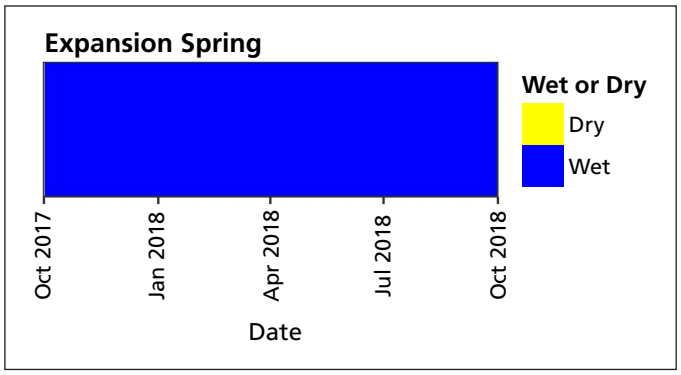


Figure 4-6. Estimated wet/dry days at Expansion Spring, Montezuma Castle National Monument, WY2018.

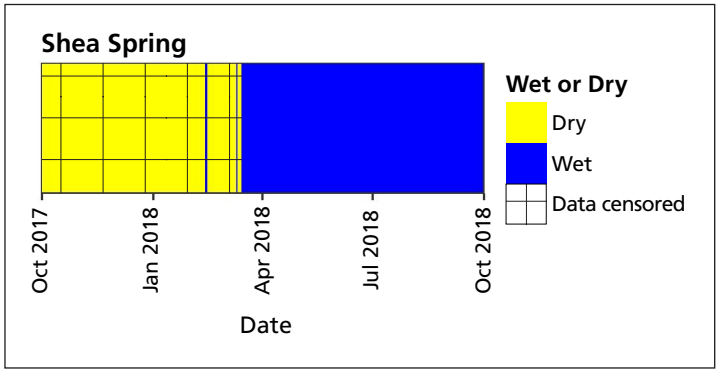


Figure 4-7. Estimated wet/dry days at Shea Spring, Tuzigoot National Monument, WY2018. Data from October 2017 to March 2018 were censored, as the sensor was displaced during this deployment.

Table 4-1. Water-quality data for Expansion Spring and Shea Spring, WY2018.

Sampling location	Orifice(s)	Sample time	Temperature (°C)	Dissolved oxygen (mg/L)	pH	Specific conductivity (µs/cm)	Total dissolved solids (mg/L)	Exposure
Expansion Spring	A	9:34	15.5	4.85*	7.49	637	416	Shade
Shea Spring (1)	A	10:34:00	20.1	6.98	7.47	677.40	357.50	Partial
Shea Spring (2)	A,B	10:44:00	20.2	6.75	7.33	554.00	357.50	Partial

*The post-sampling calibration check for dissolved oxygen failed. After review, it was noted that the ambient air and water temperature during the post-sampling calibration check was 4–5°C higher than during the sampling event. This abrupt change in temperature may have caused the post-sampling check to fail. The probe collected a value twice during the sampling event, and both results were the same. We conclude that the recorded DO value above is valid.

Table 4-2. Water-chemistry data (mg/L) for Expansion Spring and Shea Spring, WY2018.

Sampling location	Orifice(s)	Alkalinity	Calcium	Chloride	Magnesium	Potassium	Sulfate
Expansion Spring	A	280	50	14	33	3.4	1
Shea Spring (1)	A	255	54	17	43	2.2	5
Shea Spring (2)	A,B	225	52	32	34	2.3	2

5 Surface Water

5.1 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. These streams are part of a large hydrologic drainage basin that directs surface and groundwater 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.

5.2 Methods

5.2.1 Sampling locations

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

All samples and field data in WY2018 were collected at the index reaches on Beaver Creek (Figure 5-1), Wet Beaver Creek (Figure 5-2), or the Verde River (Figure 5-3). The figures below show where water quantity and water quality samples were collected (index site), where macroinvertebrates were collected (index reach), and show the boundaries of the overall sampling unit (stream segment).

5.2.2 Water quality core parameters

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

- On arrival at the site, a multi-parameter water quality meter (YSI Professional Plus) is 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 is left in the stream for the duration of the visit. Turbidity samples are collected and analyzed within one hour using a portable turbidimeter (HACH 2100P). Discharge is measured using a FlowTracker Acoustic Doppler Velocimeter.
- In addition to regular sampling, we use 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.

5.2.3 Water quality samples

During each site visit, water samples are 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 transfer the sample water to smaller bottles for analysis of bacteria, turbidity, metals, and other constituents. The sample water is filtered and/or treated as required, kept on ice, and dropped off at the contract laboratory. For WY2018, that lab was TestAmerica, in Phoenix, Arizona.

5.2.4 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) gages: 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 5-4).

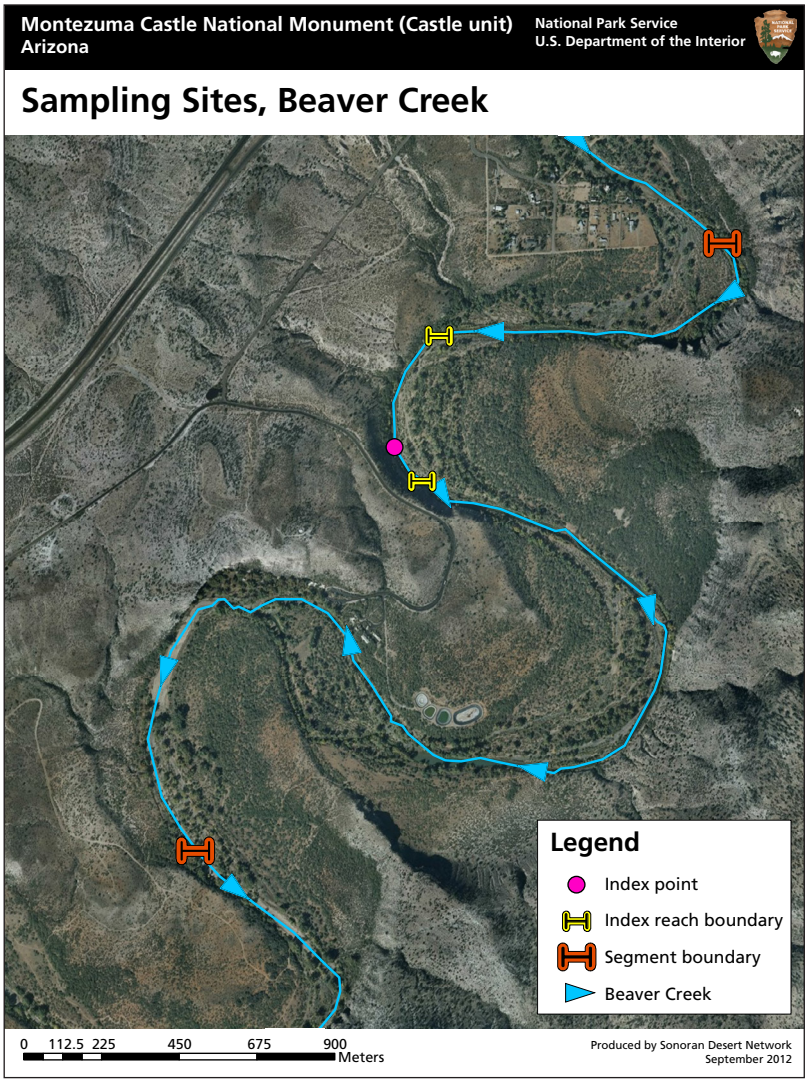


Figure 5-1. Sampling sites on Beaver Creek, Montezuma Castle National Monument (Castle unit).

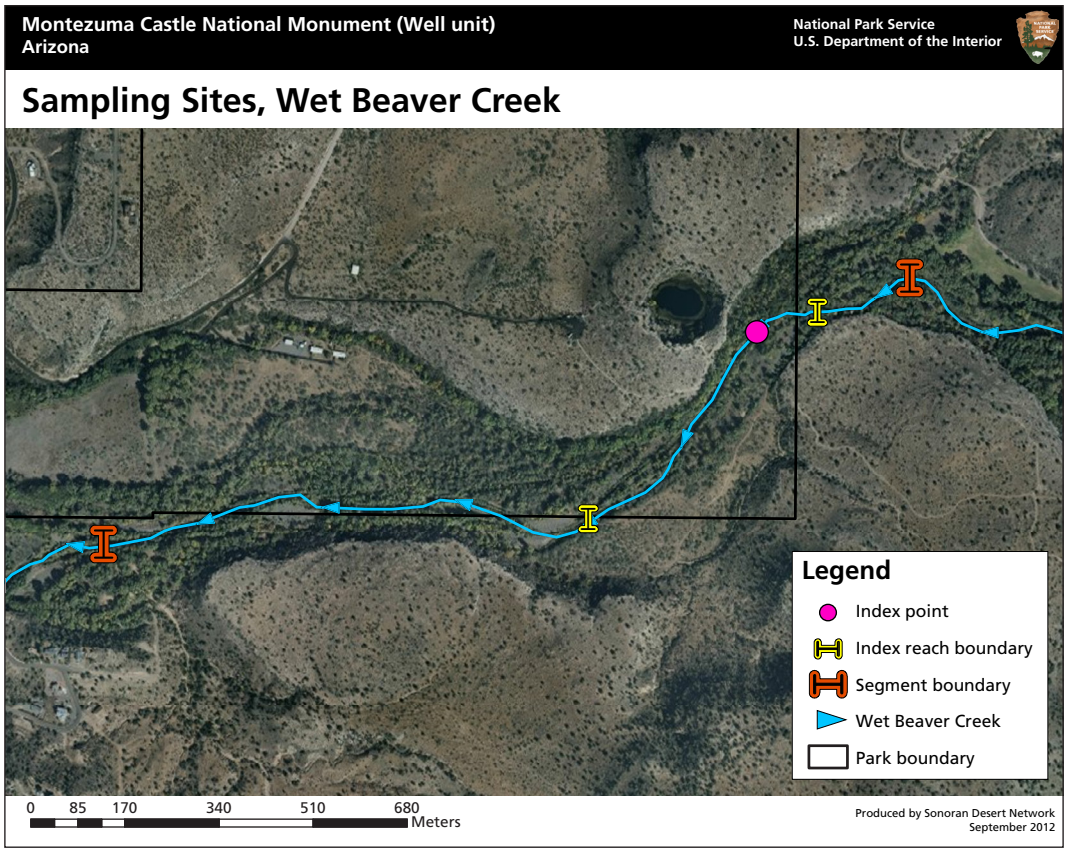


Figure 5-2. Sampling sites on Wet Beaver Creek, Montezuma Castle National Monument (Well unit).

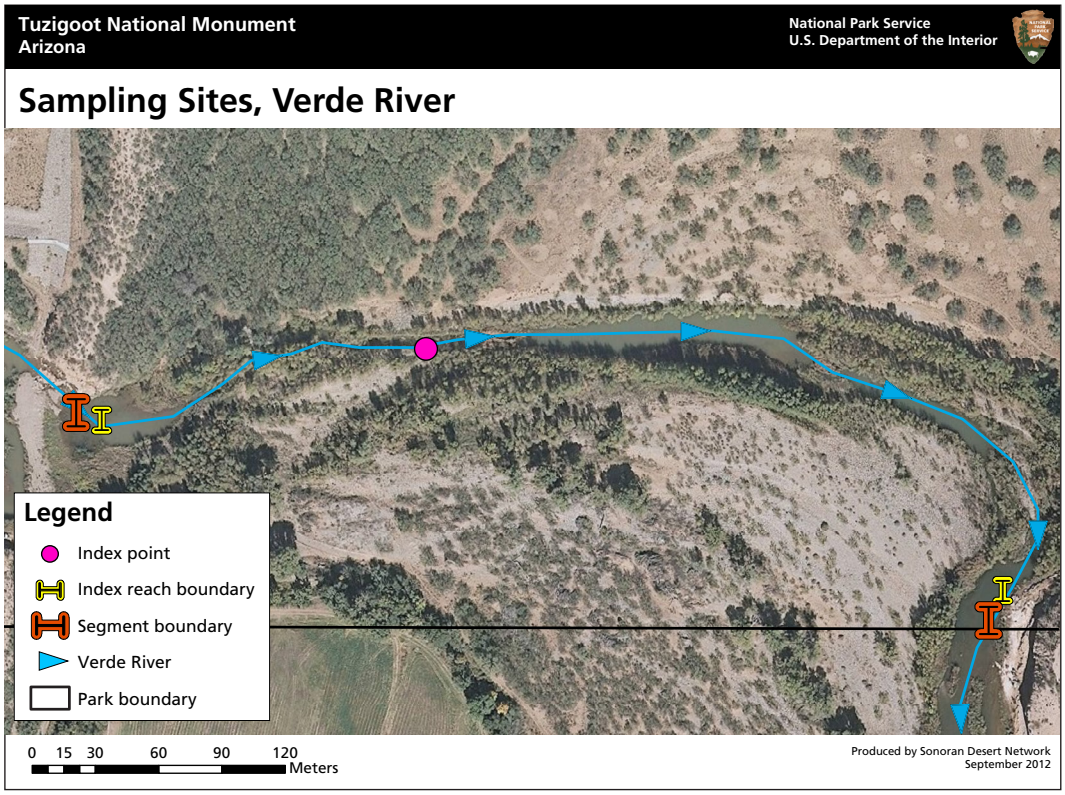


Figure 5-3. Sampling sites on the Verde River, Tuzigoot National Monument.

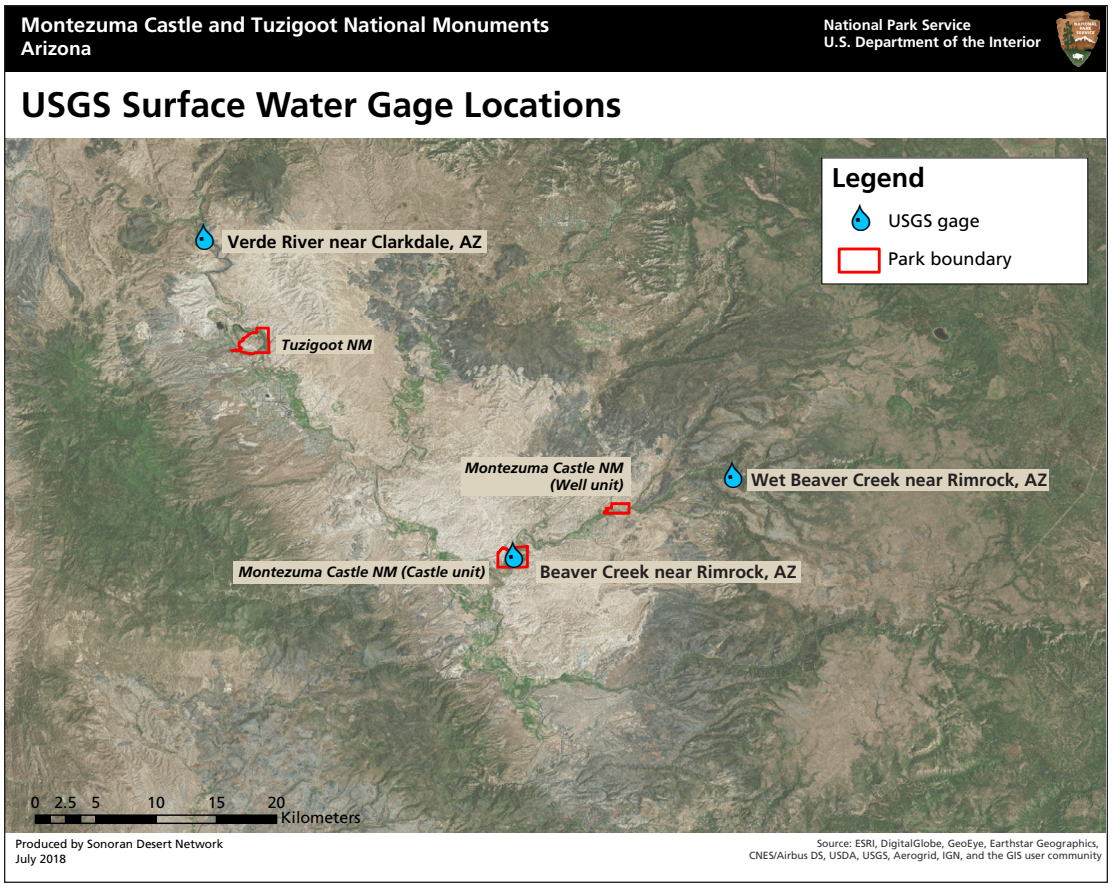


Figure 5-4. Locations of USGS stream gages used for this report.

5.2.4.1 Beaver Creek

The USGS has created a valid rating curve for this site, estimating discharge from the stream gage. Data for this report were taken from the USGS dataset.

5.2.4.2 Wet Beaver Creek

The Wet Beaver Creek gage 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 gage and the Wet Beaver Creek index site. A simple regression analysis of concurrent stage data during baseflow from the USGS gage 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=0635; 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 at the Wet Beaver Creek index site (Gwilliam et al. 2014).

5.2.4.3 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 gage (09504000), located upstream from the Verde River index site. The presence of an agricultural diversion dam between the gage 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 river-based hydrologic and morphologic processes to drive ecological function in the stream segment (Gwilliam et al. 2013).

5.2.5 Aquatic macroinvertebrates and habitat

SODN macroinvertebrate sample collection uses methods prescribed 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 to ensure compatibility of monitoring samples (Lawson 2005).

SODN sampling typically occurs in late May, to accommodate the Arizona Department of Environmental Quality (ADEQ) QA/QC (quality assurance/quality control) rule of requiring four weeks to pass between a bankfull flow event and a sampling event (ADEQ 2015a). 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 5-1. Each reach contains 11 equally spaced transects. At each transect, we measure 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 are collected in the reach:

- A *quantitative sample* is collected from five targeted riffle habitats to provide data on organism abundance. A total of 12 replicate samples are collected from a 0.09-m^2 area, using a kicknet with a 0.3-meter opening for one minute. At each of the five habitats, we also measure depth, velocity, particle size, and particle embeddedness.
- A *qualitative sample* is 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 are sent to the National Aquatic Monitoring Center's BugLab, a Bureau of Land Management laboratory at Utah State University in Logan, Utah. The goal is to have a taxonomist, certified by the North American Benthological Society, identify all aquatic macroinvertebrates to the lowest taxonomic level possible.

5.2.6 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 is 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 2018) and notes any exceedances.

Table 5-1. Sampling dates and index reach lengths at Montezuma Castle and Tuzigoot national monuments during WY2018.

Unit	Stream	Sample date	Index reach length (m)
Montezuma Castle (Castle unit)	Beaver Creek	5/18/2018	423
Montezuma Castle (Well unit)	Wet Beaver Creek	5/17/2018–5/18/2018	567
Tuzigoot NM	Verde River	5/19/2018	311

5.3 Results and discussion

SODN staff sampled each index site quarterly during WY2018 (Table 5-2). We collected data on water quantity, water quality, and macroinvertebrates.

5.3.1 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.

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

5.3.1.1 Beaver Creek

The Beaver Creek gage, 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 and at the USGS gage website.

Mean daily discharge on Beaver Creek was 7.13 cubic feet per second (cfs) in WY2018—approximately one-tenth of the mean value (69 cfs) from WY2005 to 2008 (the years of data from the gage records that meet QA/QC standards). The median value for WY2018 was 6.79 cfs, with a maximum value of 1,100 cfs and a minimum value of 0.13 cfs.

The hydrograph from WY2018 at Beaver Creek (Figure 5-5) demonstrates the typical flow found in the region, with a general increase in flow during the winter, then larger flow events in response to precipitation events during the monsoon season. It is of interest to note that the high-flow events in August 2018 originated from isolated precipitation in the Dry Beaver Creek drainage (Figure 5-6). The hydrograph from the Wet Beaver Creek gage (Figure 5-7) does not show increases in flow in August. However, these spikes in flow are clear on the hydrograph from Dry Beaver Creek.

Park managers should be aware that a large proportion of the water that travels through the Castle unit originates during monsoon flow events in the Dry Beaver Creek drainage (Table 5-3). As such, any industrial (e.g., sand pits), ranching, commercial, or housing (e.g., failing septic systems) activity or point source for pollutants or nutrients in the Dry Beaver Creek drainage could impact water quality and stream ecology at the Castle unit stream segment.

5.3.1.2 Wet Beaver Creek

At Wet Beaver Creek, mean daily discharge during WY2018 was 7.05 cfs, well below the gage record mean of 30.2 cfs. There was a striking lack of flow events, including from snowmelt and from monsoon events. Figure 5-7 illustrates that there was no snowmelt flow in WY2018, well below the gage average. The area in green represents where most (from 25% to 75% of the flow events) would fall, but the WY2018 spring snowmelt (black line) stays in the brown area (indicating the lowest 10% of observations). Simply put, stream flow in WY2018 was at or below 10% of the gage record observations, indicating a very low-flow year.

This type of low flow is rare. Figure 5-8, available from the USGS, is a raster hydrograph of mean daily flow at the Wet Beaver Creek gage. Each pixel represents one day's mean flow value in cfs (x-axis) compared to year (y-axis). This method creates a "color map" of the entire gage record. The top row of pixels represents WY2018. All are in yellow and orange tones, corresponding to

Table 5-2. Dates of sampling visits to index sites at Montezuma Castle and Tuzigoot monuments in WY2018.

Unit	Site	Q1	Q2	Q3	Q4
Montezuma Castle (Castle unit)	Beaver Creek	10/9/2017	2/14/2018	5/21/2018	8/23/2018
Montezuma Castle (Well unit)	Wet Beaver Creek	10/9/2017	2/14/2018	5/21/2018	8/23/2018
Tuzigoot NM	Verde River	10/8/2017	2/13/2018	5/20/2018	8/22/2018

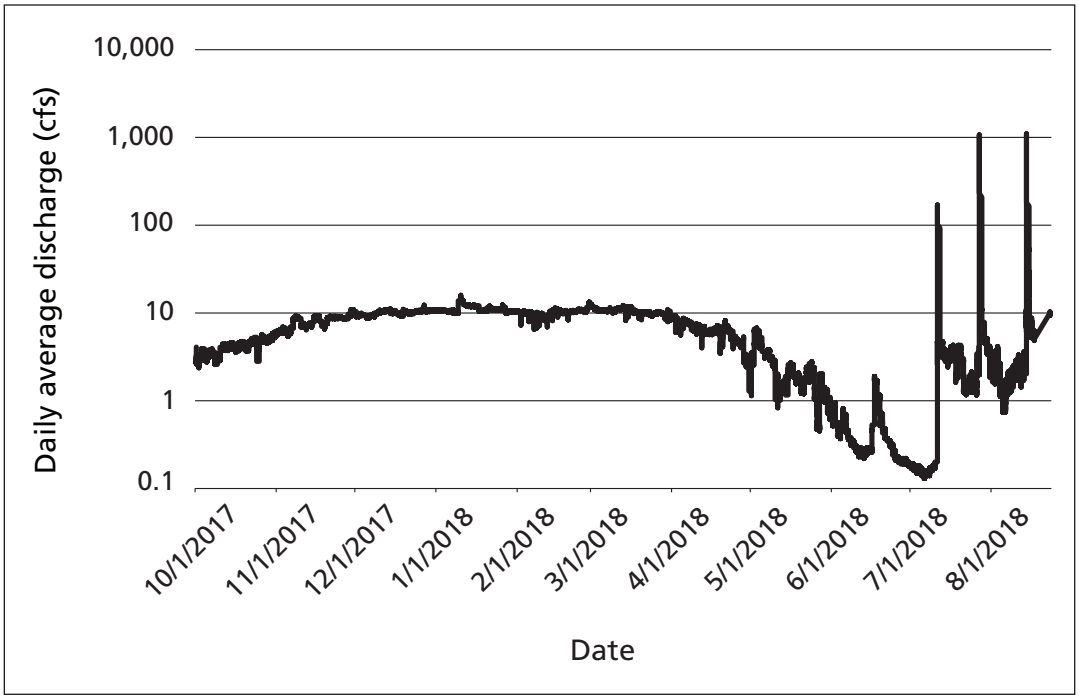


Figure 5-5. Hydrograph from Beaver Creek, Montezuma Castle National Monument (Castle unit), WY2018.

(Data are provisional, ending on 8/23/2018 due to technical issues that are being addressed.)

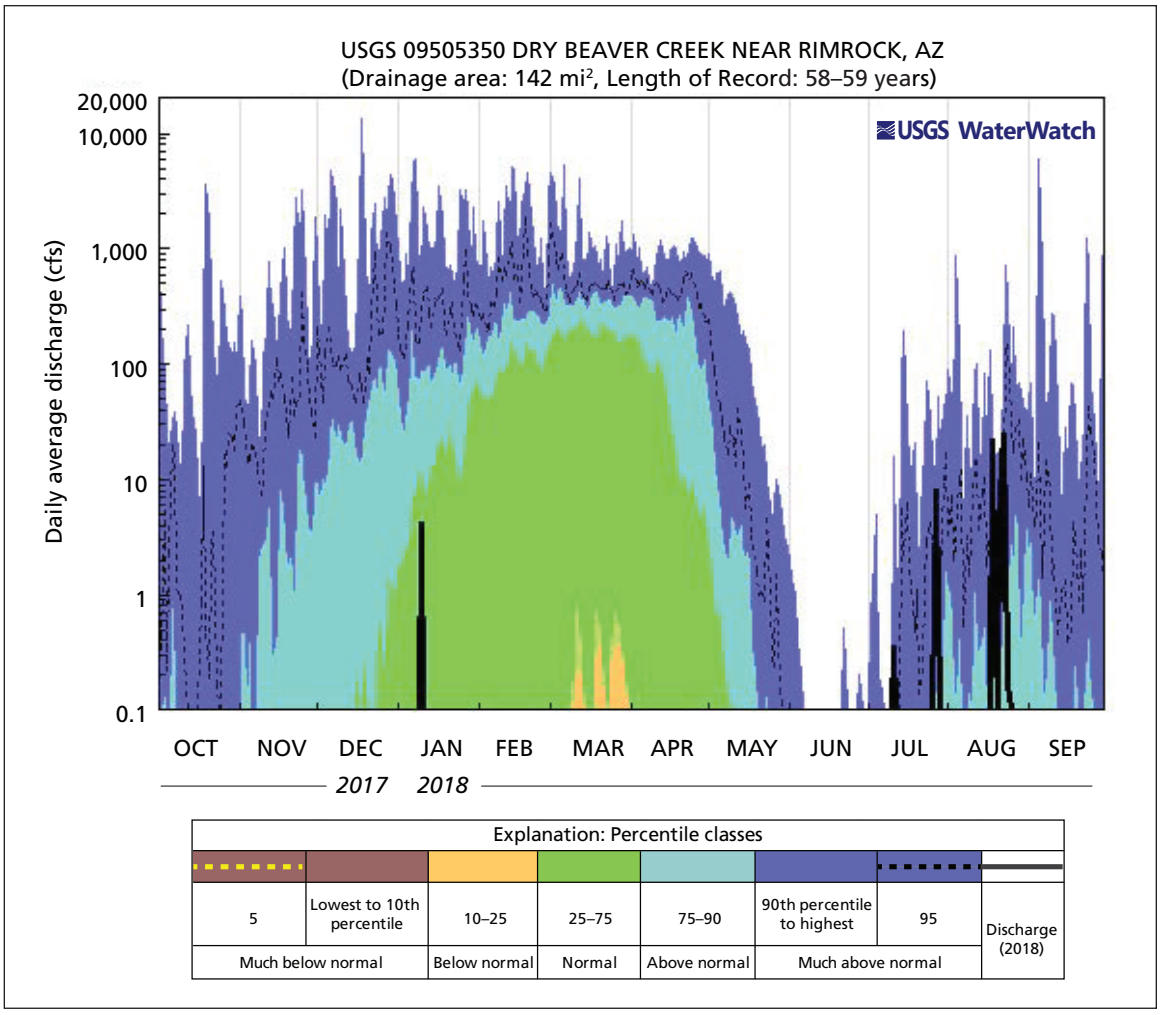


Figure 5-6. Hydrograph from Dry Beaver Creek. Black line represents median discharge value in WY2018.

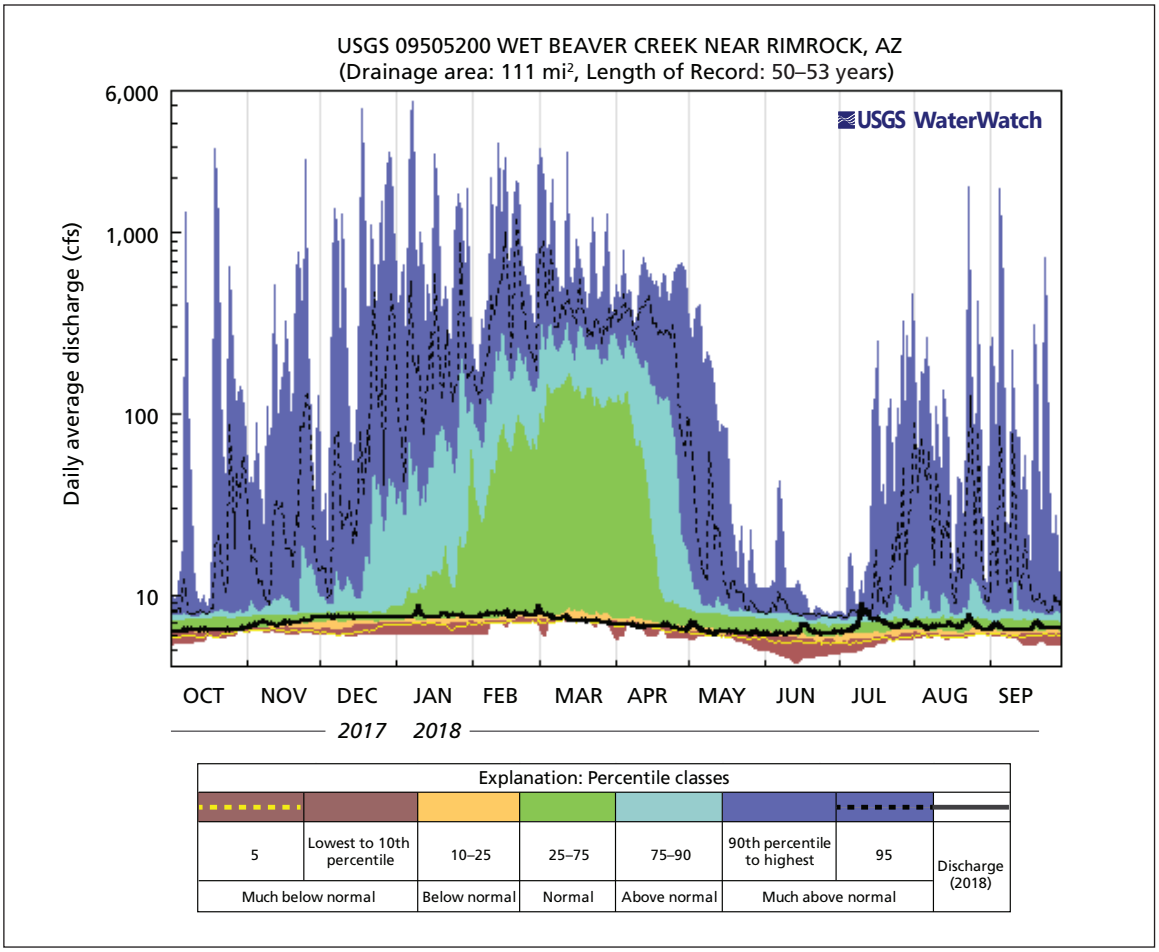


Figure 5-7. Hydrograph for Wet Beaver Creek WY2018.

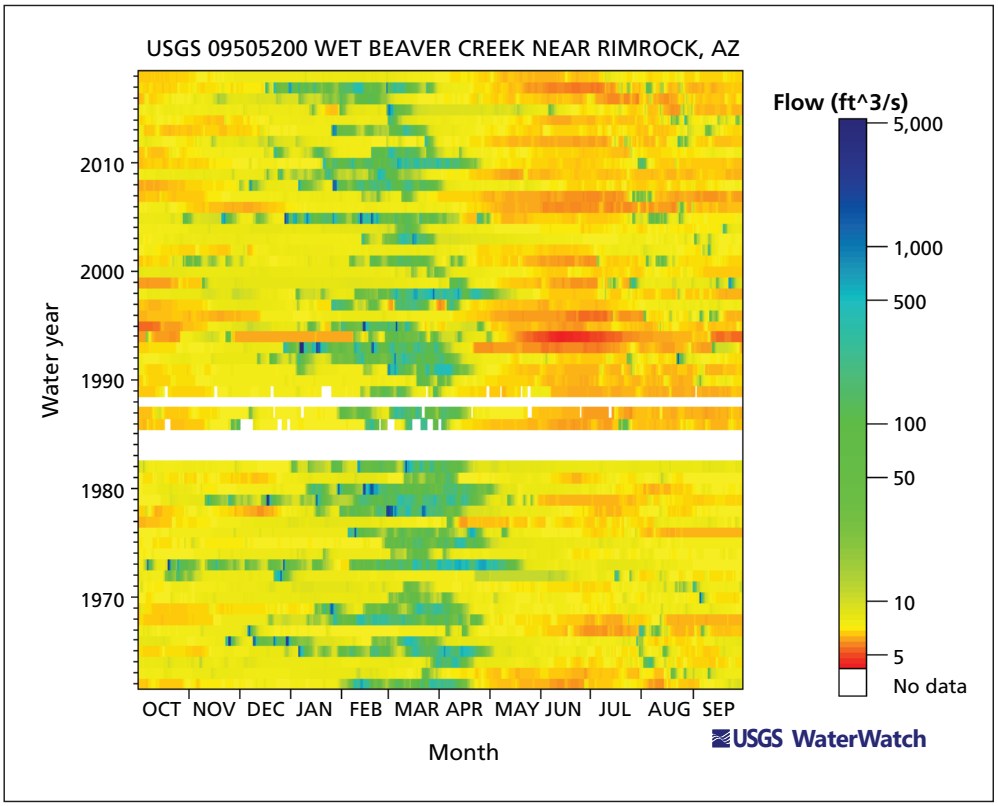


Figure 5-8. Raster hydrograph for Wet Beaver Creek.

Table 5-3. Annual contribution to total water amount flowing in Beaver Creek, WY2008.*

Site	Acre feet/year	% contribution
Dry Beaver Creek	47,056	52%
Wet Beaver Creek	31,448	35%
Other	11,605	13%
Total	90,109	100%

*Latest year data available for all three gages. Data from USGS gage site websites. "Other" sources are smaller ephemeral streams between the Dry and Wet Beaver Creek gages and the Beaver Creek gage, and surface runoff.

mean daily discharge values of 5–10 cfs for the entire year. Looking carefully, WY2006 was similar, along with just a few others since 1962, when the gage began recording.

5.3.1.3 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 5-3), lies below an agricultural diversion 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 3.9 to 29.4 cfs during WY2018 (see Table 5-4, below), and varied depending on the integrity of the dam—that is, how much water leaked through the earthen agricultural diversion 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; Gwilliam et al. 2013), causing a high-flow event in the stream segment. No such event occurred in WY2018.

The recorded flow at this gage during WY2018 was either at or below the 25th percentile for most of the year. The hydrograph at the Verde River gage (Figure 5-9) showed patterns similar to those at the Wet Beaver Creek gage—there was no snowmelt pulse observed this year. From February to April, the Verde River typically experiences a pulse of increased flow (indicated by the green region on Figure 5-9); this did not occur in WY2018. The mean daily discharge at the Verde River gage was 69.8 cfs, versus the gage record of 645.3 cfs—nearly 10 times less than usual, emphasizing the importance of the spring pulse of flow.

5.3.2 Water quality

In WY2018, 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 (see Table 5-2). Samples were collected for analysis by a contracted laboratory (TestAmerica in WY2018) or analyzed by SODN staff on site. A multiparameter water-quality logger was deployed for 2–3 weeks each quarter at the Wet Beaver Creek index site. A total of 744 discrete analyses were performed at the three index site locations (Table 5-4). Of those 744 discrete analyses, 306 analyses had associated state standards.

There were 10 exceedances of state water-quality standards during WY2018, resulting in 94% compliance with state standards across the three units (Table 5-4). Seven of the exceedances were at the Beaver Creek index site (Montezuma Castle NM, Castle unit): three for total arsenic, one for *E. coli*, and three for dissolved oxygen. The others were for total arsenic at the Wet Beaver Creek index site (Montezuma Castle NM, Well unit), and *E. coli* and total lead at the Verde River index site (Tuzigoot NM). These events will be examined below.

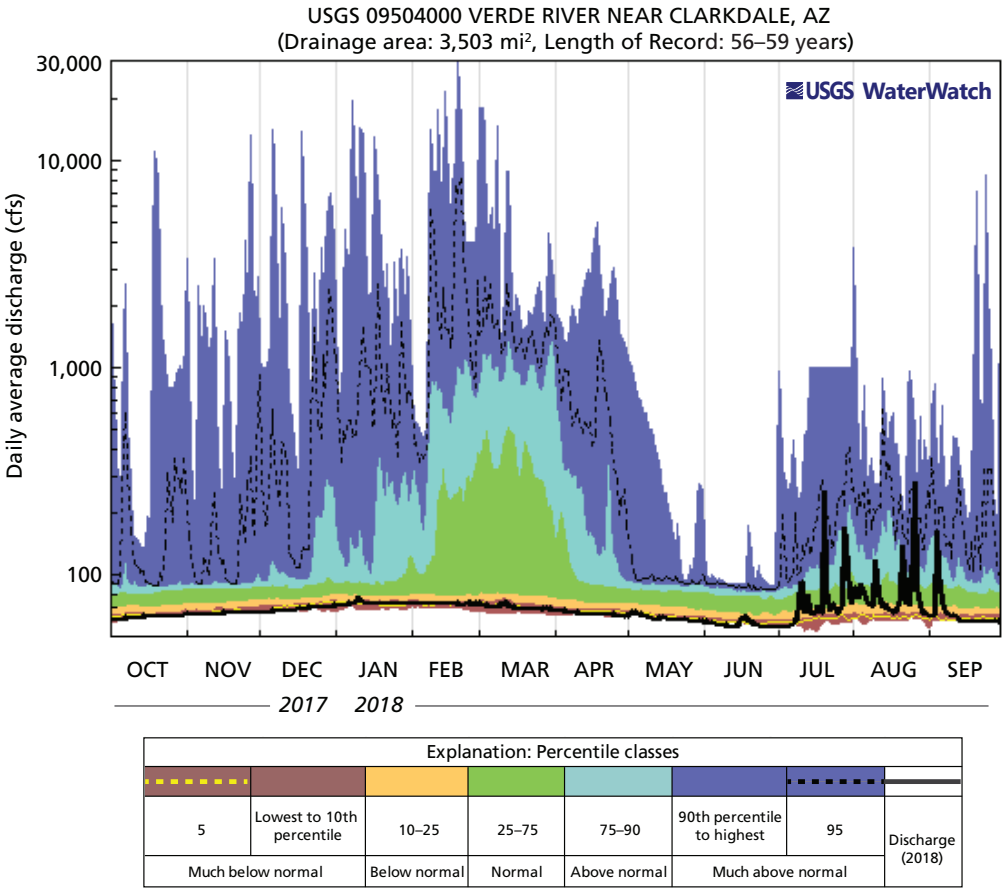


Figure 5-9. Hydrograph for Verde River, Tuzigoot National Monument, WY2018.

Table 5-4. Discrete sampling summary for Beaver Creek, Wet Beaver Creek, and the Verde River, WY2018.

Parameter	Beaver Creek	Wet Beaver Creek	Verde River	Total
Total analyses	248	248	248	744
Analytes with standards	52	52	52	156
Analytes that exceeded standards	7	1	2	10
Parameters in exceedance	Dissolved oxygen (Q1, Q3, Q4); *E. coli* (Q2); Total arsenic (Q1, Q3, Q4)	Total arsenic (Q3)	*E. coli* (Q4); Total lead (Q4)	–
% compliance (# analytes that met standards)	87%	98%	96%	94%

5.3.2.1 Core parameters

Discrete measurements collected in the field represent conditions at each index site during site visits in WY2018 (Table 5-5). Results were all within the range for a warmwater stream, except for the dissolved-oxygen measurements collected at the Beaver Creek site during the Q1, Q3, and Q4 samples.

In WY2017, there was one exceedance of the dissolved-oxygen standard (during Q3, late May). The Q4 sample was close to the state standard in WY2017 (6.04 mg/L vs. standard value of 6 mg/L).

Generally, flow in the three systems was very low (see Section 5.3.1) during WY2018. Low flow can lead to lower water levels and less water passing through the system. The water can pool, and biological activity, along with warmer water, can impact the amount of dissolved oxygen in the stream water column. Low flow decreases mixing of oxygen and water as it flows across the riffles in the stream, and higher temperatures can increase biological and chemical activity that reduces dissolved oxygen. At the Beaver Creek site, this lower flow likely led to the exceedances of state standards for dissolved oxygen.

Continuous core water quality results—. A multiparameter sonde was deployed for approximately two weeks at the Beaver Creek index site during the Q4 period (8/23/2018–9/18/2018) to collect data on temperature, pH, specific conductivity, and dissolved oxygen at 15-minute intervals. This was the first deployment at this site.

A total of 2,500 distinct measurements were collected at Beaver Creek during WY2018. Values from the sonde deployment fell within the expected range of values (Table 5-6). Although the minimum for dissolved oxygen was below the state standard of 6 mg/L, the duration of the low dissolved-oxygen (DO) value did not meet the required period of time required to be identified as an exceedance of the state standard.

Table 5-5. Discrete measurements of core water-quality parameters at Beaver Creek during WY2018.

Parameter	Stream	Quarter				Arizona state standard	
		Q1	Q2	Q3	Q4	Metric	Beneficial use
Temperature (°C)	Beaver Creek	14.5	10.4	18.1	24.0	NS[1]	–
Temperature (°C)	Wet Beaver Creek	14.4	10.3	17.6	20.9	NS[1]	–
Temperature (°C)	Verde River	18.0	12.0	23.4	23.7	NS[1]	–
Specific conductivity (µS/cm)	Beaver Creek	541.0	520	524.0	379.1	NS[1]	–
Specific conductivity (µS/cm)	Wet Beaver Creek	458.1	415	458.9	442.7	NS[1]	–
Specific conductivity (µS/cm)	Verde River	295.4	538	514.0	341.5	NS[1]	–
pH	Beaver Creek	8.14	7.99	7.84	7.71	6.5–9.0	A&W-W[2], FBC[3], A[4]
pH	Wet Beaver Creek	8.40	7.63	7.90	7.91	6.5–9.0	A&W-W[2]; FBC[3]; A[4]
pH	Verde River	8.31	7.99	8.17	7.65	6.5–9.0	A&W-W[2]; FBC[3]; A[4]
Dissolved oxygen (mg/L)	Beaver Creek	**5.83**[5]	10.4	**4.63**[5]	**5.5**[5]	>6	A&W-W[2]
Dissolved oxygen (mg/L)	Wet Beaver Creek	7.59	10.2	6.64	7.77	>6	A&W-W[2]
Dissolved oxygen (mg/L)	Verde River	8.60	10.21	8.32	7.98	>6	A&W-W[2]
Turbidity (NTU)	Beaver Creek	7.53	3.33	6.85	134.7	NS[1]	–
Turbidity (NTU)	Wet Beaver Creek	1.30	0.63	2.75	7.09	NS[1]	–
Turbidity (NTU)	Verde River	20.6	3.43	30.7	1451.3	NS[1]	–
Discharge	Beaver Creek	2.94	NC[6]	1.89	7.84	NS[1]	–
Discharge	Wet Beaver Creek	7.38	NC[6]	7.56	9.40	NS[1]	–
Discharge	Verde River	8.24	NC[6]	3.93	29.40	NS[1]	–

[1]No Standard. [2]Aquatic and Wildlife–Warmwater. [3]Full Body Contact. [4]Agricultural Livestock. [5]Exceedance of state water quality standard (these values are shown in bolded red). [6]Not Collected.

Table 5-6. Summary statistics from sonde deployment during Q4, Beaver Creek index site, WY2018.

Measurement	Temp (°C)	Specific conductivity	pH	Dissolved oxygen (mg/L)
Minimum	19.15	346.00	7.73	4.79
Maximum	27.20	581.00	8.18	11.35
Median	23.81	559.00	7.91	7.17
Mean	23.67	552.10	7.94	7.57
Standard deviation	1.75	32.25	0.10	1.74

When considered in conjunction with the exceedances detected during the discrete sampling (see Table 5-5), the low values of DO during the deployment indicate that some combination of site conditions (e.g., low flow) have resulted in frequent hypoxic events (chronically low DO concentrations) in the stream. These hypoxic events can alter the stream chemistry (although no strong evidence is noted in other results) and impact the fauna found in the stream.

SODN, in conjunction with park staff, will continue to monitor Beaver Creek.

At the Wet Beaver Creek index site, a logging multi-parameter sonde was deployed for approximately two weeks during each quarter in WY2018 (Table 5-7). A total of 5,983 distinct measurements were collected during WY2018. Results from this sampling (Figure 5-10) were within the expected range for each site (Gwilliam et al. 2017, Gwilliam et al. 2013), with several exceptions. Because of equipment failure, no data were collected at the Wet Beaver Creek index site during the Q4 deployment.

The median value for specific conductivity during Q2 was higher than 95% of the site records. Low flow during this period may have contributed to the high value. SODN will continue to consider why this value is high.

The dissolved-oxygen result for Q2 was just below the 25th percentile of data from this site. The data passed QA/QC checks. The cause for this low result is unknown, but may be related to the low flow at the site.

Table 5-7. Deployment periods and number of samples collected, Wet Beaver Creek, WY2018.

Quarter	Dates	Number of samples
Q1	10/09/2017–10/31/2017	2,102
Q2	2/14/2018–3/12/2018	2,522
Q3	5/21/2018–6/4/2018	1,359
Q4	8/23/2018–9/18/2018	–

5.3.2.2 Nutrients

Nutrients were sampled at each index site during each quarter of WY2018 (Table 5-8). Results were in the expected range of values.

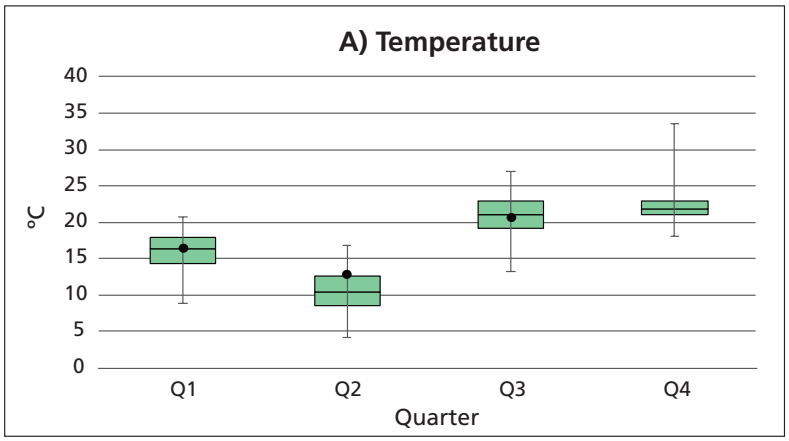
5.3.2.3 Biological condition

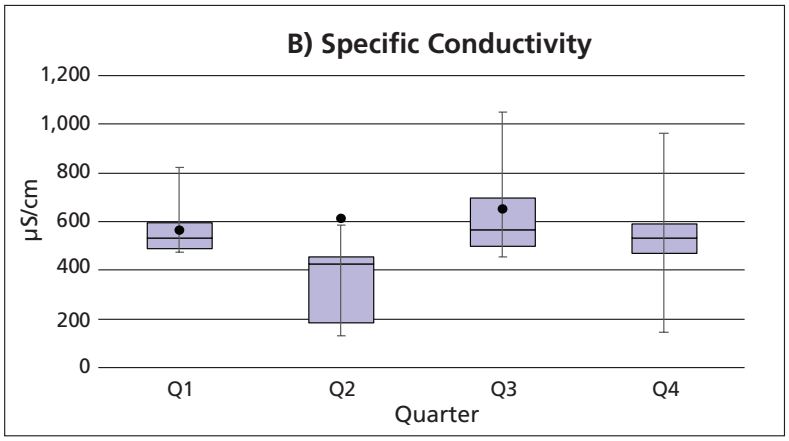
Analytes of biological condition were sampled at each index site during each quarter of WY2018 (Table 5-9). *E. coli* exceeded Arizona state water-quality standards at the Beaver Creek index site during Q2 and the Verde River index site in Q4.

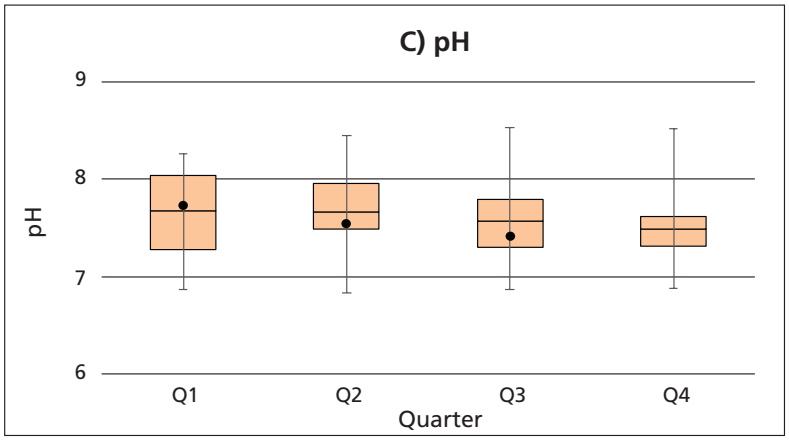
E. coli is a ubiquitous environmental bacterium that specializes in the gut environment of mammals. It has been used as an indicator of fecal contamination of surface waters (ADEQ 2015b). *E. coli* itself is a possible pathogen, and an indicator of other microbiological pathogens. **SODN urges park managers to continue to limit public access to 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. 2017, Gwilliam et al. 2013). Those past exceedances, and the two in WY2018, have been associated with precipitation events in the watershed. There was a small (~10 cfs) flow event the week before the Q2 sampling event at Beaver Creek (precipitation data can be accessed from the Climate Analyzer). Precipitation washes material (including wild and domestic animal waste) from the surface into adjoining streams.

The exceedance at the Verde River site is likely due to the lack of higher-flow events breaching or degrading the agricultural diversion structure, preventing a higher







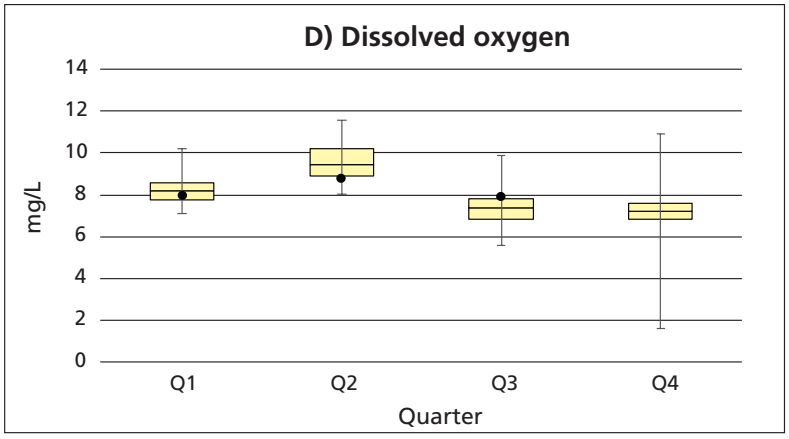


Figure 5-10. Results of continuous sampling at Wet Beaver Creek. Box and whiskers indicate data from WY2011 to WY2017.

The boxes indicate the 25th (bottom of box) to 75th (top of box) percentile of the data, with the line in the middle as the median value. The solid black dots mark the median value from WY2018 sampling for each parameter. No data were collected during the Q4 deployment in WY2018.

Table 5-8. Results of nutrient sampling, Beaver Creek, Wet Beaver Creek, and Verde River, WY2018.

Analyte (mg/L)	Site	Quarter[1]				Method[2]	Arizona state standard	
		Q1	Q2	Q3	Q4		Metric	Beneficial use
Ammonia	Beaver Creek	<0.1	<0.1	<0.1	<0.1	350.1	CALC[3]	A&W-W[4]
Ammonia	Wet Beaver Creek	<0.1	<0.1	<0.1	<0.1	350.1	CALC[3]	A&W-W[4]
Ammonia	Verde River	<0.1	<0.1	<0.1	<0.1	350.1	CALC[3]	A&W-W[4]
Nitrate Nitrite as N	Beaver Creek	<0.1	0.19	<0.1	<0.1	353.2	NS[5]	NS[5]
Nitrate Nitrite as N	Wet Beaver Creek	<0.1	<0.1	<0.1	<0.1	353.2	NS[5]	NS[5]
Nitrate Nitrite as N	Verde River	<0.1	<0.1	<0.1	0.65	353.2	NS[5]	NS[5]
Nitrate, dissolved	Beaver Creek	<0.5	<0.5	<0.5	<0.5	300.0	3,733	FBC[6]
Nitrate, dissolved	Wet Beaver Creek	<0.5	<0.5	<0.5	<0.5	300.0	3,733	FBC[6]
Nitrate, dissolved	Verde River	<0.5	<0.5	<0.5	0.63	300.0	3,733	FBC[6]
Nitrite, dissolved	Beaver Creek	<0.5	<0.5	<0.5	<0.5	300.0	233	FBC[6]
Nitrite, dissolved	Wet Beaver Creek	<0.5	<0.5	<0.5	<0.5	300.0	233	FBC[6]
Nitrite, dissolved	Verde River	<0.5	<0.5	<0.5	<0.5	300.0	233	FBC[6]
Nitrogen, Kjeldahl	Beaver Creek	<1	1.1	<1	<1	351.2	NS[5]	NS[5]
Nitrogen, Kjeldahl	Wet Beaver Creek	<1	<1	<1	1.4	351.2	NS[5]	NS[5]
Nitrogen, Kjeldahl	Verde River	<1	<1	<1	<1	351.2	NS[5]	NS[5]
Nitrogen, total	Beaver Creek	<0.1	1.1	<0.1	<0.1	353.2[7]	3	Verde-River specific
Nitrogen, total	Wet Beaver Creek	<0.1	<0.1	<0.1	1.4	353.2[7]	3	Verde-River specific
Nitrogen, total	Verde River	<0.1	<0.1	<0.1	0.63	353.2[7]	3	Verde-River specific

[1]Parameters reported with a "<" symbol 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. [2]Eaton and others (2005). [3]Calculated using a hardness of 250 mg/L, temperature of 25.6°C, and pH of 8.11. [4]Aquatic and Wildlife–Warmwater, [5]No Standard. [6]Full Body Contact. [7]USEPA (1983).

Table 5-9. Results of biological condition sampling, Beaver Creek, Wet Beaver Creek, and Verde River, WY2018.

Analyte (mg/L)	Site	Quarter[1]				Method[2]	Arizona state standard	
		Q1	Q2	Q3	Q4		Metric	Beneficial use
Biochemical Oxygen Demand	Beaver Creek	<2	3.7	<2	<2	SM 5130B	NS[3]	NS[3]
Biochemical Oxygen Demand	Wet Beaver Creek	<2	<2	<2	<2	SM 5130B	NS[3]	NS[3]
Biochemical Oxygen Demand	Verde River	<2	<2	<2	<2	SM 5130B	NS[3]	NS[3]
Total Organic Carbon - Duplicates	Beaver Creek	NC[4]	5	NC[4]	NC[4]	SM 5210B	NS[3]	NS[3]
Total Organic Carbon – Duplicates	Wet Beaver Creek	NC[4]	NC[4]	1.4	NC[4]	SM 5210B	NS[3]	NS[3]
Total Organic Carbon - Duplicates	Verde River	NC[4]	NC[4]	NC[4]	6.4	SM 5210B	NS[3]	NS[3]
E. coli (MPN[5]/100m/L)	Beaver Creek	24.6	**441**[6]	12.4	46.7	SM 9223B	<235[7]	FBC[8]
E. coli (MPN[5]/100m/L)	Wet Beaver Creek	37.5	55.0	21.1	107.1	SM 9223B	<235[7]	FBC[8]
E. coli (MPN[5]/100m/L)	Verde River	24.6	20.7	17.7	**1,696.8**[6]	SM 9223B	<235[7]	FBC[8]

[1]Parameters reported with a "<" symbol 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. [2]Standard Method (Eaton et al. 2005). [3]No Standard. [4]Not Collected. [5]Most Probable Number. [6]Exceedance of state water quality standard (these values are shown in bolded red). [7]Calculated with single sample method. [8]Full Body Contact.

volume of water from flowing through the stream.

5.3.2.4 Metals

Analytes of the metals group were sampled at each index site during each quarter of WY2018 (Tables 5-9 and 5-10). Four exceedances of the total arsenic standard were recorded during WY2018: three at the Beaver Creek index site (Q1, Q3, Q4), and one at the Wet Beaver Creek index site (Q3) (Table 5-11).

Please note that detectable arsenic concentrations were recorded at all sites during WY2018 visits. These WY2018 concentrations are typical for the region. Arsenic concentrations have exceeded state standards in the past (e.g., WY2017, WY2016, WY2011, WY2010) (Gwilliam et al. 2018a, Gwilliam et al. 2017, Gwilliam et al. 2014). 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 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, making them more susceptible to disruptions in ecological function (e.g., low flow).

It is strongly recommended that park managers restrict visitors from having contact with stream water, and 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.

5.3.2.5 Total suspended sediments and dissolved solids

Total suspended sediments and total dissolved solids were sampled at each index site during each quarter of WY2018 (Table 5-12). Total suspended sediments varied in concentration during WY2018. Some of the variation was attributable to flow events (e.g., the Verde River TDS of 100 mg/L in Q4). Other variation may be due to impacts from diversion dams (e.g., the Verde River TSS of 510 mg/L in Q4).

5.3.2.6 General water quality and inorganics

Analytes of this group were sampled at each index site during each quarter of WY2018 (Table 5-13). Results remained within the range of expected values (Gwilliam et al. 2017, Gwilliam et al. 2013).

WARNING

Contact with the natural waters found at Montezuma Castle NM and Tuzigoot NM be avoided, or minimized when contact is required (i.e., through use of proper personal protective equipment, limiting exposure time, and washing with hot, soapy water after exposure). There has been a reoccurring exceedance of the Arizona state water quality standard (partial and full body contact) for arsenic due to mineral arsenic in the rocks and other materials that compose the geology of the region.

This includes Beaver Creek, Wet Beaver Creek, the Verde River, Tavasci Marsh, and Montezuma Well, including the ditch that carries water from the Well to Wet Beaver Creek. These waters should not be ingested under any circumstances. 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 5-10. Sampling results for dissolved metals, Beaver Creek, Wet Beaver Creek, and Verde River, WY2018.

Analyte (mg/L)	Site	Quarter[1]				Method[2]	Arizona state standard	
		Q1	Q2	Q3	Q4		Metric	Beneficial use
Aluminum	Beaver Creek	<0.1	<0.1	<0.1	<0.1	200.7/200.7 r 4.4	NS[3]	NS[3]
Aluminum	Wet Beaver Creek	<0.1	<0.1	<0.1	<0.1	200.7/200.7 r 4.4	NS[3]	NS[3]
Aluminum	Verde River	<0.1	<0.1	<0.1	<0.1	200.7/200.7 r 4.4	NS[3]	NS[3]
Antimony	Beaver Creek	NC[4]	NC[4]	NC[4]	<0.002	200.7/200.8	0.03	A&W-W[5]
Antimony	Wet Beaver Creek	NC[4]	NC[4]	NC[4]	<0.002	200.7/200.8	0.03	A&W-W[5]
Antimony	Verde River	NC[4]	NC[4]	NC[4]	<0.002	200.7/200.8	0.03	A&W-W[5]
Arsenic	Beaver Creek	0.026	0.022	0.033	0.025	200.7/200.8	0.15	A&W-W[5]
Arsenic	Wet Beaver Creek	0.022	0.016	0.027	0.024	200.7/200.8	0.15	A&W-W[5]
Arsenic	Verde River	0.019	0.019	0.017	0.01	200.7/200.8	0.15	A&W-W[5]
Barium	Beaver Creek	NC[4]	NC[4]	NC[4]	0.16	200.8	NS[3]	NS[3]
Barium	Wet Beaver Creek	NC[4]	NC[4]	NC[4]	0.29	200.8	NS[3]	NS[3]
Barium	Verde River	NC[4]	NC[4]	NC[4]	0.29	200.8	NS[3]	NS[3]
Beryllium	Beaver Creek	NC[4]	NC[4]	NC[4]	<0.001	200.7/200.8	NS[3]	NS[3]
Beryllium	Wet Beaver Creek	NC[4]	NC[4]	NC[4]	<0.001	200.7/200.8	NS[3]	NS[3]
Beryllium	Verde River	NC[4]	NC[4]	NC[4]	<0.001	200.7/200.8	NS[3]	NS[3]
Boron	Beaver Creek	0.28	0.27	0.33	0.19	200.7/200.7 r 4.4	NS[3]	NS[3]
Boron	Wet Beaver Creek	0.14	0.12	0.17	0.15	200.7/200.7 r 4.4	NS[3]	NS[3]
Boron	Verde River	0.15	0.15	0.17	0.1	200.7/200.7 r 4.4	NS[3]	NS[3]
Cadmium	Beaver Creek	NC[4]	NC[4]	NC[4]	<0.001	200.7/200.8	Calculated	A&W-W[5]
Cadmium	Wet Beaver Creek	NC[4]	NC[4]	NC[4]	<0.001	200.7/200.8	Calculated	A&W-W[5]
Cadmium	Verde River	NC[4]	NC[4]	NC[4]	<0.001	200.7/200.8	Calculated	A&W-W[5]
Calcium	Beaver Creek	48	53	38	42	200.7/200.7 r 4.4	NS[3]	NS[3]
Calcium	Wet Beaver Creek	49	48	49	47	200.7/200.7 r 4.4	NS[3]	NS[3]
Calcium	Verde River	53	53	49	38	200.7/200.7 r 4.4	NS[3]	NS[3]
Chromium	Beaver Creek	NC[4]	NC[4]	NC[4]	<0.003	200.7/200.8	NS[3]	NS[3]
Chromium	Wet Beaver Creek	NC[4]	NC[4]	NC[4]	<0.003	200.7/200.8	NS[3]	NS[3]
Chromium	Verde River	NC[4]	NC[4]	NC[4]	<0.003	200.7/200.8	NS[3]	NS[3]
Copper	Beaver Creek	<0.015	<0.015	<0.015	<0.002	200.7/200.8	Calculated	A&W-W[5]
Copper	Wet Beaver Creek	<0.015	<0.015	<0.015	<0.002	200.7/200.8	Calculated	A&W-W[5]
Copper	Verde River	<0.015	<0.015	<0.015	0.0042	200.7/200.8	Calculated	A&W-W[5]
Iron	Beaver Creek	<0.1	<0.1	<0.1	<0.1	200.7/200.7 r 4.4	1	A&W-W[5]
Iron	Wet Beaver Creek	<0.1	<0.1	<0.1	0.19	200.7/200.7 r 4.4	1	A&W-W[5]
Iron	Verde River	<0.1	<0.1	<0.1	<0.1	200.7/200.7 r 4.4	1	A&W-W[5]
Lead	Beaver Creek	<0.009	<0.009	<0.009	<0.001	200.7/200.8	Calculated	A&W-W[5]
Lead	Wet Beaver Creek	<0.009	<0.009	<0.009	<0.001	200.7/200.8	Calculated	A&W-W[5]
Lead	Verde River	<0.009	<0.009	<0.009	<0.001	200.7/200.8	Calculated	A&W-W[5]
Magnesium	Beaver Creek	26	28	29	14	200.7/200.7 r 4.4	NS[3]	NS[3]
Magnesium	Wet Beaver Creek	21	23	23	21	200.7/200.7 r 4.4	NS[3]	NS[3]
Magnesium	Verde River	26	26	27	13	200.7/200.7 r 4.4	NS[3]	NS[3]
Manganese	Beaver Creek	0.032	0.01	0.016	0.028	200.7/200.8	NS[3]	NS[3]
Manganese	Wet Beaver Creek	0.028	0.018	0.029	0.035	200.7/200.8	NS[3]	NS[3]
Manganese	Verde River	<0.01	<0.01	0.01	<0.002	200.7/200.8	NS[3]	NS[3]
Mercury	Beaver Creek	NC[4]	NC[4]	NC[4]	<2e-04	245.1	1.00E-05	A&W-W[5]
Mercury	Wet Beaver Creek	NC[4]	NC[4]	NC[4]	<2e-04	245.1	1.00E-05	A&W-W[5]

Table 5-10. Sampling results for dissolved metals, Beaver Creek, Wet Beaver Creek, and Verde River, WY2018, cont.

Analyte (mg/L)	Site	Quarter[1]				Method[2]	Arizona state standard	
		Q1	Q2	Q3	Q4		Metric	Beneficial use
Mercury	Verde River	NC[4]	NC[4]	NC[4]	<2e-04	245.1	1.00E-05	A&W-W[5]
Molybdenum	Beaver Creek	<0.02	<0.02	<0.02	<0.002	200.7/200.8	NS[3]	NS[3]
Molybdenum	Wet Beaver Creek	<0.02	<0.02	<0.02	<0.02	200.7/200.8	NS[3]	NS[3]
Molybdenum	Verde River	<0.02	<0.02	<0.02	<0.02	200.7/200.8	NS[3]	NS[3]
Nickel	Beaver Creek	NC[4]	NC[4]	NC[4]	0.0023	200.7/200.8	Calculated	A&W-W[5]
Nickel	Wet Beaver Creek	NC[4]	NC[4]	NC[4]	<0.02	200.7/200.8	Calculated	A&W-W[5]
Nickel	Verde River	NC[4]	NC[4]	NC[4]	<0.02	200.7/200.8	Calculated	A&W-W[5]
Phosphorus	Beaver Creek	<3	<3	<3	<3	200.7/200.7 r 4.4	NS[3]	NS[3]
Phosphorus	Wet Beaver Creek	<3	<3	<3	<3	200.7/200.7 r 4.4	NS[3]	NS[3]
Phosphorus	Verde River	<3	<3	<3	<3	200.7/200.7 r 4.4	NS[3]	NS[3]
Potassium	Beaver Creek	<3	<3	3	4.1	200.7/200.7 r 4.4	NS[3]	NS[3]
Potassium	Wet Beaver Creek	<3	<3	<3	<3	200.7/200.7 r 4.4	NS[3]	NS[3]
Potassium	Verde River	<3	<3	<3	3.4	200.7/200.7 r 4.4	NS[3]	NS[3]
Selenium	Beaver Creek	NC[4]	NC[4]	NC[4]	<0.005	200.7/200.8	NS[3]	NS[3]
Selenium	Wet Beaver Creek	NC[4]	NC[4]	NC[4]	<0.005	200.7/200.8	NS[3]	NS[3]
Selenium	Verde River	NC[4]	NC[4]	NC[4]	<0.005	200.7/200.8	NS[3]	NS[3]
Silver	Beaver Creek	NC[4]	NC[4]	NC[4]	<0.001	200.7/200.8	Calculated	A&W-WA[6]
Silver	Wet Beaver Creek	NC[4]	NC[4]	NC[4]	<0.001	200.7/200.8	Calculated	A&W-WA[6]
Silver	Verde River	NC[4]	NC[4]	NC[4]	<0.001	200.7/200.8	Calculated	A&W-WA[6]
SiO_2, Silica	Beaver Creek	19	20	19	16	200.7/200.7 r 4.4	NS[3]	NS[3]
SiO_2, Silica	Wet Beaver Creek	22	21	22	24	200.7/200.7 r 4.4	NS[3]	NS[3]
SiO_2, Silica	Verde River	18	18	19	13	200.7/200.7 r 4.4	NS[3]	NS[3]
Sodium	Beaver Creek	28	25	30	15	200.7/200.7 r 4.4	NS[3]	NS[3]
Sodium	Wet Beaver Creek	17	15	18	15	200.7/200.7 r 4.4	NS[3]	NS[3]
Sodium	Verde River	27	27	27	15	200.7/200.7 r 4.4	NS[3]	NS[3]
Thallium	Beaver Creek	NC[4]	NC[4]	NC[4]	<0.001	200.7/200.8	0.15	A&W-W[5]
Thallium	Wet Beaver Creek	NC[4]	NC[4]	NC[4]	<0.001	200.7/200.8	0.15	A&W-W[5]
Thallium	Verde River	NC[4]	NC[4]	NC[4]	<0.001	200.7/200.8	0.15	A&W-W[5]
Uranium	Beaver Creek	NC[4]	NC[4]	NC[4]	<0.001	200.7/200.8	NS[3]	NS[3]
Uranium	Wet Beaver Creek	NC[4]	NC[4]	NC[4]	<0.001	200.7/200.8	NS[3]	NS[3]
Uranium	Verde River	NC[4]	NC[4]	NC[4]	<0.001	200.7/200.8	NS[3]	NS[3]
Zinc	Beaver Creek	<0.02	<0.02	<0.02	<0.01	200.7/200.8	Calculated	A&W-W[5]
Zinc	Wet Beaver Creek	<0.02	<0.02	<0.02	<0.01	200.7/200.8	Calculated	A&W-W[5]
Zinc	Verde River	<0.02	<0.02	<0.02	<0.01	200.7/200.8	Calculated	A&W-W[5]

[1]Parameters reported with a "<" symbol 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. [2]Methods are from USEPA (1983). [3]No Standard. [4]Not Collected. [5]Aquatic and Wildlife–Warmwater Chronic. [6]Aquatic and Wildlife–Warmwater Acute.

Table 5-11. Sampling results for total metals, Beaver Creek, Wet Beaver Creek, and Verde River, WY2018.

Analyte (mg/L)	Site	Quarter[1]				Method[2]	Arizona state standard	
		Q1	Q2	Q3	Q4		Metric	Beneficial use
Aluminum	Beaver Creek	0.14	<0.1	0.18	3.7	200.7/200.7 r 4.4	NS[3]	NS[3]
Aluminum	Wet Beaver Creek	<0.1	<0.1	<0.1	0.29	200.7/200.7 r 4.4	NS[3]	NS[3]
Aluminum	Verde River	<0.1	<0.1	1	21	200.7/200.7 r 4.4	NS[3]	NS[3]
Antimony	Beaver Creek	NC[4]	NC[4]	NC[4]	<0.002	200.7/200.8	0.64	F[5]
Antimony	Wet Beaver Creek	NC[4]	NC[4]	NC[4]	<0.002	200.7/200.8	0.64	F[5]
Antimony	Verde River	NC[4]	NC[4]	NC[4]	<0.002	200.7/200.8	0.64	F[5]
Arsenic	Beaver Creek	0.034[6]	0.022	0.038[6]	0.03[6]	200.7/200.8	0.03	FBC[7]
Arsenic	Wet Beaver Creek	0.024	<0.015	0.031[6]	0.025	200.7/200.8	0.03	FBC[7]
Arsenic	Verde River	<0.015	<0.015	0.023	0.021	200.7/200.8	0.03	FBC[7]
Barium	Beaver Creek	NC[4]	NC[4]	NC[4]	0.2	200.8	98	FBC[7]
Barium	Wet Beaver Creek	NC[4]	NC[4]	NC[4]	0.28	200.8	98	FBC[7]
Barium	Verde River	NC[4]	NC[4]	NC[4]	0.31	200.8	98	FBC[7]
Beryllium	Beaver Creek	NC[4]	NC[4]	NC[4]	<0.001	200.7/200.8	0.084	F[5]
Beryllium	Wet Beaver Creek	NC[4]	NC[4]	NC[4]	<0.001	200.7/200.8	0.084	F[5]
Beryllium	Verde River	NC[4]	NC[4]	NC[4]	0.0012	200.7/200.8	0.084	F[5]
Boron	Beaver Creek	0.3	0.42	0.35	0.19	200.7/200.7 r 4.4	1	AI[8,9]
Boron	Wet Beaver Creek	0.22	0.11	0.17	0.15	200.7/200.7 r 4.4	1	AI[8]
Boron	Verde River	0.15	0.15	0.18	0.12	200.7/200.7 r 4.4	1	AI[8]
Cadmium	Beaver Creek	NC[4]	NC[4]	NC[4]	<0.001	200.7/200.8	0.05	AI[8] - AL[10]
Cadmium	Wet Beaver Creek	NC[4]	NC[4]	NC[4]	<0.001	200.7/200.8	0.05	AI[8] - AL[10]
Cadmium	Verde River	NC[4]	NC[4]	NC[4]	0.0023	200.7/200.8	0.05	AI[8] - AL[10]
Calcium	Beaver Creek	51	52	40	48	200.7/200.7 r 4.4	NS[3]	NS[3]
Calcium	Wet Beaver Creek	51	42	47	47	200.7/200.7 r 4.4	NS[3]	NS[3]
Calcium	Verde River	51	51	51	82	200.7/200.7 r 4.4	NS[3]	NS[3]
Chromium	Beaver Creek	NC[4]	NC[4]	NC[4]	0.0064	200.7/200.8	1	AL[10]
Chromium	Wet Beaver Creek	NC[4]	NC[4]	NC[4]	<0.003	200.7/200.8	1	AL[10]
Chromium	Verde River	NC[4]	NC[4]	NC[4]	0.02	200.7/200.8	1	AL[10]
Copper	Beaver Creek	<0.015	<0.015	<0.015	0.0044	200.7/200.8	0.5	AL[10] and AI[8,9]
Copper	Wet Beaver Creek	<0.015	<0.015	<0.015	<0.002	200.7/200.8	0.5	AL[10] and AI[8,9]
Copper	Verde River	<0.015	<0.015	<0.015	0.061	200.7/200.8	0.5	AL[10] and AI[8,9]
Iron	Beaver Creek	0.22	0.12	0.2	2.9	200.7/200.7 r 4.4	NS[3]	NS[3]
Iron	Wet Beaver Creek	0.14	<0.1	0.21	0.44	200.7/200.7 r 4.4	NS[3]	NS[3]
Iron	Verde River	<0.1	<0.1	0.83	16	200.7/200.7 r 4.4	NS[3]	NS[3]
Lead	Beaver Creek	<0.009	<0.009	<0.009	0.0013	200.7/200.8	0.015	FBC[7]
Lead	Wet Beaver Creek	<0.009	<0.009	<0.009	<0.001	200.7/200.8	0.015	FBC[7]
Lead	Verde River	<0.009	<0.009	<0.009	0.038[6]	200.7/200.8	0.015	FBC[7]
Magnesium	Beaver Creek	28	28	31	15	200.7/200.7 r 4.4	NS[3]	NS[3]
Magnesium	Wet Beaver Creek	22	21	22	21	200.7/200.7 r 4.4	NS[3]	NS[3]
Magnesium	Verde River	25	25	27	20	200.7/200.7 r 4.4	NS[3]	NS[3]
Manganese	Beaver Creek	0.039	0.013	0.03	0.089	200.7/200.8	10	AI[8,11]
Manganese	Wet Beaver Creek	0.033	0.02	0.042	0.052	200.7/200.8	10	AI[8,11]
Manganese	Verde River	0.012	0.012	0.04	0.44	200.7/200.8	10	AI[8,11]
Mercury	Beaver Creek	NC[4]	NC[4]	NC[4]	<2e-04	245.1	0.01	AL[10]

Table 5-11. Sampling results for total metals, Beaver Creek, Wet Beaver Creek, and Verde River, WY2018, cont.

Analyte (mg/L)	Site	Quarter[1]				Method[2]	Arizona state standard	
		Q1	Q2	Q3	Q4		Metric	Beneficial use
Mercury	Wet Beaver Creek	NC[4]	NC[4]	NC[4]	<2e-04	245.1	0.01	AL[10]
Mercury	Verde River	NC[4]	NC[4]	NC[4]	<2e-04	245.1	0.01	AL[10]
Molybdenum	Beaver Creek	<0.02	<0.02	<0.02	<0.002	200.7/200.8	NS[3]	NS[3]
Molybdenum	Wet Beaver Creek	<0.02	<0.02	<0.02	<0.02	200.7/200.8	NS[3]	NS[3]
Molybdenum	Verde River	<0.02	<0.02	<0.02	<0.02	200.7/200.8	NS[3]	NS[3]
Nickel	Beaver Creek	NC[4]	NC[4]	NC[4]	0.0092	200.7/200.8	0.511	F[5]
Nickel	Wet Beaver Creek	NC[4]	NC[4]	NC[4]	<0.002	200.7/200.8	0.511	F[5]
Nickel	Verde River	NC[4]	NC[4]	NC[4]	0.03	200.7/200.8	0.511	F[5]
Phosphorus	Beaver Creek	<3	<3	<3	<3	200.7/200.7 r 4.4	1	AI[8,12]
Phosphorus	Wet Beaver Creek	<3	<3	<3	<3	200.7/200.7 r 4.4	1	AI[8,12]
Phosphorus	Verde River	<3	<3	<3	<3	200.7/200.7 r 4.4	1	AI[8,12]
Potassium	Beaver Creek	3.3	3.2	3.1	4.8	200.7/200.7 r 4.4	NS[3]	NS[3]
Potassium	Wet Beaver Creek	<3	<3	<3	<3	200.7/200.7 r 4.4	NS[3]	NS[3]
Potassium	Verde River	<3	<3	<3	8.4	200.7/200.7 r 4.4	NS[3]	NS[3]
Selenium	Beaver Creek	NC[4]	NC[4]	NC[4]	<0.005	200.7/200.8	0.002	A&W-W[13]
Selenium	Wet Beaver Creek	NC[4]	NC[4]	NC[4]	<0.005	200.7/200.8	0.002	A&W-W[13]
Selenium	Verde River	NC[4]	NC[4]	NC[4]	<0.005	200.7/200.8	0.002	A&W-W[13]
Silver	Beaver Creek	NC[4]	NC[4]	NC[4]	<0.001	200.7/200.8	4.667	FBC[7]
Silver	Wet Beaver Creek	NC[4]	NC[4]	NC[4]	<0.001	200.7/200.8	4.667	FBC[7]
Silver	Verde River	NC[4]	NC[4]	NC[4]	<0.001	200.7/200.8	4.667	FBC[7]
SiO_2, Silica	Beaver Creek	20	19	20	34	200.7/200.7 r 4.4	NS[3]	NS[3]
SiO_2, Silica	Wet Beaver Creek	23	19	22	25	200.7/200.7 r 4.4	NS[3]	NS[3]
SiO_2, Silica	Verde River	18	18	24	82	200.7/200.7 r 4.4	NS[3]	NS[3]
Sodium	Beaver Creek	28	26	30	16	200.7/200.7 r 4.4	NS[3]	NS[3]
Sodium	Wet Beaver Creek	22	15	17	16	200.7/200.7 r 4.4	NS[3]	NS[3]
Sodium	Verde River	27	27	25	16	200.7/200.7 r 4.4	NS[3]	NS[3]
Thallium	Beaver Creek	NC[4]	NC[4]	NC[4]	<0.001	200.7/200.8	0.001	F[5]
Thallium	Wet Beaver Creek	NC[4]	NC[4]	NC[4]	<0.001	200.7/200.8	0.001	F[5]
Thallium	Verde River	NC[4]	NC[4]	NC[4]	<0.001	200.7/200.8	0.001	F[5]
Uranium	Beaver Creek	NC[4]	NC[4]	NC[4]	<0.001	200.7/200.8	2.8	FBC[7]
Uranium	Wet Beaver Creek	NC[4]	NC[4]	NC[4]	<0.001	200.7/200.8	2.8	FBC[7]
Uranium	Verde River	NC[4]	NC[4]	NC[4]	<0.001	200.7/200.8	2.8	FBC[7]
Zinc	Beaver Creek	<0.02	<0.02	<0.02	<0.01	200.7/200.8	5.106	F[5]
Zinc	Wet Beaver Creek	<0.02	<0.02	<0.02	<0.01	200.7/200.8	5.106	F[5]
Zinc	Verde River	<0.02	<0.02	<0.02	0.14	200.7/200.8	5.106	F[5]

[1]Parameters reported with a "<" symbol 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. [2]Methods are from USEPA (1983). [3]No Standard. [4]Not Collected. [5]Fish Consumption. [6]Exceedance of state water quality standard (these values are shown in bolded red). [7]Full Body Contact. [8]Agricultural Irrigation. [9]Montezuma Castle National Monument (Castle unit) is not considered for agricultural irrigation. Standard is 186 mg/L for full body contact. [10]Agricultural Livestock. [11]Montezuma Castle National Monument (Castle unit) is not considered for agricultural irrigation. Standard is 131 mg/L for full body contact. [12]Montezuma Castle National Monument (Castle unit) is not considered for agricultural irrigation. There is no standard applicable to this site. [13]Aquatic and Wildlife–Warmwater Chronic.

Table 5-12. Results of sampling for total suspended sediments and total dissolved solids, Beaver Creek, Wet Beaver Creek, and Verde River, WY2018.

Analyte (mg/L)	Site	Quarter[1]				Method[2]	Arizona state standard[3]
		Q1	Q2	Q3	Q4		
Total dissolved solids	Beaver Creek	300	250	260	320	SM 2540C	NS
Total dissolved solids	Wet Beaver Creek	310	260	250	290	SM 2540C	NS
Total dissolved solids	Verde River	270	250	320	100	SM 2540C	NS
Total suspended solids	Beaver Creek	5.6	56	<4	4.8	SM 2540D	NS
Total suspended solids	Wet Beaver Creek	<4	<4	6.4	34	SM 2540D	NS
Total suspended solids	Verde River	5.6	<4	4.8	510	SM 2540D	NS

[1]Parameters reported with a "<" symbol 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. [2]SM = standard method (Eaton et al. 2005). [3]NS = No Standard.

Table 5-13. Results of general water chemistry and inorganic sampling, Beaver Creek, Wet Beaver Creek, and Verde River, WY2018.

Analyte (mg/L)	Site	Quarter[1]				Method[2]
		Q1	Q2	Q3	Q4	
Alkalinity as $CaCO_3$	Beaver Creek	270	250	260	180	SM 2320B
Alkalinity as $CaCO_3$	Wet Beaver Creek	230	210	240	220	SM 2320B
Alkalinity as $CaCO_3$	Verde River	250	250	250	170	SM 2320B
Bicarbonate Alkalinity as $CaCO_3$	Beaver Creek	270	250	260	180	SM 2320B
Bicarbonate Alkalinity as $CaCO_3$	Wet Beaver Creek	220	210	240	220	SM 2320B
Bicarbonate Alkalinity as $CaCO_3$	Verde River	240	240	240	170	SM 2320B
Carbonate Alk. as $CaCO_3$	Beaver Creek	<5	<5	<5	<5	SM 2320B
Carbonate Alk. as $CaCO_3$	Wet Beaver Creek	9.1	<5	<5	<5	SM 2320B
Carbonate Alk. as $CaCO_3$	Verde River	<5	<5	9.8	<5	SM 2320B
Biochemical Oxygen Demand	Beaver Creek	ND	ND	<2.0	3.7	SM 5210B
Biochemical Oxygen Demand	Wet Beaver Creek	<2.0	<2.0	<2.0	<2.0	SM 5210B
Biochemical Oxygen Demand	Verde River	<2.0	<2.0	<2.0	<2.0	SM 5210B
Chloride	Beaver Creek	19	16	20	11	EPA 300.0
Chloride	Wet Beaver Creek	10	8.2	10	9.7	EPA 300.0
Chloride	Verde River	14	14	14	8.1	EPA 300.0
Sulfate	Beaver Creek	<5	5.5	6	<5	EPA 300.0
Sulfate	Wet Beaver Creek	<5	<5	<5	<5	EPA 300.0
Sulfate	Verde River	19	19	21	15	EPA 300.0
Total Hardness	Beaver Creek	240	240	230	180	SM 2340B
Total Hardness	Wet Beaver Creek	220	190	210	210	SM 2340B
Total Hardness	Verde River	230	230	240	290	SM 2340B
Anion/Cation Balance	Beaver Creek	-1.5	4.5	-1.9	1.2	SM 1030E
Anion/Cation Balance	Wet Beaver Creek	0.36	5.5	0.42	0.71	SM 1030E
Anion/Cation Balance	Verde River	1.5	1.5	0.12	-3.6	SM 1030E

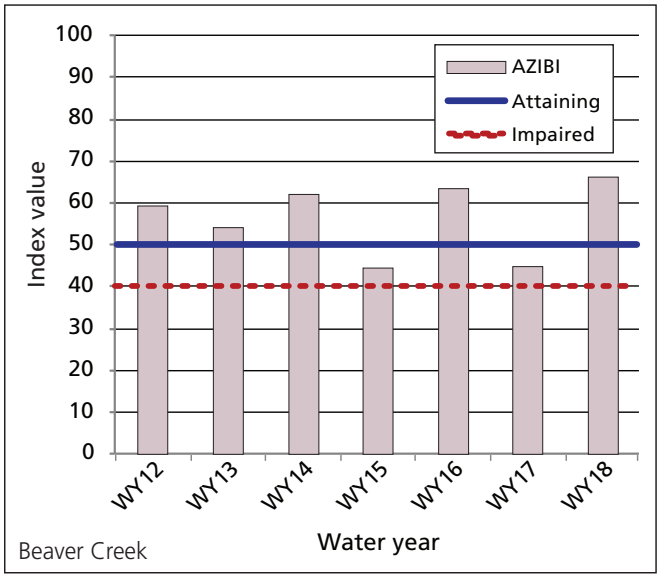
[1]Parameters reported with a "<" symbol are not assumed to be zero, but rather below the detection limit of the analytical equipment. They may have been present in very low concentrations. [2]SM = standard method (Eaton et al. 2005); other methods are from USEPA (1983).

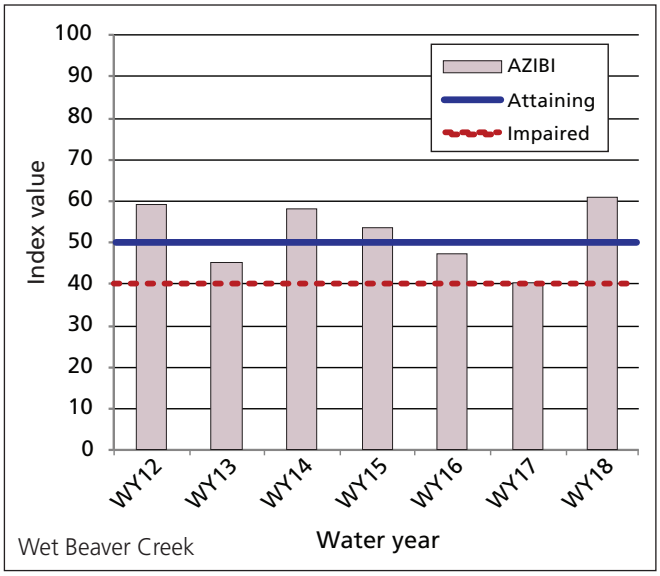
5.3.3 Macroinvertebrates

Macroinvertebrate biological samples and associated habitat data were collected at the three index reaches on May 17–19, 2018. The analytical lab received the samples on May 30, 2018, and issued the report on June 26, 2018.

The Arizona Index of Biological Integrity (AZIBI) for warmwater streams was calculated from WY2018 samples (Figure 5-11) following methods prescribed by the ADEQ (2015b). The State of Arizona has determined that index values above 49 indicate that the stream is attaining the state standard, with the index value falling above the 25th percentile of reference scores (ADEQ 2015b).

In WY2018, all sample sites met the "attaining" standard. The values for Beaver and Wet Beaver Creek were the highest recorded by SODN. This was good news after several years of either not attaining or scoring in the inconclusive category (Figure 5-12). The cause of the low AZIBI values across all three sites in WY2017 was primarily driven by a great abundance of a few taxa, mainly blackfly larvae, mayfly larvae and midge larvae (Gwilliam et. al 2018a), leading to a steep decline in diversity (especially at the Wet Beaver Creek site). In WY2018, the numbers of these taxa, and their diversity returned to values that greatly improved the AZIBI values. It is unknown what led to the increase in certain taxa at the sample sites in WY2017. However, SODN is considering options to engage independent researchers to examine this topic.





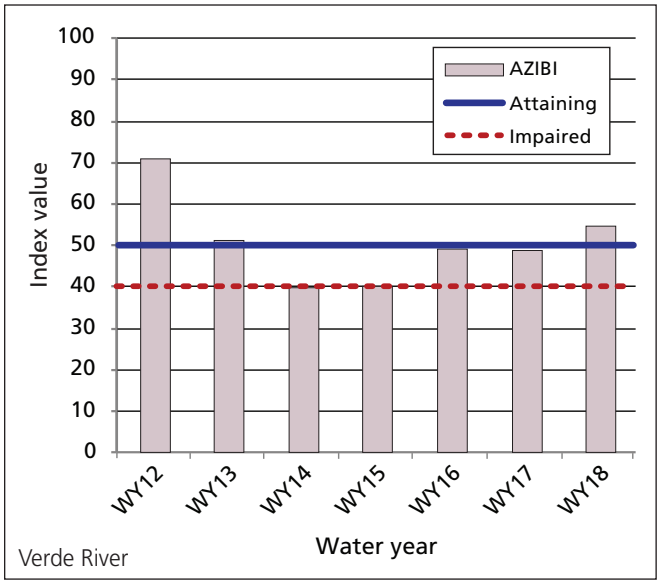


Figure 5-11. Arizona Index of Biotic Integrity values for the Beaver Creek, Wet Beaver Creek, and Verde River index reaches, WY2012–2018. Any values falling between the "impaired" and "attaining" lines are considered "inconclusive" relative to the state standard.

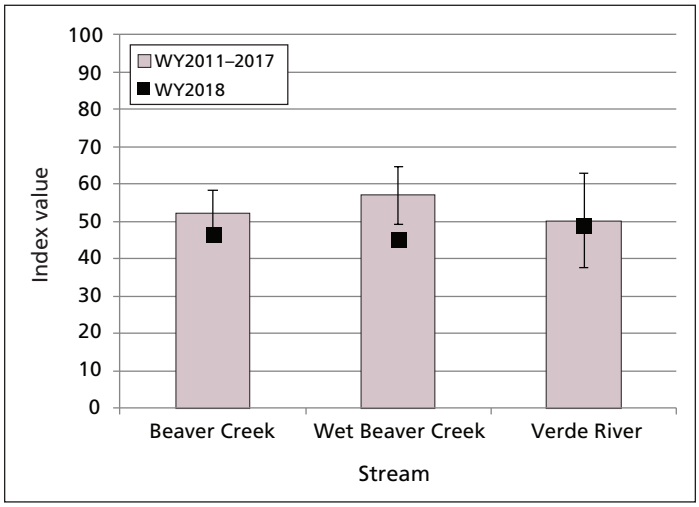


Figure 5-12. Comparison of mean AZIBI (WY2011–2017) to WY2018 AZIBI result. Error bar represents one standard deviation.

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Appendix A. Macroinvertebrate Taxa Lists

Table A-1. Macroinvertebrate taxa list for Beaver Creek, WY2018.

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

Table A-1. Macroinvertebrate taxa list for Beaver Creek, WY2018, cont.

Phylum	Class	Order	Family	Genus	Species
Arthropoda	Insecta	Ephemeroptera	Heptageniidae	–	–
Arthropoda	Insecta	Ephemeroptera	Leptohyphidae	Tricorythodes	–
Arthropoda	Insecta	Ephemeroptera	Leptohyphidae	–	–
Arthropoda	Insecta	Ephemeroptera	Leptophlebiidae	–	–
Arthropoda	Insecta	Ephemeroptera	–	–	–
Arthropoda	Insecta	Hemiptera	Belostomatidae	Abedus	–
Arthropoda	Insecta	Hemiptera	Belostomatidae	–	–
Arthropoda	Insecta	Hemiptera	Corixidae	–	–
Arthropoda	Insecta	Hemiptera	Gerridae	–	–
Arthropoda	Insecta	Hemiptera	Naucoridae	Ambrysus	–
Arthropoda	Insecta	Hemiptera	Veliidae	Microvelia	–
Arthropoda	Insecta	Hemiptera	Veliidae	Rhagovelia	–
Arthropoda	Insecta	Hemiptera	Veliidae	–	–
Arthropoda	Insecta	Lepidoptera	Crambidae	Petrophila	–
Arthropoda	Insecta	Megaloptera	Corydalidae	Corydalus	cornutus
Arthropoda	Insecta	Odonata	Calopterygidae	Hetaerina	americana
Arthropoda	Insecta	Odonata	Calopterygidae	Hetaerina	–
Arthropoda	Insecta	Odonata	Coenagrionidae	Argia	–
Arthropoda	Insecta	Odonata	Coenagrionidae	Enallagma	–
Arthropoda	Insecta	Odonata	Coenagrionidae	–	–
Arthropoda	Insecta	Odonata	Gomphidae	Progomphus	–
Arthropoda	Insecta	Odonata	Gomphidae	–	–
Arthropoda	Insecta	Odonata	Lestidae	Archilestes	–
Arthropoda	Insecta	Odonata	Libellulidae	Brechmorhoga	mendax
Arthropoda	Insecta	Odonata	Libellulidae	–	–
Arthropoda	Insecta	Trichoptera	Glossosomatidae	Glossosoma	–
Arthropoda	Insecta	Trichoptera	Helicopsychidae	Helicopsyche	–
Arthropoda	Insecta	Trichoptera	Hydropsychidae	Cheumatopsyche	–
Arthropoda	Insecta	Trichoptera	Hydropsychidae	Hydropsyche	–
Arthropoda	Insecta	Trichoptera	Hydropsychidae	Smicridea	–
Arthropoda	Insecta	Trichoptera	Hydropsychidae	–	–
Arthropoda	Insecta	Trichoptera	Hydroptilidae	Hydroptila	–
Arthropoda	Insecta	Trichoptera	Hydroptilidae	Leucotrichia	–
Arthropoda	Insecta	Trichoptera	Hydroptilidae	Ochrotrichia	–
Arthropoda	Insecta	Trichoptera	Hydroptilidae	–	–
Arthropoda	Insecta	Trichoptera	Hydroptilidae	Ithytrichia	clavata
Arthropoda	Insecta	Trichoptera	Leptoceridae	Nectopsyche	–
Arthropoda	Insecta	Trichoptera	Philopotamidae	Chimarra	–
Arthropoda	Malacostraca	Amphipoda	Gammaridae	Gammarus	–
Arthropoda	Malacostraca	Amphipoda	–	–	–
Arthropoda	Malacostraca	Decapoda	Cambaridae	–	–
Arthropoda	Malacostraca	Decapoda	–	–	–
Mollusca	Bivalvia	Veneroida	Corbiculidae	Corbicula	–
Mollusca	Gastropoda	Basommatophora	Ancylidae	Ferrissia	rivularis
Mollusca	Gastropoda	Basommatophora	Physidae	Physa	–
Platyhelminthes	Turbellaria	–	–	–	–

Table A-2. Macroinvertebrate taxa list for Wet Beaver Creek, WY2018.

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

Table A-2. Macroinvertebrate taxa list for Wet Beaver Creek, WY2018, cont.

Phylum	Class	Order	Family	Genus	Species
Arthropoda	Insecta	Ephemeroptera	Leptohyphidae	–	–
Arthropoda	Insecta	Ephemeroptera	Leptophlebiidae	–	–
Arthropoda	Insecta	Ephemeroptera	–	–	–
Arthropoda	Insecta	Hemiptera	Belostomatidae	Abedus	–
Arthropoda	Insecta	Hemiptera	Belostomatidae	–	–
Arthropoda	Insecta	Hemiptera	Corixidae	–	–
Arthropoda	Insecta	Hemiptera	Gerridae	–	–
Arthropoda	Insecta	Hemiptera	Naucoridae	Ambrysus	–
Arthropoda	Insecta	Hemiptera	Veliidae	Microvelia	–
Arthropoda	Insecta	Hemiptera	Veliidae	Rhagovelia	–
Arthropoda	Insecta	Hemiptera	Veliidae	–	–
Arthropoda	Insecta	Lepidoptera	Crambidae	Petrophila	–
Arthropoda	Insecta	Megaloptera	Corydalidae	Corydalus	cornutus
Arthropoda	Insecta	Odonata	Calopterygidae	Hetaerina	americana
Arthropoda	Insecta	Odonata	Calopterygidae	Hetaerina	–
Arthropoda	Insecta	Odonata	Coenagrionidae	Argia	–
Arthropoda	Insecta	Odonata	Coenagrionidae	Enallagma	–
Arthropoda	Insecta	Odonata	Coenagrionidae	–	–
Arthropoda	Insecta	Odonata	Gomphidae	Progomphus	–
Arthropoda	Insecta	Odonata	Gomphidae	–	–
Arthropoda	Insecta	Odonata	Lestidae	Archilestes	–
Arthropoda	Insecta	Odonata	Libellulidae	Brechmorhoga	mendax
Arthropoda	Insecta	Odonata	Libellulidae	–	–
Arthropoda	Insecta	Trichoptera	Glossosomatidae	Glossosoma	–
Arthropoda	Insecta	Trichoptera	Helicopsychidae	Helicopsyche	–
Arthropoda	Insecta	Trichoptera	Hydropsychidae	Cheumatopsyche	–
Arthropoda	Insecta	Trichoptera	Hydropsychidae	Hydropsyche	–
Arthropoda	Insecta	Trichoptera	Hydropsychidae	Smicridea	–
Arthropoda	Insecta	Trichoptera	Hydropsychidae	–	–
Arthropoda	Insecta	Trichoptera	Hydroptilidae	Hydroptila	–
Arthropoda	Insecta	Trichoptera	Hydroptilidae	Leucotrichia	–
Arthropoda	Insecta	Trichoptera	Hydroptilidae	Ochrotrichia	–
Arthropoda	Insecta	Trichoptera	Hydroptilidae	–	–
Arthropoda	Insecta	Trichoptera	Hydroptilidae	Ithytrichia	clavata
Arthropoda	Insecta	Trichoptera	Leptoceridae	Nectopsyche	–
Arthropoda	Insecta	Trichoptera	Philopotamidae	Chimarra	–
Arthropoda	Malacostraca	Amphipoda	Gammaridae	Gammarus	–
Arthropoda	Malacostraca	Amphipoda	–	–	–
Arthropoda	Malacostraca	Decapoda	Cambaridae	–	–
Arthropoda	Malacostraca	Decapoda	–	–	–
Mollusca	Bivalvia	Veneroida	Corbiculidae	Corbicula	–
Mollusca	Gastropoda	Basommatophora	Ancylidae	Ferrissia	rivularis
Mollusca	Gastropoda	Basommatophora	Physidae	Physa	–
Platyhelminthes	Turbellaria	–	–	–	–

Table A-3. Macroinvertebrate taxa list for the Verde River, WY2018.

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

Table A-3. Macroinvertebrate taxa list for the Verde River, WY2018, cont.

Phylum	Class	Order	Family	Genus	Species
Arthropoda	Insecta	Ephemeroptera	Leptohyphidae	–	–
Arthropoda	Insecta	Ephemeroptera	Leptophlebiidae	–	–
Arthropoda	Insecta	Ephemeroptera	–	–	–
Arthropoda	Insecta	Hemiptera	Belostomatidae	Abedus	–
Arthropoda	Insecta	Hemiptera	Belostomatidae	–	–
Arthropoda	Insecta	Hemiptera	Corixidae	–	–
Arthropoda	Insecta	Hemiptera	Gerridae	–	–
Arthropoda	Insecta	Hemiptera	Naucoridae	Ambrysus	–
Arthropoda	Insecta	Hemiptera	Veliidae	Microvelia	–
Arthropoda	Insecta	Hemiptera	Veliidae	Rhagovelia	–
Arthropoda	Insecta	Hemiptera	Veliidae	–	–
Arthropoda	Insecta	Lepidoptera	Crambidae	Petrophila	–
Arthropoda	Insecta	Megaloptera	Corydalidae	Corydalus	cornutus
Arthropoda	Insecta	Odonata	Calopterygidae	Hetaerina	americana
Arthropoda	Insecta	Odonata	Calopterygidae	Hetaerina	–
Arthropoda	Insecta	Odonata	Coenagrionidae	Argia	–
Arthropoda	Insecta	Odonata	Coenagrionidae	Enallagma	–
Arthropoda	Insecta	Odonata	Coenagrionidae	–	–
Arthropoda	Insecta	Odonata	Gomphidae	Progomphus	–
Arthropoda	Insecta	Odonata	Gomphidae	–	–
Arthropoda	Insecta	Odonata	Lestidae	Archilestes	–
Arthropoda	Insecta	Odonata	Libellulidae	Brechmorhoga	mendax
Arthropoda	Insecta	Odonata	Libellulidae	–	–
Arthropoda	Insecta	Trichoptera	Glossosomatidae	Glossosoma	–
Arthropoda	Insecta	Trichoptera	Helicopsychidae	Helicopsyche	–
Arthropoda	Insecta	Trichoptera	Hydropsychidae	Cheumatopsyche	–
Arthropoda	Insecta	Trichoptera	Hydropsychidae	Hydropsyche	–
Arthropoda	Insecta	Trichoptera	Hydropsychidae	Smicridea	–
Arthropoda	Insecta	Trichoptera	Hydropsychidae		–
Arthropoda	Insecta	Trichoptera	Hydroptilidae	Hydroptila	–
Arthropoda	Insecta	Trichoptera	Hydroptilidae	Leucotrichia	–
Arthropoda	Insecta	Trichoptera	Hydroptilidae	Ochrotrichia	–
Arthropoda	Insecta	Trichoptera	Hydroptilidae		–
Arthropoda	Insecta	Trichoptera	Hydroptilidae	Ithytrichia	clavata
Arthropoda	Insecta	Trichoptera	Leptoceridae	Nectopsyche	–
Arthropoda	Insecta	Trichoptera	Philopotamidae	Chimarra	–
Arthropoda	Malacostraca	Amphipoda	Gammaridae	Gammarus	–
Arthropoda	Malacostraca	Amphipoda	–	–	–
Arthropoda	Malacostraca	Decapoda	Cambaridae	–	–
Arthropoda	Malacostraca	Decapoda	–	–	–
Mollusca	Bivalvia	Veneroida	Corbiculidae	Corbicula	–
Mollusca	Gastropoda	Basommatophora	Ancylidae	Ferrissia	rivularis
Mollusca	Gastropoda	Basommatophora	Physidae	Physa	–
Platyhelminthes	Turbellaria	–	–	–	–

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