



Status of Climate and Water Resources at Tonto National Monument

Water Year 2018

Natural Resource Report NPS/SODN/NRR—2019/2000



ON THE COVER

Davis weather station, Tonto National Monument. NPS photo.

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September 2019

U.S. Department of the Interior

National Park Service

Natural Resource Stewardship and Science

Fort Collins, Colorado

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Please cite this publication as:

Gwilliam, E. L., L. Palacios, and K. Raymond. 2019. Status of climate and water resources at Tonto National Monument: Water year 2018. Natural Resource Report NPS/SODN/NRR—2019/2000. National Park Service, Fort Collins, Colorado.

Contents

Figures v

Tables v

Executive Summary vii

Acknowledgements ix

1 Introduction 1

2 Climate..... 3

 2.1 Background and methods 3

 2.2 Results and discussion 3

3 Groundwater 7

 3.1 Background 7

 3.2 Methods..... 8

 3.3 Results and discussion 8

4 Springs 13

 4.1 Background 13

 4.2 Methods..... 13

 4.3 Results and discussion 14

5 Literature Cited 17

Figures

Figure 2-1. Aridity index and elevation of selected southwestern national parks, including Tonto National Monument..... 3

Figure 2-2. Departures from 30-year (1981–2010) normal precipitation, Repeater Ridge Davis station, Tonto National Monument, water year 2018. 5

Figure 2-3. Climogram for Tonto National Monument, Repeater Ridge Davis station, water year 2018 5

Figure 3-1. Springs and groundwater monitoring sites at Tonto National Monument 7

Figure 3-2. Piezometer at the shallow groundwater monitoring site, Cave Canyon Creek, Tonto National Monument..... 9

Figure 3-4. Water level above the sensor at the Cave Canyon monitoring site and daily precipitation at Tonto National Monument, water years 2014–2018. 9

Figure 3-3. Piezometer at the Cinda’s Seep monitoring site, Tonto National Monument..... 9

Figure 3-5. Water level above the sensor at the Cave Canyon monitoring site and daily precipitation at Tonto National Monument, water year 2018. 10

Figure 3-6. Water levels above the sensor at the Cinda’s Seep monitoring site and monthly precipitation at Tonto National Monument, water years 2009–2018. 11

Figure 4-1. Cave Canyon Spring orifice and sampling location, Tonto National Monument, March 2018. 14

Figure 4-2. Upper Dwellings Trail through Cave Canyon Spring flow, Tonto National Monument, March 2018. 15

Figure 4-3. Estimated wet/dry days at Cave Canyon Spring, Tonto National Monument, water year 2018. 15

Tables

Table 4-1. Water-quality data, Cave Canyon Spring, Tonto National Monument, WY2018..... 16

Table 4-2. Water-chemistry data (mg/L), Cave Canyon Spring, Tonto National Monument, WY2018. . 16

Executive Summary

Climate and hydrology are major drivers of ecosystems. They dramatically shape ecosystem structure and function, particularly in arid and semi-arid ecosystems. Understanding changes in climate, groundwater, streamflow, and water quality is central to assessing the condition of park biota and key cultural resources. This report combines data collected on climate, groundwater, and surface water at Tonto National Monument (NM) to provide an integrated look at climate and water conditions during water year 2018 (October 2017–September 2018).

Water year 2018 was drier than normal. Overall annual precipitation was 32% of normal, based on a 30-year record (1981–2010). Precipitation was just 20.3% of normal (-8.42”) for the fall and winter of WY2018; October and November were completely dry. Precipitation was about half of normal for the spring and summer months, though a single, 0.33” storm event dropped over four times the normal rainfall for June. Temperatures in the cool season ranged from 31.9 to 90.4°F, with peaks in October and lows in February. Temperatures in the warm season ranged from 47.0 to 106°F, with peaks in July and lows in May. Extremely cold days (<35°F) occurred on five days, and temperatures remained below 32°F for 24 hours just once. The largest precipitation event was 0.49”, on August 12. Additional information can be found at The Climate Analyzer.

Shallow groundwater was monitored at Cave Canyon Creek and Cinda’s Seep. Mean water level in Cave Canyon Creek in WY2018 was 1.03 feet above the sensor. The water level rose in response to winter rains and decreased through the dry, warm months. After the monsoon rains started, the water level increased. Data from Cinda’s Seep indicated that the water level did not rise above the sensor in WY2018. The monitoring record for Cinda’s Seep indicates that the shallow water table increased above the sensor only in winter or early spring WY2010–2012, then dropped below the sensor in late spring.

Disturbance surveys at Cave Canyon Spring resulted in a median value of 1 = undisturbed for both anthropogenic and natural disturbance. Temperature sensors indicated that the spring was wetted throughout the entire sampling period. Sampled parameters for water quality and water chemistry were all within the expected ranges for this site.

Acknowledgements

We thank Superintendent Duane Hubbard, Chief of Resources Brett Cockrell, and the staff of Tonto National Monument for their on-site support of the monitoring effort. Gregory Goodrum and Kate McNicholas assisted with springs monitoring. Kristen Bonebrake led the management and posting of all data products. Mike Tercek developed the Climate Analyzer tool used for all climate data analysis. Andy Hubbard and Colleen Filippone 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, and water quality is central to assessing the condition of park biota and key cultural resources. This document summarizes climate and water resource conditions for water

year (WY) 2018 (October 2017–September 2018) at Tonto National Monument (NM), a small (453-ha) National Park Service unit 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 the Sonoran Desert Network website.

2 Climate

2.1 Background and methods

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

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

Tonto NM had a nearby National Oceanic and Atmospheric Administration Cooperative Observer Program (COOP) weather station (ROOSEVELT DAM #27281) from 1905 to 2017. This station provides a reliable long-term climate dataset. In 2014, The Sonoran Desert Network (SODN) established

two Davis weather stations to record real-time weather conditions: one at the visitor center and one at a high-elevation location on the park’s Repeater Ridge.

An aridity index (UNEP 1992), based on the long-term average annual precipitation relative to the average annual potential evapotranspiration, can be a useful tool for contrasting the local climate of national parks (Figure 2-1). Used globally to classify climate zones, aridity indices seek to answer the question, “How dry is dry?” (Tsakiris and Vangelis 2005). Using the period of record (1905–present), the climate of Tonto NM is classified as semi-arid.

2.2 Results and discussion

Monitoring at the COOP station ended in December 2017. Data quality at the Repeater Ridge Davis station was good, with missing precipitation data on two days and missing temperature data on nine days, primarily in September. Data quality at the visitor center Davis station was poor, with missing precipitation and temperature data on 100 days due to technical issues. All discussion for WY2018 is based on data from the Repeater Ridge Davis station, compared

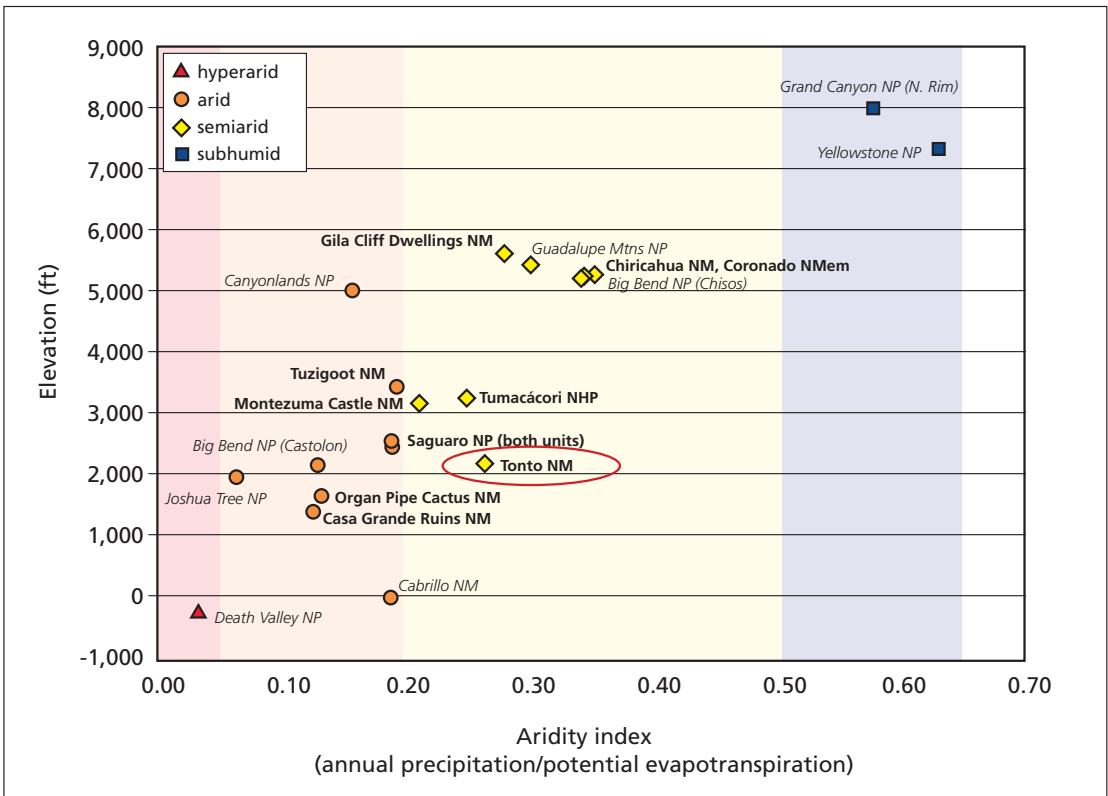


Figure 2-1. Aridity index and elevation of selected southwestern national parks, including Tonto National Monument. Figure from Hubbard and others (in prep).

to the 30-year normal from the COOP station. These two sites are considered to be relatively comparable for precipitation, but local topography near each station prevents direct comparison of temperature. Overall annual precipitation was 32% of normal for Tonto NM (5.29" vs 16.48").

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

2.2.1.1 Cool season (October–March)

Precipitation was extremely below normal (20.3% or -8.42") for the fall and winter of WY2018. Rainfall in February was 59% of normal (Figure 2-2). All other months were ≤30% of normal, with October and November being completely dry. Temperatures in the cool season ranged from 31.9 to 90.4°F, with peaks in October and lows in February (Figure 2-3).

2.2.1.2 Warm season (April–September)

Precipitation was about half of normal (53%, -2.77") for the spring and summer months in WY2018 (see Figure 2-2). In June, residual moisture from a Pacific hurricane caused unseasonable precipitation across southern Arizona, leading to a single, 0.33" storm event. This represented over four times the normal rainfall for June. The monsoon was slow to start in July, followed by near-normal rainfall in August. It tapered

off quickly in September. Temperatures in the warm season ranged from 47.0 to 106°F, with peaks in July and lows in May (see Figure 2-3).

2.2.2 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 Sonoran Desert ecosystems. For example, sustained low air temperatures can damage or even kill long-lived keystone plants, such as columnar cacti (e.g., saguaro and organ pipe cacti) and native trees (e.g., velvet mesquite; Turner et al. 2003). Extreme precipitation events can also cause localized flooding and erosion events, spur or inhibit plant productivity and reproduction, and modify animal behavior.

Extremely cold days (<35°F, 5th percentile of 1981–2010 data) occurred on five days. Only one day was below <32°F. There were no extreme precipitation events (>1") in WY2018, compared to a mean of 2.3 days for 1981–2010. The largest rain event (0.49") occurred on August 12.

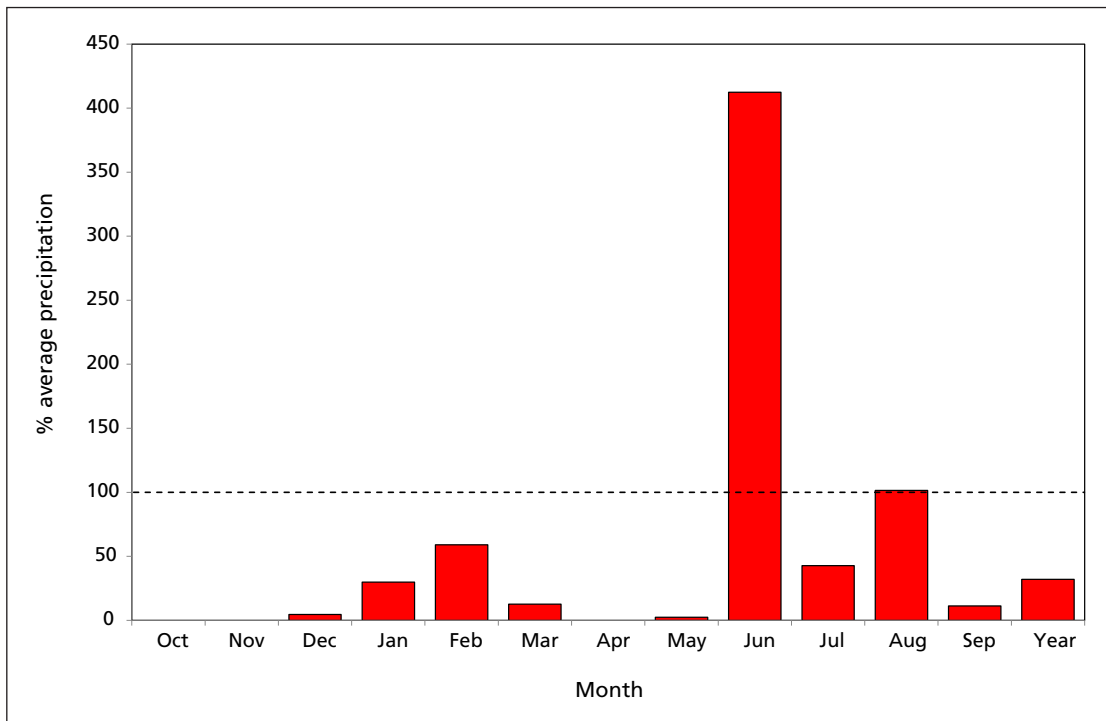


Figure 2-2. Departures from 30-year (1981–2010) normal precipitation, Repeater Ridge Davis station, Tonto National Monument, water year 2018.

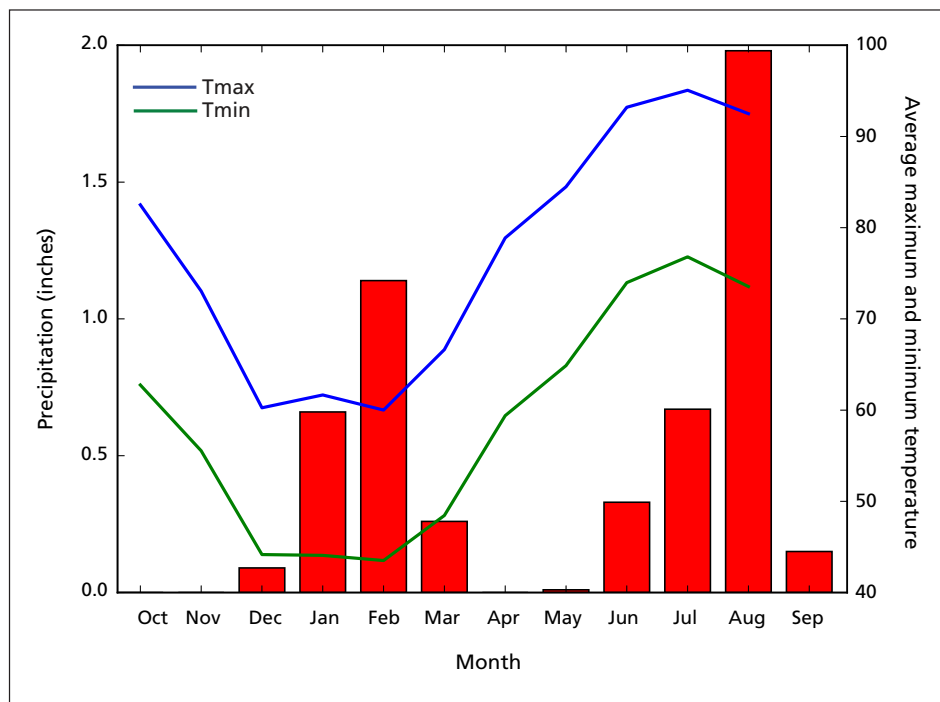


Figure 2-3. Climogram for Tonto National Monument, Repeater Ridge Davis station, water year 2018. Graphics generated by climateanalyzer.org.

3 Groundwater

3.1 Background

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

Geologically, Tonto NM is split into two sections: the southwestern part of the park, with mountainous Precambrian rocks, and the northeastern part of the park, with a plain of Tertiary sediments (Martin 2001). These areas are separated by the Two Bar North Fault, running from northwest to southeast.

The southwestern part of the park is characterized by exposed bedrock of the Apache Group, composed of Basalt, Mescal Limestone, Dripping Spring Quartzite (including the caves used by Salado people), Barnes Conglomerate, and Pioneer Formation, with intrusions of diabase (Raup 1959). Talus and colluvium are present at the base of the steep slopes, with alluvium in the canyon bottoms. Nearly vertical faults, joints, and shear fractures are common throughout the bedrock formations (Raup 1959). Precipitation and snowmelt infiltrate through these fractures, which act as pathways for groundwater flow and storage. The groundwater is discharged as springs at fractures in the canyons and as subsurface flow in the alluvium.

In the northeastern part of the park, bedrock has been down-dropped by faulting along the Two Bar North Fault, up to a depth of up to 1,600 feet (Richard et al. 2007). The basin is filled with Gila Conglomerate,

composed of gravel, cemented gravel, sandstone, and siltstone (Raup 1959). This area is characterized by a gently sloped alluvial fan and terrace bajada.

Cave Canyon Spring (also identified as Cholla Spring #1 in Martin 2001) occurs within the the Cave Canyon Creek channel, in the southwestern part of park, where groundwater flows to the surface through fractured bedrock. Supplemental flow comes from water infiltrated into shallow soils in the watershed, 90% of which lies outside and above the park boundary (Figure 3-1). Surface flow from the spring orifice is limited. However, shallow subsurface flow is also likely occurring.

Cave Canyon Creek is a losing stream, and the springbrook from Cave Canyon Spring generally disappears 100–300 feet down-

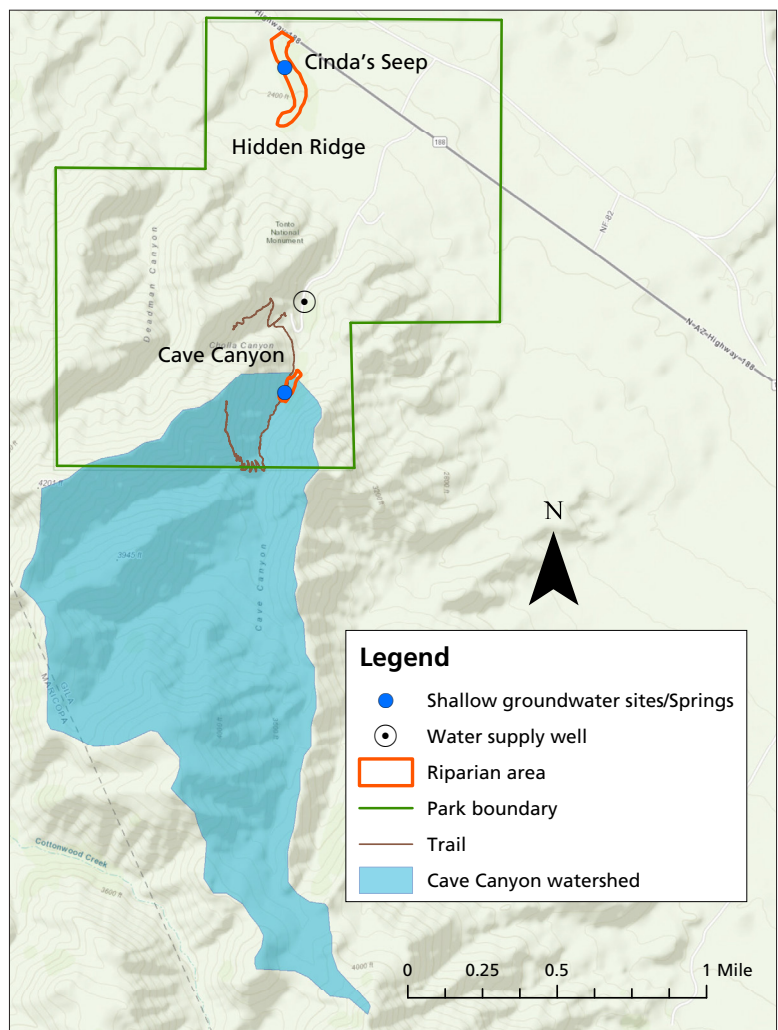


Figure 3-1. Springs and groundwater monitoring sites at Tonto National Monument

stream from the spring orifice, depending on the season and time of day. Other springs have been previously observed in the canyon, but currently are not expressed at the surface—likely as a result of groundwater pumping, sedimentation, and drought (Albrecht et al. 2005, Martin 2001). The perennial spring supports a relatively small (1.13 ha) riparian area. The area is dominated by Arizona sycamore (*Platanus wrightii*) and Arizona walnut (*Juglans major*) (Studd et al. 2017), which provide a shaded ecological environment.

The park's water-supply well (ADWR 55-629108) is located approximately 1,800 feet downstream from Cave Canyon Spring. This well was constructed in 1963 (Dennis 1963), at an elevation of 2,730.6 feet (Jacob DeGaynor, pers. comm., 2015). It was built at the intersection of two faults, to a depth of 145 feet.

In the northwestern part of the park is the Hidden Ridge riparian woodland, located in an area of younger alluvium (Pearthree et al. 1997). The riparian area is dominated by velvet mesquite (*Prosopis velutina*), netleaf hackberry (*Celtis reticulata*), catclaw acacia (*Senegalia greggii*), and yellow paloverde (*Parkinsonia microphylla*) (Studd et al. 2017). The differences between the riparian plant communities at Cave Canyon and Hidden Ridge likely indicate the relative availability of water at the two locations. The Hidden Ridge woodland is likely supported by a perched aquifer (Lindsay et al. 1994). Cinda's Seep is located in a drainage in the Hidden Ridge riparian area. The seep has historically discharged water at the surface during sufficiently wet periods.

3.2 Methods

Shallow groundwater is monitored at two sites associated with springs: Cave Canyon Creek and Cinda's Seep. Shallow groundwater monitoring is outside the scope of the SODN groundwater monitoring protocol (Filippone et al. 2014), but these activities were initiated and continued to support the park's management and understanding of natural and cultural resources. The water-supply well at Tonto NM (ADWR 55-629108) is not monitored to prevent poten-

tial disruption of drinking-water production.

The Cave Canyon site is approximately 30 feet downstream from the current Cave Canyon Spring orifice, at a piezometer adjacent to the creek (Figure 3-2). Since WY2006, pressure transducers have been used to collect automated measurements of the groundwater level every 20 minutes. However, data collection prior to WY2014 was intermittent due to equipment issues. The sensor is 2.31 feet below the ground surface, and approximately 1.15 feet below the channel thalweg.

A piezometer was installed at Cinda's Seep in WY2009 (Figure 3-3). A pressure transducer collects automated measurements of the groundwater level every six hours. The sensor is approximately 3.6 feet below the ground surface.

3.3 Results and discussion

3.3.1 Cave Canyon Creek

Figure 3-4 shows the water level above the sensor at Cave Canyon Creek, and provides the approximate level of the channel thalweg immediately adjacent to the monitoring site. The thalweg elevation is not precise due to constant channel erosion and aggradation, but it does generally indicate the depth of the water table relative to the thalweg elevation. Although the pressure transducer is located only two horizontal feet from the channel thalweg, the water table is generally lower than the surface-water elevation in the channel. This is because the spring discharge is infiltrating into the alluvium. On March 3, 2018, the barometer used to compensate the raw pressure transducer data was replaced. A subsequent drop of 0.034 feet was observed in the data (Figure 3-5).

The mean water level in Cave Canyon Creek during WY2018 was 1.03 feet above the sensor—the same as in WY2017. However, the water level during WY2018 was above the channel-thalweg elevation for 12.6% of the year, compared to 1.2% in WY2017. During January and February, the water level rose above the channel-thalweg elevation. When the winter rains ended and air temperatures increased, the water level



Figure 3-2. Piezometer at the shallow groundwater monitoring site, Cave Canyon Creek, Tonto National Monument. NPS/Jacob DeGayner.



Figure 3-3. Piezometer at the Cinda's Seep monitoring site, Tonto National Monument.

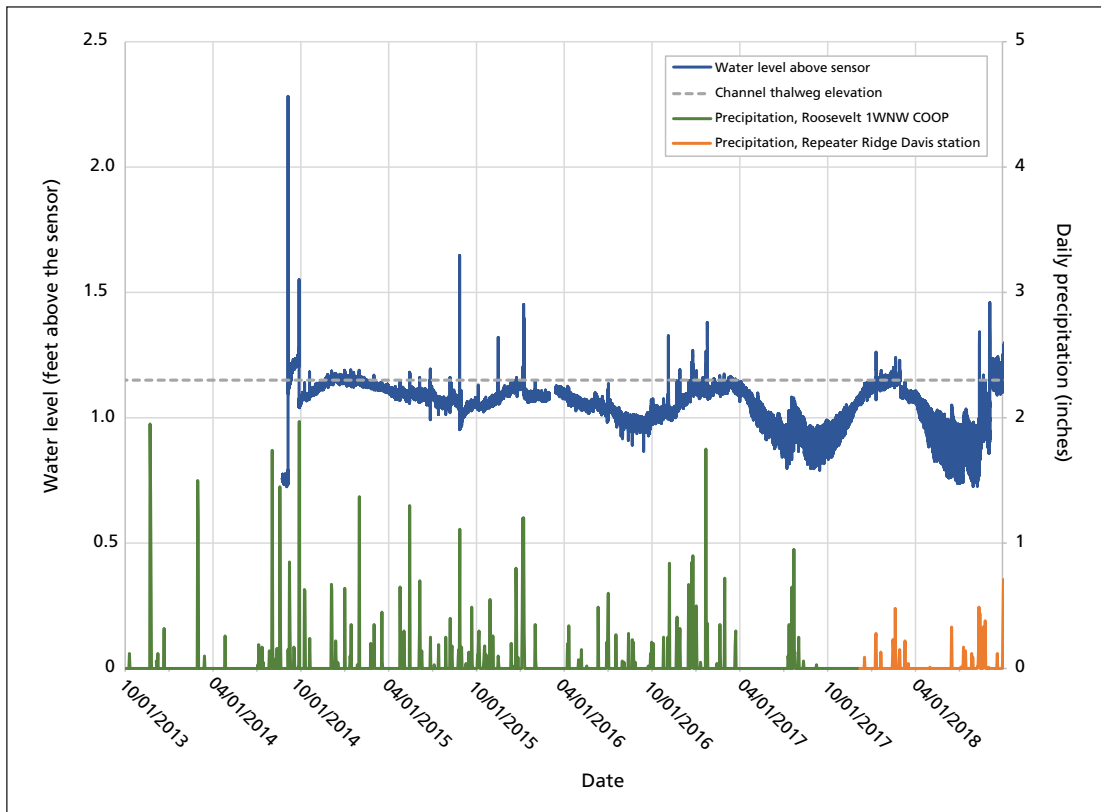


Figure 3-4. Water level above the sensor at the Cave Canyon monitoring site and daily precipitation at Tonto National Monument, water years 2014–2018.

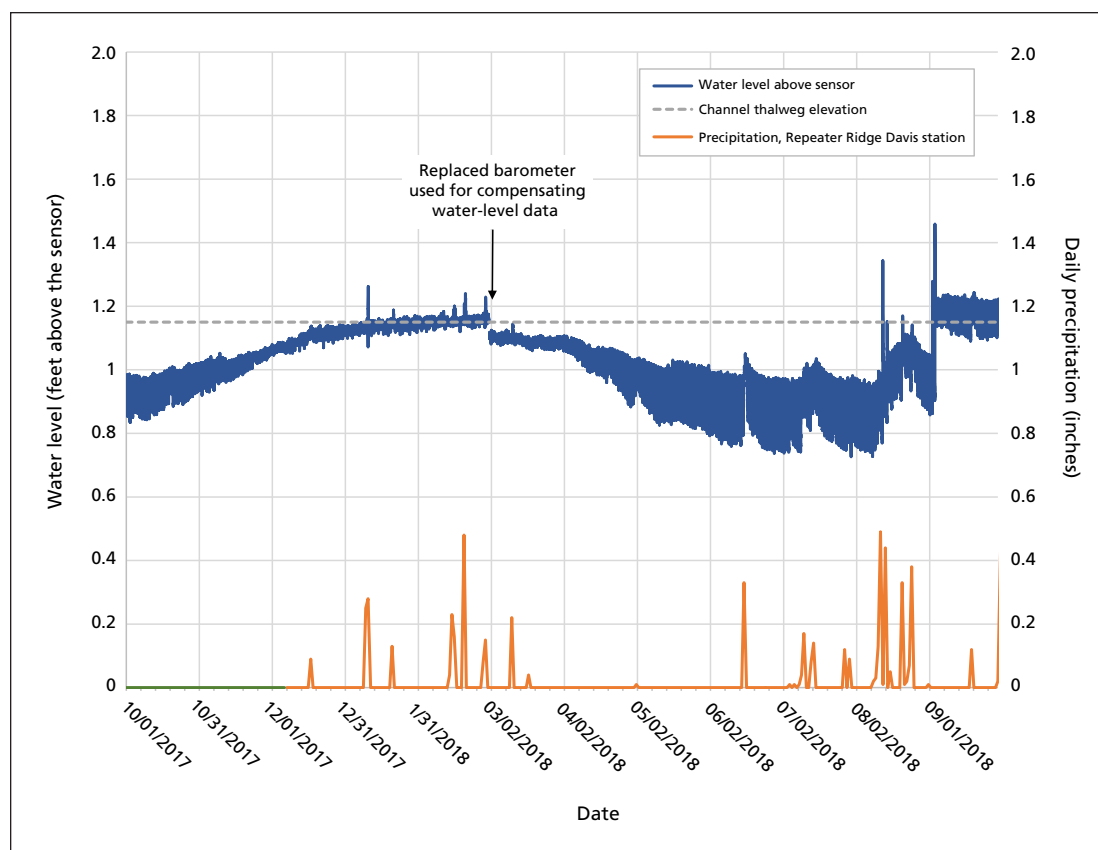


Figure 3-5. Water level above the sensor at the Cave Canyon monitoring site and daily precipitation at Tonto National Monument, water year 2018.

decreased. The water level during the dry, warm months of WY2018 experienced high daily fluctuations of up to 0.25 feet, a greater range than observed in previous years. This was likely caused by high evapotranspiration rates in the Cave-Canyon riparian area. The minimum water level for WY2018 (and the monitoring record), 0.73 feet, was recorded on July 30. In August, a series of moderate (<0.5 inches) precipitation events occurred, causing temporary spikes in the water level and likely indicating stormwater runoff in Cave Canyon Creek. On August 3, water levels spiked to the maximum for WY2018, 1.46 feet above the sensor. The water level subsequently remained above the approximate channel-thalweg elevation. No precipitation event was recorded immediately prior to this water-level increase, so its cause is unclear.

3.3.2 Cinda's Seep

During WY2018, instrumentation indicated that Cinda's Seep varied by 0.14 feet, with highs in winter and lows in summer, similar

to WY2015–2017 (Figure 3-6). However, the water table was likely below the sensor during most or all of water years 2015–2018, with data indicating water levels above the sensor being a product of noise. Changes to the piezometer may have contributed to the observed data discrepancy. In August 2011, a well-cap expander with a tight-fitting cap was added to the top of the piezometer, after which the data included substantially more noise (Figure 3-6). Between August 2011 and May 2012, the piezometer was pulled out of the ground, possibly by an animal, and replaced by park staff. It is unclear whether that disturbance affected the piezometer and the accuracy of the sensor. Efforts will be made to reduce the noise.

The monitoring record for Cinda's Seep indicates that the shallow water table increased above the sensor only in winter or early spring WY2010–2012, then dropped below the sensor in late spring. The increase was likely a response to winter precipitation events and reduced evapotranspiration.

The water table peaked on April 12, 2010, at 1.60 feet above the sensor (approximately 2.0 feet below the ground surface). The reduced peak water levels observed in water years 2010–2012, and dry conditions

since WY2015, indicate that the climatic conditions over the past several years have diminished groundwater levels below the bottom of the shallow piezometer in the perched aquifer at Cinda's Seep.

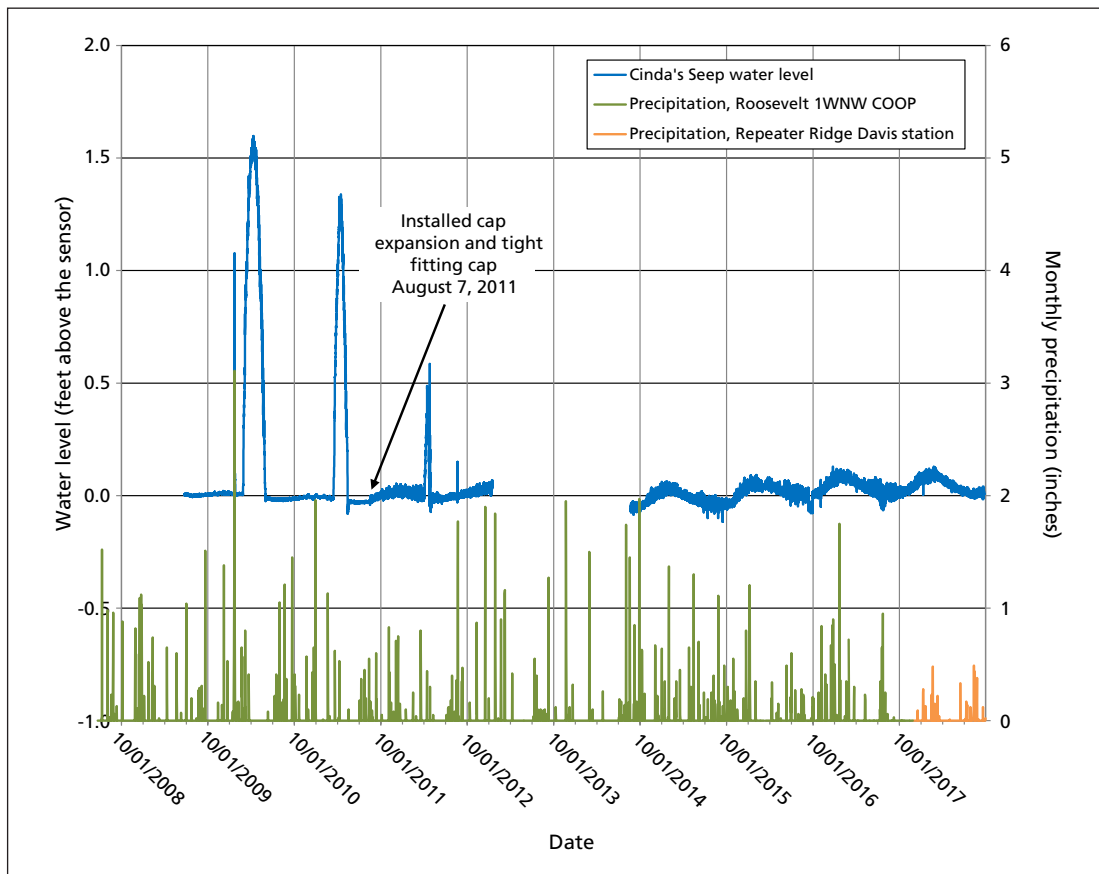


Figure 3-6. Water levels above the sensor at the Cinda's Seep monitoring site and monthly precipitation at Tonto National Monument, water years 2009–2018.

4 Springs

4.1 Background

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

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

4.2 Methods

At Tonto NM, Sonoran Desert Network springs monitoring focuses on one sentinel site: Cave Canyon Spring. The statistical inference provided by this design is limited to each individual spring monitored over time. SODN monitors a suite of vital signs and parameters for springs organized into four modules: site characterization, site condition, water quantity, and water quality. A brief description of the data-collection methodologies followed during WY2018 is presented below. See McIntyre and others (2018) for additional details.

4.2.1 Site characterization

The site-characterization module is a modification of the inventory methods developed for the Mojave Desert Network (Sada and Pohlmann 2006). This module is completed once every five years, or after significant

events, and provides context for interpreting change in the other modules. The module includes spring type and characterization, GPS locations, site diagram and site description, and vegetation community description. See the springs monitoring protocol for details (McIntyre et al. 2018). This module was completed at Tonto NM in 2017 and will be recollected in 2022.

4.2.2 Site condition

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

4.2.3 Water quantity

The water-quantity module provides information on the persistence of surface water, spring discharge, and wetted extent. The persistence of surface water at springs is estimated by analyzing the variance of temperature measurements between paired sensors deployed in each spring near the primary orifice (point of groundwater emergence) and in a nearby tree or shrub (McIntyre et al. 2018). When the variance from the two sensors becomes statistically indistinguishable, the spring is likely dry. (Work continues to refine methods to reduce the occurrence of false-positive and false-negative results.)

A timed sample of water volume measures the system's surface discharge. Wetted extent is a comprehensive metric assessment of the physical length (up to 100 m), width, and depth of present surface water.

4.2.4 Water quality

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

4.3 Results and discussion

4.3.1.1 Site characterization

Cave Canyon Spring (Figure 4-1) is a rheochrene spring dominated by run-off discharge. The monitoring orifice is a small pool amidst scattered other pools at the base of an Arizona sycamore in the center of the channel. This pool appears to be the most persistent and largest contributor to flow. The emergence flows slightly with cool, clear water until sinking back into the channel. The location where the water emerges from



Figure 4-1. Cave Canyon Spring orifice and sampling location, Tonto National Monument, March 2018.

the streambed can fluctuate several meters up and down the channel each day. Surface flow ranges from approximately 10 to 30 centimeters. Overall, the substrate majority is sand and silt, with dispersed gravel and boulders.

4.3.1.2 Site condition

Disturbance surveys resulted in a median value of 1 = undisturbed for both anthropogenic and natural disturbance. The crew noted that the Upper Cliff Dwellings Trail runs near, over, and along the majority of the spring system, causing a single high disturbance rating (Figure 4-2).

The crew observed two obligate/facultative wetland plant genera: willow (*Salix* sp.) and Arizona sycamore (*Platanus wrightii*). No invasive plants or animals were observed.

4.3.1.3 Water quantity

Temperature sensors indicated that the spring was wetted throughout the entire sampling period (Figure 4-3). Data were missing midway through the year due to differences in temperature-sensor deployments between years. Discharge from orifice A was estimated at 7.3 ± 0.5 liters/second. Channel length was 83.3 meters. Width and depth averaged 68.7 and 3.1 centimeters, respectively.

4.3.1.4 Water quality

In 2018, core water-quality parameters (Table 4-1) and water chemistry (Table 4-2) were measured at the orifice. The sampled parameters were all within the expected ranges for this site.

Although the pH probe used to collect this measurement had some difficulty meeting required values during pre-sampling calibration, it was successfully calibrated before the sample was collected. However, it failed the post-calibration check after the sampling event. pH probes are sensitive, easily damaged equipment with a limited lifespan. Because the probe met the pre-sampling calibration requirements, we believe the data collected during this sample were valid.

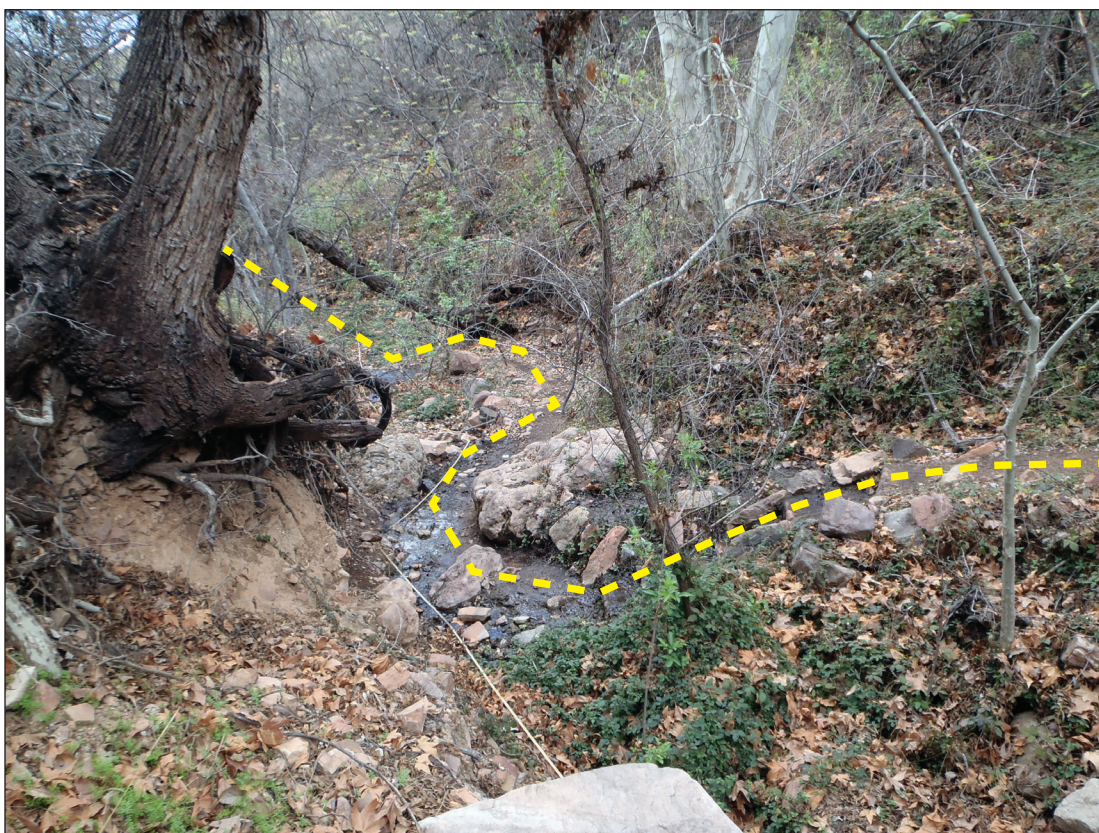


Figure 4-2. Upper Dwellings Trail through Cave Canyon Spring flow, Tonto National Monument, March 2018.

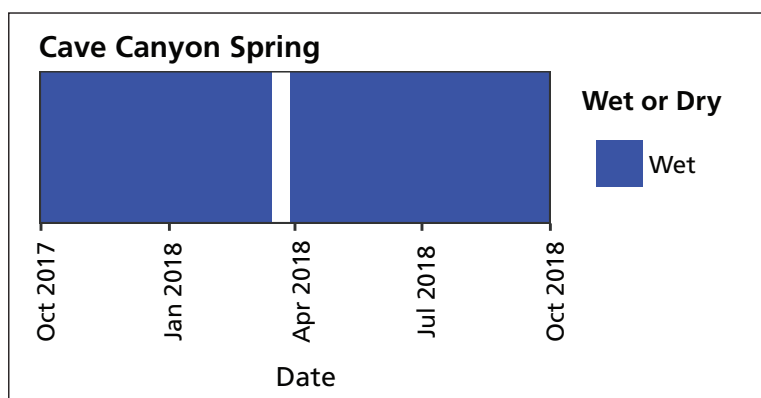


Figure 4-3. Estimated wet/dry days at Cave Canyon Spring, Tonto National Monument, water year 2018.

Table 4-1. Water-quality data, Cave Canyon Spring, Tonto National Monument, WY2018.

Sampling location	Sample time	Temperature (°C)	Dissolved oxygen (mg/L)	pH	Specific conductivity (µS/cm)	Total dissolved solids (mg/L)	Exposure
1	11:30	16.9	5.34	7.78*	532.90	345.45	Partial

*pH did not pass post-sampling calibration but the data were determined to be valid.

Table 4-2. Water-chemistry data (mg/L), Cave Canyon Spring, Tonto National Monument, WY2018.

Sampling location	Alkalinity	Calcium	Chloride	Magnesium	Potassium	Sulfate
1	225	42	175	33	0	11

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