



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

## *Water Year 2017*

Natural Resource Report NPS/SODN/NRR—2018/1692



ON THE COVER

Dragonfly on Beaver Creek, Montezuma Castle National Monument. NPS photo.

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# Contents

Figures ..... v

Tables ..... v

Executive Summary ..... ix

Acknowledgements ..... xi

1 Introduction ..... 1

2 Climate..... 3

    2.1 Background and methods ..... 3

    2.2 Results and discussion ..... 4

3 Springs ..... 11

    3.1 Background ..... 11

    3.2 Methods..... 11

    3.3 Results and discussion ..... 13

4 Surface Water..... 21

    4.1 Background ..... 21

    4.2 Methods..... 21

    4.3 Results and discussion ..... 26

5 Literature Cited ..... 41



# Figures

|                                                                                                                                                       |    |
|-------------------------------------------------------------------------------------------------------------------------------------------------------|----|
| Figure 2-1. Aridity index vs. elevation of selected southwestern national parks, including Montezuma Castle and Tuzigoot national monuments .....     | 3  |
| Figure 2-2. Departures from 30-year (1981–2010) normal minimum and maximum air temperature and precipitation, Montezuma Castle National Monument..... | 5  |
| Figure 2-3. Climogram for water year 2017, Montezuma Castle National Monument.....                                                                    | 5  |
| Figure 2-4. Departures from 30-year (1981–2010) normal minimum and maximum air temperature and precipitation, Tuzigoot National Monument.....         | 6  |
| Figure 2-5. Climogram for water year 2017, Tuzigoot National Monument.....                                                                            | 6  |
| Figure 2-6. Reconnaissance drought index (RDI), Montezuma Castle National Monument, water years 1981–2017 .....                                       | 8  |
| Figure 2-7. Five-year moving mean of annual precipitation, Montezuma Castle National Monument, 1981–2017 .....                                        | 8  |
| Figure 2-8. Reconnaissance drought index (RDI), Tuzigoot National Monument, water years 1981– 2017.....                                               | 9  |
| Figure 2-9. Five-year moving mean of annual precipitation, Tuzigoot National Monument, 1981–2017 .....                                                | 9  |
| Figure 3-1. Expansion Spring orifice, Montezuma Castle National Monument (Castle unit).....                                                           | 14 |
| Figure 3-2. Shea Spring orifice, Tuzigoot National Monument.....                                                                                      | 15 |
| Figure 3-3. Slope where Expansion Spring emerges .....                                                                                                | 17 |
| Figure 3-4. Shea Spring at Tuzigoot National Monument, 2015–2017. ....                                                                                | 17 |
| Figure 3-5. Raster of hydroperiod data from Expansion Spring (Montezuma Castle NM) and Shea Spring (Tuzigoot NM).....                                 | 18 |
| Figure 3-6. Daily mean surface elevation of Montezuma Well, WY2016–2017 .....                                                                         | 19 |
| Figure 3-7. Water discharging in the bottom of the pool at Shea Spring.....                                                                           | 20 |
| Figure 4-1. Sampling sites on Beaver Creek, Montezuma Castle NM (Castle unit). ....                                                                   | 22 |
| Figure 4-2. Sampling sites on Wet Beaver Creek, Montezuma Castle NM (Well unit). ....                                                                 | 23 |
| Figure 4-3. Sampling sites on the Verde River, Tuzigoot NM.....                                                                                       | 23 |
| Figure 4-4. Locations of USGS stream gauges near Montezuma Castle and Tuzigoot national monuments.....                                                | 24 |
| Figure 4-5. Hydrograph from Beaver Creek, Montezuma Castle National Monument (Castle unit), WY2017.....                                               | 26 |
| Figure 4-6. Mean daily discharge, Wet Beaver Creek, Montezuma Castle NM (Well unit), WY2017.....                                                      | 27 |
| Figure 4-7. Centroid of flow volume, Wet Beaver Creek, Montezuma Castle NM (Well unit), WY2017 vs. gauge record (56 years) .....                      | 28 |
| Figure 4-8. Mean daily discharge at the USGS gauge near Clarkdale, Arizona, WY2017 .....                                                              | 29 |
| Figure 4-9. Data on (A) water temperature, (B) specific conductivity, (C) pH, and (D) dissolved oxygen concentration, Wet Beaver Creek, WY2017 .....  | 32 |

|                                                                                                                                                            |    |
|------------------------------------------------------------------------------------------------------------------------------------------------------------|----|
| Figure 4-10. Arizona Index of Biotic Integrity values for the (A) Beaver Creek, (B) Wet Beaver Creek, and (C) Verde River index reaches, WY2012–2017 ..... | 38 |
| Figure 4-11. Arizona Index of Biotic Integrity macroinvertebrate scores from water years 2012–2017 .....                                                   | 39 |

# Tables

## Main Report

|                                                                                                                                                        |    |
|--------------------------------------------------------------------------------------------------------------------------------------------------------|----|
| Table 3-1. Objectives and metrics for monitoring modules of the Sonoran Desert Network springs monitoring protocol.....                                | 12 |
| Table 3-2. Disturbance classifications for Sonoran Desert Network springs monitoring. ....                                                             | 13 |
| Table 3-3. Dates visited and wet/dry status, Montezuma Castle and Tuzigoot national monuments, FY2017.....                                             | 13 |
| Table 3-4. Summary of site location information and metrics for sentinel springs at Montezuma Castle and Tuzigoot national monuments, WY2017.....      | 14 |
| Table 3-5. Anthropogenic disturbance ratings for sentinel springs at Montezuma Castle and Tuzigoot national monuments, WY2017. ....                    | 16 |
| Table 3-6. Natural disturbance ratings for sentinel springs at Montezuma Castle and Tuzigoot national monuments, WY2017.....                           | 16 |
| Table 3-7. Wetted channel and morphometric data for sentinel springs at Montezuma Castle and Tuzigoot national monument, WY2017.....                   | 19 |
| Table 3-8. Core water quality parameters for sentinel springs at Montezuma Castle and Tuzigoot national monument, WY2017. ....                         | 19 |
| Table 3-9. Water chemistry data for sentinel springs at Montezuma Castle and Tuzigoot national monument, WY2017. ....                                  | 20 |
| Table 4-1. Sampling dates and index reach lengths at Montezuma Castle and Tuzigoot national monuments, WY2017.....                                     | 25 |
| Table 4-2. Dates of sampling visits to index sites at Montezuma Castle and Tuzigoot monuments, WY2017.....                                             | 26 |
| Table 4-3. Discrete sampling summary for Beaver Creek, Wet Beaver Creek, and the Verde River, WY2017. ....                                             | 30 |
| Table 4-4. Results of discrete core water quality sampling parameters at Beaver Creek, WY2017. ....                                                    | 30 |
| Table 4-5. Sonde deployment periods and number of samples collected during each deployment, Wet Beaver Creek index site, WY2017. ....                  | 31 |
| Table 4-6. Results of nutrient sampling, Beaver Creek Wet Beaver Creek, and Verde River, WY2017.....                                                   | 33 |
| Table 4-7. Results of biological condition sampling, Beaver Creek, Wet Beaver Creek, and Verde River, WY2017.....                                      | 33 |
| Table 4-8. Sampling results for dissolved metals, Beaver Creek, Wet Beaver Creek, and Verde River, WY2017.....                                         | 34 |
| Table 4-9. Sampling results for total metals, Beaver Creek, Wet Beaver Creek, and Verde River, WY2017.....                                             | 35 |
| Table 4-10. Results of sampling for total suspended sediments and total dissolved solids, Beaver Creek, Wet Beaver Creek, and Verde River, WY2017..... | 37 |
| Table 4-11. Results of general water chemistry and inorganic sampling, Beaver Creek, Wet Beaver Creek, and Verde River, WY2017. ....                   | 37 |

## Appendices

|                                                                          |    |
|--------------------------------------------------------------------------|----|
| Table A-1. Macroinvertebrate taxa list for Beaver Creek, WY2017.....     | 45 |
| Table A-2. Macroinvertebrate taxa list for Wet Beaver Creek, WY2017..... | 48 |
| Table A-3. Macroinvertebrate taxa list for Verde River, WY2017.....      | 51 |

## 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) 2017 for Montezuma Castle and Tuzigoot national monuments, two small National Park Service units in central Arizona.

Overall annual precipitation was 117% of normal for Montezuma Castle National Monument (NM) and 129% of normal for Tuzigoot NM. Mean monthly temperatures tended to be warmer than normal and there were substantially fewer extremely cold days. However, the reconnaissance drought index for Tuzigoot NM indicates a recovery over the past three years from a regional drought that began in 2000; while an initial recovery began at Montezuma Castle NM in WY2017.

The Sonoran Desert Network (SODN) monitors three springs at Montezuma Castle and Tuzigoot national monuments, one at each unit. At Montezuma Castle NM are Expansion Spring (Castle unit) and Montezuma Well (Well unit). At Tuzigoot NM is Shea Spring. The full complement of SODN springs monitoring (site condition, water quantity, and water quality) is done only at Expansion and Shea springs. In WY2017, both springs had surface water present, were flowing, and showed little sign of change or disturbance.

The network also monitors one stream at each unit of Montezuma Castle and Tuzigoot national monuments. At Montezuma Castle NM, index sites are on Beaver Creek (Castle unit) and Wet Beaver Creek (Well unit). At Tuzigoot NM, the network monitors the Verde River. SODN staff sampled each index site quarterly during WY2017, collecting data on water quantity, water quality, and macroinvertebrates. At Wet Beaver Creek, mean daily discharge during WY2017 was 44.6 cubic feet per second (cfs)—well above the 56-year gauge record mean of 30.3 cfs. However, during the ecologically important spring snowmelt period (typically mid-January to mid-May), mean daily discharge was below or approaching the lower 5<sup>th</sup> percentile. Recorded flow for the Verde River was either at or below the 25<sup>th</sup> percentile for most of the year. There were five exceedances of state water quality standards during WY2017, resulting in a 98.1% overall compliance with state standards across the three units. Four of the exceedances were at the Beaver Creek index site: two for total arsenic, one for *E. coli*, and one for dissolved oxygen. The other was for total arsenic at the Wet Beaver Creek index site. SODN urges park managers to continue to limit public access to the streams and water bodies, and to provide guidance and personal protective equipment to employees who need to come in contact with the water. No one should ever drink or otherwise ingest untreated stream water from these sites. None of the WY2017 Arizona indices of biotic integrity calculated from macroinvertebrate data was in the “attaining” range for any site.



## Acknowledgements

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. Colombe Lefort assisted with data collection and processing. Kristen Bonebrake led the management and posting of all data products. Macroinvertebrate identifications were determined by the Utah State University BugLab. TestAmerica processed the water chemistry samples. Andy Hubbard contributed to this report.



# 1 Introduction

Climate and hydrology are major drivers of ecosystems. They dramatically shape ecosystem structure and function, particularly in arid and semi-arid ecosystems. Understanding changes in climate, 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) 2017 (October 2016–

September 2017) for Montezuma Castle and Tuzigoot national monuments, both small National Park Service units (341 and 329 ha, respectively) in central Arizona. Detailed analyses of trends will follow in subsequent reports as the period of record warrants such assessments. For details on the monitoring protocols, park setting and resources, and information on other resources of management focus, please see <http://www.nps.gov/im/sodn/>.



# 2 Climate

## 2.1 Background and methods

Climate is the suite of characteristic meteorological conditions of the near-surface atmosphere at a given place (Strahler 2013). It 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 three Davis weather stations at the monuments (one at each unit of Montezuma Castle NM and one at Tuzigoot NM) to provide real-time data on weather conditions. All three stations are linked to the NOAA Citizen Weather Observer Program, with data accessible through [www.climate-analyzer.org](http://www.climate-analyzer.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. 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 classified as semi-arid. The climate of Tuzigoot NM (1946–present) is classified as arid, though near the threshold of semi-arid (Figure 2-1).

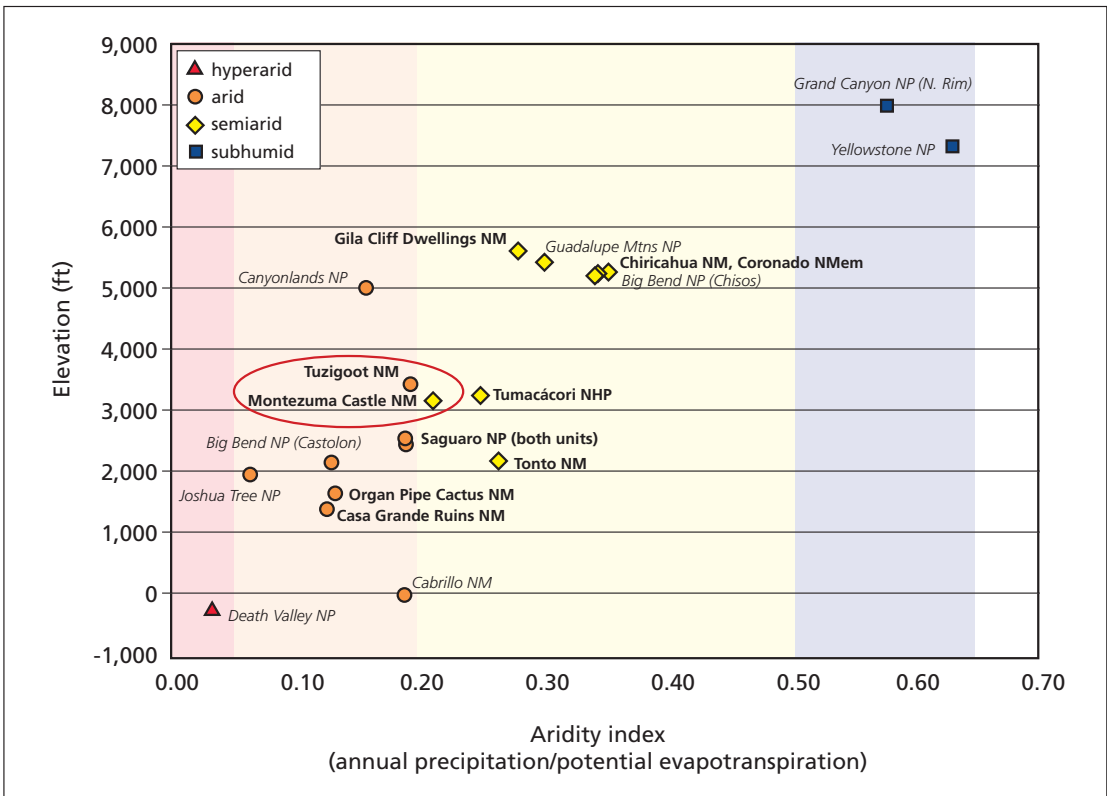


Figure 2-1. Aridity index vs. elevation of selected southwestern national parks, including Montezuma Castle and Tuzigoot national monuments. Figure from Hubbard and others (in prep).

## 2.2 Results and discussion

Data quality from the Montezuma Castle NM COOP station in WY2017 was excellent, with data missing on only four days. Data quality from the Tuzigoot NM COOP station was excellent, with data missing for only six days.

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

Overall annual precipitation was above normal for both national monuments: 117% of normal for Montezuma Castle NM (16.8" vs 14.4"), and 129% of normal for Tuzigoot NM (16.36" versus 12.71").

#### 2.2.1.1 Cool season (October–March)

At Montezuma Castle NM, maximum and minimum temperatures were generally warmer than normal, except in January, when the mean maximum temperature was 5.7°F below normal (Figure 2-2). Mean monthly low temperatures were below freezing in December and January (Figure 2-3), which is normal. The mean minimum temperature is usually below freezing in February, but was not in WY2017. Precipitation was above normal (118% or +1.28") for the fall and winter of WY2017. While October and March were much drier than usual, December and January received over twice the normal amount of rain (Figure 2-2).

At Tuzigoot NM, precipitation was above normal (139% or +2.52") for the fall and win-

ter of WY2017. Precipitation in December was three times normal (Figure 2-4). Rainfall for all other months, except October, was at or above normal amounts. Maximum and minimum temperatures were generally warmer than normal, except in January, when the mean maximum temperature was 5.0°F below normal. Mean monthly low temperatures were below freezing only in December (Figure 2-5). Normally, January's mean minimum temperature is also below freezing.

#### 2.2.1.2 Warm season (April–September)

At Montezuma Castle NM, overall precipitation was above normal (116% or +1.13") for the spring and summer of WY2017. Rainfall in the spring was lower than normal, but the monsoon in July and August was stronger than normal. Maximum and minimum air temperatures were generally close to normal (within -2.1 and 3.1°F of normal), except in June, when the mean high air temperature was slightly higher (4.6°F above normal).

At Tuzigoot NM, the spring and summer of WY2017 was wetter than normal (117% or +1.13"). However, the rainfall was concentrated in July and August. The other spring and summer months received 39% or less of normal rainfall. Maximum and minimum air temperatures were generally close to normal (within -2.3 and 3.9°F of normal), except in June, when the mean high air temperatures were 7.1°F above normal.

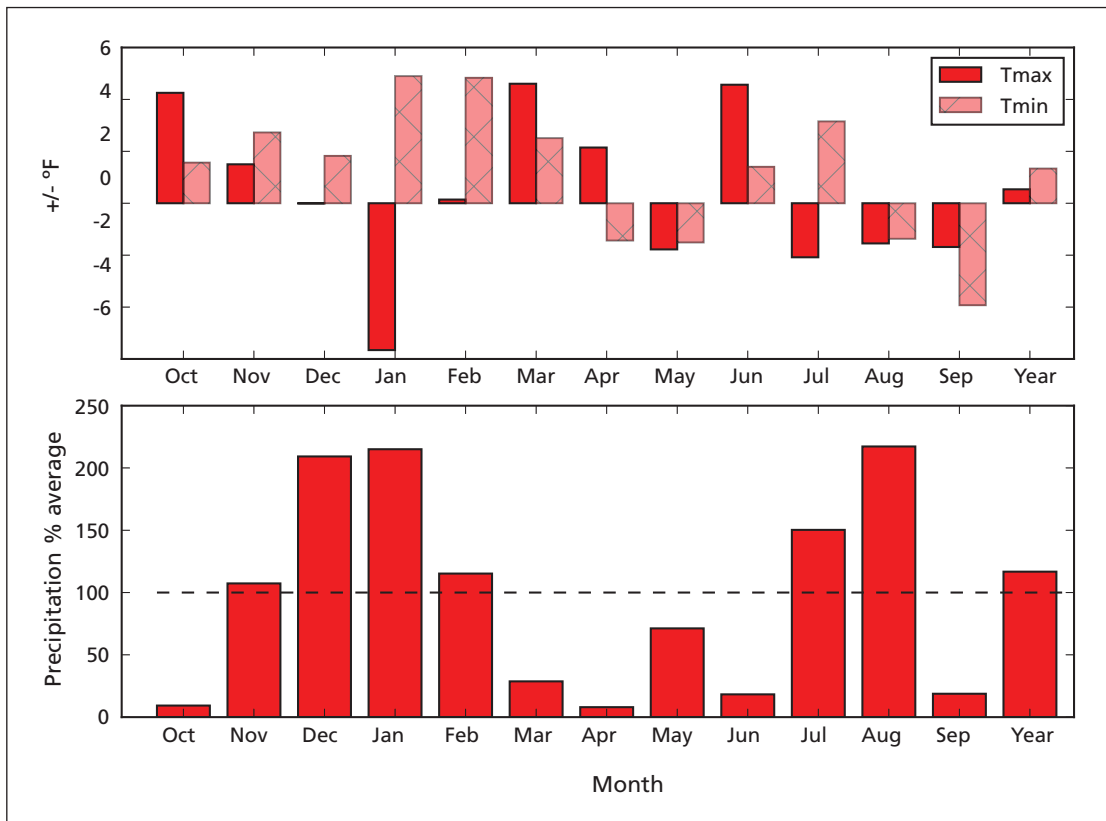


Figure 2-2. Departures from 30-year (1981–2010) normal minimum and maximum air temperature and precipitation, Montezuma Castle National Monument. "n/a" = insufficient data to generate reliable data. Graphics generated by climateanalyzer.org.

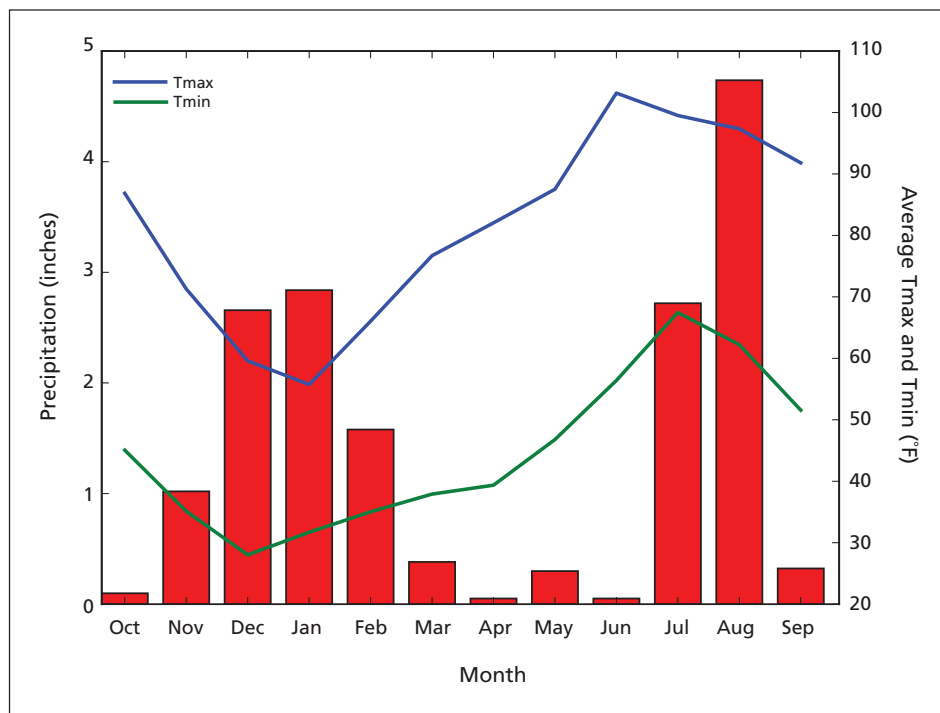


Figure 2-3. Climogram for water year 2017, Montezuma Castle National Monument. "n/a" = insufficient data to generate reliable data. Graphics generated by climateanalyzer.org

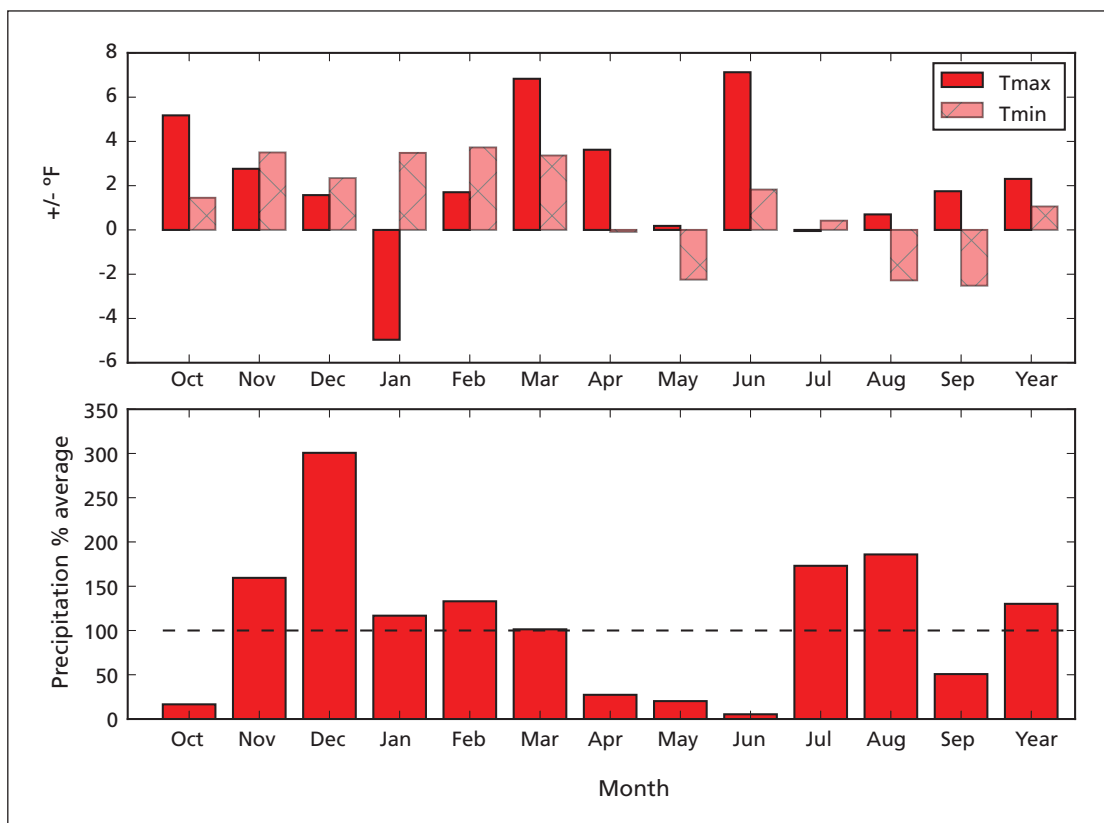


Figure 2-4. Departures from 30-year (1981–2010) normal minimum and maximum air temperature and precipitation, Tuzigoot National Monument. Graphics generated by climateanalyzer.org.

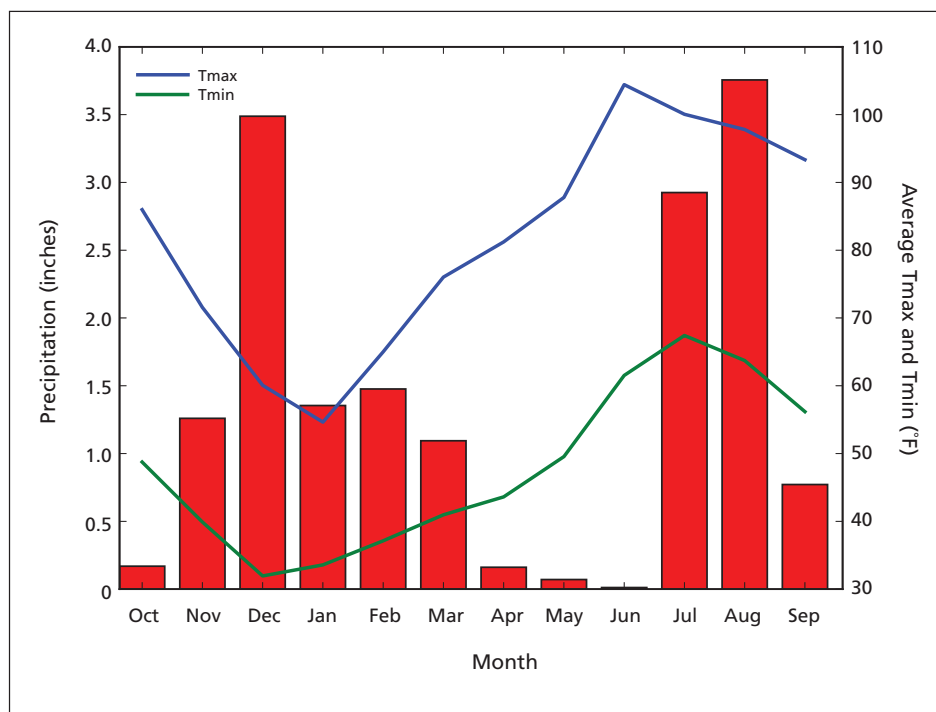


Figure 2-5. Climogram for water year 2017, Tuzigoot National Monument. Graphics generated by climateanalyzer.org

### 2.2.2 Reconnaissance Drought Index

Reconnaissance drought index (RDI; 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 reflected the extended drought that began in 2000 (Figure 2-6), although conditions in WY2017 indicated a limited recovery, as higher-than-normal precipitation compensated for increased evaporative demand. The five-year moving mean of total annual precipitation from years 1981–2017 (Figure 2-7) demonstrates the continued multi-year precipitation deficit.

The RDI for Tuzigoot NM also reflected the extended drought since 2000 (Figure 2-8), although a recovery begun in WY2015 continued through WY2017. The five-year running mean of total precipitation for water years 1981–2017 demonstrates that recent higher rainfall rates have remedied the multi-year precipitation deficit (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, sus-

tained low air temperatures can damage or even kill long-lived keystone plants (including the large deciduous trees that dominate the parks' riparian woodlands) (Turner et al. 2003), and the aquatic organisms that live in the river environments. 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 ( $<22^{\circ}\text{F}$ , 5<sup>th</sup> percentile of 1981–2010 data) occurred less often than normal (6 vs.  $22.3 \pm 1.4$  days) in WY2017, and were of a shorter duration than normal (1.2 consecutive days vs.  $2.5 \pm 0.1$  days). The number of extreme precipitation events ( $>1"$ ) in WY2017 was approximately normal (2 vs. 2.2 days for 1981–2010). Large events occurred on August 5 (1.31") and August 12 (2.90"). The storm event on August 12 exceeded the 10-year, 24-hour return frequency (2.64"). This means the high rainfall total on August 12 was unusual but not extremely rare; an event expected to occur once every 10 years, based on the historic record.

Tuzigoot NM experienced fewer extremely cold days and more extremely warm days in WY2017. Extremely cold days ( $<26^{\circ}\text{F}$ , 5<sup>th</sup> percentile of 1981–2010 data) were less frequent (10 days vs.  $14.6 \pm 1.1$  days), and were of shorter duration (1.4 consecutive days vs.  $2.1 \pm 0.1$  days). The number of extreme precipitation events ( $>1"$ ) in WY2017 was above normal (3 vs. 1.8 days for 1981–2010) normal. Large events were spread throughout the year, occurring on December 12 (1.34"), March 23 (1.03"), and September 24 (1.02").

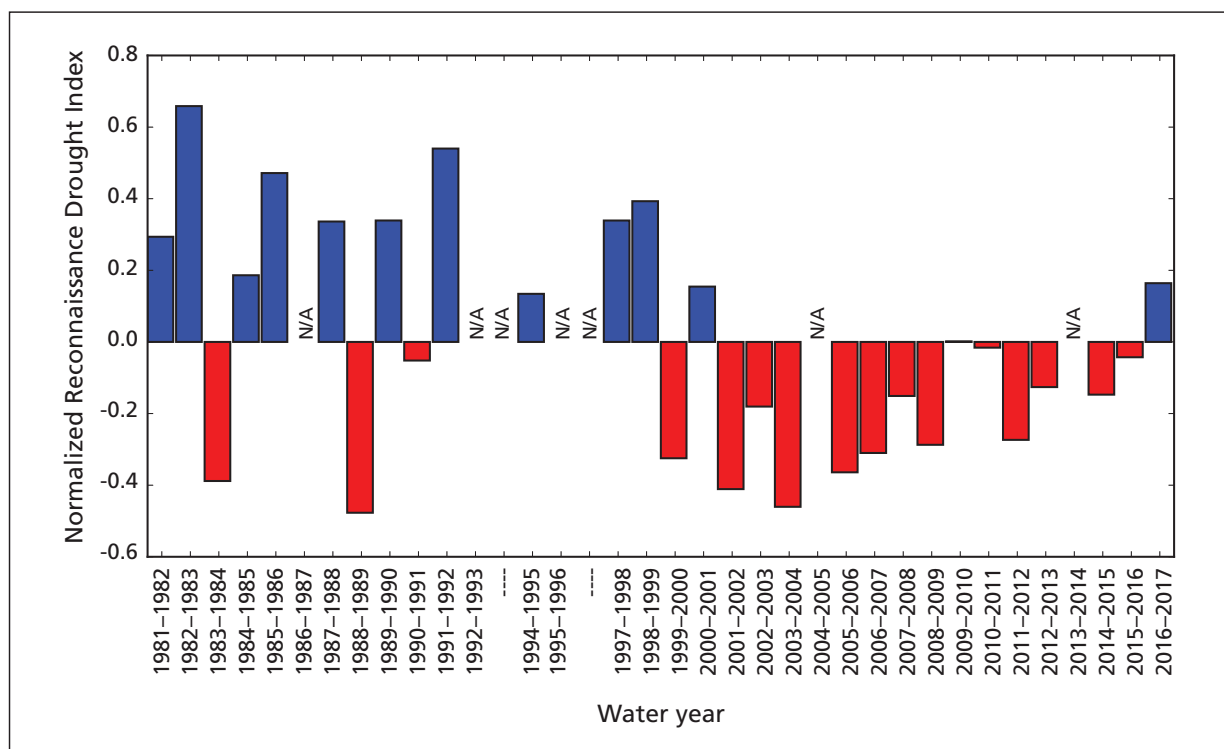


Figure 2-6. Reconnaissance drought index (RDI), Montezuma Castle National Monument, water years 1981–2017. “n/a” = insufficient data to generate reliable RDI estimates. Graphics generated by climateanalyzer.org.

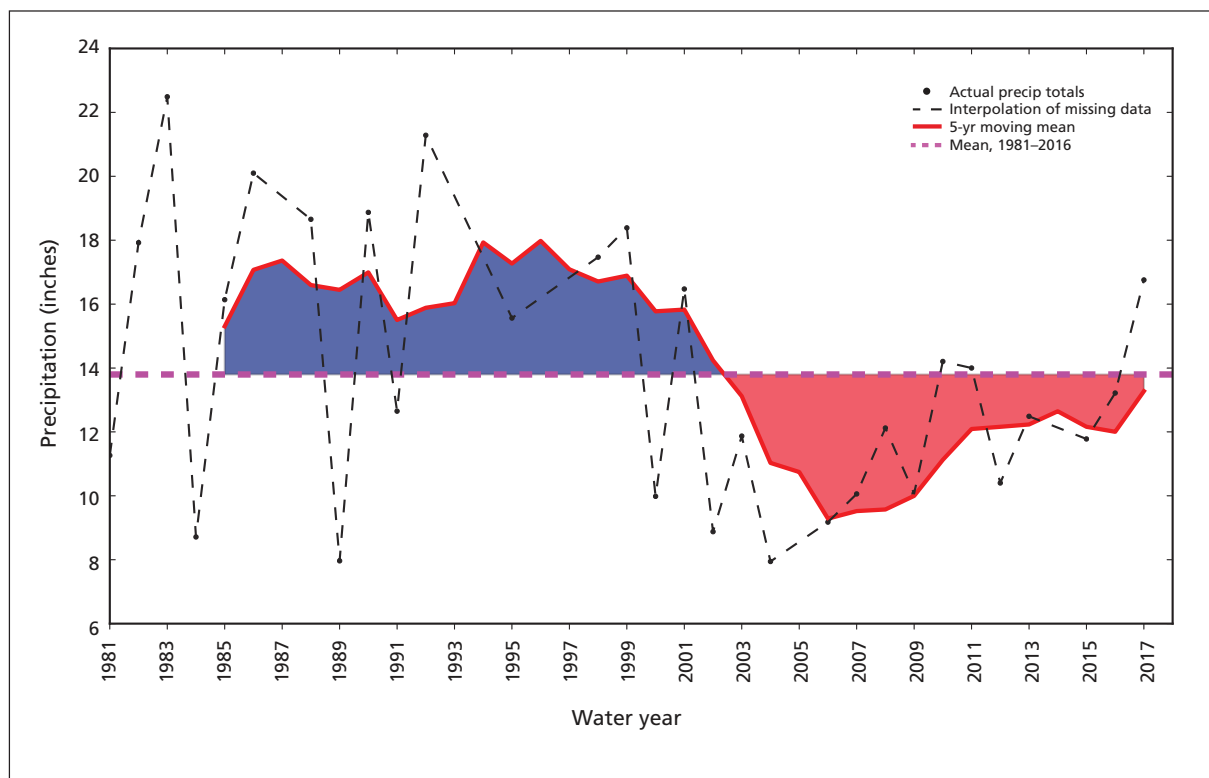


Figure 2-7. Five-year moving mean of annual precipitation, Montezuma Castle National Monument, 1981–2017. The moving mean (solid red line) is based on a timeseries with 18.9% (7 of 37) missing values, and includes the current year and previous four years. Blue and red fields represent water surplus and deficit. Missing years are linearly interpolated (dashed grey lines). Graphics generated by climateanalyzer.org.

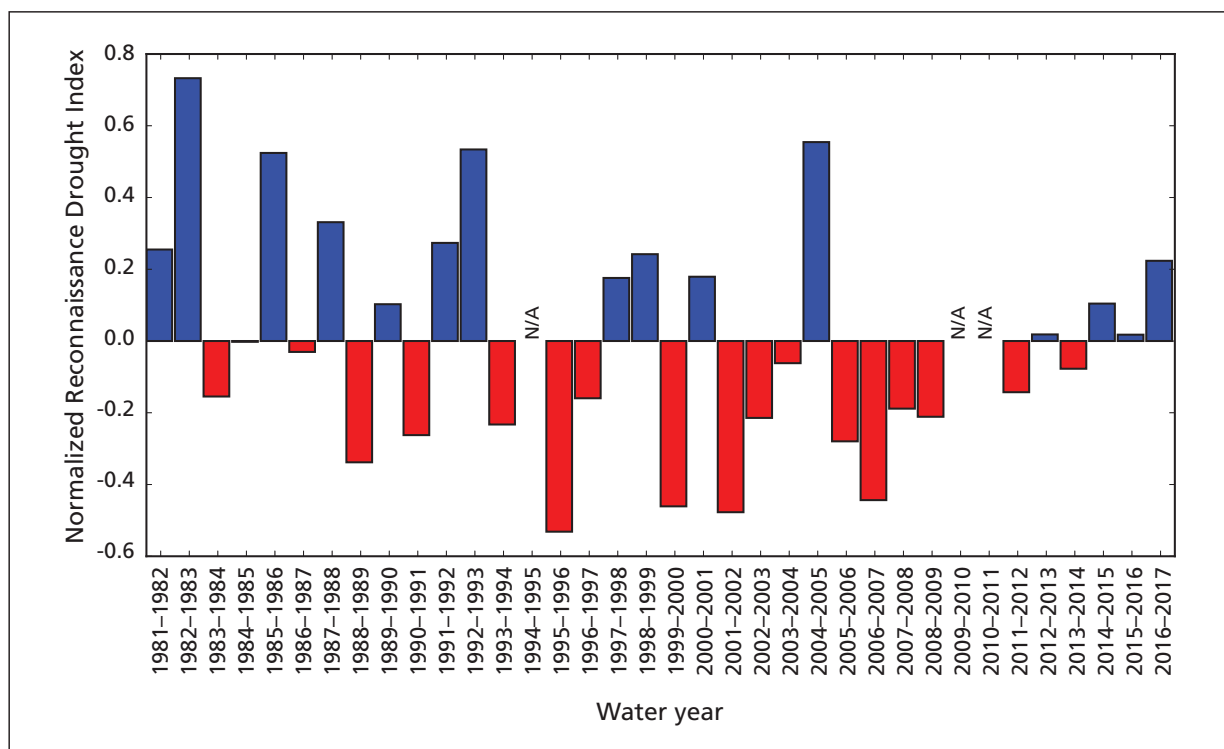


Figure 2-8. Reconnaissance drought index (RDI), Tuzigoot National Monument, water years 1981– 2017. "n/a" = insufficient data to generate reliable RDI estimates. Graphics generated by climateanalyzer.org.

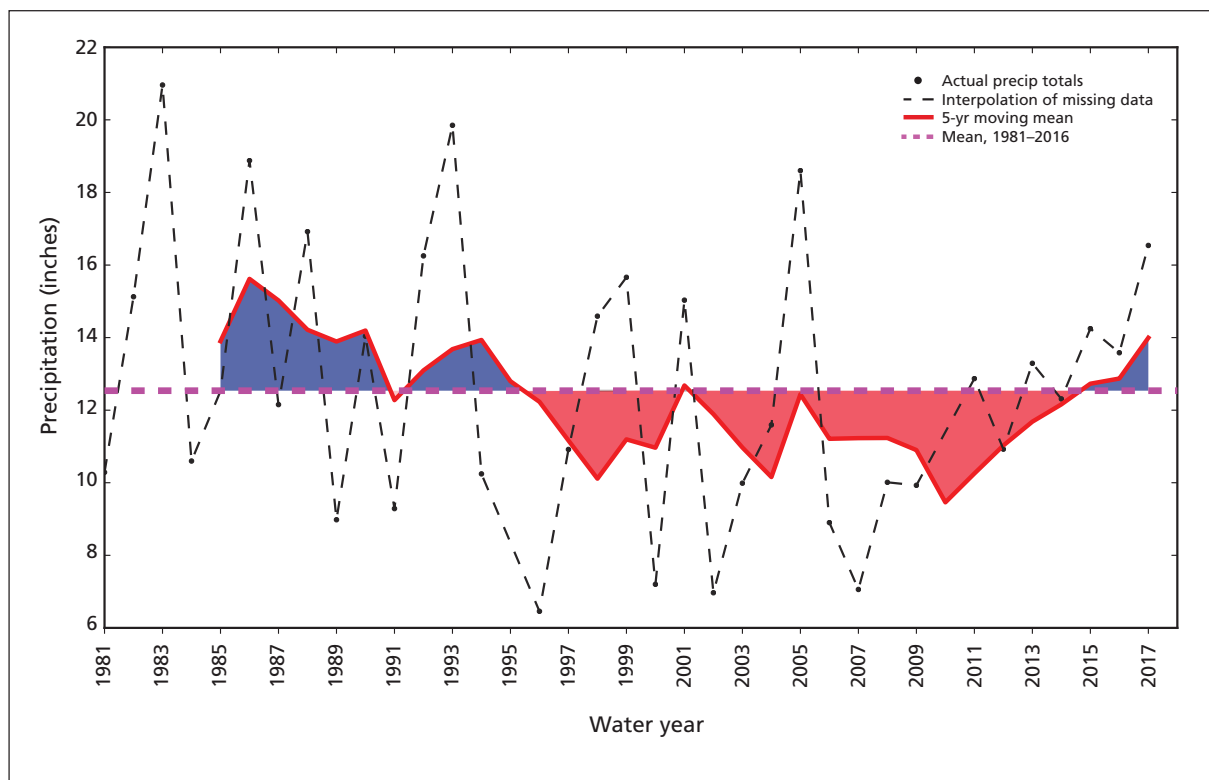


Figure 2-9. Five-year moving mean of annual precipitation, Tuzigoot National Monument, 1981–2017. The moving mean (solid red line) is based on a timeseries with 5.4% (2 of 37) missing values, and includes the current year and previous four years. Blue and red fields represent water surplus and deficit. Missing years are linearly interpolated (dashed grey lines). Graphics generated by climateanalyzer.org.



## 3 Springs

### 3.1 Background

Surface water is rare in the desert southwest. Perennial rivers and lakes are few, and are widely distributed across the region. Because most water from thundershowers produces scouring flows that quickly pass through ephemeral streams and arroyos, springs often provide the most persistent, reliable water for humans and wildlife (Sada and Pohlmann 2007).

Springs support aquatic and riparian systems where groundwater reaches the land surface through natural processes. They provide much of the aquatic environment in arid lands, as well as a substantial portion of regional aquatic and riparian biodiversity (Hubbs 1995). Springs and their related ecosystems are considered to be of high priority for providing goods and services to humans and wildlife (Stevens and Meretsky 2008).

Alteration of surface water resources within desert ecosystems has profound ecological and management implications, including loss of species diversity, extinction or extirpation of special-status and endemic species, alteration in the composition and distribution of plant and animal communities, alteration of culturally significant sites, and inability of parks to meet legal and policy mandates.

There are three springs at Montezuma Castle and Tuzigoot national monuments, one at each unit. At Montezuma Castle NM are Expansion Spring (Castle unit) and Montezuma Well (Well unit). At Tuzigoot NM is Shea Spring. The full complement of SODN springs monitoring is done only at Expansion and Shea springs.

### 3.2 Methods

The overarching goal of SODN springs monitoring is to detect broad-scale changes in aquatic and riparian ecological condition by observing selected drivers, stressors, and processes. To meet this goal, we monitor a suite of vital signs and measures organized into four modules: water quantity, water quality, site condition, and site characterization (Table 3-1).

At time of writing, the SODN springs monitoring protocol (McIntyre et al. 2017) was undergoing peer review. A brief description of the data collection and processing methodologies followed at Montezuma Castle and Tuzigoot NM during WY2017 is presented below. Detailed descriptions of these procedures will be available in the completed protocol.

#### 3.2.1 Site characterization

Variations in local geology and hydrology make it difficult to specify meaningful target populations for springs, even on local scales (Predick 2016; Weissinger et al. 2017). Instead, SODN monitoring focuses on “sentinel springs,” selected using a decision tree that incorporates management priority, access, and stable sampling locations in a fashion similar to that employed by the Northern Colorado Plateau Network (Weissinger et al. 2017). We also rely on Sada’s (2013a, 2013b) methods for measuring presence of wetland species, aquatic habitat (surface water) persistence, scouring, and human disturbance; and the criteria developed by Thompson and others (2002) for monitoring surface water presence and persistence, wetland species, and disturbance.

In general, springs were *not* chosen as sentinel sites if:

1. They were inaccessible according to network safety protocols and/or took too long to access (>3-hour hike).
2. They were too small for any type of survey (e.g., had no observable or measurable flow, no perennial riparian vegetation, or if they consisted of little more than “wet spots” on the ground or cliff face).
3. They had extensive modification or diversion.
4. They were intermittent streams (i.e., channel was runoff-dominated and subject to scour).
5. They showed signs of frequent scouring (i.e., erosion).
6. Park managers had requested the site be excluded from sampling.

**Table 3-1. Objectives and metrics for monitoring modules of the Sonoran Desert Network springs monitoring protocol.**

| Module                | Vital signs                                              | Monitoring objective                                                                                                                                                             | Measured parameters                                                                       | Measurement frequency |
|-----------------------|----------------------------------------------------------|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-------------------------------------------------------------------------------------------|-----------------------|
| Site Characterization | None                                                     | Provides on-site contextual information to assist in the interpretation of data collected for the other three modules                                                            | Contextual information                                                                    | Every 5 years         |
| Site Condition        | Invasive/non-native plants                               | Determine presence (status) of select obligate/facultative wetland plants and nonnative plants<br>Determine status and long-term trend of anthropogenic and natural disturbances | Presence of species, genera, and families<br>Categorical rating of disturbance categories | Annual, in spring     |
| Water Quantity        | Persistence of springs                                   | Determine status and long-term trend in the persistence of surface water (number of dry days)                                                                                    | Number of wet and dry days                                                                | Every 1 or 2 hours    |
|                       | Surface water dynamics                                   | Determine status of spring discharge and wetted extent                                                                                                                           | Spring discharge, wetted extent (length, width, depth)                                    | Annual, in spring     |
| Water Quality         | Water quality (core parameters)                          | Determine status and long-term trend in core water quality parameters (temperature, pH, conductivity, and dissolved oxygen)                                                      | Temperature, pH, specific conductance, dissolved oxygen                                   | Annual, in spring     |
|                       | Water chemistry, pollutant metals (metal and metalloids) | Determine status in select metals and metalloids, inorganics and alkalinity                                                                                                      | Potassium, magnesium, calcium, sulfate, alkalinity, chloride                              | Annual, in spring     |

It is acknowledged that the statistical inference provided by this design is limited to only the individual springs monitored over time.

### 3.2.2 Site condition

The disturbance assessment is a qualitative measure of natural and anthropogenic disturbance and the level of stress on vegetation and soils in springs ecosystems. Types of natural disturbance evaluated include flooding, drying, fire, wildlife, wind throw, and insects. Types of anthropogenic disturbance include roads and off-highway vehicle trails, hiking trails, and evidence of contemporary human use, such as campsites, fire rings, and trash. An “other” category is also included. The magnitude of each disturbance on the spring is classified on a scale of 1–4, where 1 = undisturbed, 2 = slightly disturbed, 3 = moderately disturbed, and 4 = highly disturbed (see Table 3-2).

### 3.2.3 Water quantity

Water quantity determines the stability and persistence of a spring system. It is influenced by aquifer size, rate of groundwater recharge, and geology (Sada 2013a, 2013b). In arid regions, recharge tends to be sporadic and confined to relatively small areas, but spring discharge can remain consistent until water tables decline below a threshold (Kreamer and Springer 2008).

SODN monitors three parameters of surface water quantity at springs: volumetric discharge, hydroperiod, and wetted extent. Volumetric discharge calculates the system’s surface outflow through a timed sample of water volume. Hydroperiod determines persistence by calculating the variance between a pair of sensors that collect temperature data from water and air at primary emergence sites. Wetted extent is a comprehen-

**Table 3-2. Disturbance classifications for Sonoran Desert Network springs monitoring.**

| Magnitude | Classification       | General definition                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                      |
|-----------|----------------------|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| 1         | Undisturbed          | No evidence of recent or historical factors or activities. Because most springs have been altered by humans, drought, fire, or flood, these types of springs are rare. Most undisturbed springs are naturalizing from past disturbances.                                                                                                                                                                                                                                                                                |
| 2         | Slightly disturbed   | Little evidence that vegetation or soils have been disturbed. Evidence of past disturbance may be present, but disturbance of vegetation and soils appears minimal or is no longer evident. Riparian vegetation community appears vigorous                                                                                                                                                                                                                                                                              |
| 3         | Moderately disturbed | Evidence of recent, comparatively high disturbance to vegetation or soils. Height or distribution of riparian vegetation is reduced. The disturbance could be of (1) relatively low magnitude that covers more than half of the spring ecosystem area or (2) higher magnitude that covers a small portion of the ecosystem. Less than 50% of spring banks are covered by vegetation. Spring brooks contain >50% of natural discharge because they are impounded or dredged, or contain spring boxes that collect water. |
| 4         | Highly disturbed     | Evidence of significant impact on vegetation and soils across most of the spring ecosystem. Less than 50% of the banks are covered by riparian vegetation.                                                                                                                                                                                                                                                                                                                                                              |

sive metric assessment of the physical length, width, and depth of present surface water (McIntyre et al. 2018).

### 3.2.4 Water quality

Core water quality parameters are a group of ecologically important metrics that provide the most basic level of information about water quality (Irwin 2008). In aquatic ecosystems, particular water quality conditions sustain the life-supporting biochemical processes to which particular plant and animal communities are adapted. In this sense, quality is relative for monitoring purposes; it is possible that deviations in any metric can change a system, even those adapted to harsh conditions.

Water quality monitoring examines core water quality parameters, water chemistry, and turbidity. 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 extracting surface water samples on site, then

subjecting samples to (YSI 9500) photometer analysis, which examines alkalinity, metals/metalloids, and inorganic compounds. A turbidimeter is used on-site to analyze samples for turbidity (Hach 2100Q).

## 3.3 Results and discussion

There is one sentinel spring at Montezuma Castle NM (Expansion Spring, Castle unit), and one at Tuzigoot NM (Shea Spring). Both springs were visited in July 2017 (Table 3-3). Both springs had surface water present, were flowing, and showed little sign of change or disturbance. Data are also presented on hydroperiod for Montezuma Well (Montezuma Castle NM, Well unit), a unique spring with a large body of literature (e.g., Konieczki and Leake 1997; Johnson et al. 2012a; Johnson et al. 2012b).

**Table 3-3. Dates visited and wet/dry status, Montezuma Castle and Tuzigoot national monuments, FY2017.**

| Site name        | Site code | Date visited      | Wet/Dry |
|------------------|-----------|-------------------|---------|
| Expansion Spring | MOCA_001  | 7/11/2017         | Wet     |
| Shea Spring      | TUZI_001  | 7/12/2017         | Wet     |
| Montezuma Well   | MOWE_002  | Oct 2015–Sep 2017 | Wet     |



Figure 3-1. Expansion Spring orifice, Montezuma Castle National Monument (Castle unit). Employee is pointing at the spring orifice.

**Table 3-4. Summary of site location information and metrics for sentinel springs at Montezuma Castle and Tuzigoot national monuments, WY2017.**

| Parameter                   | MOCA_001* | TUZI_001   |
|-----------------------------|-----------|------------|
| Spring type                 | Rheocrene | Limnocrene |
| Multiple orifices (<200 m)? | No        | Yes        |
| Dominant discharge type     | Spring    | Spring     |
| Slope (deg)                 | ND        | ND         |
| Slope variability           | Low       | Low        |
| Aspect (deg)                | 270       | 120        |
| Channel present (#)         | 1         | No         |
| Channel length (m)          | 11.5      | NA         |

\*In WY2016, this spring was reported under the code "MOCA\_004." The correct code is MOCA\_001. ND=no data; NA=not applicable

### 3.3.1 Site characterization

#### 3.3.1.1 Expansion Spring

Expansion Spring (MOCA\_001; Figure 3-1) is a rheocrene spring that emerges from the west-facing drainage near the bank of Beaver Creek (Table 3-4). The spring emerges from a dirt embankment in the bed of a runoff-dominated channel, from which it forms a diffuse, low-flowing springbrook that extends for 11.5 meters. The water is warm and turbid, and flows over a loose silt substrate. Despite the springbrook terminating at 11.5 meters, a channel continues the remaining two meters to a confluence with Beaver Creek. In WY2017, the springbrook orifice had moved two meters downstream from its 2016 location.

#### 3.3.1.2 Shea Spring

Shea Spring (TUZI\_001; Figure 3-2) is a limnocrene spring that emerges as an orifice pool



Figure 3-2. Shea Spring orifice, Tuzigoot National Monument.

on the banks of Tavaschi Marsh (Table 3-4). The spring emerges from multiple orifices. These include a small, rheocrene-like emergence from a soil embankment on the north end of the pool and multiple active upwellings on the bottom of the orifice pool. The substrate is primarily sand, with scattered gravel and cobbles throughout. The north, east, and west banks of the pool are distinct. The west (downstream) edge of the pool is an indistinct mix of surface water, soil, and dense southern cattail (*Typha domingensis*) and hardstem bulrush (*Schoenoplectus acutus*) that makes it challenging to characterize the features of the pool, such as possible location of multiple orifices or existence and metrics associated with spring channels. The water is clear and cool, with notable macroinvertebrate presence. Invasive northern crayfish (*Orconectes virilis*) were noted during sampling.

### **3.3.1.3 Montezuma Well**

*The following information is drawn from the substantial body of literature on Montezuma Well, rather than from SODN assessments.* Montezuma Well is a collapsed-mound spring (Springer and Stevens 2009), in which mineral-rich water deposits travertine as it emerges, then wears the travertine away to a point where the structure collapses into a “well” (Johnson et al. 2012a). It is home to several endemic species, including a diatom, a spring snail, a water scorpion, an amphipod, and a leech (Blinn 2008), and has complex chemistry (Johnson et al. 2012b). Current research indicates that the source of the water for Montezuma Well is originally from the Mogollon Rim, possibly with a component of ancient brine. Carbon-14 dating shows that the water in the well is between 5,400 and 13,300 years old (Johnson et al. 2012b).

**Table 3-5. Anthropogenic disturbance ratings for sentinel springs at Montezuma Castle and Tuzigoot national monuments, WY2017.**

| Site code                    | MOCA_001 | TUZI_001 |
|------------------------------|----------|----------|
| Roads/OHV trails             | 1        | 1        |
| Hiking trails                | 1        | 1        |
| Contemporary human occupancy | 1        | 1        |
| Historic human occupancy     | 1        | 1        |
| Livestock                    | 1        | 1        |
| Feral animals                | 1        | 1        |
| Exotic plant treatments      | 1        | 1        |
| Flow modification            | 1        | 1        |
| Other                        | –        | –        |

### 3.3.2 Site condition

#### 3.3.2.1 Anthropogenic

**Expansion Spring**—. There was little to no observed anthropogenic disturbance at Expansion Spring. The median value in this category was a 1 (undisturbed) (Table 3-5; see Table 3-2 for description of ordinal ranking). Results from pilot work in WY2016 yielded the same result, with a median value of 1. This indicates that the site is not frequently impacted by human activity. This is likely due to its location on the east side of the stream, away from most human activity. Public access to this area of the park is restricted.

**Shea Spring**—. There was little to no observed anthropogenic disturbance at Shea Spring. The median value in this category was a 1 (undisturbed) (Table 3-5). Results from pilot work in WY2016 were the same, with a median value for this category of 1. This indicates that the site is likely not recently impacted by human activity. There is a foot trail adjacent to the spring (following the base of the steep slope adjacent to most of Tavasci Marsh), but access to the trail is limited to NPS personnel and it does not appear to be frequently used. There is some indication that rock dams may have been installed

**Table 3-6. Natural disturbance ratings for sentinel springs at Montezuma Castle and Tuzigoot national monuments, WY2017.**

| Site code          | MOCA_001 | TUZI_001 |
|--------------------|----------|----------|
| Recent flooding    | 1        | 1        |
| Drying             | 1        | 1        |
| Fire               | 1        | 1        |
| Non-livestock use  | 1        | 1        |
| Wind throw         | 1        | 1        |
| Insect infestation | 1        | 1        |
| Beaver activity    | 1        | 1        |
| Other              | –        | –        |

in the past, but recent growth of cattails (*Typha* spp.) has hidden this feature.

#### 3.3.2.2 Natural disturbance

**Expansion Spring**—. There was little indication of natural disturbance at Expansion Spring in WY2017 (Table 3-6). The spring is located at the base of a collapsed ravine in the adjoining limestone slope. It is suspected that the ravine channels groundwater from upgradient, with the groundwater eventually emerging at the spring (Figure 3-3). The site may be susceptible to erosion; it is only several meters away from the active channel of Beaver Creek. Any erosion of the active channel of Beaver Creek could impact this spring (as noted above, the terminus of the springbrook is only two meters from the active channel).

**Shea Spring**—. There was little indication of natural disturbance at Shea Spring in WY2017 (Table 3-6). Observers noted that the cover of southern cattails (*Typha dominicensis*) had increased since 2015 (Figure 3-4). The reason for the apparent increase in cover is unknown, but could indicate a change in nutrient availability or hydrologic regime (Urban et al. 1993).



Figure 3-3. Slope where Expansion Spring emerges. The upper half of this photo (from 2011) includes the bottoms of the collapsed ravine(s).



Figure 3-4. Shea Spring at Tuzigoot National Monument, 2015–2017.

### 3.3.3 Water quantity

#### 3.3.3.1 Volumetric discharge

Both of the springs visited during WY2017 were flowing. However, acceptable measurements of flow could not be made due to the depth of the water and condition of the substrate. The spring channel at Expansion Spring is very shallow (0.56 cm) and the bottom of the channel was covered in a proportionally large (0.86 cm) layer of fine organic and inorganic material (Table 3-7). Additionally, water is discharged from diffuse seeps on the slope. Attempts to collect the discharge in the main channel caused changes to the channel morphology as the benthic materials were disturbed. This system of diffuse seeps and change to the channel morphology and suspension of material made collecting a valid measurement impossible. At Shea Spring, the water flows into the bottom of the main pool via multiple orifices through fine silt and sand.

#### 3.3.3.2 Hydroperiod

**Expansion Spring**—. Data from temperature sensors indicated that this spring was wet for the entire sample period (Figure 3-5).

**Shea Spring**—. Data from temperature sensors indicated that this spring was wet until the end of WY2017 (Figure 3-5). When the temperature sensor was recovered, it was found hanging from its cable, tangled in the juniper tree that serves as an anchor point. It is suspected that unknown parties removed the sensor from its deployment location and left it hanging in the tree.

**Montezuma Well**—. SODN and park resource staff collect data on water level in Montezuma Well. This is done with logging pressure transducers that collect water-

level data every 15 minutes, and staff plate measurements.

Data from WY2016 to 2017 indicate that the well's water elevation fluctuates ~0.4 meters, possibly with an annual signal of a brief increase in July and August (Figure 3-6). However, care must be taken to not interpret too much from this assessment, which is based on only two annual cycles. Most literature argues that nearly all water enters the well from a deep aquifer with a long residence time. There may be input from local sources, but this is unlikely (Johnson et al. 2012a,b).

#### 3.3.3.3 Wetted extent and channel morphometrics

The length and morphometrics of the springbrook convey information about the status and processes occurring at the sample sites. The depth and width of the springbrook, considered in conjunction with associated variability (expressed at standard deviation), can provide information about flow and scour events at the sites (Table 3-7).

### 3.3.4 Water quality

The results for water quality core parameters were generally in the range of expected values (Table 3-8). Core parameters were collected at two locations at Shea Spring. Results of interest are described below.

**Expansion Spring**—. Sample collection was challenging at Expansion Spring. The depth of the spring at the orifice and along the springbrook was less than one centimeter, and generally less than 0.5 centimeters (Table 3-7), making it difficult to sample for water quality. The dissolved oxygen reading was 0.85 mg/L, much lower than expected. This reading likely resulted from a combination of the operational requirements of the dissolved oxygen probe and the very shallow water.

**Shea Spring**—. Water was collected for analysis from two locations at Shea Spring (Table 3-8). Location A included data from water collected at the orifice. Location B included data collected from the pool below the orifice. In addition to receiving the water discharging at the orifice (through a short ~1-meter channel containing a dense stand

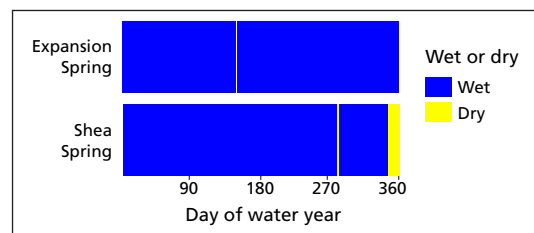


Figure 3-5. Raster of hydroperiod data from Expansion Spring (Montezuma Castle NM) and Shea Spring (Tuzigoot NM). The X axis represents the day of the water year (October 1 is day one).

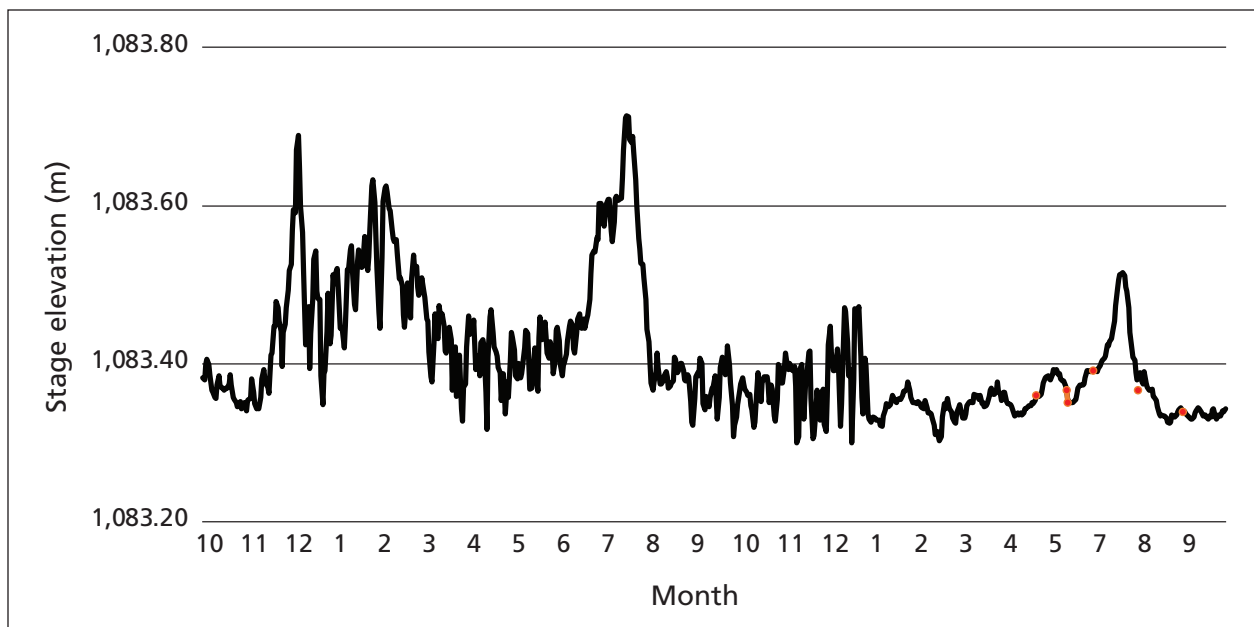


Figure 3-6. Daily mean surface elevation of Montezuma Well, WY2016–2017. The black line indicates the daily mean water elevation from October 2015 through September 2017. Red dots indicate measurements collected from a staff gauge at Montezuma Well. Data from October 2015 to January 2017 are not corrected for barometric pressure because the sensor was removed by unknown parties.

**Table 3-7. Wetted channel and morphometric data for sentinel springs at Montezuma Castle and Tuzigoot national monument, WY2017.**

| Site code | Mean wetted width (cm) | Mean depth (cm) | Detritus depth (mm) | Mean substrate particle size (mm) |
|-----------|------------------------|-----------------|---------------------|-----------------------------------|
| MOCC_001  | 19.15                  | 0.56            | 0.89                | 0.06 (Fine Sand)                  |
| TUZI_001  | ND                     | ND              | ND                  | ND                                |

ND=no data

**Table 3-8. Core water quality parameters for sentinel springs at Montezuma Castle and Tuzigoot national monument, WY2017.**

| Site code | Temperature (°C) | Dissolved oxygen (mg/L) | Specific conductivity (μS/cm) | Total dissolved solids (mg/L) | pH   | Turbidity | Comments         |
|-----------|------------------|-------------------------|-------------------------------|-------------------------------|------|-----------|------------------|
| MOCC_001  | 20.0             | 0.85                    | 883                           | 572                           | 7.32 | 4.89      | Shaded           |
| TUZI_001A | 20.3             | 6.2                     | 560                           | 364                           | 6.06 | 3.65      | Partial sunlight |
| TUZI_001B | 20.4             | 6.93                    | 561                           | 367.5                         | 7.14 | 0.42      | Partial sunlight |



Figure 3-7. Water discharging in the bottom of the pool at Shea Spring. Note the roiling sediment in the center of the photo.

of mature *Typha*), Location B also receives groundwater discharged from the bottom of the pool (Figure 3-7). The pool is connected to the rest of Tavaschi Marsh.

The pH measurement from Location A (6.06 units) was more than one pH unit less than the measurement from Location B (7.14). Data from 2016 and 2010 indicate that the pH from this location has been circum-neutral, between 7 and 7.5 units. The low WY2017 value for Location A may be due to observer error, or a combination of the operational requirements of the equipment and the shallow water. However, the dissolved oxygen measurement appeared to be within expected range at this site (6.2 mg/L), indicating that the amount of discharge facilitated proper function of the water quality probes.

### 3.3.5 Water chemistry

The water chemistry from both spring sites (Table 3-9) was within the expected range. Elevated mineral concentrations (e.g., Ca and Mg) are typical for the region (Johnson et al. 2012b).

**Table 3-9. Water chemistry data for sentinel springs at Montezuma Castle and Tuzigoot national monument, WY2017.**

| Parameter                       | MOCC_001 | TUZI_001A | TUZI_001B |
|---------------------------------|----------|-----------|-----------|
| Alkalinity (CaCO <sub>3</sub> ) | 350      | 185       | 210       |
| Chloride                        | 21       | 26        | 21        |
| Magnesium                       | 70       | 40        | 37        |
| Nitrate                         | NC       | NC        | NC        |
| Sulfate                         | 0        | 0         | 0         |
| Calcium                         | 66       | 40        | 46        |
| Potassium                       | 3.1      | 1.9       | 1.8       |

NC = not collected

## 4 Surface Water

### 4.1 Background

The Verde River and two of its tributaries flow through Montezuma Castle and Tuzigoot national monuments. The Verde River flows through Tuzigoot NM. Beaver Creek flows through the Castle unit of Montezuma Castle NM, and Wet Beaver Creek flows through the Well unit of Montezuma Castle NM. These streams are part of a large hydrologic drainage basin that directs surface and 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.

### 4.2 Methods

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

All samples and field data in WY2017 were collected at the index reaches on Beaver Creek (Figure 4-1), Wet Beaver Creek (Figure 4-2), or the Verde River (Figure 4-3). These figures indicate the location where water quantity and water quality samples are collected (index point) and where macroinvertebrates are collected (index reach), and show the boundaries of the overall sampling unit (stream segment).

#### 4.2.1 Water quality core parameters

Core water quality parameters are a group of ecologically important metrics that provide the most basic level of information about water quality (Irwin 2008). Parameters sampled by SODN included water temperature, pH, specific conductivity, dissolved oxygen,

turbidity, and discharge. During each visit, we noted hydrologic conditions and sampled core parameters using the following methods:

On arrival at the site, a multi-parameter water quality meter (YSI Professional Plus) was calibrated and deployed in a well-mixed part of the stream channel, logging temperature, pH, specific conductivity, and dissolved oxygen data at one-minute intervals. The meter was left in the stream for the duration of the visit. Turbidity samples were collected and analyzed within one hour using a portable turbidimeter (HACH 2100P). Discharge was measured using a FlowTracker Acoustic Doppler Velocimeter.

In addition to regular sampling, we used a logging multi-parameter instrument (YSI XLM600 V2) to collect data on temperature, pH, specific conductivity, and dissolved oxygen at 15-minute intervals for a minimum of two weeks every quarter.

#### 4.2.2 Water quality samples

During each site visit, water samples were collected in a three-liter Nalgene sample collection bottle, following non-isokinetic sampling methods as described in the U.S. Geological Survey's National Field Manual for the Collection of Water Quality Data (USGS 2006). We transferred the sample water to bottles for analysis of bacteria, turbidity, metals, and other constituents. The sample water was filtered and/or treated as required, kept on ice, and dropped off at the contract laboratory. For WY2016, that lab was TestAmerica.

#### 4.2.3 Water quantity data

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



## Sampling Sites, Beaver Creek

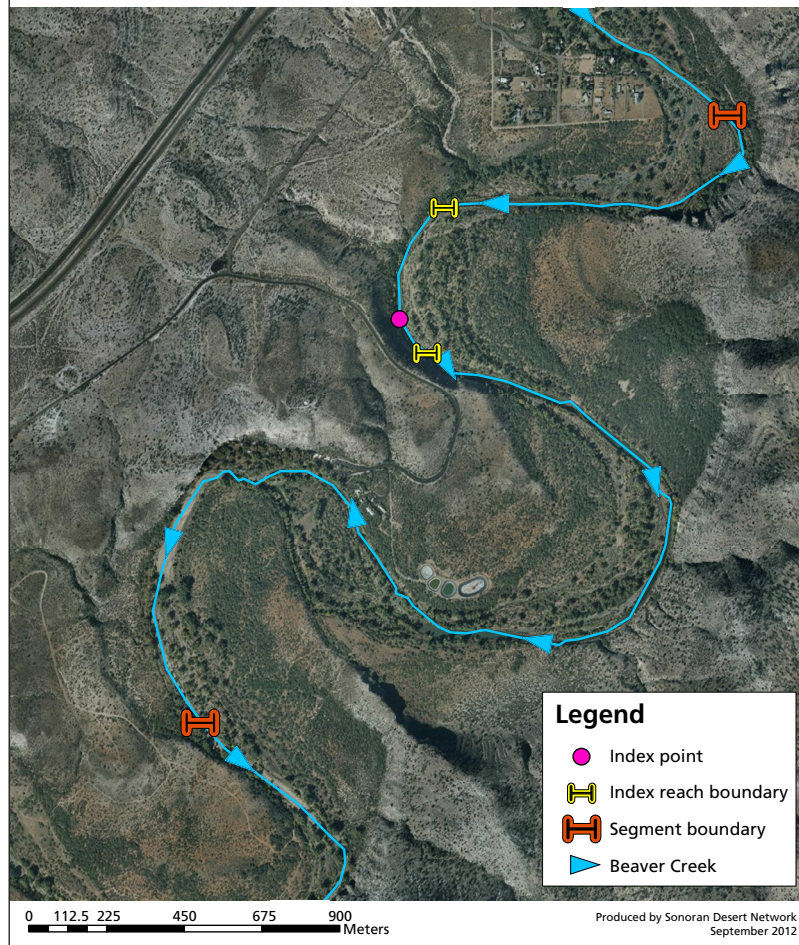


Figure 4-1. Sampling sites on Beaver Creek, Montezuma Castle NM (Castle unit).

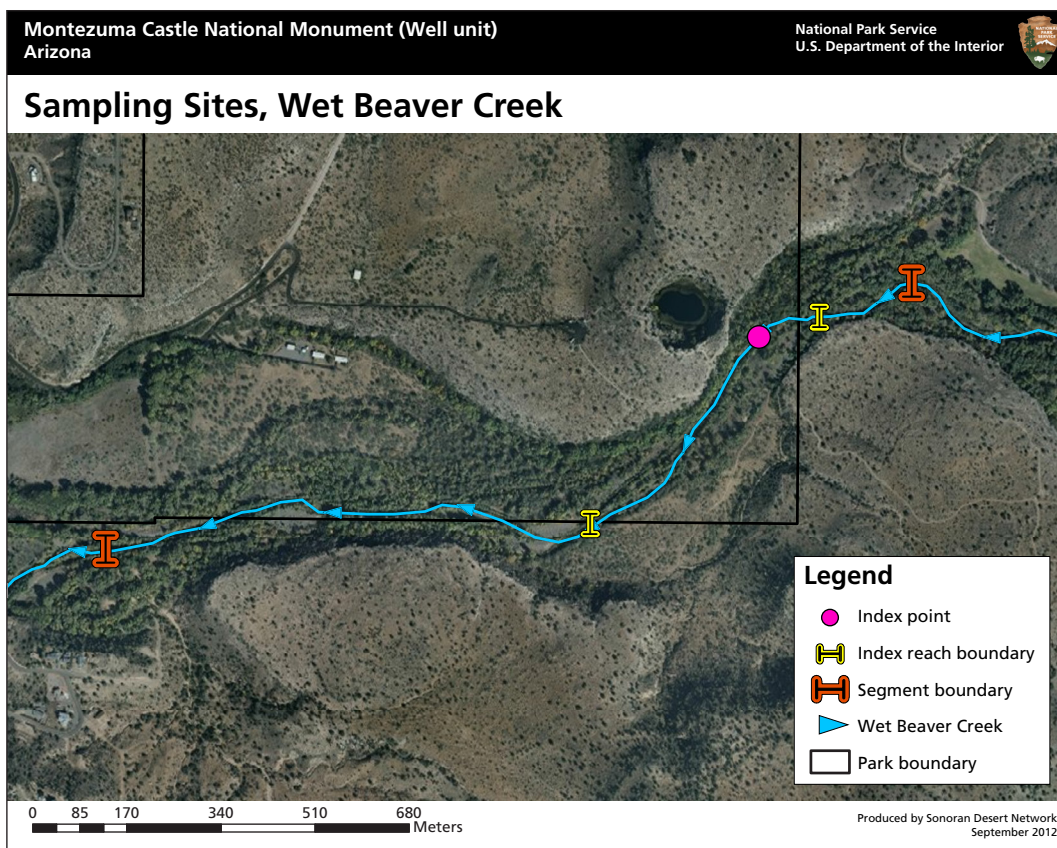


Figure 4-2. Sampling sites on Wet Beaver Creek, Montezuma Castle NM (Well unit).

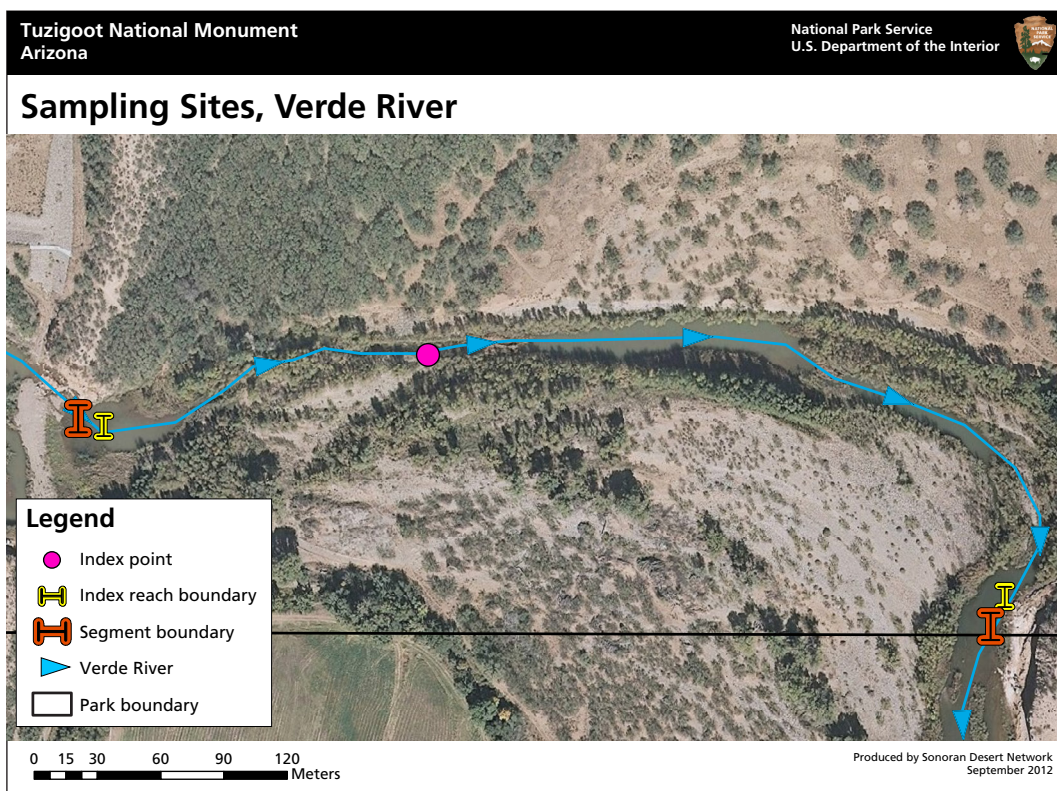


Figure 4-3. Sampling sites on the Verde River, Tuzigoot NM.



## USGS Surface Water Gauge Locations

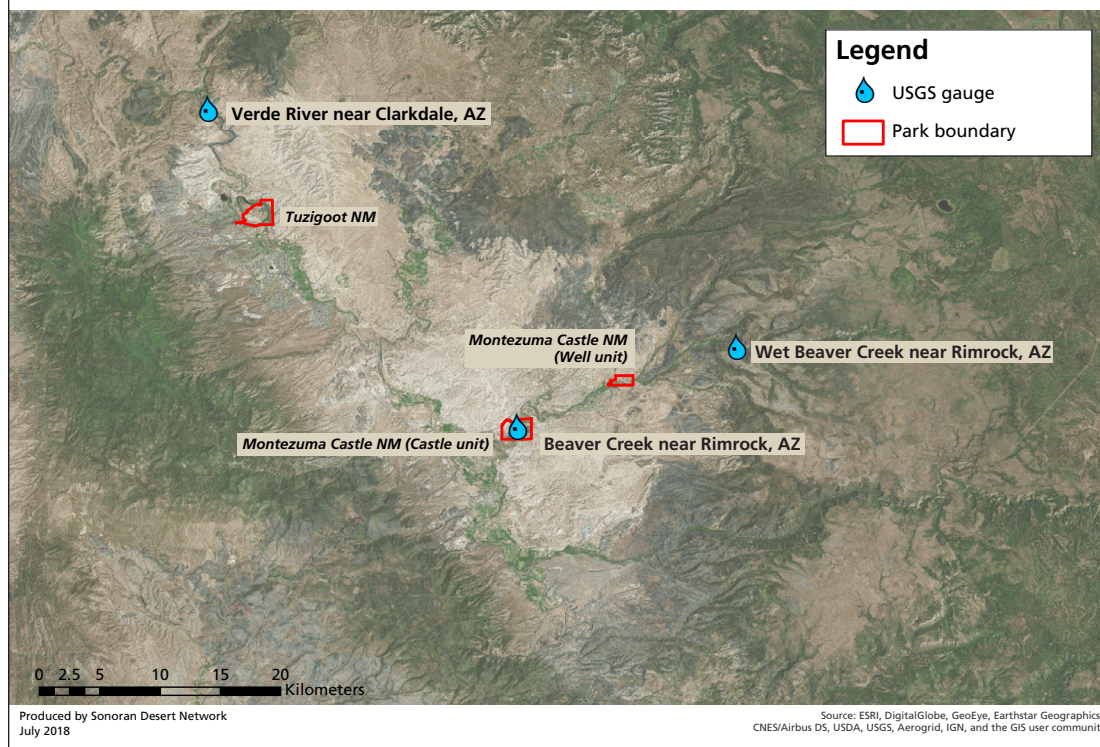


Figure 4-4. Locations of USGS stream gauges near Montezuma Castle and Tuzigoot national monuments.

### 4.2.3.1 Beaver Creek

Data from the gauge on Beaver Creek for WY2017 were used to generate a provisional rating curve for the site.

### 4.2.3.2 Wet Beaver Creek

The Wet Beaver Creek gauge is 4.6 kilometers upstream from the index site on Wet Beaver Creek. Several ephemeral streams and intermittent springs flow into Wet Beaver Creek between the USGS gauge and the Wet Beaver Creek index site. A simple regression analysis of concurrent stage data during baseflow from the USGS gauge and a logging pressure transducer at the Wet Beaver Creek index site indicates that the discharge recorded at the USGS site is very similar ( $r^2=0.635$ ;  $p<0.0001$ ). During precipitation events this similarity decreases, especially if the ephemeral streams between the two sites are flowing. Overall, however, the hydrograph from the USGS site provides an accurate year-round representation of flow at the Wet Beaver Creek index site (Gwilliam et al. 2013).

### 4.2.3.3 Verde River

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

### 4.2.4 Aquatic macroinvertebrates and habitat

SODN macroinvertebrate sample collection uses methods proscribed by the State of Arizona for calculating TMDL (total maximum

daily load) indices for warmwater streams at elevations below 5,000 feet. It also coincides with the index period (April–May) used by the Arizona Department of Environmental Quality (ADEQ) to ensure compatibility of monitoring samples (Lawson 2005).

SODN sampling typically occurs in late May, to accommodate the ADEQ QA/QC (quality assurance/quality control) rule of requiring four weeks to pass between a bankfull flow event and a sampling event (ADEQ 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 4-1. Each reach contains 11 equally spaced transects. At each transect, we measured wetted width, water depth, velocity, and canopy cover, and estimated substrate size, bank erosion (using the Rosgen Bank Erosion Hazard Index), and diversity of aquatic habitat. Two types of samples were collected in the reach:

- A *quantitative sample* was collected from five targeted riffle habitats to provide data on organism abundance. A total of 12 replicate samples were collected from a 0.09 m<sup>2</sup> area, using a kick-net with a 0.3-meter opening for one minute. At each of the five habitats, we also measured depth, velocity, particle size, and particle embeddedness.
- A *qualitative sample* was collected to develop a comprehensive list of spe-

cies present in the reach. Using nets, samples were actively collected from all habitat types within the reach during a one-hour collection period and compiled into one composite sample.

Aquatic macroinvertebrate samples were sent to the National Aquatic Monitoring Center’s BugLab, a Bureau of Land Management laboratory at Utah State University in Logan, Utah. The goal was to have a taxonomist, certified by the North American Benthological Society, identify all aquatic macroinvertebrates to the lowest taxonomic level possible.

#### 4.2.5 Data handling and analysis

All water quality and quantity data are stored on the SODN server. This report includes all discrete water quality data collected except for turbidity, coliform, and *E. coli* samples, for which the mean of the triplicate samples are presented. For total coliforms and *E. coli* samples, most probable numbers (MPN/100 mL) are reported; these were determined using IDEXX MPN Generator software provided by the manufacturer (IDEXX Inc.). The continuous multi-parameter sonde measurements are presented with the minimum, first quartile, median, third quartile, and maximum to demonstrate variability.

When applicable, this report compares SODN water quality data against the State of Arizona’s water quality standards (ADEQ 2016) and notes any exceedances.

**Table 4-1. Sampling dates and index reach lengths at Montezuma Castle and Tuzigoot national monuments, WY2017.**

| Unit                           | Stream           | Sample date     | Index reach length (m) |
|--------------------------------|------------------|-----------------|------------------------|
| Montezuma Castle (Castle unit) | Beaver Creek     | 5/18–5/19, 2017 | 423                    |
| Montezuma Castle (Well unit)   | Wet Beaver Creek | 5/19–5/20, 2017 | 567                    |
| Tuzigoot NM                    | Verde River      | 5/21/2017       | 311                    |

**Table 4-2. Dates of sampling visits to index sites at Montezuma Castle and Tuzigoot monuments, WY2017.**

| Unit                           | Site             | Q1         | Q2        | Q3        | Q4        |
|--------------------------------|------------------|------------|-----------|-----------|-----------|
| Montezuma Castle (Castle unit) | Beaver Creek     | 10/12/2016 | 2/16/2017 | 5/24/2017 | 8/24/2017 |
| Montezuma Castle (Well unit)   | Wet Beaver Creek | 10/12/2016 | 2/16/2017 | 5/24/2017 | 8/24/2017 |
| Tuzigoot NM                    | Verde River      | 10/11/2016 | 2/15/2017 | 5/23/2017 | 8/23/2017 |

### 4.3 Results and discussion

SODN staff sampled each index site quarterly during WY2017 (Table 4-2). We collected data on water quantity, water quality, and macroinvertebrates.

#### 4.3.1 Water quantity

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

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

##### 4.3.1.1 Beaver Creek

The Beaver Creek gauge, a cooperative project between Montezuma Castle NM, the Sonoran Desert Network, and the USGS, was

upgraded in WY2015. Provisional raw-stage data are available in near real-time from the Climate Analyzer at [http://www.climateanalyzer.org/sonoran\\_desert/HADS/bcma3/](http://www.climateanalyzer.org/sonoran_desert/HADS/bcma3/).

SODN generated a provisional rating curve for the WY2017 Beaver Creek gauge (USGS 09505200) (Figure 4-5). However, a lack of discharge measurements at flow rates higher than 35 cubic feet per second (cfs) severely limited the accuracy of the rating at levels higher than 35 cfs. Any discharge estimates from this calculation should be considered provisional, and any estimate above 35 cfs should be carefully considered.

Between 12/14/2016 and 2/8/2017, a transition from one satellite to another, combined with technical issues at the gauge, caused data loss. There were several sustained high-flow events during this period, which impacts the statistics derived from the dataset. SODN staff is working to recover available data and publish revisions in future reports.

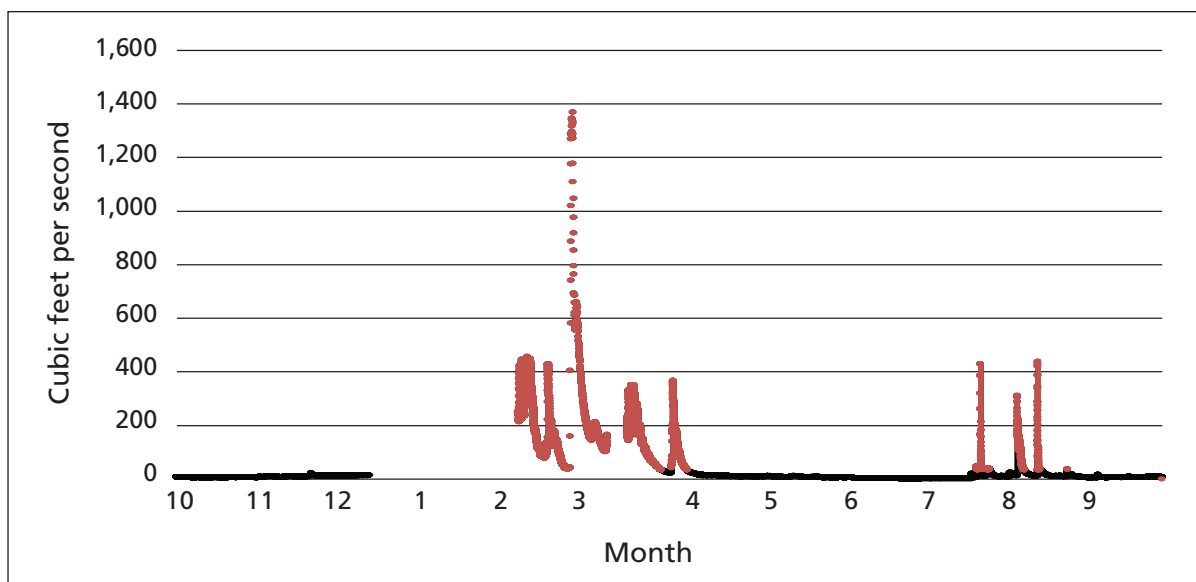


Figure 4-5. Hydrograph from Beaver Creek, Montezuma Castle National Monument (Castle unit), WY2017. Please note that any data above 35 cfs (indicated in red) should be considered with caution.

Mean daily discharge on Beaver Creek was 32.7 cfs (SE 2.2)—approximately one-half the mean value from WY2005 to WY2008 (69 cfs). The median value for WY2017 was 9.4 cfs, with a maximum value of 1,368.9 cfs and a minimum value of 0.6 cfs.

As noted above, the WY2017 rating curve for Beaver Creek gauge data is provisional, especially for results above 35 cfs. Comparisons to flow events observed on Wet Beaver and Dry Beaver creeks (Gwilliam et al. 2017) indicate that the Beaver Creek gauge accurately captures the occurrence and duration of flow events (with available data), but not their magnitude.

SODN remains confident that the rating developed for Beaver Creek in WY2017 adequately identified when events occurred with available data. However, it was not a reliable measure of the intensity of events. SODN

will continue explore ways to improve the rating for the Beaver Creek gauge.

#### 4.3.1.2 Wet Beaver Creek

At Wet Beaver Creek, mean daily discharge during WY2017 was 44.6 cfs, well above the 56-year gauge record mean of 30.3 cfs. The mean daily discharge at Wet Beaver Creek was greater, typically at or above the 75<sup>th</sup> percentile, from December to March (Figure 4-6). Flow from April to the beginning of the monsoon was slightly lower than average. This low flow was especially evident during the latter half of the spring snowmelt period, typically occurring mid-January to mid-May. During that important ecological period for flow, the mean daily discharge was below or approaching the lower 5<sup>th</sup> percentile.

These low-flow periods at the Wet Beaver and Beaver Creek stations were likely expressed as no-flow events in the areas of the

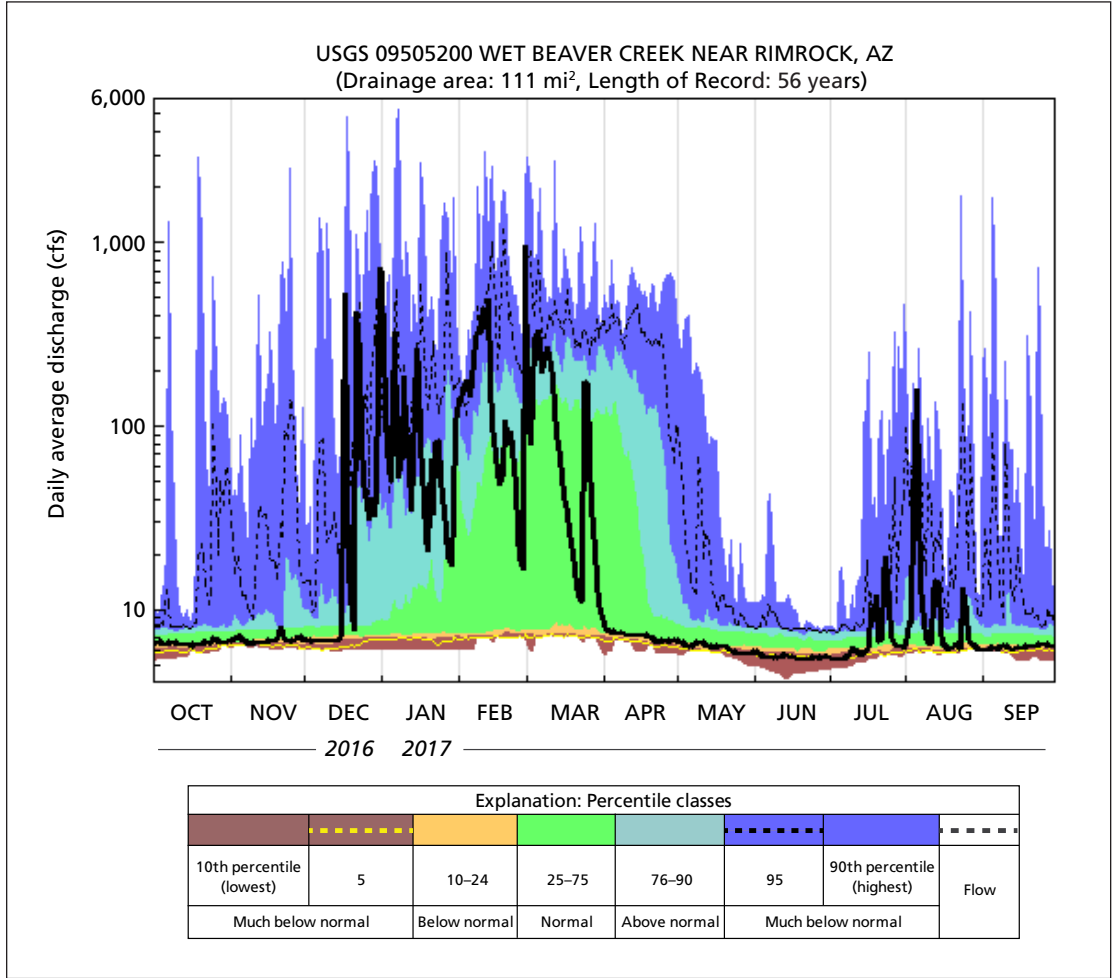


Figure 4-6. Mean daily discharge, Wet Beaver Creek, Montezuma Castle NM (Well unit), WY2017. The solid black line represents mean daily discharge. The various colors represent the range of data, coded by percentile range (USGS 2018).

stream segments where the loss of elevation is the least (e.g., glides). Such events can lead to stream discontinuity and drying events in pools.

The USGS gauge on Wet Beaver Creek has a 56-year record. Using this dataset, we can examine the difference of the centroid of flow on Wet Beaver Creek between the gauge record and WY2017. This pattern was noted in past years (Gwilliam et al. 2017), and continued in WY2017. The centroid is the temporal middle of the large pulse of water that moves through the watershed as water from snowmelt on the Mogollon Rim flows through the system. At Wet Beaver Creek, the centroid for WY2017 was approximately one month earlier in the year than the centroid for the gauge record (Figure 4-7). Earlier peak runoff may impact plants and animals that depend on the timing of the spring melt pulse for successful recruitment (Bunn and Arthington 2002; Stromberg 1998).

#### 4.3.1.3 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 4-3), lies below an agricultural dam. Due to this diversion, only about 14% of the flow on the Verde River flows through the Verde River segment in the park (Gwilliam et al. 2013), and most of that flow occurs when the dam is leaking or has failed. This flow value varied from 2.61 to 10.4 cfs during WY2017 (Figure 4-8, see Table 4-4, below), and varied depending on the integrity of the dam—that is, how much water leaked through the earthen structure.

The most important hydrologic events that occur on the Tuzigoot NM stream segment are flow events that exceed the elevation or degrade the integrity of the diversion dam (estimated to be ~4,000 cfs; Gwilliam et al. 2013), causing a high-flow event in the stream segment. No such event occurred in WY2017.

The recorded flow at this gauge during WY2017 was either at or below the 25<sup>th</sup> percentile for most of the year. However, in comparison with WY2016 (Gwilliam et al. 2017), the winter and early spring flows were more persistent and higher in magnitude. This prolonged winter and spring flow in-

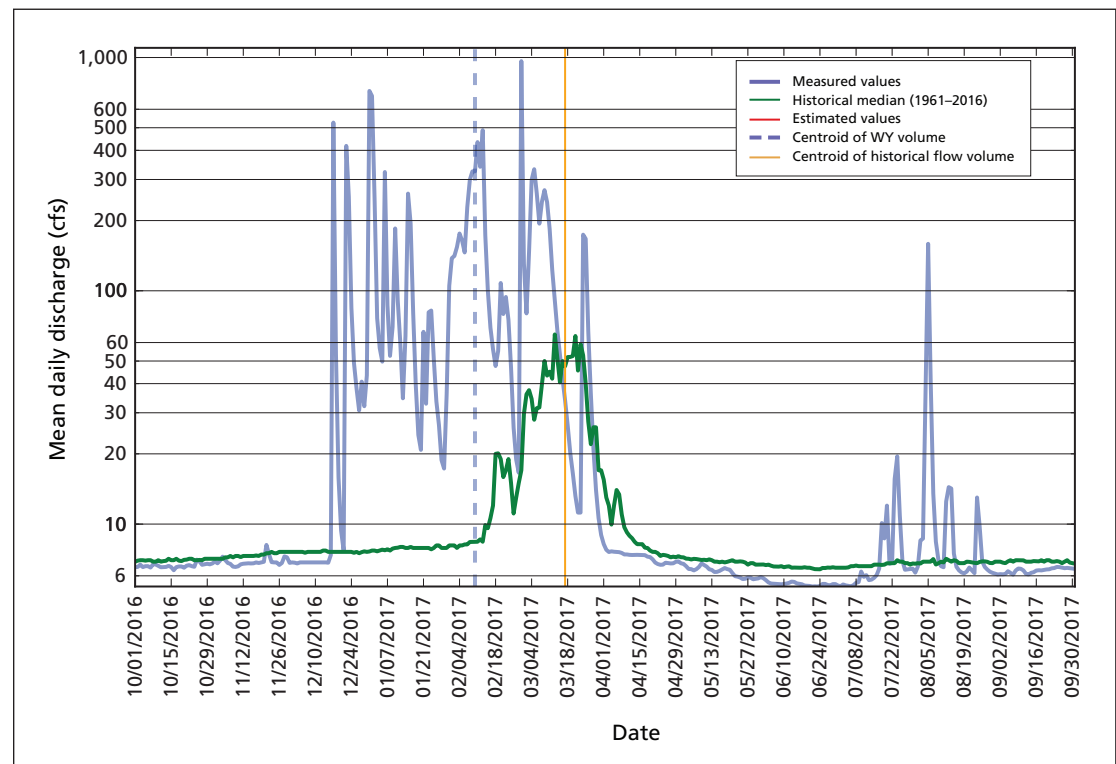


Figure 4-7. Centroid of flow volume, Wet Beaver Creek, Montezuma Castle NM (Well unit), WY2017 vs. gauge record (56 years). The dotted blue line indicates the WY2017 flow centroid. The orange line indicates the gauge-record centroid. Peak flow has moved nearly a month earlier. Graphic from Climate Analyzer.

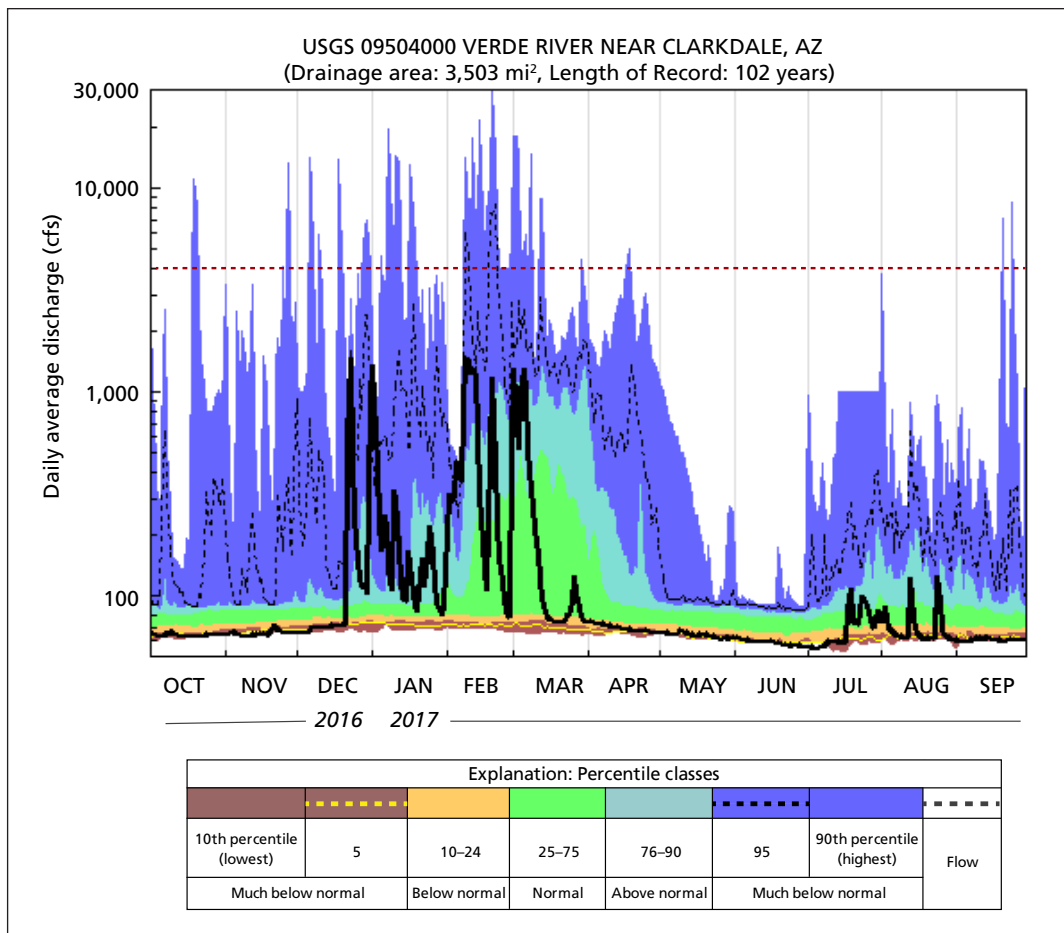


Figure 4-8. Mean daily discharge at the USGS gauge near Clarkdale, Arizona, WY2017. The solid black line represents mean daily discharge. The various colors represent the range of data, coded by percentile range (USGS 2018). The red dotted line indicates the discharge value that is estimated to cause the diversion dam upstream of the Tuzigoot NM stream segment to breach (Gwilliam et al. 2013).

creased the annual mean flow (157.9 cfs) to an amount that approached the gauge record mean (164.7 cfs).

#### 4.3.2 Water quality

In WY2017, 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 4-2). Samples were collected for analysis by a contracted laboratory (TestAmerica in WY2017) or analyzed by SODN staff on site. A multi-parameter water quality logger was deployed for 2–3 weeks each quarter at the Wet Beaver Creek index site. A total of 720 discrete analyses were performed at the three index site locations. Of those 720 discrete analyses, 264 analyses had associated state standards.

There were five exceedances of state standards during WY2017, resulting in a 98.1%

overall compliance with state water quality standards across the three units (Table 4-3). Four of the exceedances were at the Beaver Creek index site at Montezuma Castle NM (Castle unit): two for total arsenic, one for *E. coli*, and one for dissolved oxygen. The other was for total arsenic at the Wet Beaver Creek index site (Montezuma Castle NM, Well unit). These events are examined below.

##### 4.3.2.1 Core parameters

Discrete measurements collected in the field represent conditions at each index site during site visits in WY2017 (Table 4-4). Results were all within the range for a warmwater stream, with the exception of the dissolved oxygen measurement collected at the Beaver Creek site during the Q3 sample (late May).

The low dissolved oxygen measurement (5.76 mg/L) may have resulted from an extended period of low flow prior to the mea-

**Table 4-3. Discrete sampling summary for Beaver Creek, Wet Beaver Creek, and the Verde River, WY2017.**

| Analyses                                     | Beaver Creek                                                                   | Wet Beaver Creek | Verde River    | Total |
|----------------------------------------------|--------------------------------------------------------------------------------|------------------|----------------|-------|
| Total analyses                               | 240                                                                            | 240              | 240            | 720   |
| Analytes with standards                      | 88                                                                             | 88               | 88             | 264   |
| Analytes that exceeded standards             | 4                                                                              | 1                | 0              | 5     |
| Parameters in exceedance                     | <i>E. coli</i> (Summer)<br>Arsenic (Fall, Summer)<br>Dissolved Oxygen (Spring) | Arsenic (Summer) | No exceedances | –     |
| % compliance (% analytes that met standards) | 95%                                                                            | 99%              | 100%           | 98.1% |

**Table 4-4. Results of discrete core water quality sampling parameters at Beaver Creek, WY2017.**

| Parameter                             | Stream           | Quarter |      |       |       | Arizona state standard |                                                                             |
|---------------------------------------|------------------|---------|------|-------|-------|------------------------|-----------------------------------------------------------------------------|
|                                       |                  | Q1      | Q2   | Q3    | Q4    | Metric                 | Beneficial use                                                              |
| Temperature (°C)                      | Beaver Creek     | 15.1    | 6.6  | 19.1  | 24.1  | NS                     | –                                                                           |
|                                       | Wet Beaver Creek | 16.1    | 7.3  | 17.3  | 21.5  | –                      | –                                                                           |
|                                       | Verde River      | 19.6    | 10.7 | 23.7  | 25.6  | –                      | –                                                                           |
| Specific conductivity (µS/cm)         | Beaver Creek     | 509     | 145  | 530   | 546   | NS                     | –                                                                           |
|                                       | Wet Beaver Creek | 441     | 127  | 464   | 469   | –                      | –                                                                           |
|                                       | Verde River      | 507     | 220  | 530   | 543   | –                      | –                                                                           |
| pH                                    | Beaver Creek     | 8.08    | 7.99 | 7.87  | 7.89  | 6.5–9.0                | Aquatic and Wildlife - Warmwater, Full Body Contact, Agricultural Livestock |
|                                       | Wet Beaver Creek | 8.21    | 8.08 | 8.14  | 8.04  | –                      | –                                                                           |
|                                       | Verde River      | 8.03    | 7.97 | 8.26  | 8.11  | –                      | –                                                                           |
| Dissolved oxygen concentration (mg/L) | Beaver Creek     | 7.8     | 10.7 | 5.76* | 6.05  | >6                     | Aquatic and Wildlife - Warmwater                                            |
|                                       | Wet Beaver Creek | 8.58    | 10.2 | 7.13  | 6.28  | –                      | –                                                                           |
|                                       | Verde River      | 9.09    | 10.4 | 7.9   | 7.81  | –                      | –                                                                           |
| Turbidity (NTU)                       | Beaver Creek     | 9.07    | 12.1 | 3.81  | 18.4  | NS                     | –                                                                           |
|                                       | Wet Beaver Creek | 1.87    | 8.9  | 0.84  | 20.7  | –                      | –                                                                           |
|                                       | Verde River      | 13.3    | 49.4 | 19.8  | 64.4  | –                      | –                                                                           |
| Discharge (cfs)                       | Beaver Creek     | 2.73    | NC   | 2.16  | 11.76 | NS                     | –                                                                           |
|                                       | Wet Beaver Creek | 7.25    | NC   | 5.62  | 8.46  | –                      | –                                                                           |
|                                       | Verde River      | 5.93    | NC   | 2.61  | 10.4  | –                      | –                                                                           |

\*Values in red indicate exceedance of state water quality standard.

NC = not collected; NS = no standard

surement (see Figure 4-5), combined with slightly higher-than-average air temperatures. Low flow decreases the mixing of oxygen with the water as it flows across the riffles in the stream, and higher temperatures can increase the biological and chemical activity in the water that reduces the amount of dissolved oxygen. The dissolved oxygen measurement from Beaver Creek (6.05 mg/L) during the summer sample (Q4; Table 4-4) approached the state standard (6 mg/L). This may indicate that there is a persistent lower concentration of dissolved oxygen at this location on Beaver Creek.

**Continuous core water quality results—** A logging multi-parameter sonde was deployed at the Wet Beaver Creek index site for approximately two weeks during each quarter to collect data on temperature, pH, specific conductivity, and dissolved oxygen at 15-minute intervals (Table 4-5). More than 7,700 distinct measurements were collected during WY2017. The results from this sampling (Figure 4-9, next page) were within the expected range for each site (Gwilliam et al. 2017; Gwilliam et al. 2013), with several exceptions: QA/QC, specific conductivity, and pH.

**QA/QC:** For the Q1 sample, the pH and conductivity failed QA/QC review and the data from this deployment were censored. SODN plans to apply correction models to the data so it can be used in future analysis.

**pH and specific conductivity:** During Q2, discharge was approximately 70 cfs (estimated from the USGS Wet Beaver Creek gauge because flow rate exceeded safety protocols, precluding wading to collect a discharge measurement). This elevated flow rate was likely responsible for specific conductivity and pH results falling below the 25<sup>th</sup> per-

**Table 4-5. Sonde deployment periods and number of samples collected during each deployment, Wet Beaver Creek index site, WY2017.**

| Quarter | Date                  | # samples |
|---------|-----------------------|-----------|
| Q1      | 10/11/2016–11/17/2016 | 3,545     |
| Q2      | 2/16/2017–3/1/2017    | 1,255     |
| Q3      | 5/24/2017–6/5/2017    | 1,157     |
| Q4      | 8/24/2017–9/12/2017   | 1,831     |

centile. This hypothesis is supported by the concurrent measurements for total dissolved solids (TDS) (see Table 4-9, below), which were half the usual concentration, and metal results (see Table 4-8, below) that were lower than results from other WY2017 samples. The higher base flow at the Wet Beaver Creek site during Q2 was associated with watershed-wide snowmelt and runoff from winter regional precipitation events, as opposed to hydrologically distinct events (e.g., monsoon events). This regionwide aspect of the flow during Q2 allowed these data to be considered for analysis; the protocol avoids samples collected during distinct hydrologic events.

**Dissolved oxygen.** The dissolved oxygen result for Q3 was above the 75<sup>th</sup> percentile of data from this site. The data passed QA/QC checks. The cause for this elevated result is unknown.

#### 4.3.2.2 Nutrients

Nutrients were sampled at each index site during each quarter of WY2017. Ammonia was detected at the Montezuma Castle site on Beaver Creek during the Q4 sample (Table 4-6). It did not exceed state standards, but detections of ammonia can possibly indicate a direct or indirect source, such as fertilizer,

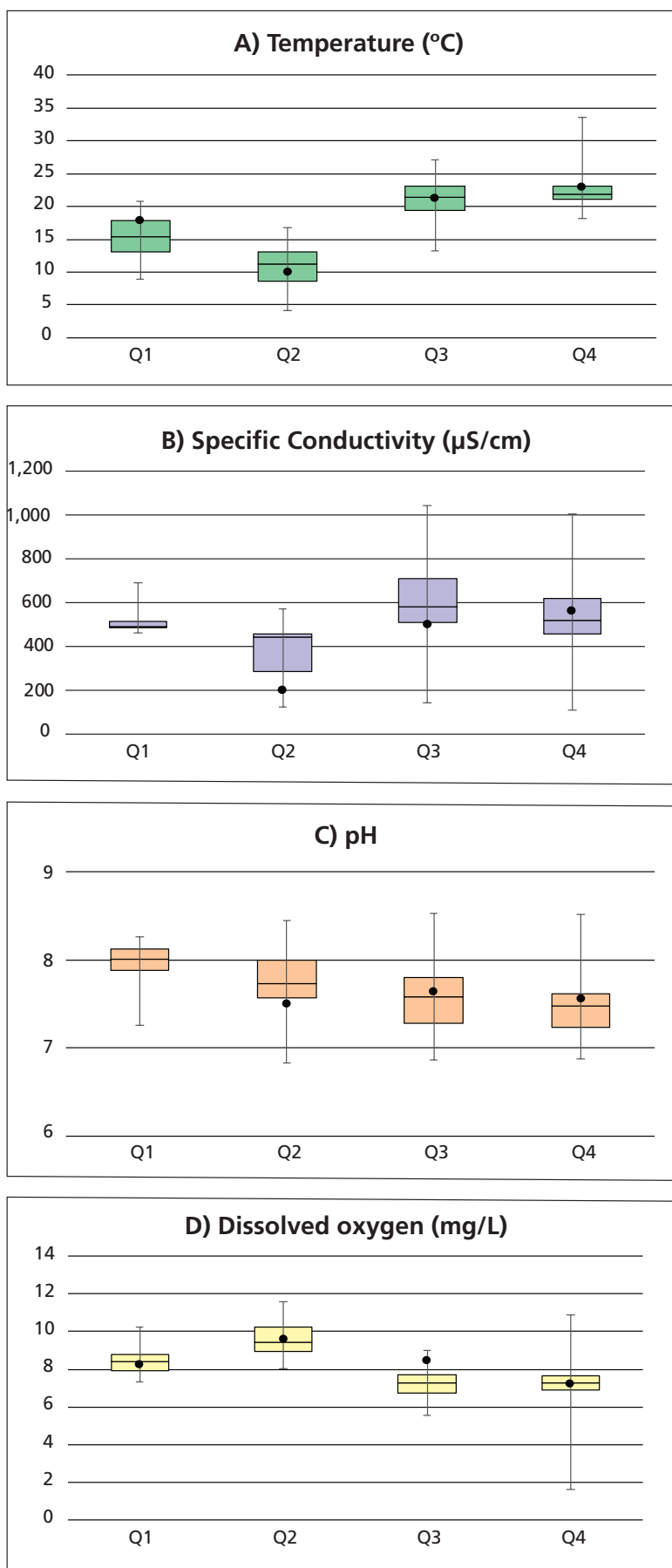
**Table 4-6. Results of nutrient sampling, Beaver Creek Wet Beaver Creek, and Verde River, WY2017.**

| Analyte        | Stream           | Q1    | Q2    | Q3    | Q4    | Method | Arizona state standard | Beneficial use                   |
|----------------|------------------|-------|-------|-------|-------|--------|------------------------|----------------------------------|
| Ammonia (mg/L) | Beaver Creek     | <0.10 | <0.10 | <0.10 | 0.2   | 350.1  | 0.99                   | Aquatic and Wildlife - Warmwater |
|                | Wet Beaver Creek | <0.10 | <0.10 | <0.10 | <0.10 | 350.1  | 0.99                   | Aquatic and Wildlife - Warmwater |
|                | Verde River      | <0.10 | <0.10 | <0.10 | <0.10 | 350.1  | 0.99                   | Aquatic and Wildlife - Warmwater |

<sup>1</sup> Calculated using a hardness of 250 mg/L, temperature of 25.6°C, and pH of 8.11

Figure 4-9. Data on (A) water temperature, (B) specific conductivity, (C) pH, and (D) dissolved oxygen concentration, Wet Beaver Creek, WY2017.

The boxes indicate the 25<sup>th</sup> (bottom of box) to 75<sup>th</sup> (top of box) percentile of the data, with the line in the middle as the median value. The solid black dots mark the median value from WY2017 sampling for each parameter. Black dots are absent for specific conductivity and pH for WY2017 Q1; data for these measurements were censored due to QA/QC issues.



animal or human waste, fires, or nitrogen fixation (USEPA 2013).

#### 4.3.2.3 Biological condition

Analytes of biological condition were sampled at each index site during each quarter of WY2017 (Table 4-7). *E. coli* exceeded Arizona state water quality standards at the Beaver Creek index site during 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 is an indicator of other microbiological pathogens.

**SODN urges park managers to continue to limit public access to the streams and water bodies, and to provide guidance and personal protective equipment to employees who need to come in contact with the water. No one should ever drink or otherwise ingest 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 one in WY2017, were associated with precipitation events in the watershed. There were flow events in the three weeks before the Q4 sampling event at Beaver Creek (precipitation data can be accessed at [http://www.climateanalyzer.org/sonoran\\_desert](http://www.climateanalyzer.org/sonoran_desert)). Precipitation washes material (including wild and domestic animal waste) from the surface into adjoining streams. The preceding flow event was observed to have caused deposition of fine particulate sedi-

ment in the stream, and several feet up the bank. Considering the flow event, elevated levels of *E. coli*, and detectable concentrations of ammonia, it is possible that there is a source for these analytes upstream of the park.

#### 4.3.2.4 Metals and metalloids

Analytes of the metals group were sampled at each index site during each quarter of WY2017 (Tables 4-8 and 4-9). Only parameters with results are reported. Parameters not reported are not assumed to be zero, but rather below the detection limit of the analytical equipment. They may have been present in very low concentrations.

Three exceedances of the total arsenic standard were recorded during WY2017: two at the Beaver Creek index site during Q1 and Q4, and one at the Wet Beaver Creek index site during Q4. **Please note that arsenic concentrations approached the state standard for full body contact at most sites during most sampling visits during WY2017.** Arsenic concentrations have occasionally exceeded state standards in the past (e.g., total arsenic 0.11 mg/L on August 18, 2010). Historically, arsenic has been regularly detected in samples from all three streams in and around the administered stream segments at Montezuma and Tuzigoot national monuments (NPS 1995). These concentrations are typical for the region.

A background concentration of arsenic is considered to be the result of natural wearing processes in the Verde River watershed, primarily from oxidized sulfides of the Verde Formation and Tertiary volcanic deposits

**Table 4-7. Results of biological condition sampling, Beaver Creek, Wet Beaver Creek, and Verde River, WY2017.**

| Analyte                    | Stream           | Q1   | Q2   | Q3   | Q4     | Method   | Arizona state standard | Beneficial use    |
|----------------------------|------------------|------|------|------|--------|----------|------------------------|-------------------|
| Total organic carbon       | Beaver Creek     | NC   | NC   | NC   | 2.1    | SM 5130B | NS                     | –                 |
|                            | Wet Beaver Creek | NC   | NC   | NC   | 1.8    | SM 5130B | NS                     | –                 |
|                            | Verde River      | NC   | NC   | NC   | 1.2    | SM 5130B | NS                     | –                 |
| <i>E. coli</i> (MPN/100mL) | Beaver Creek     | 30   | 16.6 | 2.03 | 399.6* | SM 9223B | <235 <sup>1</sup>      | Full-body contact |
|                            | Wet Beaver Creek | 32.1 | 9.3  | 44   | 75.1   | SM 9223B | <235 <sup>1</sup>      | Full-body contact |
|                            | Verde River      | 43.6 | 11.9 | 8.2  | 9.4    | SM 9223B | <235 <sup>1</sup>      | Full-body contact |

\*Values in red indicate exceedance of state water quality standard.

**Table 4-8. Sampling results for dissolved metals, Beaver Creek, Wet Beaver Creek, and Verde River, WY2017.**

| Analyte (mg/L) | Stream           | Q1     | Q2     | Q3     | Q4                | Method          | Arizona state standard | Beneficial use |
|----------------|------------------|--------|--------|--------|-------------------|-----------------|------------------------|----------------|
| Arsenic        | Beaver Creek     | 0.032  | <0.015 | 0.021  | 0.037             | EPA 200.7/200.8 | 0.15                   | AWW            |
|                | Wet Beaver Creek | 0.017  | <0.015 | 0.023  | 0.024             | EPA 200.7/200.8 | 0.15                   | AWW            |
|                | Verde River      | 0.021  | <0.015 | 0.02   | 0.016             | EPA 200.7/200.8 | 0.15                   | AWW            |
| Barium         | Beaver Creek     | NC     | NC     | NC     | 0.23 <sup>a</sup> | 200.8           | NS                     | –              |
|                | Wet Beaver Creek | NC     | NC     | NC     | 0.27              | 200.8           | NS                     | –              |
|                | Verde River      | NC     | NC     | NC     | 0.18              | 200.8           | NS                     | –              |
| Boron          | Beaver Creek     | 0.32   | <0.10  | 0.26   | 0.3               | EPA 200.7       | NS                     | –              |
|                | Wet Beaver Creek | 0.16   | <0.10  | 0.16   | 0.16              | EPA 200.7       | NS                     | –              |
|                | Verde River      | 0.18   | <0.10  | 0.17   | 0.16              | EPA 200.7       | NS                     | –              |
| Calcium        | Beaver Creek     | 48     | 16     | 48     | 43                | EPA 200.7       | NS                     | –              |
|                | Wet Beaver Creek | 49     | 13     | 46     | 45                | EPA 200.7       | NS                     | –              |
|                | Verde River      | 51     | 25     | 47     | 48                | EPA 200.7       | NS                     | –              |
| Magnesium      | Beaver Creek     | 30     | 6.3    | 26     | 24                | EPA 200.7       | NS                     | –              |
|                | Wet Beaver Creek | 24     | 6.5    | 22     | 20                | EPA 200.7       | NS                     | –              |
|                | Verde River      | 28     | 9.2    | 26     | 23                | EPA 200.7       | NS                     | –              |
| Manganese      | Beaver Creek     | 0.015  | <0.010 | 0.04   | 0.021             | EPA 200.7/200.8 | NS                     | –              |
|                | Wet Beaver Creek | 0.019  | <0.010 | 0.014  | 0.044             | EPA 200.7/200.8 | NS                     | –              |
|                | Verde River      | <0.010 | <0.010 | <0.010 | 0.006             | EPA 200.7/200.8 | NS                     | –              |
| Potassium      | Beaver Creek     | 3      | <3.0   | <3.0   | 3.1               | EPA 200.7       | NS                     | –              |
|                | Wet Beaver Creek | <3.0   | <3.0   | <3.0   | <3.0              | EPA 200.7       | NS                     | –              |
|                | Verde River      | <3.0   | <3.0   | <3.0   | <3.0              | EPA 200.7       | NS                     | –              |
| Silica         | Beaver Creek     | 22     | 15     | 19     | 20                | EPA 200.7       | NS                     | –              |
|                | Wet Beaver Creek | 22     | 16     | 19     | 20                | EPA 200.7       | NS                     | –              |
|                | Verde River      | 20     | 18     | 17     | 18                | EPA 200.7       | NS                     | –              |
| Sodium         | Beaver Creek     | 27     | <5.0   | 24     | 26                | EPA 200.7       | NS                     | –              |
|                | Wet Beaver Creek | 16     | <5.0   | 17     | 17                | EPA 200.7       | NS                     | –              |
|                | Verde River      | 26     | 7.8    | 25     | 25                | EPA 200.7       | NS                     | –              |

AWW = Aquatic and Wildlife - Warmwater; NS = no standard; <sup>a</sup>The spike recovery value is unusable since the analyte concentration in the sample is disproportionate to the spike level. The associated blank spike was acceptable.

## 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 4-9. Sampling results for total metals, Beaver Creek, Wet Beaver Creek, and Verde River, WY2017.**

| Analyte (mg/L) | Stream           | Q1      | Q2               | Q3      | Q4             | Method                | Arizona state standard | Beneficial use  |
|----------------|------------------|---------|------------------|---------|----------------|-----------------------|------------------------|-----------------|
| Aluminum       | Beaver Creek     | 0.18    | 1.2              | 0.1     | 0.94           | EPA 200.7/200.7 r 4.4 | NS                     | –               |
|                | Wet Beaver Creek | <0.10   | 0.95             | <0.10   | 1 <sup>a</sup> | EPA 200.7/200.7 r 4.4 | NS                     | –               |
|                | Verde River      | 0.7     | 3.4 <sup>a</sup> | 0.58    | 2.1            | EPA 200.7/200.7 r 4.4 | NS                     | –               |
| Arsenic        | Beaver Creek     | 0.037*  | <0.015           | 0.028   | 0.04*          | EPA 200.7/200.8       | 0.03                   | FBC             |
|                | Wet Beaver Creek | 0.028   | <0.015           | 0.023   | 0.03*          | EPA 200.7/200.8       | 0.03                   | FBC             |
|                | Verde River      | 0.015   | <0.015           | 0.026   | 0.019          | EPA 200.7/200.8       | 0.03                   | FBC             |
| Barium         | Beaver Creek     | NC      | NC               | NC      | 0.23           | 200.8                 | 98                     | FBC             |
|                | Wet Beaver Creek | NC      | NC               | NC      | 0.3            | 200.8                 | 98                     | FBC             |
|                | Verde River      | NC      | NC               | NC      | 0.2            | 200.8                 | 98                     | FBC             |
| Boron          | Beaver Creek     | 0.3     | <0.10            | 0.26    | 0.31           | EPA 200.7/200.7 r 4.4 | 1                      | Al <sup>b</sup> |
|                | Wet Beaver Creek | 0.16    | <0.10            | 0.15    | 0.16           | EPA 200.7/200.7 r 4.4 | 1                      | Al <sup>b</sup> |
|                | Verde River      | 0.16    | <0.10            | 0.17    | 0.17           | EPA 200.7/200.7 r 4.4 | 1                      | Al <sup>b</sup> |
| Calcium        | Beaver Creek     | 47      | 17               | 51      | 48             | EPA 200.7/200.7 r 4.4 | NS                     | –               |
|                | Wet Beaver Creek | 49      | 14               | 49      | 51             | EPA 200.7/200.7 r 4.4 | NS                     | –               |
|                | Verde River      | 52      | 27               | 55      | 58             | EPA 200.7/200.7 r 4.4 | NS                     | –               |
| Chromium       | Beaver Creek     | NC      | NC               | NC      | <0.003         | EPA 200.7/200.8       | 1                      | Al, AL          |
|                | Wet Beaver Creek | NC      | NC               | NC      | <0.003         | EPA 200.7/200.8       | 1                      | Al, AL          |
|                | Verde River      | NC      | NC               | NC      | 0.003          | EPA 200.7/200.8       | 1                      | Al, AL          |
| Copper         | Beaver Creek     | <0.015  | <0.015           | <0.015  | <0.002         | EPA 200.7/200.8       | 0.5                    | AL              |
|                | Wet Beaver Creek | <0.015  | <0.015           | <0.015  | <0.002         | EPA 200.7/200.8       | 0.5                    | AL              |
|                | Verde River      | <0.015  | <0.015           | <0.015  | 0.011          | EPA 200.7/200.8       | 0.5                    | AL              |
| Iron           | Beaver Creek     | 0.2     | 0.88             | 0.26    | 0.82           | EPA 200.7/200.7 r 4.4 | NS                     | –               |
|                | Wet Beaver Creek | 0.11    | 0.73             | <0.10   | 1              | EPA 200.7/200.7 r 4.4 | NS                     | –               |
|                | Verde River      | 0.51    | 2.6              | 0.43    | 1.6            | EPA 200.7/200.7 r 4.4 | NS                     | –               |
| Lead           | Beaver Creek     | <0.0090 | <0.0090          | <0.0090 | <0.001         | EPA 200.7/200.8       | 0.015                  | FBC             |
|                | Wet Beaver Creek | <0.0090 | <0.0090          | <0.0090 | <0.001         | EPA 200.7/200.8       | 0.015                  | FBC             |
|                | Verde River      | <0.0090 | <0.0090          | <0.0090 | 0.006          | EPA 200.7/200.8       | 0.015                  | FBC             |
| Magnesium      | Beaver Creek     | 28      | 6.6              | 26      | 26             | EPA 200.7/200.7 r 4.4 | NS                     | –               |
|                | Wet Beaver Creek | 23      | 6.7              | 21      | 22             | EPA 200.7/200.7 r 4.4 | NS                     | –               |
|                | Verde River      | 26      | 9.7              | 27      | 26             | EPA 200.7/200.7 r 4.4 | NS                     | –               |
| Manganese      | Beaver Creek     | 0.023   | 0.017            | 0.067   | 0.055          | EPA 200.7/200.8       | 10                     | Al <sup>c</sup> |
|                | Wet Beaver Creek | 0.022   | 0.011            | 0.017   | 0.086          | EPA 200.7/200.8       | 10                     | Al <sup>c</sup> |
|                | Verde River      | 0.025   | 0.043            | 0.03    | 0.055          | EPA 200.7/200.8       | 10                     | Al <sup>c</sup> |
| Nickel         | Beaver Creek     | NC      | NC               | NC      | 0.004          | EPA 200.7/200.8       | 0.51                   | F               |
|                | Wet Beaver Creek | NC      | NC               | NC      | 0.036          | EPA 200.7/200.8       | 0.51                   | F               |
|                | Verde River      | NC      | NC               | NC      | 0.038          | EPA 200.7/200.8       | 0.51                   | F               |
| Potassium      | Beaver Creek     | 3.2     | <3.0             | <3.0    | 3.7            | EPA 200.7/200.7 r 4.4 | NS                     | –               |
|                | Wet Beaver Creek | <3.0    | <3.0             | <3.0    | <3.0           | EPA 200.7/200.7 r 4.4 | NS                     | –               |
|                | Verde River      | <3.0    | <3.0             | <3.0    | <3.0           | EPA 200.7/200.7 r 4.4 | NS                     | –               |
| Silica         | Beaver Creek     | 23      | 19               | 19      | 26             | EPA 200.7/200.7 r 4.4 | NS                     | –               |
|                | Wet Beaver Creek | 23      | 19               | 19      | 27             | EPA 200.7/200.7 r 4.4 | NS                     | –               |
|                | Verde River      | 23      | 33               | 21      | 30             | EPA 200.7/200.7 r 4.4 | NS                     | –               |

**Table 4-9. Sampling results for total metals, Beaver Creek, Wet Beaver Creek, and Verde River, WY2017, cont.**

| Analyte (mg/L) | Stream           | Q1     | Q2     | Q3     | Q4     | Method                | Arizona state standard | Beneficial use |
|----------------|------------------|--------|--------|--------|--------|-----------------------|------------------------|----------------|
| Sodium         | Beaver Creek     | 27     | <5.0   | 24     | 27     | EPA 200.7/200.7 r 4.4 | NS                     | –              |
|                | Wet Beaver Creek | 18     | <5.0   | 17     | 17     | EPA 200.7/200.7 r 4.4 | NS                     | –              |
|                | Verde River      | 27     | 8.2    | 26     | 26     | EPA 200.7/200.7 r 4.4 | NS                     | –              |
| Uranium        | Beaver Creek     | NC     | NC     | NC     | <0.001 | EPA 200.7/200.8       | 2.8                    | FBC            |
|                | Wet Beaver Creek | NC     | NC     | NC     | <0.001 | EPA 200.7/200.8       | 2.8                    | FBC            |
|                | Verde River      | NC     | NC     | NC     | 0.001  | EPA 200.7/200.8       | 2.8                    | FBC            |
| Zinc           | Beaver Creek     | <0.020 | <0.020 | <0.020 | <0.01  | EPA 200.7/200.8       | 5.1                    | F              |
|                | Wet Beaver Creek | <0.020 | <0.020 | <0.020 | <0.01  | EPA 200.7/200.8       | 5.1                    | F              |
|                | Verde River      | <0.020 | <0.020 | <0.020 | 0.018  | EPA 200.7/200.8       | 5.1                    | F              |

\*Values in red indicate exceedance of state water quality standard.

A&W-W = Aquatic and Wildlife - Warmwater Chronic; FBC = Full Body Contact; AI = Agricultural Irrigation; F = Fish Consumption

<sup>a</sup>Matrix spike recovery was high, the associated blank spike recovery was acceptable.

<sup>b</sup> MOCC is not considered for agricultural irrigation. Standard is 186 mg/L for full body contact

<sup>c</sup> MOCC is not considered for agricultural irrigation. Standard is 131 mg/L for full body contact.

NC = not collected; NS = no standard; Methods are from Eaton and others (2005).

(Blasch et al. 2006). These elevated levels of arsenic have the potential to decrease the resilience of plant and animal populations and make them more susceptible to disruptions in ecological function from other stressors (e.g., low flow).

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

#### **4.3.2.5 Total suspended sediments and dissolved solids**

Total suspended sediments (TSS) and total dissolved solids (TDS) were sampled at each index site during each quarter of WY2017 (Table 4-10). Total suspended sediments varied in concentration during WY2017. Some of the variation was attributable to flow events, (e.g., Q2 Wet Beaver Creek TDS of 110 mg/L). Other variation may have been due to impacts of diversion dams (e.g., Q4 Verde River TSS of 68 mg/L).

#### **4.3.2.6 General water quality and inorganics**

Analytes of this group were sampled at each index site during each quarter of WY2016

(Table 4-11). Results remained within the range of expected values (Gwilliam et al. 2017; Gwilliam et al. 2013). Values for hardness and alkalinity were low at the Beaver Creek and Wet Beaver Creek index sites during Q2, likely due to elevated flow.

#### **4.3.3 Macroinvertebrates**

Macroinvertebrate biological samples and associated habitat data were collected at the three index reaches on May 18–21, 2017. The analytical lab received the samples in mid-June 2016, and issued the report on June 20, 2017.

The Arizona Index of Biological Integrity (AZIBI) for warmwater streams was calculated from WY2017 samples (Figure 4-10) following methods proscribed by the ADEQ (2015b). The State of Arizona has determined that index values above a score of 49 indicate that the stream is attaining the state standard, with the index value falling above the 25<sup>th</sup> percentile of reference scores (ADEQ 2015b). None of the WY2017 AZIBI indices calculated from macroinvertebrate data from the Montezuma Castle/Well or Tuzigoot samples were in the “attaining” range. The WY2017 AZIBI values were in the “inconclusive” category for Beaver Creek (45.06) and the Verde

**Table 4-10. Results of sampling for total suspended sediments and total dissolved solids, Beaver Creek, Wet Beaver Creek, and Verde River, WY2017.**

| Analyte (mg/L)            | Stream           | Q1   | Q2   | Q3   | Q4  | Method   | Arizona state standard |
|---------------------------|------------------|------|------|------|-----|----------|------------------------|
| Total suspended sediments | Beaver Creek     | 5.2  | 6.4  | <4.0 | 26  | SM 2540D | NS                     |
|                           | Wet Beaver Creek | <4.0 | <4.0 | <4.0 | 38  | SM 2540D | NS                     |
|                           | Verde River      | 20   | 28   | 19   | 68  | SM 2540D | NS                     |
| Total dissolved solids    | Beaver Creek     | 430  | 84   | 280  | 300 | SM 2540C | NS                     |
|                           | Wet Beaver Creek | 250  | 110  | 240  | 260 | SM 2540C | NS                     |
|                           | Verde River      | 320  | 160  | 320  | 330 | SM 2540C | NS                     |

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

**Table 4-11. Results of general water chemistry and inorganic sampling, Beaver Creek, Wet Beaver Creek, and Verde River, WY2017.**

| Analyte (mg/L)                              | Stream           | Q1    | Q2     | Q3     | Q4     | Method    |
|---------------------------------------------|------------------|-------|--------|--------|--------|-----------|
| Alkalinity as CaCO <sub>3</sub>             | Beaver Creek     | 260   | 74     | 260    | 260    | SM 2320B  |
|                                             | Wet Beaver Creek | 240   | 66     | 260    | 240    | SM 2320B  |
|                                             | Verde River      | 250   | 110    | 250    | 250    | SM 2320B  |
| Bicarbonate alkalinity as CaCO <sub>3</sub> | Beaver Creek     | 260   | 74     | 260    | 260    | SM 2320B  |
|                                             | Wet Beaver Creek | 240   | 66     | 240    | 240    | SM 2320B  |
|                                             | Verde River      | 240   | 110    | 230    | 240    | SM 2320B  |
| Carbonate alkalinity as CaCO <sub>3</sub>   | Beaver Creek     | <5.0  | <5.0   | <5.0   | <5.0   | SM 2320B  |
|                                             | Wet Beaver Creek | <5.0  | <5.0   | 14     | <5.0   | SM 2320B  |
|                                             | Verde River      | 16    | <5.0   | 15     | 12     | SM 2320B  |
| Biochemical oxygen demand                   | Beaver Creek     | <2.0  | <2.0   | 2.7    | <2.0   | SM 5210B  |
|                                             | Wet Beaver Creek | <2.0  | <2.0   | <2.0   | <2.0   | SM 5210B  |
|                                             | Verde River      | <2.0  | <2.0   | <2.0   | <2.0   | SM 5210B  |
| Chloride                                    | Beaver Creek     | 18    | <3.0   | 17     | 19     | EPA 300.0 |
|                                             | Wet Beaver Creek | 10    | <3.0   | 10     | 11     | EPA 300.0 |
|                                             | Verde River      | 14    | 4      | 14     | 14     | EPA 300.0 |
| Sulfate                                     | Beaver Creek     | <5.0  | <5.0   | <5.0   | <5.0   | EPA 300.0 |
|                                             | Wet Beaver Creek | <5.0  | <5.0   | <5.0   | <5.0   | EPA 300.0 |
|                                             | Verde River      | 17    | 5.7    | 24     | 20     | EPA 300.0 |
| Total hardness                              | Beaver Creek     | 230   | 70     | 230    | 230    | SM 2340B  |
|                                             | Wet Beaver Creek | 220   | 62     | 210    | 220    | SM 2340B  |
|                                             | Verde River      | 240   | 110    | 250    | 250    | SM 2340B  |
| Anion/Cation balance                        | Beaver Creek     | 3.50% | -5.80% | -0.85% | -3.50% | SM 1030E  |
|                                             | Wet Beaver Creek | 0.38% | -5.40% | -6.10% | -4.90% | SM 1030E  |
|                                             | Verde River      | 2.00% | -1.80% | -2.80% | -3.90% | SM 1030E  |

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

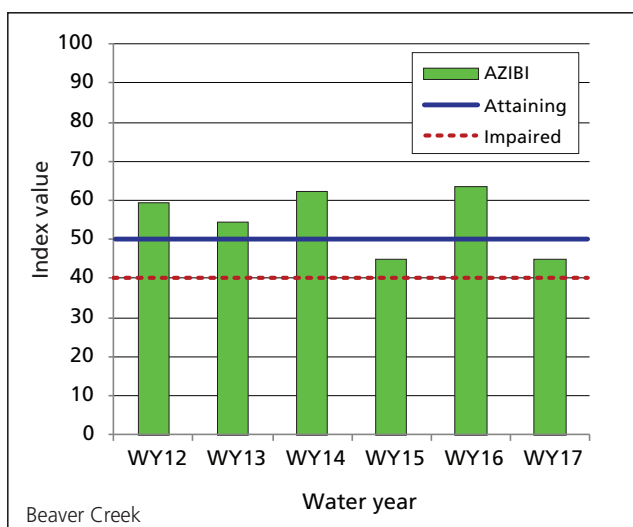
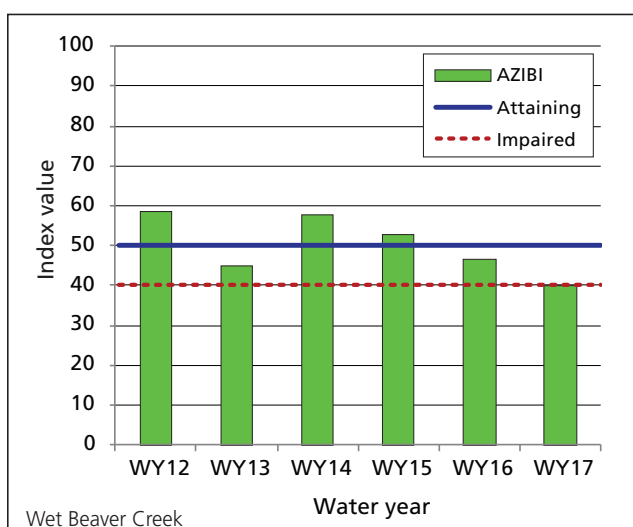
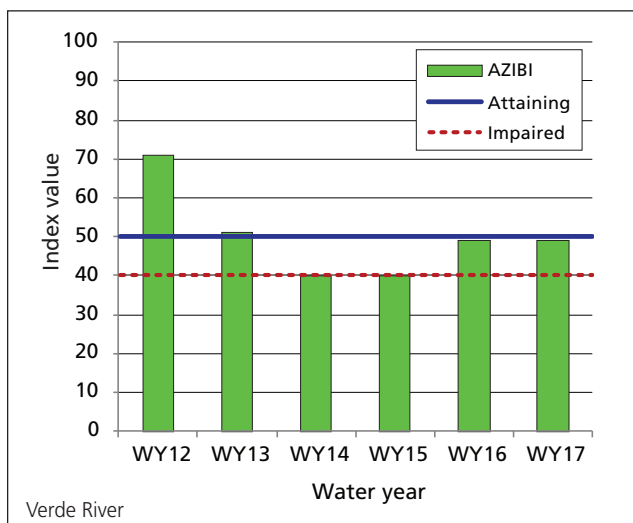
**A****B****C**

Figure 4-10. Arizona Index of Biotic Integrity values for the (A) Beaver Creek, (B) Wet Beaver Creek, and (C) Verde River index reaches, WY2012–2017. Any values falling between the “impaired” and “attaining” lines are considered “inconclusive” relative to the state standard.

River (48.89). The Wet Beaver Creek site was in the “Impaired” category (Figure 4-10).

In WY2017, the data from the Beaver Creek and Verde River index reaches scored in the “inconclusive” range, or between percentiles 10–25 of reference scores. For a conclusive outcome, the ADEQ requires a second sample during the same index period (ADEQ 2015b). This second visit was not conducted in WY2017 (or in preceding years) because the lab SODN uses to sort and identify the macroinvertebrate samples does not generate the results for at least six months. This delay precludes a return visit.

To attempt to accommodate the delay when “inconclusive” ratings occur, the SODN program estimates whether the current WY value was likely attaining by comparing values for the current WY to the mean of the site-record index results (Figure 4-11).

The Beaver Creek AZIBI for WY2017 was lower than the mean value for water years 2012–2016, falling just outside one standard deviation of the mean. This indicated that the WY2017 value was uncommonly low, and likely not attaining the state standard.

The individual metric that caused the reduction in the AZIBI at the Beaver Creek site was the abundance of blackfly larvae (*Simuliidae*). In WY2016, abundance for this taxa was 360 individuals. In WY2017, abundance was calculated at 14,594 individuals—a forty-fold increase.

The AZIBI for the Wet Beaver Creek site was in the impaired category, not meeting the state standard. The main reason for this low value was a large decline in the richness (# of taxa) at the site. The median richness value for the Wet Beaver site WY2012–2016 was 24; in WY2017, the richness metric was 11.

Additionally, the abundance of one taxa of mayfly, from the genus *Baetis*, and closely related genus *Fallceon* (primarily *F. quilleri*) accounted for 94% of the dominant taxa abundance, decreasing overall richness.

Looking more closely at the data, WY2017 saw a continued increased abundance of the non-biting midge larvae, *Chironomidae*

(Gwilliam et al. 2017), and increased abundance of blackfly larvae (Simuliidae), from 854 in WY2016 to 3,589 in WY2017.

In summary, the decline in the index for Beaver Creek, and the impaired score for Wet

Beaver Creek, were due to a large increase in the abundance of blackfly (Simuliidae) and mayfly (*Baetis*) larvae at both sites. A sharp decline in the richness contributed to the AZIBI decline at the Wet Beaver Creek site.

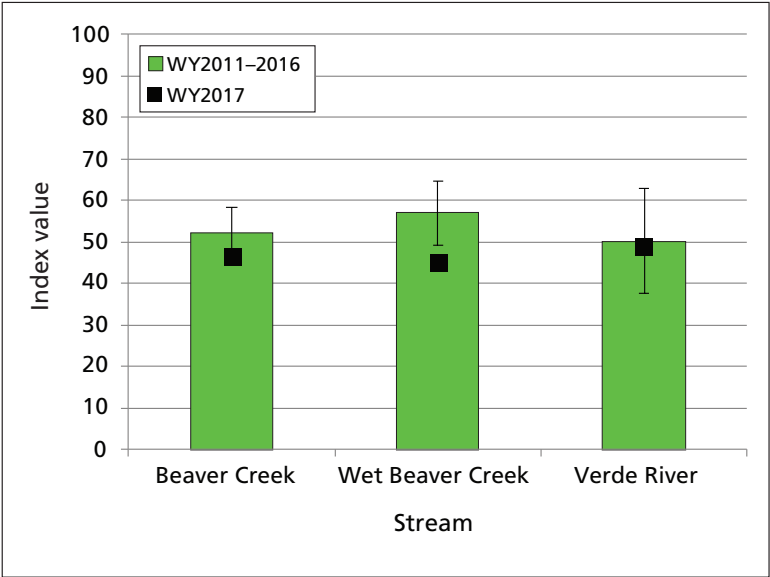


Figure 4-11. Arizona Index of Biotic Integrity macroinvertebrate scores from water years 2012–2017. Grey bars indicate the mean value for water years 2012–2016. The black solid square indicates the AZIBI score for WY2017. Error bar represents one standard deviation.



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## Appendix A. Macroinvertebrate Taxa Lists

**Table A-1. Macroinvertebrate taxa list for Beaver Creek, WY2017.**

| Phylum     | Class      | Order          | Family          | Genus          | Species  |
|------------|------------|----------------|-----------------|----------------|----------|
| Annelida   | Clitellata | –              | –               | –              | –        |
| Arthropoda | Arachnida  | Trombidiformes | Hygrobatidae    | –              | –        |
| Arthropoda | Arachnida  | Trombidiformes | Sperchonidae    | Sperchon       | –        |
| Arthropoda | Arachnida  | Trombidiformes | Torrenticolidae | Torrenticola   | –        |
| Arthropoda | Arachnida  | Trombidiformes | –               | –              | –        |
| Arthropoda | Entognatha | Collembola     | –               | –              | –        |
| Arthropoda | Insecta    | Coleoptera     | Dryopidae       | Helichus       | –        |
| Arthropoda | Insecta    | Coleoptera     | Dytiscidae      | Agabus         | –        |
| Arthropoda | Insecta    | Coleoptera     | Elmidae         | Dubiraphia     | –        |
| Arthropoda | Insecta    | Coleoptera     | Elmidae         | Heterelmis     | –        |
| Arthropoda | Insecta    | Coleoptera     | Elmidae         | Microcylloepus | pusillus |
| Arthropoda | Insecta    | Coleoptera     | Elmidae         | –              | –        |
| Arthropoda | Insecta    | Coleoptera     | Elmidae         | Neelmis        | –        |
| Arthropoda | Insecta    | Coleoptera     | Gyrinidae       | Gyretes        | –        |
| Arthropoda | Insecta    | Coleoptera     | Halipilidae     | Peltodytes     | –        |
| Arthropoda | Insecta    | Coleoptera     | Hydrophilidae   | Berosus        | –        |
| Arthropoda | Insecta    | Coleoptera     | Hydrophilidae   | –              | –        |
| Arthropoda | Insecta    | Coleoptera     | Psephenidae     | Psephenus      | –        |
| Arthropoda | Insecta    | Coleoptera     | Psephenidae     | –              | –        |
| Arthropoda | Insecta    | Diptera        | Ceratopogonidae | Atrichopogon   | –        |
| Arthropoda | Insecta    | Diptera        | Ceratopogonidae | Dasyhelea      | –        |
| Arthropoda | Insecta    | Diptera        | Ceratopogonidae | Forcipomyia    | –        |
| Arthropoda | Insecta    | Diptera        | Ceratopogonidae | Probezzia      | –        |
| Arthropoda | Insecta    | Diptera        | Ceratopogonidae | –              | –        |
| Arthropoda | Insecta    | Diptera        | Chironomidae    | –              | –        |
| Arthropoda | Insecta    | Diptera        | Culicidae       | –              | –        |
| Arthropoda | Insecta    | Diptera        | Dixidae         | Dixa           | –        |
| Arthropoda | Insecta    | Diptera        | Dixidae         | Dixella        | –        |
| Arthropoda | Insecta    | Diptera        | Empididae       | Hemerodromia   | –        |
| Arthropoda | Insecta    | Diptera        | Empididae       | –              | –        |
| Arthropoda | Insecta    | Diptera        | Psychodidae     | Maruina        | –        |
| Arthropoda | Insecta    | Diptera        | Psychodidae     | Pericoma       | –        |
| Arthropoda | Insecta    | Diptera        | Simuliidae      | Simulium       | –        |
| Arthropoda | Insecta    | Diptera        | Simuliidae      | –              | –        |
| Arthropoda | Insecta    | Diptera        | Tabanidae       | Tabanus        | –        |
| Arthropoda | Insecta    | Diptera        | Tipulidae       | Limonia        | –        |
| Arthropoda | Insecta    | Diptera        | Tipulidae       | Tipula         | –        |
| Arthropoda | Insecta    | Diptera        | Tipulidae       | –              | –        |
| Arthropoda | Insecta    | Diptera        | Tipulidae       | Dicranota      | –        |
| Arthropoda | Insecta    | Diptera        | Tipulidae       | Helius         | –        |
| Arthropoda | Insecta    | Diptera        | –               | –              | –        |

**Table A-1. Macroinvertebrate taxa list for Beaver Creek, WY2017, cont.**

| Phylum     | Class        | Order         | Family          | Genus           | Species  |
|------------|--------------|---------------|-----------------|-----------------|----------|
| 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   | –        |
| Arthropoda | Insecta      | Ephemeroptera | Leptohyphidae   | –               | –        |
| Arthropoda | Insecta      | Hemiptera     | Belostomatidae  | –               | –        |
| Arthropoda | Insecta      | Hemiptera     | Gerridae        | –               | –        |
| Arthropoda | Insecta      | Hemiptera     | Naucoridae      | Ambrysus        | –        |
| Arthropoda | Insecta      | Hemiptera     | Veliidae        | Microvelia      | –        |
| Arthropoda | Insecta      | Hemiptera     | Veliidae        | Rhagovelia      | –        |
| Arthropoda | Insecta      | Megaloptera   | Corydalidae     | Corydalus       | cornutus |
| Arthropoda | Insecta      | Odonata       | Calopterygidae  | Hetaerina       | –        |
| Arthropoda | Insecta      | Odonata       | Calopterygidae  | –               | –        |
| Arthropoda | Insecta      | Odonata       | Coenagrionidae  | Argia           | –        |
| Arthropoda | Insecta      | Odonata       | Coenagrionidae  | –               | –        |
| Arthropoda | Insecta      | Odonata       | Gomphidae       | Progomphus      | borealis |
| Arthropoda | Insecta      | Odonata       | Lestidae        | Archilestes     | –        |
| Arthropoda | Insecta      | Odonata       | Libellulidae    | Brechmorhoga    | mendax   |
| Arthropoda | Insecta      | Odonata       | Libellulidae    | –               | –        |
| Arthropoda | Insecta      | Trichoptera   | Calamoceratidae | Phylloicus      | aeneus   |
| Arthropoda | Insecta      | Trichoptera   | Glossosomatidae | –               | –        |
| 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   | –               | –        |
| Arthropoda | Insecta      | Trichoptera   | Leptoceridae    | Nectopsyche     | –        |
| Arthropoda | Insecta      | Trichoptera   | Philopotamidae  | Chimarra        | –        |
| Arthropoda | Insecta      | Trichoptera   | Philopotamidae  | –               | –        |
| Arthropoda | Insecta      | Trichoptera   | –               | –               | –        |
| Arthropoda | Malacostraca | Amphipoda     | Gammaridae      | Gammarus        | –        |
| Arthropoda | Malacostraca | Amphipoda     | Hyalellidae     | Hyalella        | –        |
| Arthropoda | Malacostraca | Amphipoda     | –               | –               | –        |
| Arthropoda | Malacostraca | Decapoda      | –               | –               | –        |

**Table A-1. Macroinvertebrate taxa list for Beaver Creek, WY2017, cont.**

| Phylum   | Class          | Order          | Family     | Genus    | Species |
|----------|----------------|----------------|------------|----------|---------|
| Chordata | Actinopterygii | –              | –          | –        | –       |
| Mollusca | Bivalvia       | Veneroida      | Pisidiidae | Pisidium | –       |
| Mollusca | Gastropoda     | Basommatophora | Lymnaeidae | Lymnaea  | –       |
| Mollusca | Gastropoda     | Basommatophora | Physidae   | Physa    | –       |
| Nemata   | –              | –              | –          | –        | –       |

**Table A-2. Macroinvertebrate taxa list for Wet Beaver Creek, WY2017.**

| Phylum     | Class      | Order          | Family          | Genus          | Species  |
|------------|------------|----------------|-----------------|----------------|----------|
| Annelida   | Clitellata | –              | –               | –              | –        |
| Arthropoda | Arachnida  | Trombidiformes | Hygrobatidae    |                | –        |
| Arthropoda | Arachnida  | Trombidiformes | Sperchonidae    | Sperchon       | –        |
| Arthropoda | Arachnida  | Trombidiformes | Torrenticolidae | Torrenticola   | –        |
| Arthropoda | Arachnida  | Trombidiformes | –               | –              | –        |
| Arthropoda | Entognatha | Collembola     | –               | –              | –        |
| Arthropoda | Insecta    | Coleoptera     | Dryopidae       | Helichus       | –        |
| Arthropoda | Insecta    | Coleoptera     | Dytiscidae      | Agabus         | –        |
| Arthropoda | Insecta    | Coleoptera     | Elmidae         | Dubiraphia     | –        |
| Arthropoda | Insecta    | Coleoptera     | Elmidae         | Heterelmis     | –        |
| Arthropoda | Insecta    | Coleoptera     | Elmidae         | Microcylloepus | pusillus |
| Arthropoda | Insecta    | Coleoptera     | Elmidae         | –              | –        |
| Arthropoda | Insecta    | Coleoptera     | Elmidae         | Neoelmis       | –        |
| Arthropoda | Insecta    | Coleoptera     | Gyrinidae       | Gyretes        | –        |
| Arthropoda | Insecta    | Coleoptera     | Haliplidae      | Peltodytes     | –        |
| Arthropoda | Insecta    | Coleoptera     | Hydrophilidae   | Berosus        | –        |
| Arthropoda | Insecta    | Coleoptera     | Hydrophilidae   | –              | –        |
| Arthropoda | Insecta    | Coleoptera     | Psephenidae     | Psephenus      | –        |
| Arthropoda | Insecta    | Coleoptera     | Psephenidae     | –              | –        |
| Arthropoda | Insecta    | Diptera        | Ceratopogonidae | Atrichopogon   | –        |
| Arthropoda | Insecta    | Diptera        | Ceratopogonidae | Dasyhelea      | –        |
| Arthropoda | Insecta    | Diptera        | Ceratopogonidae | Forcipomyia    | –        |
| Arthropoda | Insecta    | Diptera        | Ceratopogonidae | Probezzia      | –        |
| Arthropoda | Insecta    | Diptera        | Ceratopogonidae | –              | –        |
| Arthropoda | Insecta    | Diptera        | Chironomidae    | –              | –        |
| Arthropoda | Insecta    | Diptera        | Culicidae       | –              | –        |
| Arthropoda | Insecta    | Diptera        | Dixidae         | Dixa           | –        |
| Arthropoda | Insecta    | Diptera        | Dixidae         | Dixella        | –        |
| Arthropoda | Insecta    | Diptera        | Empididae       | Hemerodromia   | –        |
| Arthropoda | Insecta    | Diptera        | Empididae       | –              | –        |
| Arthropoda | Insecta    | Diptera        | Psychodidae     | Maruina        | –        |
| Arthropoda | Insecta    | Diptera        | Psychodidae     | Pericoma       | –        |
| Arthropoda | Insecta    | Diptera        | Simuliidae      | Simulium       | –        |
| Arthropoda | Insecta    | Diptera        | Simuliidae      | –              | –        |
| Arthropoda | Insecta    | Diptera        | Tabanidae       | Tabanus        | –        |
| Arthropoda | Insecta    | Diptera        | Tipulidae       | Limonia        | –        |
| Arthropoda | Insecta    | Diptera        | Tipulidae       | Tipula         | –        |
| Arthropoda | Insecta    | Diptera        | Tipulidae       | –              | –        |
| Arthropoda | Insecta    | Diptera        | Tipulidae       | Dicranota      | –        |
| Arthropoda | Insecta    | Diptera        | Tipulidae       | Helius         | –        |
| Arthropoda | Insecta    | Diptera        | –               | –              | –        |
| Arthropoda | Insecta    | Ephemeroptera  | Baetidae        | Acentrella     | –        |
| Arthropoda | Insecta    | Ephemeroptera  | Baetidae        | Baetis         | –        |

**Table A-2. Macroinvertebrate taxa list for Wet Beaver Creek, WY2017, cont.**

| Phylum     | Class          | Order         | Family          | Genus           | Species  |
|------------|----------------|---------------|-----------------|-----------------|----------|
| 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   | –        |
| Arthropoda | Insecta        | Ephemeroptera | Leptohyphidae   | –               | –        |
| Arthropoda | Insecta        | Hemiptera     | Belostomatidae  | –               | –        |
| Arthropoda | Insecta        | Hemiptera     | Gerridae        | –               | –        |
| Arthropoda | Insecta        | Hemiptera     | Naucoridae      | Ambrysus        | –        |
| Arthropoda | Insecta        | Hemiptera     | Veliidae        | Microvelia      | –        |
| Arthropoda | Insecta        | Hemiptera     | Veliidae        | Rhagovelia      | –        |
| Arthropoda | Insecta        | Megaloptera   | Corydalidae     | Corydalus       | cornutus |
| Arthropoda | Insecta        | Odonata       | Calopterygidae  | Hetaerina       | –        |
| Arthropoda | Insecta        | Odonata       | Calopterygidae  | –               | –        |
| Arthropoda | Insecta        | Odonata       | Coenagrionidae  | Argia           | –        |
| Arthropoda | Insecta        | Odonata       | Coenagrionidae  | –               | –        |
| Arthropoda | Insecta        | Odonata       | Gomphidae       | Progomphus      | borealis |
| Arthropoda | Insecta        | Odonata       | Lestidae        | Archilestes     | –        |
| Arthropoda | Insecta        | Odonata       | Libellulidae    | Brechmorhoga    | mendax   |
| Arthropoda | Insecta        | Odonata       | Libellulidae    | –               | –        |
| Arthropoda | Insecta        | Trichoptera   | Calamoceratidae | Phylloicus      | aeneus   |
| Arthropoda | Insecta        | Trichoptera   | Glossosomatidae | –               | –        |
| 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   | –               | –        |
| Arthropoda | Insecta        | Trichoptera   | Leptoceridae    | Nectopsyche     | –        |
| Arthropoda | Insecta        | Trichoptera   | Philopotamidae  | Chimarra        | –        |
| Arthropoda | Insecta        | Trichoptera   | Philopotamidae  | –               | –        |
| Arthropoda | Insecta        | Trichoptera   | –               | –               | –        |
| Arthropoda | Malacostraca   | Amphipoda     | Gammaridae      | Gammarus        | –        |
| Arthropoda | Malacostraca   | Amphipoda     | Hyalellidae     | Hyalella        | –        |
| Arthropoda | Malacostraca   | Amphipoda     | –               | –               | –        |
| Arthropoda | Malacostraca   | Decapoda      | –               | –               | –        |
| Chordata   | Actinopterygii | –             | –               | –               | –        |
| Mollusca   | Bivalvia       | Veneroida     | Pisidiidae      | Pisidium        | –        |

**Table A-2. Macroinvertebrate taxa list for Wet Beaver Creek, WY2017, cont.**

| <b>Phylum</b> | <b>Class</b> | <b>Order</b>   | <b>Family</b> | <b>Genus</b> | <b>Species</b> |
|---------------|--------------|----------------|---------------|--------------|----------------|
| Mollusca      | Gastropoda   | Basommatophora | Lymnaeidae    | Lymnaea      | –              |
| Mollusca      | Gastropoda   | Basommatophora | Physidae      | Physa        | –              |
| Nemata        | –            | –              | –             | –            | –              |

**Table A-3. Macroinvertebrate taxa list for Verde River, WY2017.**

| Phylum     | Class      | Order          | Family          | Genus          | Species  |
|------------|------------|----------------|-----------------|----------------|----------|
| Annelida   | Clitellata | –              | –               | –              | –        |
| Arthropoda | Arachnida  | Trombidiformes | Hygrobatidae    | –              | –        |
| Arthropoda | Arachnida  | Trombidiformes | Sperchonidae    | Sperchon       | –        |
| Arthropoda | Arachnida  | Trombidiformes | Torrenticolidae | Torrenticola   | –        |
| Arthropoda | Arachnida  | Trombidiformes | –               | –              | –        |
| Arthropoda | Entognatha | Collembola     | –               | –              | –        |
| Arthropoda | Insecta    | Coleoptera     | Dryopidae       | Helichus       | –        |
| Arthropoda | Insecta    | Coleoptera     | Dytiscidae      | Agabus         | –        |
| Arthropoda | Insecta    | Coleoptera     | Elmidae         | Dubiraphia     | –        |
| Arthropoda | Insecta    | Coleoptera     | Elmidae         | Heterelmis     | –        |
| Arthropoda | Insecta    | Coleoptera     | Elmidae         | Microcylloepus | pusillus |
| Arthropoda | Insecta    | Coleoptera     | Elmidae         | –              | –        |
| Arthropoda | Insecta    | Coleoptera     | Elmidae         | Neoelmis       | –        |
| Arthropoda | Insecta    | Coleoptera     | Gyrinidae       | Gyretes        | –        |
| Arthropoda | Insecta    | Coleoptera     | Haliplidae      | Peltodytes     | –        |
| Arthropoda | Insecta    | Coleoptera     | Hydrophilidae   | Berosus        | –        |
| Arthropoda | Insecta    | Coleoptera     | Hydrophilidae   | –              | –        |
| Arthropoda | Insecta    | Coleoptera     | Psephenidae     | Psephenus      | –        |
| Arthropoda | Insecta    | Coleoptera     | Psephenidae     | –              | –        |
| Arthropoda | Insecta    | Diptera        | Ceratopogonidae | Atrichopogon   | –        |
| Arthropoda | Insecta    | Diptera        | Ceratopogonidae | Dasyhelea      | –        |
| Arthropoda | Insecta    | Diptera        | Ceratopogonidae | Forcipomyia    | –        |
| Arthropoda | Insecta    | Diptera        | Ceratopogonidae | Probezzia      | –        |
| Arthropoda | Insecta    | Diptera        | Ceratopogonidae | –              | –        |
| Arthropoda | Insecta    | Diptera        | Chironomidae    | –              | –        |
| Arthropoda | Insecta    | Diptera        | Culicidae       | –              | –        |
| Arthropoda | Insecta    | Diptera        | Dixidae         | Dixa           | –        |
| Arthropoda | Insecta    | Diptera        | Dixidae         | Dixella        | –        |
| Arthropoda | Insecta    | Diptera        | Empididae       | Hemerodromia   | –        |
| Arthropoda | Insecta    | Diptera        | Empididae       | –              | –        |
| Arthropoda | Insecta    | Diptera        | Psychodidae     | Maruina        | –        |
| Arthropoda | Insecta    | Diptera        | Psychodidae     | Pericoma       | –        |
| Arthropoda | Insecta    | Diptera        | Simuliidae      | Simulium       | –        |
| Arthropoda | Insecta    | Diptera        | Simuliidae      | –              | –        |
| Arthropoda | Insecta    | Diptera        | Tabanidae       | Tabanus        | –        |
| Arthropoda | Insecta    | Diptera        | Tipulidae       | Limonia        | –        |
| Arthropoda | Insecta    | Diptera        | Tipulidae       | Tipula         | –        |
| Arthropoda | Insecta    | Diptera        | Tipulidae       | –              | –        |
| Arthropoda | Insecta    | Diptera        | Tipulidae       | Dicranota      | –        |
| Arthropoda | Insecta    | Diptera        | Tipulidae       | Helius         | –        |
| Arthropoda | Insecta    | Diptera        | –               | –              | –        |
| Arthropoda | Insecta    | Ephemeroptera  | Baetidae        | Acentrella     | –        |
| Arthropoda | Insecta    | Ephemeroptera  | Baetidae        | Baetis         | –        |

**Table A-3. Macroinvertebrate taxa list for Verde River, WY2017, cont.**

| Phylum     | Class          | Order         | Family          | Genus           | Species  |
|------------|----------------|---------------|-----------------|-----------------|----------|
| 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   | –        |
| Arthropoda | Insecta        | Ephemeroptera | Leptohyphidae   | –               | –        |
| Arthropoda | Insecta        | Hemiptera     | Belostomatidae  | –               | –        |
| Arthropoda | Insecta        | Hemiptera     | Gerridae        | –               | –        |
| Arthropoda | Insecta        | Hemiptera     | Naucoridae      | Ambrysus        | –        |
| Arthropoda | Insecta        | Hemiptera     | Veliidae        | Microvelia      | –        |
| Arthropoda | Insecta        | Hemiptera     | Veliidae        | Rhagovelia      | –        |
| Arthropoda | Insecta        | Megaloptera   | Corydalidae     | Corydalus       | cornutus |
| Arthropoda | Insecta        | Odonata       | Calopterygidae  | Hetaerina       | –        |
| Arthropoda | Insecta        | Odonata       | Calopterygidae  | –               | –        |
| Arthropoda | Insecta        | Odonata       | Coenagrionidae  | Argia           | –        |
| Arthropoda | Insecta        | Odonata       | Coenagrionidae  | –               | –        |
| Arthropoda | Insecta        | Odonata       | Gomphidae       | Progomphus      | borealis |
| Arthropoda | Insecta        | Odonata       | Lestidae        | Archilestes     | –        |
| Arthropoda | Insecta        | Odonata       | Libellulidae    | Brechmorhoga    | mendax   |
| Arthropoda | Insecta        | Odonata       | Libellulidae    | –               | –        |
| Arthropoda | Insecta        | Trichoptera   | Calamoceratidae | Phylloicus      | aeneus   |
| Arthropoda | Insecta        | Trichoptera   | Glossosomatidae | –               | –        |
| 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   | –               | –        |
| Arthropoda | Insecta        | Trichoptera   | Leptoceridae    | Nectopsyche     | –        |
| Arthropoda | Insecta        | Trichoptera   | Philopotamidae  | Chimarra        | –        |
| Arthropoda | Insecta        | Trichoptera   | Philopotamidae  | –               | –        |
| Arthropoda | Insecta        | Trichoptera   | –               | –               | –        |
| Arthropoda | Malacostraca   | Amphipoda     | Gammaridae      | Gammarus        | –        |
| Arthropoda | Malacostraca   | Amphipoda     | Hyalellidae     | Hyalella        | –        |
| Arthropoda | Malacostraca   | Amphipoda     | –               | –               | –        |
| Arthropoda | Malacostraca   | Decapoda      | –               | –               | –        |
| Chordata   | Actinopterygii | –             | –               | –               | –        |
| Mollusca   | Bivalvia       | Veneroida     | Pisidiidae      | Pisidium        | –        |

**Table A-3. Macroinvertebrate taxa list for Verde River, WY2017, cont.**

| Phylum   | Class      | Order          | Family     | Genus   | Species |
|----------|------------|----------------|------------|---------|---------|
| Mollusca | Gastropoda | Basommatophora | Lymnaeidae | Lymnaea | –       |
| Mollusca | Gastropoda | Basommatophora | Physidae   | Physa   | –       |
| Nemata   | –          | –              | –          | –       | –       |



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