



Status of Climate and Water Resources at Chiricahua National Monument, Coronado National Memorial, and Fort Bowie National Historic Site

Water Year 2019

Natural Resource Report NPS/SODN/NRR—2022/2378



ON THE COVER

Springs monitoring at Chiricahua National Monument. NPS photo.

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Kara Raymond¹
Laura Palacios²
Andy Hubbard²
Cheryl McIntyre³
Evan Gwilliam²

¹Southern Arizona Office
National Park Service
3636 N. Central Ave., Suite 410
Phoenix, AZ 85012

²Sonoran Desert Network
National Park Service
12661 E. Broadway Blvd.
Tucson, AZ 85748

³Chihuahuan Desert Network
National Park Service
New Mexico State University, MSC 3ARP
3655 Research Dr., Genesis Building D
Las Cruces, NM 88003

Editing and Design

Alice Wondrak Biel
National Park Service
Sonoran Desert Network
12661 E. Broadway Blvd.
Tucson, AZ 85748

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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, and water quality and quantity is central to assessing the condition of park biota and key cultural resources. The Sonoran Desert Network collects data on climate, groundwater, and surface water at 11 National Park Service units in southern Arizona and New Mexico. This report provides an integrated look at climate, groundwater, and springs conditions at Chiricahua National Monument (NM), Coronado National Memorial (NMem), and Fort Bowie National Historic Site (NHS) during water year (WY) 2019 (October 2018–September 2019).

Overall annual precipitation at Chiricahua NM and Coronado NMem in WY2019 was approximately the same as the normals for 1981–2010. (The weather station at Fort Bowie NHS had missing values on 275 days, so data were not presented for that park.) Fall and winter rains were greater than normal. The monsoon season was generally weaker than normal, but storm events related to Hurricane Lorena led to increased late-season rain in September. Mean monthly maximum temperatures were generally cooler than normal at Chiricahua, whereas mean monthly minimum temperatures were warmer than normal. Temperatures at Coronado were more variable relative to normal. The reconnaissance drought index (RDI) indicated that Chiricahua NM was slightly wetter than normal. (The WY2019 RDI could not be calculated for Coronado NMem due to missing data.) The five-year moving mean of annual precipitation showed both park units were experiencing a minor multi-year precipitation deficit relative to the 39-year average.

Mean groundwater levels in WY2019 increased at Fort Bowie NHS, and at two of three wells monitored at Chiricahua NM, compared to WY2018. Levels in the third well at Chiricahua slightly decreased. By contrast, water levels declined in five of six wells at Coronado NMem over the same period, with the sixth well showing a slight increase over WY2018. Over the monitoring record (2007–present), groundwater levels at Chiricahua have been fairly stable, with seasonal variability likely caused by transpiration losses and recharge from runoff events in Bonita Creek. At Fort Bowie’s WSW-2, mean groundwater level was also relatively stable from 2004 to 2019, excluding temporary drops due to routine pumping. At Coronado, four of the six wells demonstrated increases (+0.30 to 11.65 ft) in water level compared to the earliest available measurements. Only WSW-2 and Baumkirchner #3 have shown net declines (-17.31 and -3.80 feet, respectively) at that park.

Springs were monitored at nine sites in WY2019 (four sites at Chiricahua NM; three at Coronado NMem, and two at Fort Bowie NHS). Most springs had relatively few indications of anthropogenic or natural disturbance. Anthropogenic disturbance included modifications to flow, such as dams, berms, or spring boxes. Examples of natural disturbance included game trails, scat, or evidence of flooding. Crews observed 0–6 facultative/obligate wetland plant taxa and 0–3 invasive non-native species at each spring. Across the springs, crews observed six non-native plant species: common mullein (*Verbascum thapsus*), spiny sowthistle (*Sonchus asper*), common sowthistle (*Sonchus oleraceus*), Lehmann lovegrass (*Eragrostis lehmanniana*), rabbitsfoot grass (*Polypogon monspeliensis*), and red brome (*Bromus rubens*). Baseline data on water quality and water chemistry were collected at all nine sites. It is likely that all nine springs had surface water for at least some part of WY2019, though temperature sensors failed at two sites. The seven sites with continuous sensor data had water present for most of the year. Discharge was measured at eight sites and ranged from <1 L/minute to 16.5 L/minute.

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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 springs is central to assessing the condition of park biota.

This document summarizes climate, groundwater, and springs conditions for water year (WY) 2019 (October 2018–September

2019) at the three National Park Service (NPS) units of the Southeast Arizona Group: Chiricahua National Monument (NM), Coronado National Memorial (NMem), and Fort Bowie National Historic Site (NHS). 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.

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 the NPS manages and protects.

A broader temporal scale (seasons to years) is what distinguishes climate from the instantaneous conditions reflected by the term “weather.” Weather is monitored at eight stations at high and low elevations across Chiricahua NM, Coronado NMem, and Fort Bowie NHS (Table 2-1 and Figures 2-1, 2-2, 2-3). They include two National Oceanic and Atmospheric Administration (NOAA) Cooperative Observer Program (COOP) stations, a Remote Automated Weather Station (RAWS), three Davis stations, and two U.S. Department of Agriculture (USDA) rain gages. The record from the Coronado NMem COOP station provides a reliable, long-term climate dataset used for analyses in this report.

Data from all eight stations were obtained from the Climate Analyzer (Walking Shadow Ecology 2021a, 2021b, 2021c, 2021d, 2021e, 2021f, 2021g, 2021h), a website that allows users to make on-demand tables and graphs with data from weather stations updated daily (Walking Shadow Ecology 2021i). See the SODN climate monitoring protocol (Hubbard et al. in prep) for details on methods and data handling.

An Aridity Index (UNEP 1992), based on the long-term average annual precipitation relative to the average annual potential evapotranspiration, can be a useful tool for contrasting the local climate of national parks (Figure 2-4). Used globally to classify climate zones, aridity index seeks to answer the question “How dry is dry?” (Tsakiris and Vangelis 2005). Using the period of record, the climate of Chiricahua NM and Coronado NMem is classified as semi-arid. Historic climate data are lacking for Fort Bowie NHS, but if we extrapolate from nearby Chiricahua NM and consider the elevation/aridity relationship, the climate of Fort Bowie NHS is likely also semi-arid.

Table 2-1. Weather stations at National Park Service units of the Southeast Arizona Group.

Type/ID	Park	Location	Elevation	Start of service
NOAA COOP/Chiricahua NM #01664	Chiricahua NM	near visitor center	5,370 ft/1,637 m	1948*
NOAA COOP/CORONADO NM HQ #22140	Coronado NMem	near visitor center	5,270 ft/1,606 m	1960
RAWS/Chiricahua Arizona #21409	Chiricahua NM	near visitor center	5,370 ft/1,637 m	1995
Davis	Chiricahua NM	near Sugarloaf parking lot	6,840 ft/2,085 m	2014
Davis	Coronado NMem	Montezuma Peak	7,650 ft/2,332 m	2014
Davis	Fort Bowie NHS	Overlook Ridge	5,050 ft/1,539 m	2014
USDA rain gage/#406	Coronado NMem	near eastern boundary	4,930 ft/1,503 m	2006
USDA rain gage/#419	Coronado NMem	near western boundary	6,600 ft/2,012 m	2007

*This station has not collected temperature data since 2006.

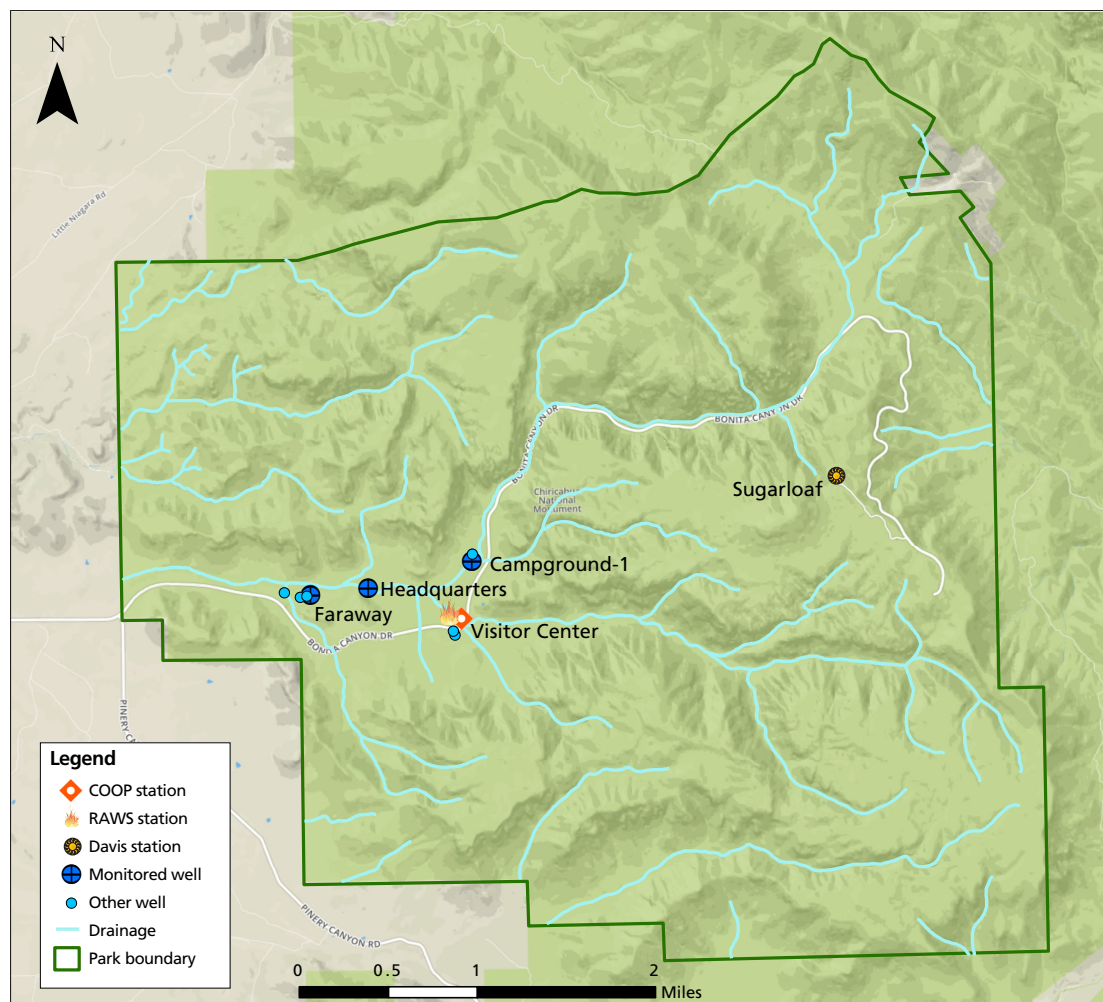


Figure 2-1. Climate stations and monitoring wells at Chiricahua National Monument.

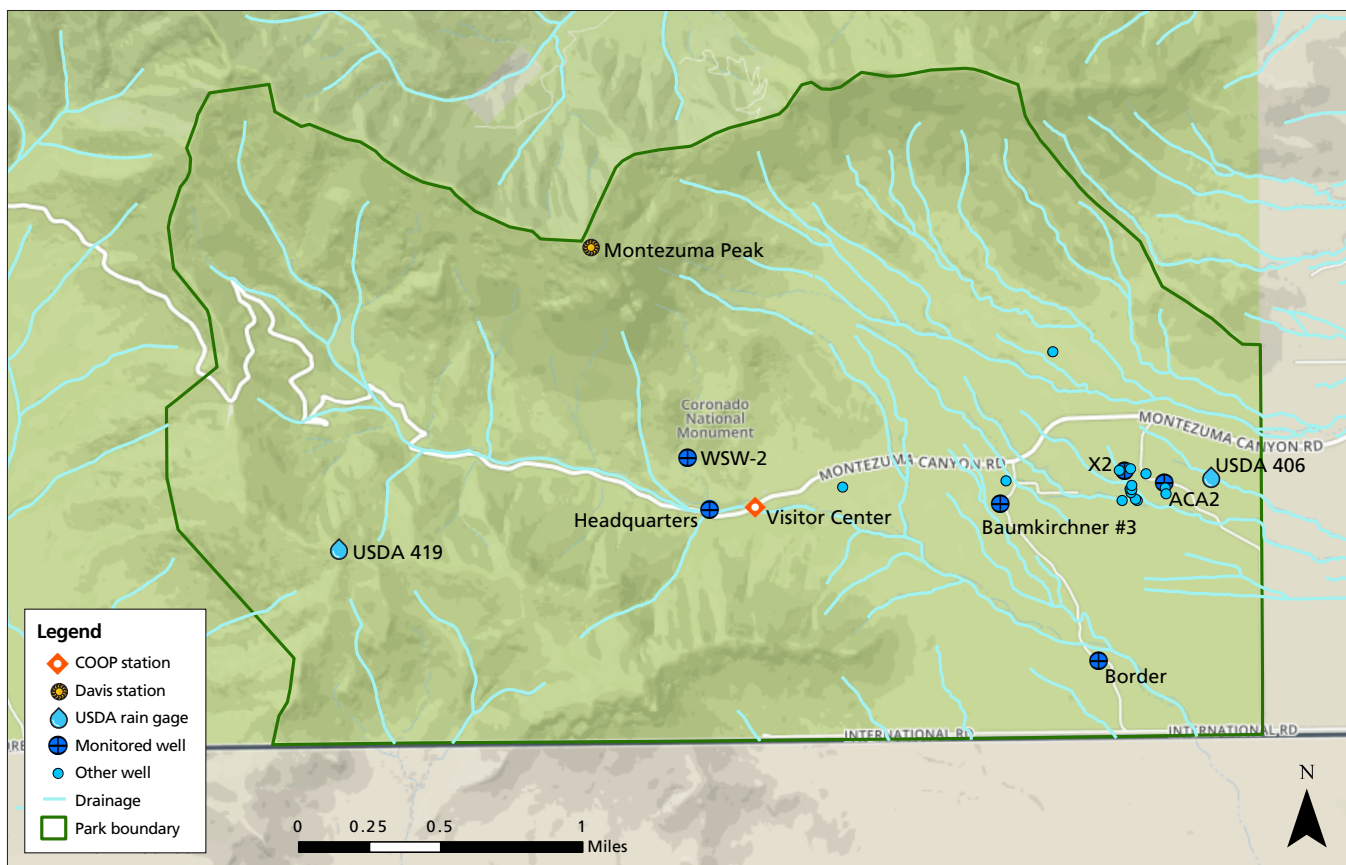


Figure 2-2. Climate stations and monitoring wells at Coronado National Memorial.

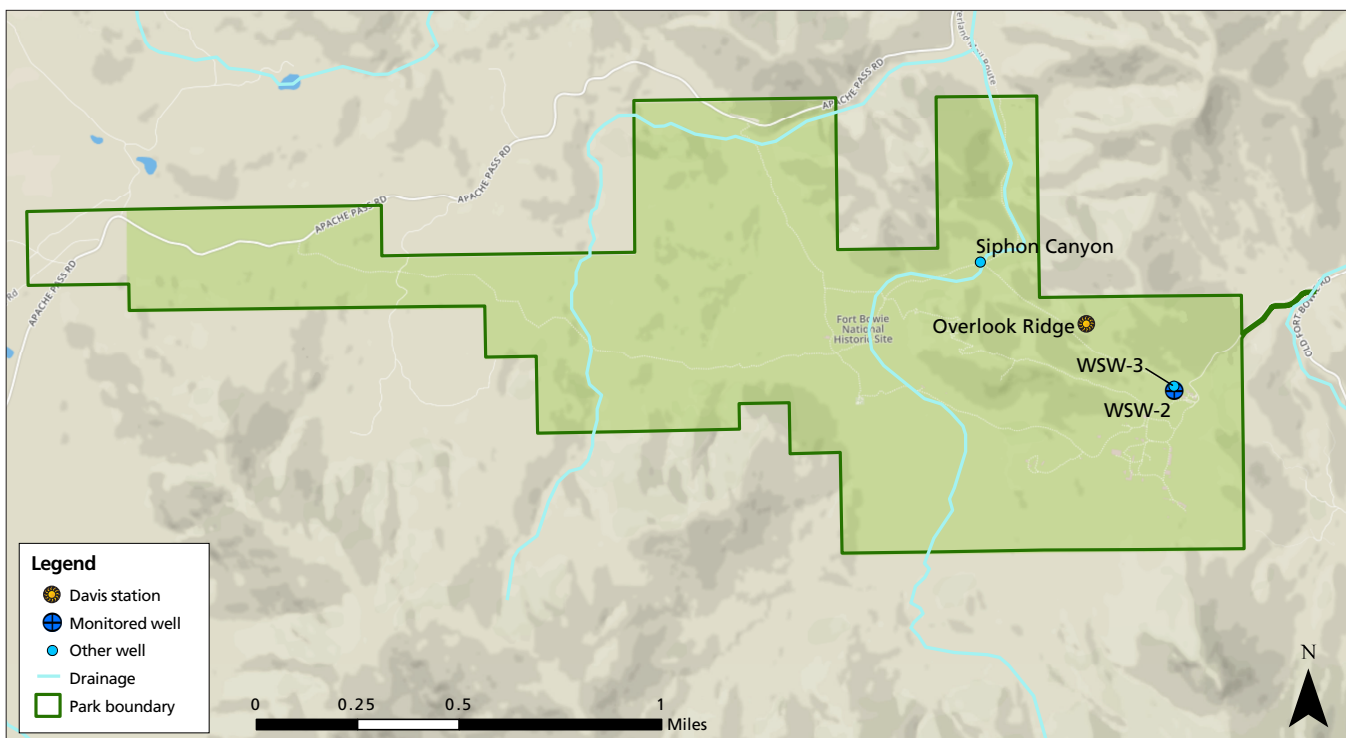


Figure 2-3. Climate stations and monitoring wells at Fort Bowie National Historic Site.

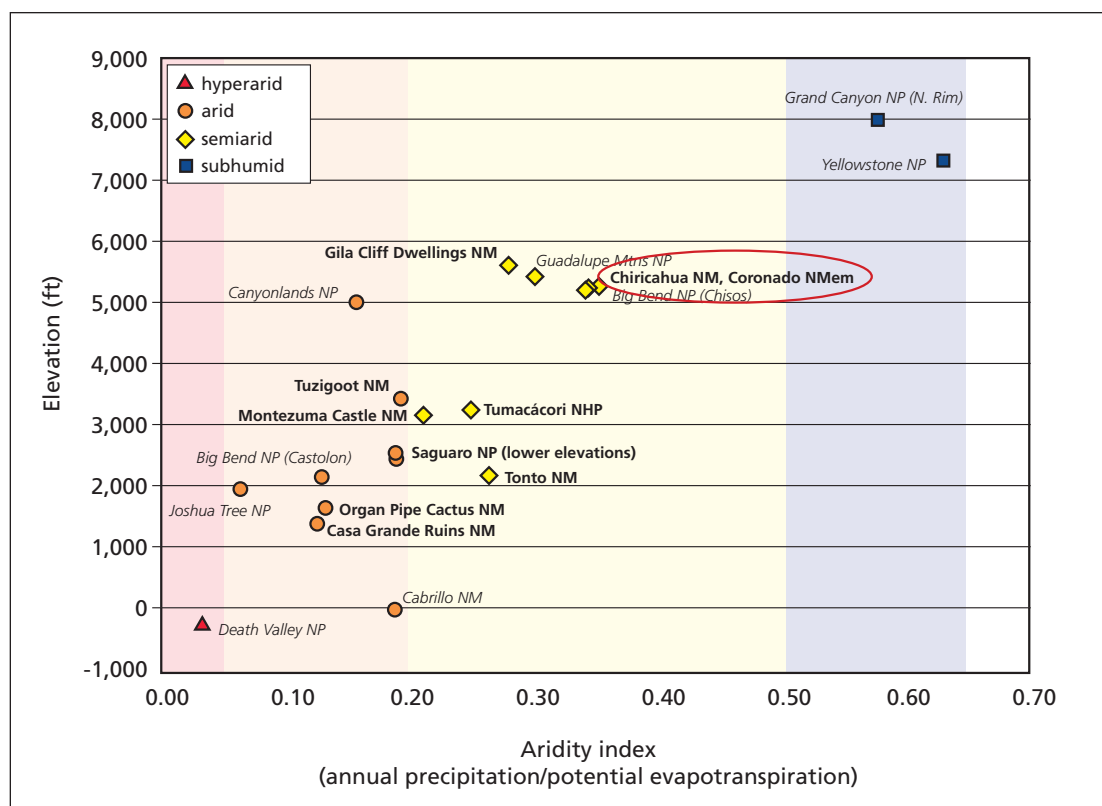


Figure 2-4. Aridity index and elevation of selected southwestern national parks, including Chiricahua National Monument and Coronado National Memorial. Figure from Hubbard and others (in prep).

2.2 Results and discussion

2.2.1 Data quality

Data quality at Chiricahua NM was good during WY2019. The RAWS station had missing values on two days and the Davis station had missing values on seven days. The COOP station had missing precipitation values on 39 days, primarily due to the 35-day government shutdown in December and January.

At Coronado NMem, data quality for the COOP station and USDA rain gages was fair, with missing values on 26–41 days at the three stations. The government shutdown contributed to missing values at the COOP station. The Davis stations at Coronado NMem and Fort Bowie NHS had missing values on 251 days and 275 days, respectively. Climate results for these two stations will not be discussed in this report.

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

Chiricahua National Monument—. At Chiricahua NM, daily data from the adjacent RAWS station were used to estimate precipitation at the COOP station in December and January. Overall annual precipitation at the COOP station was estimated to be normal (20.77" vs 20.70") (Figure 2-5). The RAWS and Davis stations received less rain (17.59" and 13.32", respectively) (Figure 2-6).

Coronado National Memorial—. At the Coronado NMem COOP station, total annual precipitation was also near normal (21.87" vs 21.95") (Figure 2-7). However, the annual total may be underestimated due to missing data. Total annual rainfall at USDA rain gages 406 and 419 was 16.89" and 18.64", respectively.

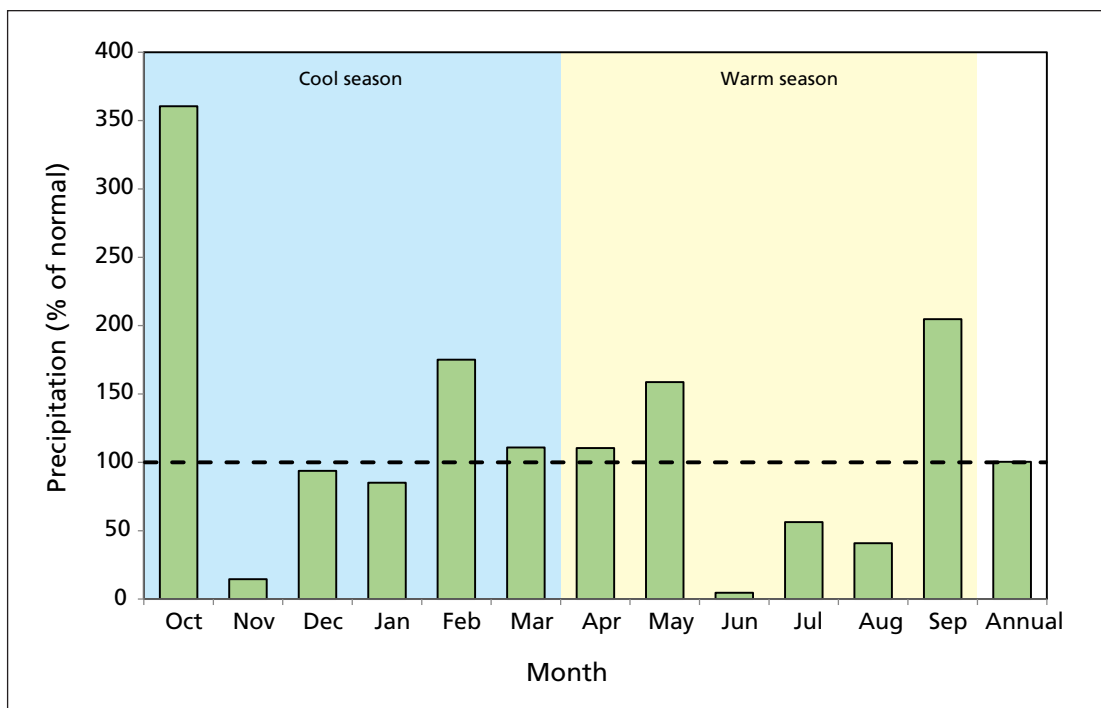


Figure 2-5. Departures from 30-year (1981–2010) normal precipitation, NOAA COOP station at Chiricahua National Monument, WY2019. Missing daily precipitation data in December and January were supplemented with data from the collocated RAWS station.

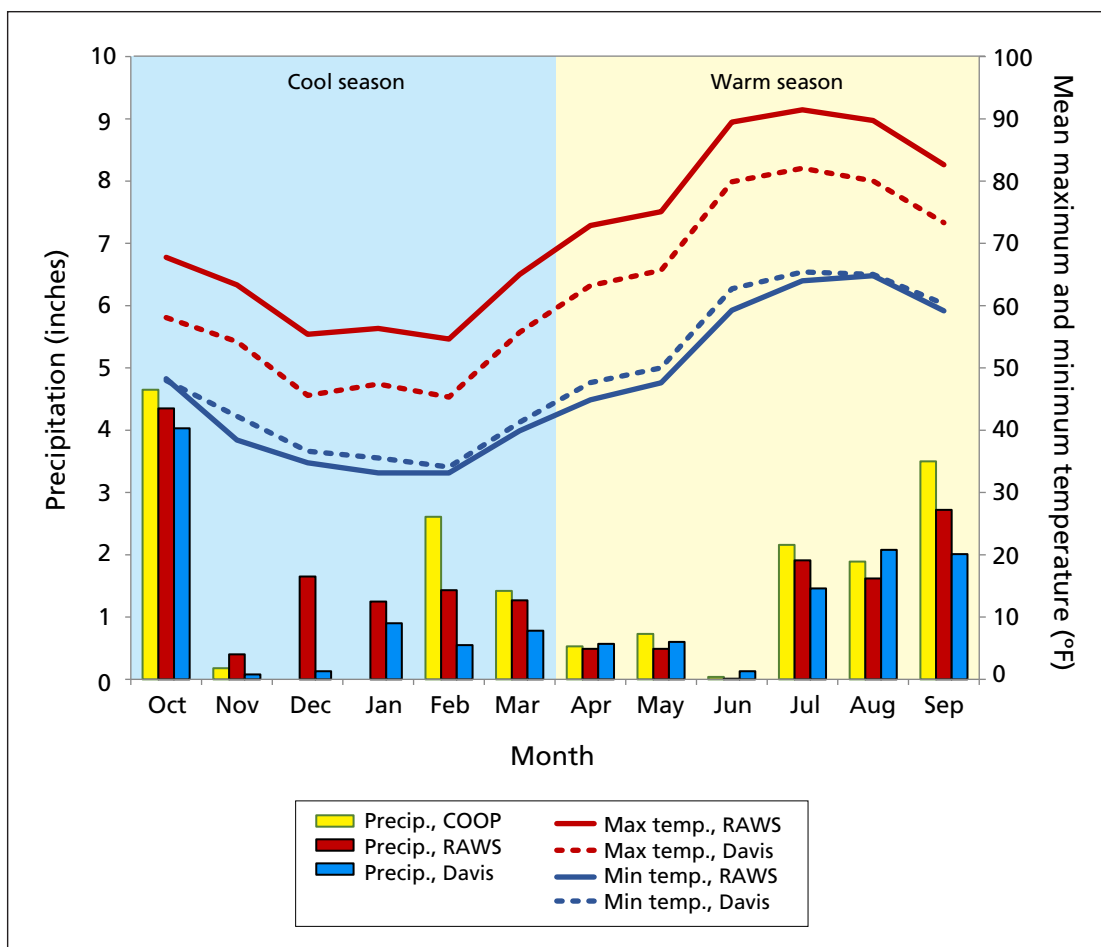


Figure 2-6. Monthly precipitation and mean monthly maximum and minimum air temperatures at the COOP, RAWS, and Davis stations, Chiricahua National Monument, WY2019. Missing daily precipitation data in December and January at the COOP station were supplemented with data from the collocated RAWS station.

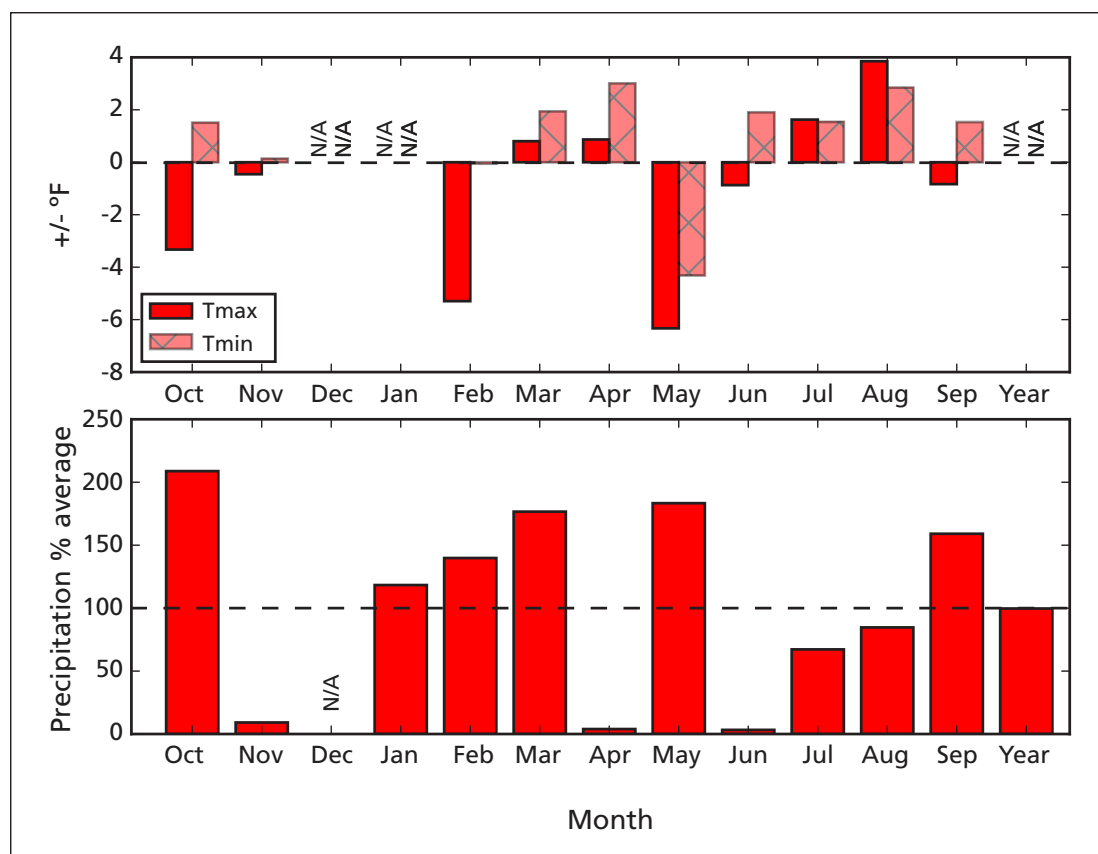


Figure 2-7. Departures from 30-year (1981–2010) normal minimum and maximum air temperature and precipitation, NOAA COOP station at Coronado National Memorial, WY2019. "N/A" = insufficient data to generate reliable estimates. Graphics generated by climateanalyzer.org (Walking Shadow Ecology 2021d).

2.2.2.1 Cool season (October–March) *Chiricahua National Monument*—

Precipitation at the Chiricahua NM COOP station was above normal (137%, +3.22") for the fall and winter of WY2019. October received more than three times its normal rainfall (see Figure 2-5), due to a series of moderate rain events. November was extremely dry compared to normal (15%, -1.06"). The higher-elevation Davis station received less rain in most months than the lower-elevation COOP and RAWS stations (see Figure 2-6).

At the RAWS station, mean monthly minimum air temperatures were generally 0–4°F warmer, and mean monthly maximum air temperatures were 9–10°F warmer, than at the Davis station. The historic record from the COOP station indicates mean minimum temperatures are normally below freezing in December and January. However, the mean monthly minimum temperatures at both the RAWS and Davis stations were not below freezing in any month.

Coronado National Memorial—. Precipitation at the Coronado NMem COOP station was also above normal (120%, 1.87") for the fall and winter of WY2019 (see Figure 2-7). October and March were approximately twice as wet as normal. November received less than one-tenth of the normal rainfall. Missing data for December prevented comparison to normal. The USDA rain gages demonstrated the same overall pattern as the COOP station, but recorded less total rain each month, with one notable exception. On March 14, the COOP station and USDA gage 406 recorded no rain, but gage 419 recorded 4.17", likely representing an error. Excluding that single daily reading, the cool-season precipitation was 6.98" at gage 419 and 7.72" at gage 406, compared to 11.02" at the COOP station (Figure 2-8).

Mean maximum temperatures were cooler than normal in October and February. November and March were within 1°F of normal. Mean monthly minimum temperatures were mildly warmer than normal, up

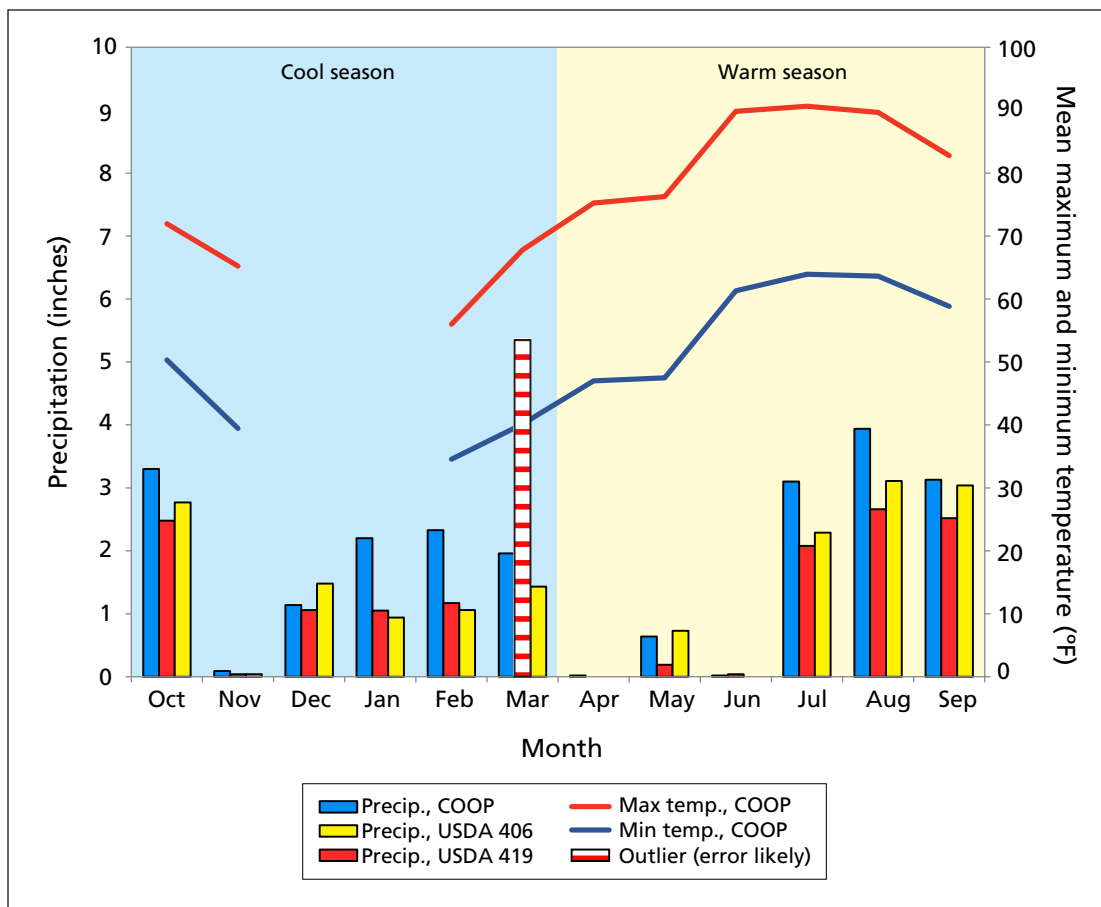


Figure 2-8. Monthly precipitation and mean monthly maximum and minimum air temperatures at the NOAA COOP station and USDA rain gages 406 and 419, Coronado National Memorial, WY2019. Precipitation at the COOP station in December may be underestimated due to missing data.

to +1.9°F. Temperature data were missing for December and January.

2.2.2.2 Warm season (April–September) Chiricahua National Monument—

Precipitation at the Chiricahua NM COOP station was below normal (74%, -3.15") for the spring and summer months in WY2019 (see Figure 2-5). A very dry June led into a weak monsoon season. September was twice as wet as normal, due in part to storms associated with residual moisture from Hurricane Lorena. During the warm season, the higher-elevation Davis station recorded substantially less rainfall than the lower-elevation COOP and RAWS stations (6.85", compared to 8.85" and 7.24", respectively) (see Figure 2-6).

The warm-season temperature differential between the RAWS and Davis stations was similar to the cool season: mean monthly minimum air temperatures were 0–3°F cooler, and mean monthly maximum air

temperatures were 9–10°F warmer, at the RAWS station than at the Davis station.

Coronado National Memorial— Precipitation at Coronado NMem was also below normal (85%, -1.95") for the spring and summer months in WY2019 (see Figure 2-7). A rare May storm led to nearly twice as much rain for the month as normal. June was very dry, leading into a less-intense monsoon season than normal. Thirty-four days in July and August had rain, but the daily totals were generally small: half were ≤0.1". Warm-season precipitation was 9.17" at USDA gage 406 and 7.49" at USDA gage 419, compared to 10.85" at the COOP station (see Figure 2-8).

Mean monthly maximum and minimum air temperatures at the COOP station were variable in the warm season. May temperatures were particularly colder (-6.3°F and -4.3°F, respectively) than normal. August temperatures exhibited the warmest departure from

normal, at +3.8°F (max) and +2.9°F (min), respectively.

2.2.3 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).

Chiricahua National Monument—. From the perspective of both precipitation and evaporative demand, the RDI for the RAWS station indicated that Chiricahua NM experienced slightly wetter conditions in WY2019 than the average for WY1996–2019 (Figure 2-9). The five-year moving mean of total annual precipitation at the COOP station from 1981 to 2019 (Figure 2-10) suggests the park has been experiencing a multi-year precipitation deficit since 2002.

Coronado National Memorial—. The RDI for Coronado NMem in WY2019 could not be calculated due to missing data (mostly air temperature). However, the RDI indicated slight drought conditions during the two previous years compared to the average for WY1981–2019 (Figure 2-11). The five-year moving mean of total annual precipitation indicated a slight multi-year precipitation deficit relative to the mean for WY1981–2019 (Figure 2-12).

2.2.4 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. High air temperatures are a defining feature of warm deserts (Strahler 2013). However, extreme heat events can also have important consequences for ecosystems. For example, sustained warm temperatures increase evapotranspiration rates, decreasing the availability of water for plants and wildlife. Extreme precipitation events can also cause localized flooding

and erosion events, enhance or inhibit plant productivity and reproduction, and modify animal behavior (Sumner 1988). We define extreme weather events as follows: “extremely warm” days have maximum temperatures that exceed the 95th percentile (P95) of 1981–2010 data. “Extremely cold” days have minimum temperatures that do not reach the 5th percentile (P5) of 1981–2010 data. “Extreme precipitation events” are days with >1 inch of precipitation.*

Chiricahua National Monument—. The COOP station at Chiricahua NM recorded two days with extreme precipitation (>1"), less than the normal frequency (3.7 ± 0.4 days for 1981–2010). However, the RAWS station recorded three days with extreme events. The discrepancy between the collocated RAWS and COOP stations was in part due to different reporting times of daily measurements, and different monitoring methods. Extreme events occurred at the COOP station on October 8 (1.26") and July 18 (1.07"). Extreme precipitation events at the RAWS station occurred on October 7 (1.07"), July 17 (1.00"), and September 24 (1.28"). The Davis station recorded only one extreme precipitation event, on September 24 (1.17").

Coronado National Memorial—. Extremely cold days at Coronado NMem (<26°F, P5 of 1981–2010 data) occurred half as frequently (8 vs. 15.8 ± 1.1 days) as normal in WY2019. Extremely warm days (>94°F, P95 of 1981–2010 data) also occurred less frequently (10 vs. 17.6 ± 3.5 days) than normal. The COOP station at Coronado NMem recorded five days with extreme precipitation (>1"), slightly more than the normal frequency (4.2 ± 0.4 days for 1981–2010). Extreme events occurred on October 12 (1.26"), March 12 (1.31"), August 31 (1.34"), September 24 (1.09") and September 25 (1.29"). Excluding the likely outlier in March, USDA rain gage 419 recorded only one extreme event, on September 24 (1.23"). Gage 406 recorded four extreme events: October 12 (1.33"), March 12 (1.25"), August 23 (1.16"), and September 24 (2.25").

*For RAWS, Davis, and USDA stations, a “day” is a 24-hour period starting and ending at midnight. For COOP stations, it is generally a 24-hour period starting and ending around 8 am, when staff arrive to record the data.

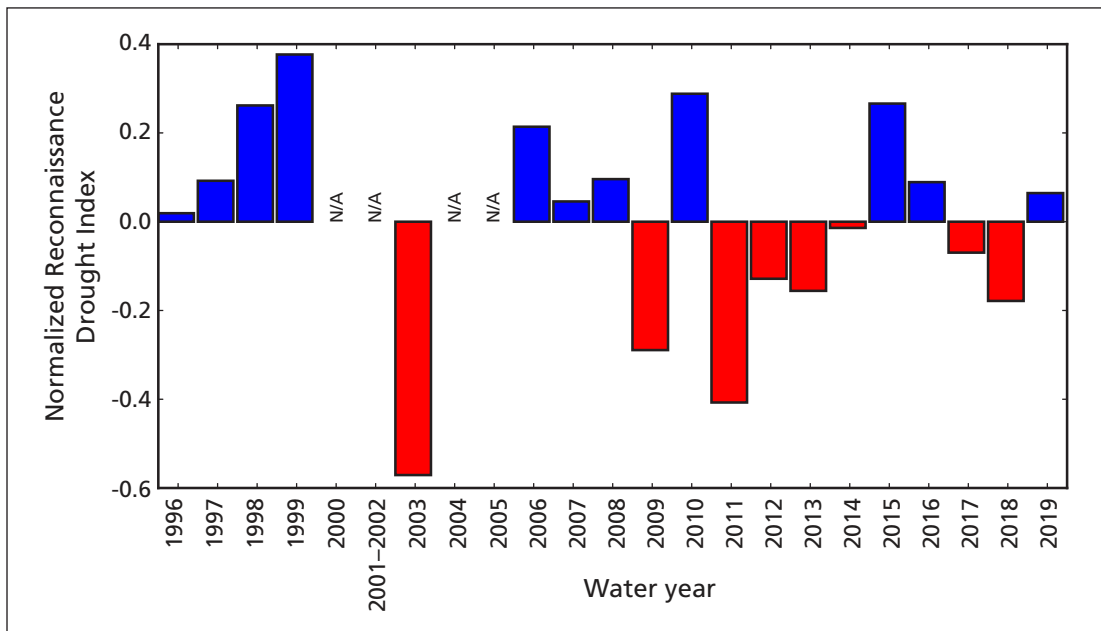


Figure 2-9. Reconnaissance drought index for the RAWS station at Chiricahua National Monument, WY1996–2019. “N/A” = insufficient data to generate reliable RDI estimates. Graphics generated by climateanalyzer.org (Walking Shadow Ecology 2021b).

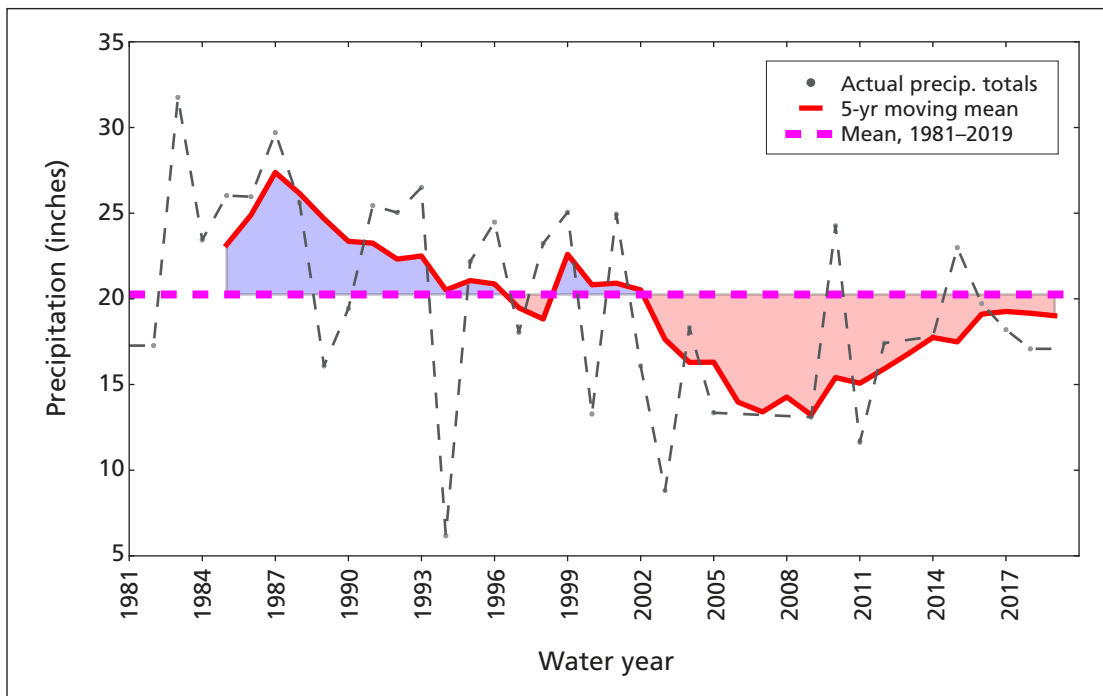


Figure 2-10. Five-year moving mean of annual precipitation for the NOAA COOP station at Chiricahua National Monument, WY1981–2019. The moving mean (solid red line) is based on a timeseries with 15.4% (6 of 39) missing values, and includes the current year and previous four years. Blue and red fields represent water surplus and deficit, respectively. Grey dots represent actual precipitation totals with missing years linearly interpolated (dashed grey lines). Graphics generated by climateanalyzer.org (Walking Shadow Ecology 2021a).

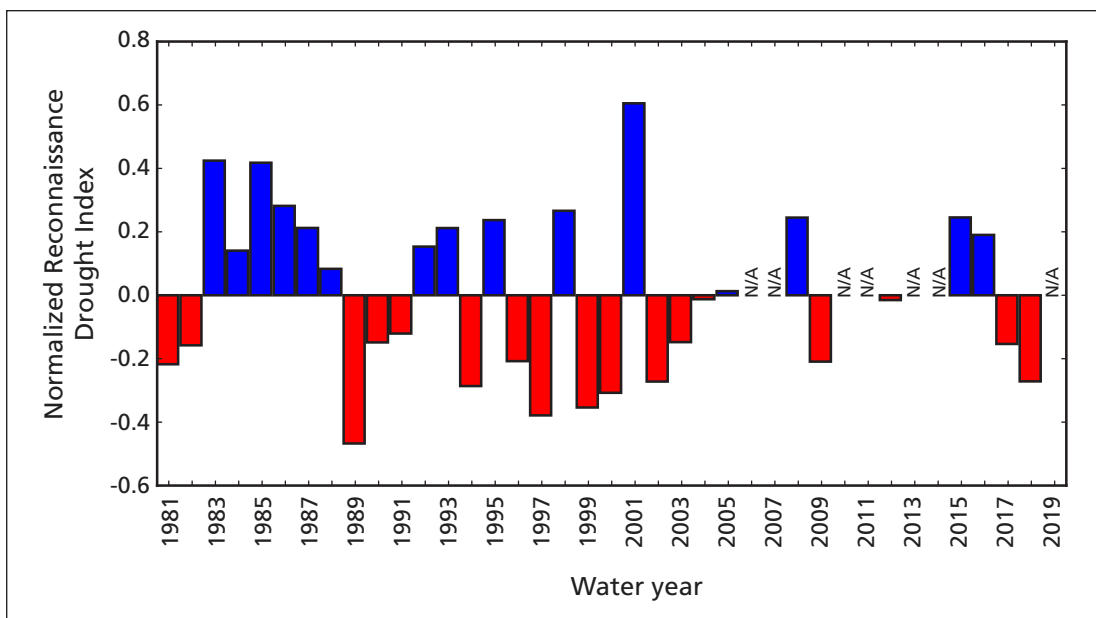


Figure 2-11. Reconnaissance drought index for Coronado National Memorial, WY1981–2019. “N/A” = insufficient data to generate reliable RDI estimates. Graphics generated by climateanalyzer.org (Walking Shadow Ecology 2021d).

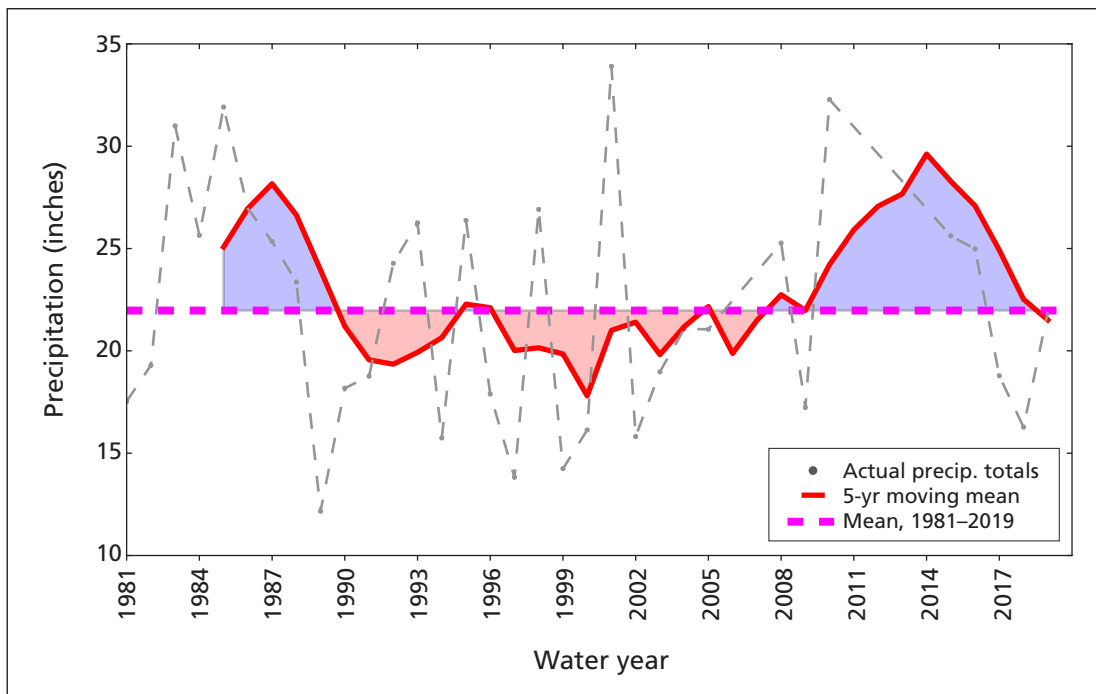


Figure 2-12. Five-year moving mean of annual precipitation, Coronado National Memorial, WY1981–2019. The moving mean (solid red line) is based on a timeseries with 15.5% (6 of 39) missing values, and includes the current year and previous four years. Blue and red fields represent water surplus and deficit, respectively. Grey dots represent actual precipitation totals with missing years linearly interpolated (dashed grey lines). Graphics generated by climateanalyzer.org (Walking Shadow Ecology 2021d).

3 Groundwater

3.1 Background

Groundwater is one of the most critical natural resources of the American Southwest. It provides drinking water, irrigates crops, and sustains rivers, streams, and springs throughout the region. Groundwater is closely linked to long-term precipitation and surface waters, as ephemeral flows sink below ground to reappear months, years, or even centuries later as perennial and intermittent streams and springs. Groundwater also sustains vegetation 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.

The three Southeast Arizona NPS units are within the Basin and Range province, characterized by steep mountain ranges separated by wide valleys. Generally, precipitation runs off the impervious mountains, flowing toward the central valleys. Groundwater is primarily found in the basin-fill deposits and, to a lesser extent, stream alluvium (ADWR 2009). The movement and storage of water within fractures is dependent on the unique geology at each park unit. Groundwater is recharged primarily through mountain-front recharge originating as winter precipitation (ADWR 2009). Evapotranspiration, pumping, and spring flow contribute to groundwater discharge. Groundwater levels at the park units may also be affected by withdrawals made throughout the groundwater basins.

3.1.1 Chiricahua National Monument

Chiricahua NM lies mainly within the Willcox groundwater basin, with a small northeast portion in the Safford groundwater basin. Groundwater storage occurs within fractured rock and the alluvium of the canyon bottoms (Dimmitt et al. 2015). A majority of the park is covered by Rhyolite Canyon Tuff, a thick, multi-layered, volcanic-ash deposit caused by several major eruptions of the Turkey Creek caldera. The tuff contains joints and fractures that formed as

the tuff cooled and contracted (Pallister et al. 1997). Erosion caused by water flowing through these joints, in addition to wind erosion, frost wedging from freezing and thawing cycles, plant-root wedging, and lichen weathering, created the rock formations characteristic of the park (Bezy 2001, Graham 2009). Within the Rhyolite Canyon Tuff are less-permeable, densely welded tuff layers (Pallister and du Bray 1997) that may laterally divert water either to a surface exposure, resulting in a spring, or to a fracture, resulting in deeper infiltration (C. Filippone, pers. comm. 2018).

Snowmelt appears to account for 60% of the groundwater recharge at Chiricahua NM, despite accounting for only 30% of annual precipitation (Earman et al. 2006). The slow percolation of winter precipitation through the fractures and alluvium can saturate the alluvium storage, creating the intermittent pools and flowing reaches often present in the canyon bottoms. High-intensity storms, characteristic of summer precipitation, are more likely to run off and be lost to evapotranspiration, decreasing the recharge rate.

3.1.2 Coronado National Memorial

Coronado NMem lies primarily within the Upper San Pedro groundwater basin, with a thin part of its western side in the San Rafael groundwater basin. The complex geology of Coronado NMem was created by eruptions from the Montezuma caldera and two major deformation processes (Graham 2011a). The west and north-central parts of the park are characterized by steep mountain slopes that are generally impermeable. Groundwater storage in the mountains is limited. Precipitation on these slopes generally runs off, and is conveyed by the drainages to the valley in the southeastern part of the park, characterized by fan terraces composed of basin-fill alluvium (Dimmitt et al. 2015). Two faults run northwest-to-southeast, with a third fault trending southwest-to-northeast across the bedrock outcrop. Former Intermountain Region hydrologist Colleen Filippone proposed that these faults continue beneath the alluvium in the southeastern part of the park, creating step-like fault blocks of bedrock. Groundwater pools on the blocks until

it rises high enough to overflow downward to the next fault block (Dimmitt et al. 2015). This may regulate groundwater level at some locations.

3.1.3 Fort Bowie National Historic Site

Fort Bowie NHS lies mainly within the Safford groundwater basin, with a small portion on the west side within the Willcox basin. Groundwater at Fort Bowie NHS is primarily stored in fractures of the Apache Pass fault zone, located on the eastern third of the park (Graham 2011b). The faults generally run from northwest to southeast. The fault zone consists of highly fractured rock layers dominated by limestone, sandstone, siltstone, and conglomerate (Graham 2011b). The geology west of the fault zone is composed of impermeable granodiorite with few faults.

3.2 Methods and monitoring wells

Groundwater measurements are generally expressed in terms of depth-to-water (feet below ground surface) or water-level elevation (feet above mean sea level). Water-level elevation, which is equal to the land-surface elevation minus depth-to-water, allows direct comparison across multiple wells. Detailed information on monitoring methods may be found in the SODN groundwater monitoring protocol (Filippone et al. 2014).

3.2.1 Chiricahua National Monument

Three wells have been monitored in Chiricahua NM since 2007 (see Figure 2-1 and Table 3-1). All three wells were constructed in the shallow alluvium of Bonita Creek. However, each well also likely intercepts

deeper water-bearing zones below the alluvium. Campground-1 was the park’s potable water supply until 2000, when Campground-2 was constructed nearby to meet new construction and treatment standards. Campground-2 is not monitored. Park staff monitor the Campground-1 and Headquarters wells monthly to quarterly. Park staff monitored the Faraway Ranch well until 2016, when the Arizona Department of Water Resources (ADWR) instrumented the well. Automated measurements are now collected every six hours, and ADWR collects manual measurements biannually. ADWR data for Faraway Ranch are available at <http://gisweb.azwater.gov/gwsi/Detail.aspx?SiteID=320029109221601>.

3.2.2 Coronado National Memorial

Of the 23 wells at Coronado NMem, six are currently monitored (see Figure 2-2 and Table 3-2). Wells chosen for monitoring are vital to park operations or representative of a group of wells for characterizing groundwater status. The Headquarters well, located in the alluvium of Montezuma Canyon, was previously used as the park’s water supply. A debris flow in 2006 damaged the water infrastructure and led to the construction of WSW-2 on the foothills of Montezuma Peak in 2008. Both wells were used for the park’s water supply from 2009 until 2015, when WSW-2 became the sole source of water for the park.

The remaining four monitoring wells are located on the fan terraces of the bajada and access different fault blocks. Baumkirchner #3 is a shallow well, likely accessing an upper block. X-2 represents the group of wells in the Montezuma Ranch area that access

Table 3-1. Groundwater wells monitored at Chiricahua National Monument.

Name	State registration number/GWSI number ^A	Year completed	Total depth (ft)	Wellhead elevation (est. ft)	Monitoring frequency
Campground-1	629082/320038109211901	1962	116	5,340.50	4–12× per year (manual)
Headquarters	629081/320032109215701	1956	78	5,256.00	4–12× per year (manual)
Faraway Ranch	629083/320029109221601	1979	120	5,216.13	2× per year (manual) 6× per day (automated)

^AGroundwater Site Inventory

Table 3-2. Groundwater wells monitored at Coronado National Memorial.

Name	State registration number/GWSI number ^A	Year completed	Total depth (ft)	Wellhead elevation (est. ft)	Monitoring frequency
WSW-2	909747/not applicable	2008	685	5,454.74	4× per year (manual)
Headquarters	629139/not applicable	1959	98	5,272.21	4× per year (manual)
Baumkirchner #3	629137/312044110141901	1969	124	5,100.00	4× per year (manual) 6× per day (automated)
X-2	509098/not applicable	1984	320	5,029.54	4× per year (manual)
ACA-2	509095/312048110134201	1984	340	4,986.59	4× per year (manual) 6× per day (automated)
Border	629142/312015110135800	1975	758	4,940.00	1× per year (manual) 6× per day (automated)

^AGroundwater Site Inventory

an intermediate block. ACA-2 represents the group of wells in the Montezuma Ranch area that access a lower block. The Border well is likely accessing the lowest fault block of any well.

Except for Baumkirchner #3, NPS staff monitor all wells quarterly. U.S. Geological Survey (USGS) staff has monitored Baumkirchner #3 since 2000, using automated and manual methods. USGS data for Baumkirchner #3 are available at https://waterdata.usgs.gov/nwis/dv/?site_no=312044110141901&agency_cd=USGS&referred_module=sw.

3.2.3 Fort Bowie National Historic Site

One well at Fort Bowie National Historic

Site is monitored quarterly, WSW-2 (ADWR 582902). Two other wells have been infrequently monitored: WSW-3 (ADWR 912051) and Siphon Canyon (ADWR 629136) (see Figure 2-3 and Table 3-3). Siphon Canyon was the park's water supply from 1992 until 2002, when WSW-2 was brought online. The presence of iron-oxidizing bacteria in WSW-2 resulted in the construction of WSW-3 in 2010, which continues to serve as the park's water supply. The Siphon Canyon well has been inaccessible for monitoring since 2016. WSW-2 and WSW-3 are both completed in the Cintura Formation, composed of siltstone, shale, and sandstone (Graham 2011b). Siphon Canyon is completed in alluvium and Concha Limestone (Graham 2011b).

Table 3-3. Groundwater wells monitored at Fort Bowie National Historic Site.

Name	State registration number/GWSI number ^A	Year completed	Total depth (ft)	Wellhead elevation (est. ft)	Monitoring frequency
WSW-2	582902/not applicable	2000	220	4,601.75	4× per year (manual)
WSW-3	912051/not applicable	2010	220	4,598.99	infrequently
Siphon Canyon	629136/320905109263001	1966	102	4,371.51	inaccessible

^AGroundwater Site Inventory

3.3 Results

Data used for this section are considered preliminary. Caution should be exercised when interpreting the results.

3.3.1 Chiricahua National Monument

In WY2019, five manual measurements were made at the Campground-1 and Headquarters wells. There was a complete automated record for the Faraway Ranch well (Figure 3-1). Table 3-4 summarizes WY2019 results. The WY2019 mean water levels in the Campground-1 and Headquarters wells were similar to those of WY2018, while mean water level in the Faraway Ranch well was more than two feet higher in WY2019 than in WY2018. Overall, groundwater in the three wells has been stable, with seasonal variability likely caused by runoff events in Bonita Creek. Water elevations in the wells

generally follow the grade of Bonita Creek (Figure 3-2).

Water-level measurements at Campground-1 often may not represent static conditions. Many measurements at Campground-1 were made when Campground-2 was pumping or had recently been pumped. Monitoring records prior to WY2015 often note sounds of dripping water inside Campground-1, indicating that the pumping of Campground-2 caused water-level draw-down in Campground-1.

Field notes made at the Headquarters well show that when the water level is higher than 10.23 feet below ground surface (bgs), Bonita Creek, adjacent to the well, is flowing. Water-level measurements deeper than 11.21 feet bgs coincided with dry conditions or stagnant pools in Bonita Creek.

Table 3-4. Groundwater monitoring results at Chiricahua National Monument, WY2019.

Well	Mean elevation (feet amsl), WY2019 ^A	Depth-to-water				
		Mean feet bgs, WY2019 ^B	Difference in mean (+/- feet) from WY2018 ^C	Net difference (+/- feet) in mean from earliest water-level measurement (Year) ^C	Minimum feet bgs for monitoring record (Year)	Maximum feet bgs for monitoring record (Year)
Campground-1	5,313.86	26.64	+0.28	+2.93 (2007)	22.96 (2010)	29.83 (2012)
Headquarters	5,245.55	10.45	-0.39	+1.09 (2007)	7.44 (2017)	12.82 (2012)
Faraway Ranch	5,201.88	14.15	+2.05	+2.82 (2007)	10.18 (2010)	17.82 (2009)

^A amsl = above mean sea level

^B bgs = below ground surface. Mean depth-to-water is calculated from automated data when available. Otherwise, manual data are used.

^C "+" indicates an increase in water level. "-" indicates a decline.

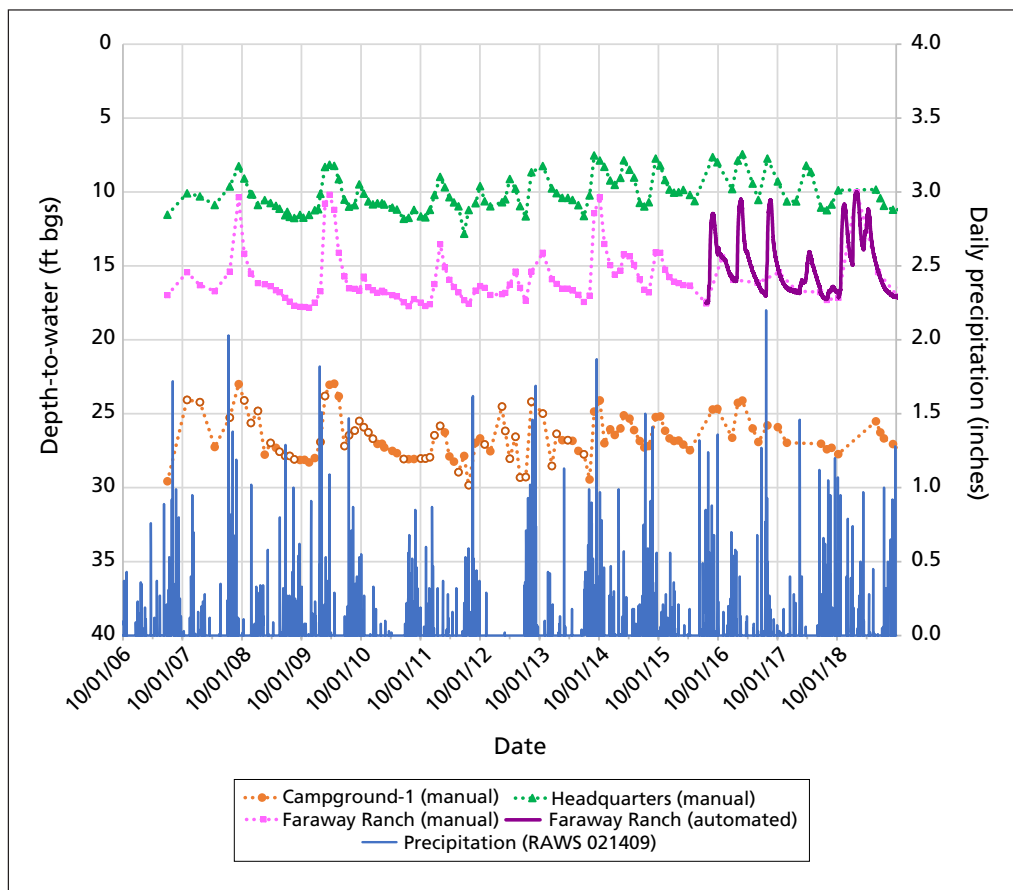


Figure 3-1. Depth-to-water measurements at three wells at Chiricahua National Monument, WY2007–2019, with daily precipitation from the RAWS station. White dots represent measurements taken when Campground-2 was actively pumping or recently pumped.

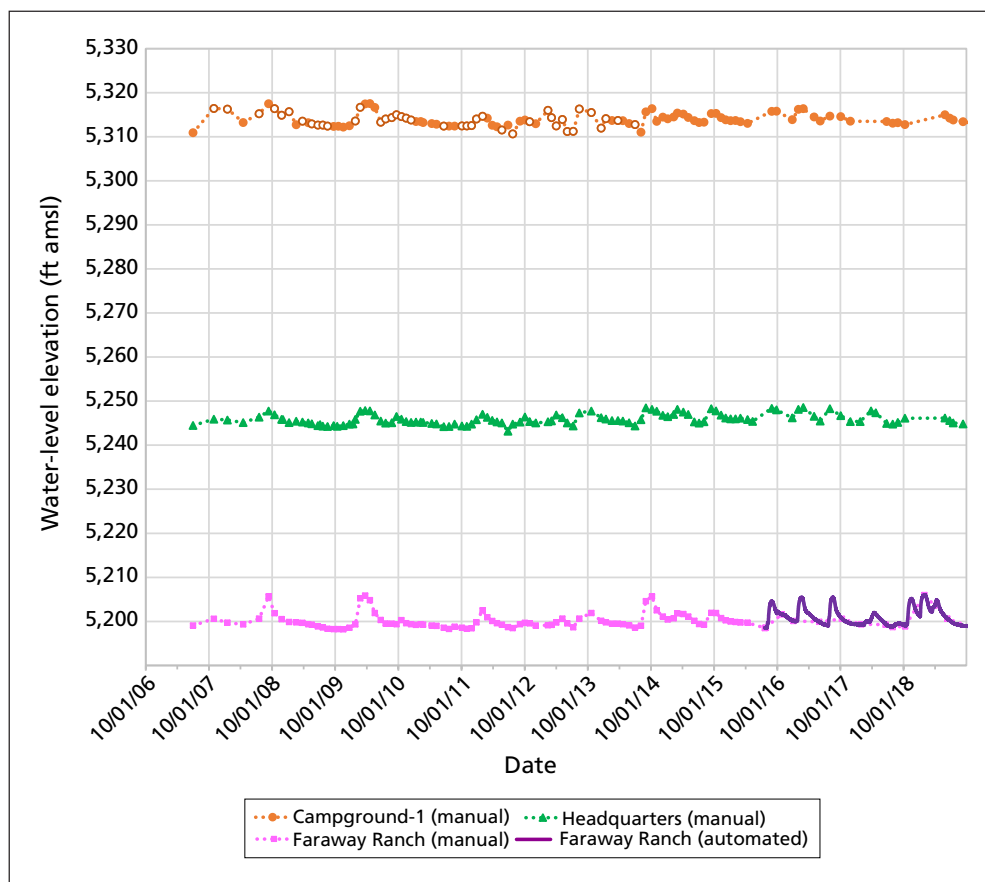


Figure 3-2. Water-level elevation at three wells at Chiricahua National Monument, WY2007–2019. White dots represent measurements taken when Campground-2 was actively pumping or recently pumped.

3.3.2 Coronado National Monument

Mean water level in all monitored wells showed a decline in WY2019 compared to WY2018, except for X-2, whose level slightly increased. Monitoring results for WY2019 at Coronado NMem are summarized in Table 3-5.

3.3.2.1 WSW-2

The mean depth-to-water at WSW-2 in WY2019 was 211.28 feet bgs. The last measurement, made on August 8, was 213.98 feet bgs, the lowest water level during the monitoring period that did not coincide with well pumping (Figure 3-3). Automated water-level readings were collected between June 2010 and August 2015, using a pressure transducer. These readings demonstrated that groundwater pumping can cause up to 119 feet of drawdown.

3.3.2.2 Headquarters well

Mean depth-to-water at the Headquarters well was 32.35 feet bgs in WY2019 (Figure 3-4). Water level in this well had a 43-foot range over the monitoring record, with the highest level occurring on October 30, 2007, when Montezuma Canyon Wash was flowing. The water level in Montezuma Canyon alluvium likely increases in response to precipitation and runoff in the channel.

3.3.2.3 Baumkirchner #3

Mean depth-to-water at Baumkirchner #3 was 33.67 feet bgs in WY2019. Water level has varied less than eight feet during the monitoring period, and shown a seasonal response to precipitation (Figure 3-5). The annual peak usually occurs in March or April, with a secondary peak following during the monsoon season. This indicates that low-intensity winter rains likely account for a larger proportion of groundwater recharge than monsoonal precipitation. Overall, water levels have showed a declining trend since WY2010.

3.3.2.4 X-2

Mean depth-to-water at X-2 was 148.01 feet bgs in WY2019, higher than WY2018 by 0.27 feet. However, a measurement made on May 15 appeared to be an outlier, indicating a water level approximately two feet higher than the previous and following measurements. This fluctuation was inconsistent with the data record, which demonstrates gradual changes in water level. It is unclear whether this measurement represented real conditions or an error on the part of the measurer. Excluding this measurement, the mean for WY2019 was 148.48 feet bgs, 0.20 feet lower than the mean for WY2018. Since 2002, water level has only varied 3.52 feet (Figure 3-6). This low variability is likely

Table 3-5. Groundwater monitoring results at Coronado National Memorial, WY2019.

Well	Mean elevation (feet amsl), WY2019 ^A	Depth-to-water				
		Mean feet bgs, WY2019 ^B	Difference in mean (+/- feet) from WY2018 ^C	Net difference (+/- feet) in mean from earliest water-level measurement (Year) ^C	Minimum feet bgs for monitoring record (Year)	Maximum feet bgs for monitoring record (Year)
WSW-2	5,243.46	211.28	-4.69	-17.31 (2008)	193.97 (2008)	321.69 (2010) (pumping)
Headquarters	5,239.86	32.35	-5.43	+11.65 (1959)	1.29 (2007)	44.54 (2004)
Baumkirchner #3	5,066.33	33.67	-0.11	-3.80 (1998)	29.87 (1998)	36.71 (2006)
X-2	4,881.54	148.01	+0.27	+0.30 (2002)	146.31 (2004)	149.83 (2010)
ACA-2	4,734.78	251.82	-10.39	-1.82 (1985)	222.17 (2009)	291.12 (2005)
Border	4,316.54	623.46	-0.02	+1.44 (1975)	621.85 (2014)	624.90 (1975)

^A amsl = above mean sea level

^B bgs = below ground surface. Mean depth-to-water is calculated from automated data when available. Otherwise, manual data are used.

^C "+" indicates an increase in water level. "-" indicates a decline.

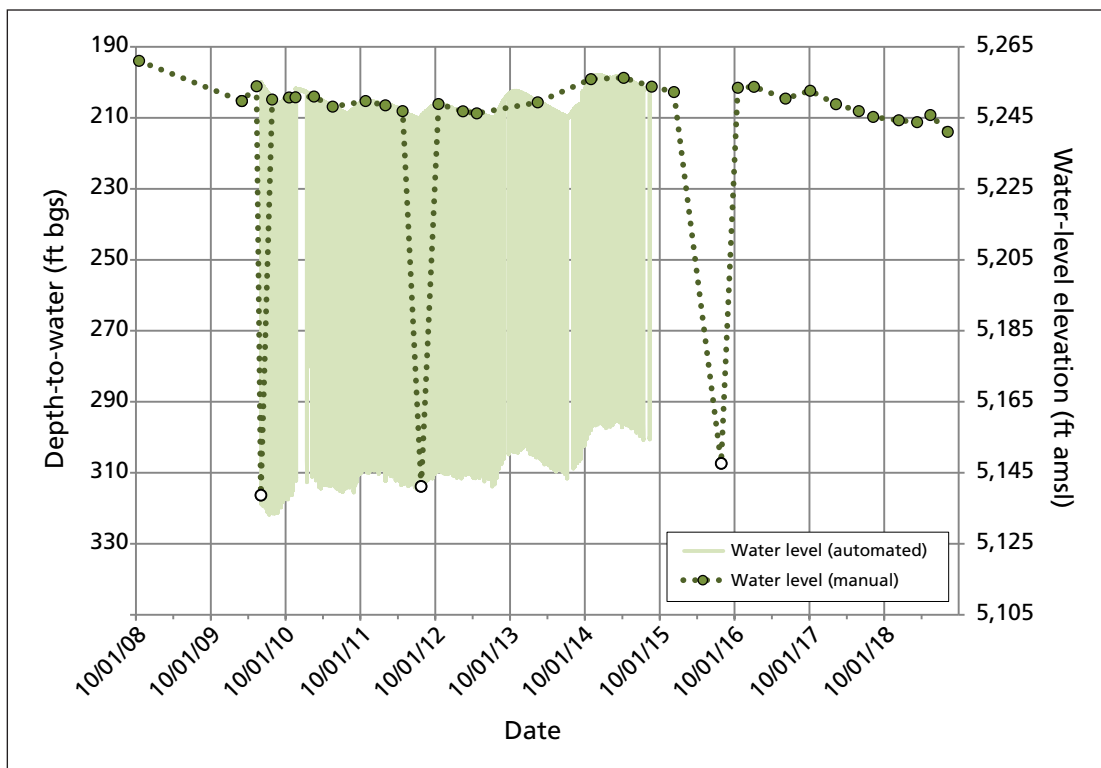


Figure 3-3. Depth-to-water and water-level elevation at WSW-2, Coronado National Memorial, WY2009–2019. White dots represent measurements taken when WSW-2 was actively pumping.

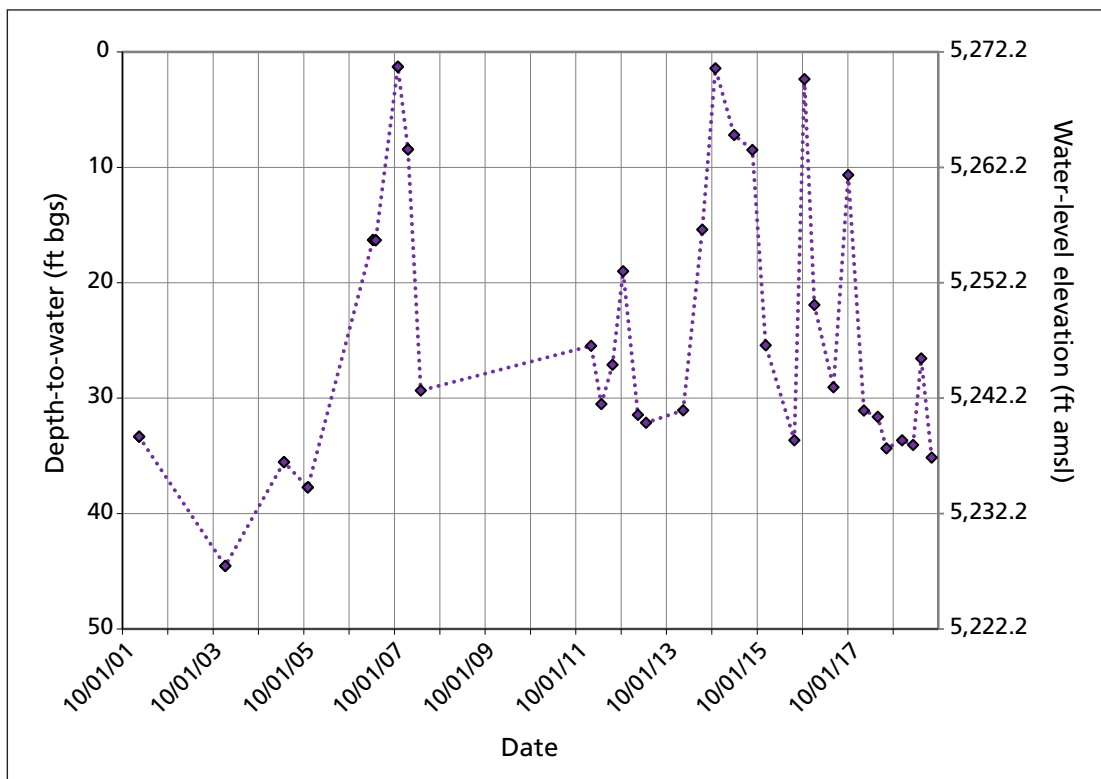


Figure 3-4. Depth-to-water and water-level elevation at the Headquarters well, Coronado National Memorial, WY2002–2019.

Figure 3-5. Depth-to-water, water-level elevation, and precipitation at Baumkirchner #3, Coronado National Memorial, WY1998–2019. Precipitation data are from COOP weather station #22140 (WY1998–2019).

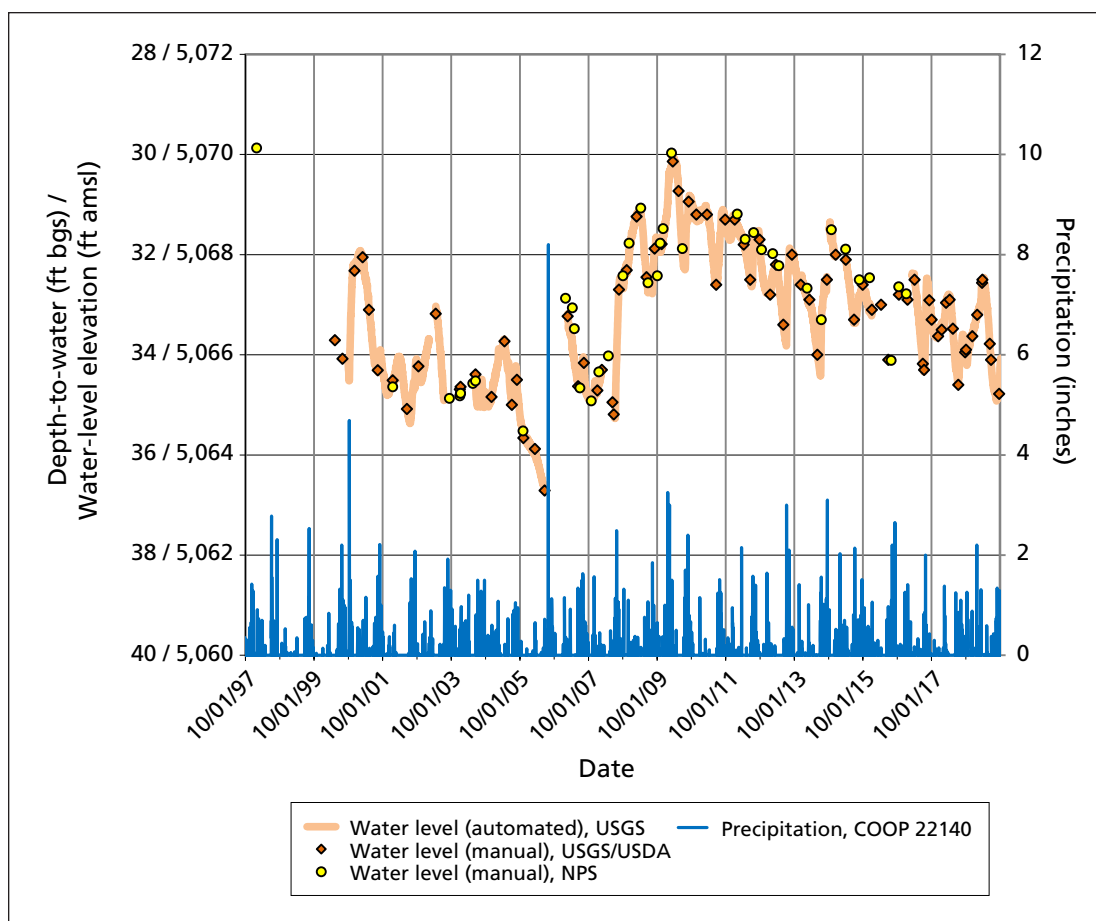
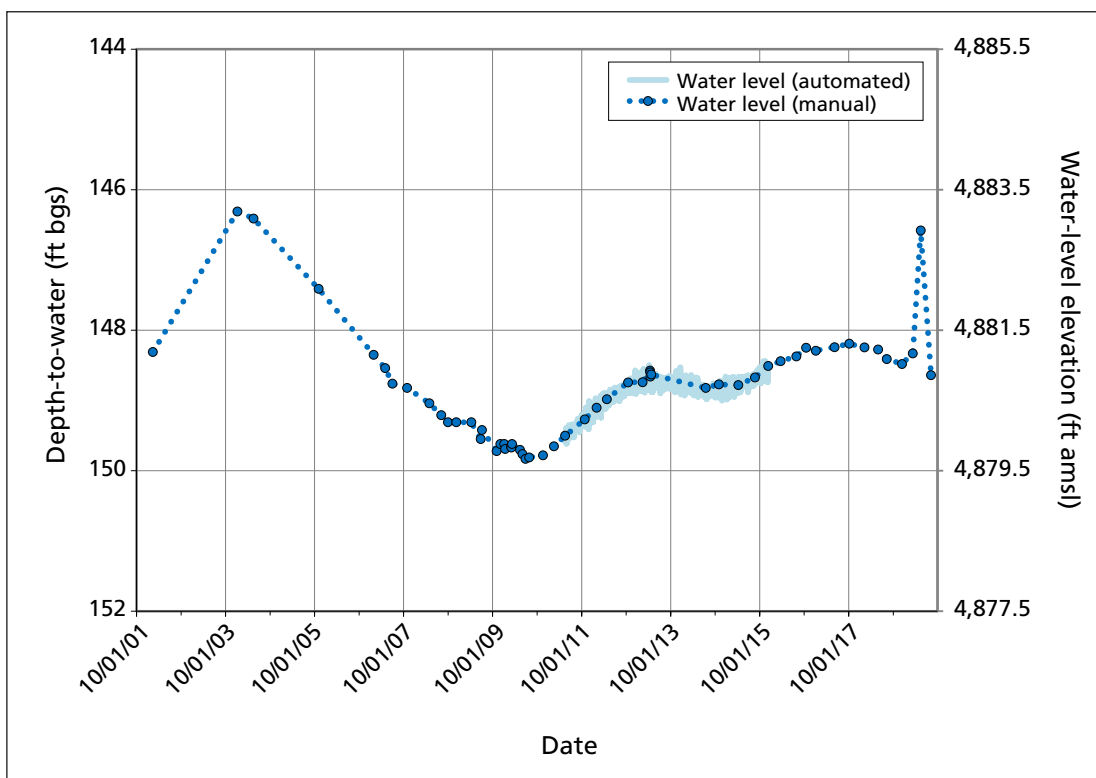


Figure 3-6. Depth-to-water and water-level elevation at X-2, Coronado National Memorial, WY2002–2019.



maintained by the alignment of the middle fault block, creating a water level at which groundwater overflows downward toward the lower fault block (C. Filippone, pers. comm. 2018).

3.3.2.5 ACA-2

Mean depth-to-water at ACA-2 was 251.82 feet bgs in WY2019, indicating a water-level decrease of more than 10 feet compared to WY2018. ACA-2 has varied nearly 69 feet over the monitoring record, which indicates substantial increases in water level during WY2007–2008 and WY2015–2016. The first increase was likely a delayed response to a large precipitation event of 8.20" on a single day in July 2006 (Figure 3-7). The cause of the second increase is less clear, but it occurred during three consecutive years of above-normal annual rainfall, WY2014–

2016. Rain events greater than 2.5", equivalent to a 2–5 year precipitation event (NOAA 2019), also appeared to coincide with minor water-level increases or reductions in the rate of decline. In the absence of these moderate-to-large events, groundwater level at ACA-2 has generally declined.

3.3.2.6 Border well

Depth-to-water at the Border well measured 623.46 feet bgs in WY2019. The limited monitoring record, starting in WY2014, indicates a gradual rate of decline with no apparent effect of precipitation, likely due to its depth (Figure 3-8). All results since WY2014 were higher than the depth-to-water collected when the well was constructed in 1975, indicating groundwater levels at this well increased between the time of construction and the start of routine monitoring.

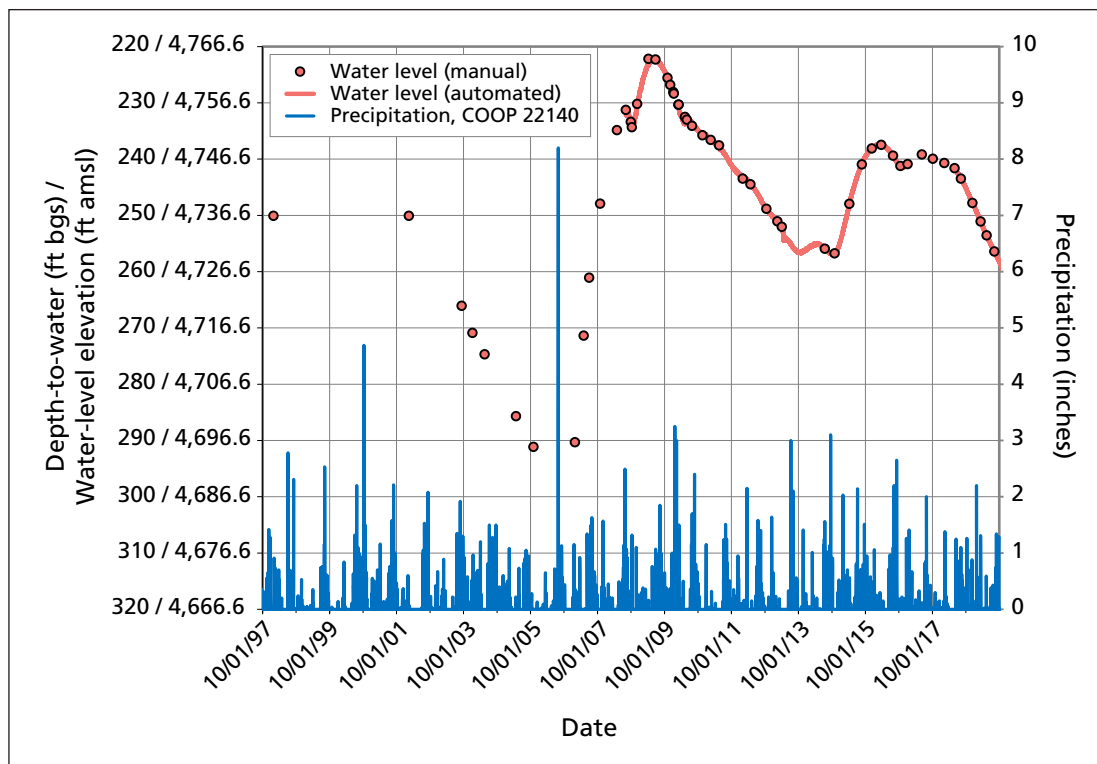


Figure 3-7. Depth-to-water, water-level elevation, and precipitation at ACA-2, Coronado National Memorial, WY1998–2019. Precipitation data are from COOP station 22140 (WY1998–2019).

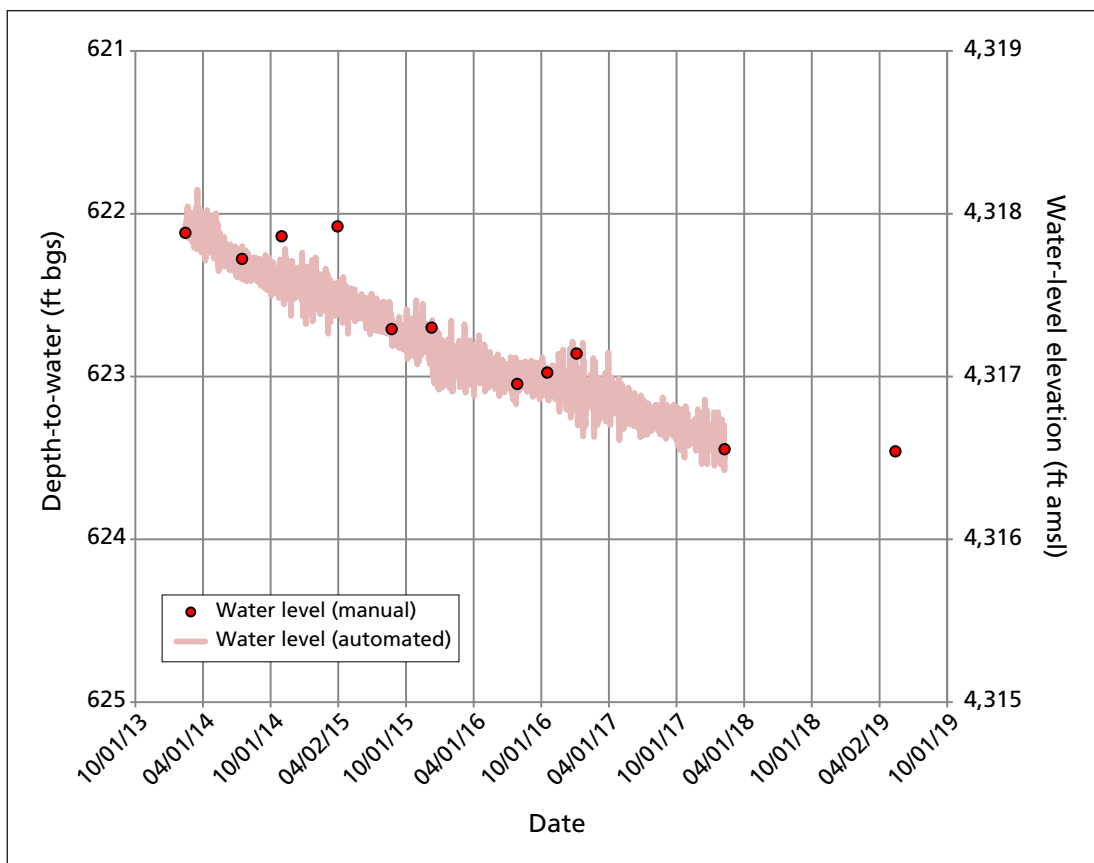


Figure 3-8. Depth-to-water and water-level elevation at the Border well, Coronado National Memorial, WY2014–2018.

3.3.3 Fort Bowie National Historic Site

Four groundwater measurements were made at WSW-2 in WY2019. Mean depth-to-water was 56.40 feet bgs, 0.58 feet higher than the mean for WY2018, and 3.17 feet higher than when monitoring began in WY2004 (Table 3-6). Overall, groundwater levels have been relatively stable, excluding temporary drops due to pumping. The high-

est water level in WSW-2 was observed in 2006, at 50.92 feet bgs (Figure 3-9). The lowest water level was observed during pumping in 2007, at 92.31 feet bgs. Historically, water-level elevation in WSW-2 and WSW-3 are similar, with water-level elevation in WSW-3 being consistently lower than WSW-2 (-0.12 to 0.98 feet) (Figure 3-10).

Table 3-6. Groundwater monitoring results at Fort Bowie National Historic Site, WY2019.

Well	Mean elevation (feet amsl), WY2019 ^A	Depth-to-water				
		Mean feet bgs, WY2019 ^B	Difference in mean (+/- feet) from WY2018 ^C	Net difference (+/- feet) in mean from earliest water-level measurement (Year) ^C	Minimum feet bgs for monitoring record (Year)	Maximum feet bgs for monitoring record (Year)
WSW-2	4,545.35	56.40	0.58	3.17 (2004)	50.92 (2006)	92.31 (2007)

^A amsl = above mean sea level

^B bgs = below ground surface. Mean depth-to-water is calculated from automated data when available. Otherwise, manual data are used.

^C "+" indicates an increase in water level. "-" indicates a decline.

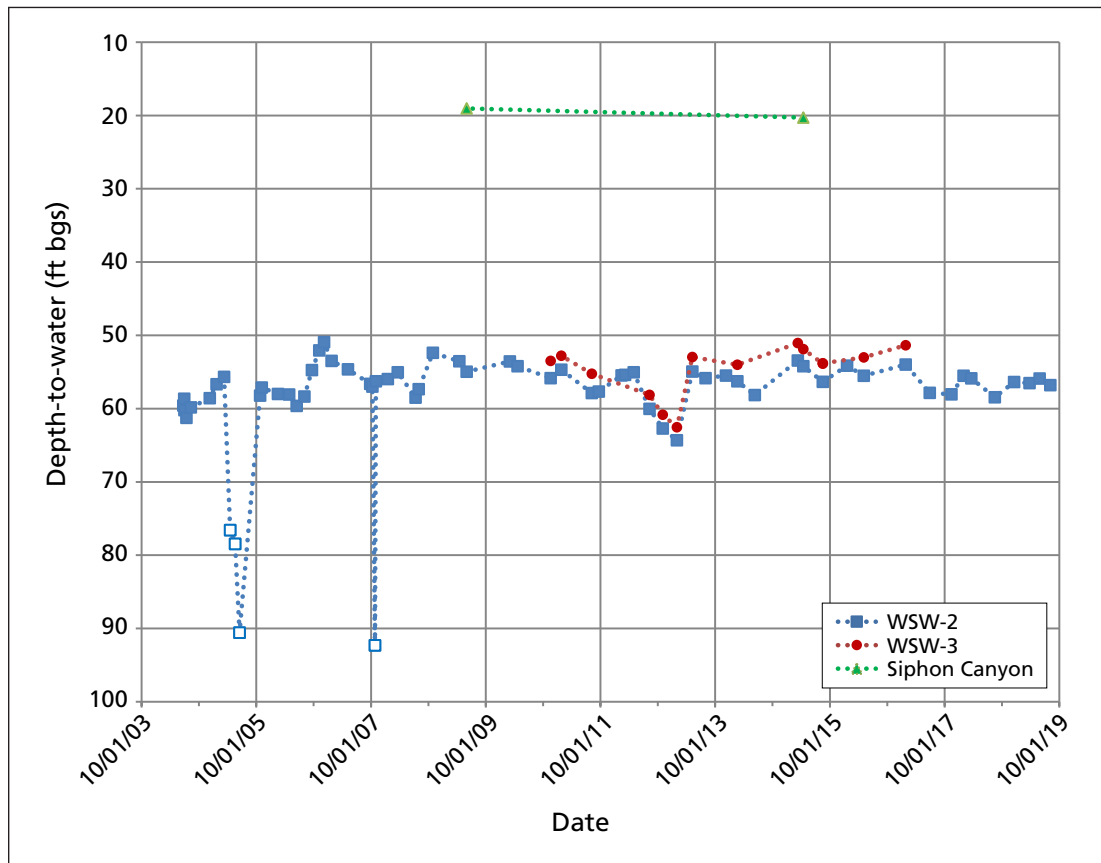


Figure 3-9. Depth-to-water measurements at three wells at Fort Bowie National Historic Site, WY2004–2019. White squares represent measurements taken when WSW-2 was actively pumping or recently pumped.

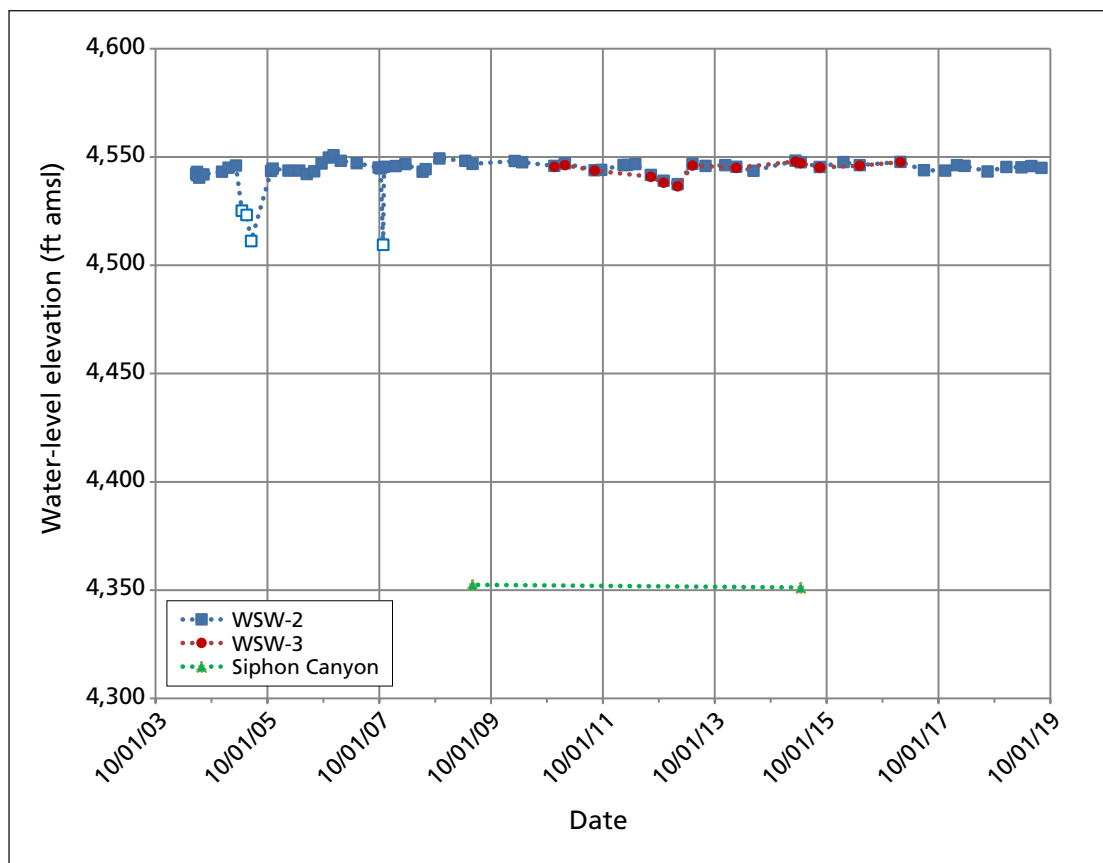


Figure 3-10. Water-level elevation at three wells at Fort Bowie National Historic Site, WY2004–2019. White squares represent measurements taken when WSW-2 was actively pumping or recently pumped.

4 Springs

4.1 Background

Spring, tinaja, and seep (hereafter “springs”) ecosystems are small, relatively rare biodiversity hotspots in arid lands. Their associated aquatic organisms and riparian vegetation 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. Anticipated changes include increased air temperatures, evaporation rates, and drought intensity; more frequent and extreme rainfall and heat events; and potentially reduced precipitation in the winter and spring (Hayhoe et al. 2018, Garfin et al. 2013). These changes may cause springs to experience reduced flow (Grimm et al. 1997, Weissinger et al. 2016) or even go dry (Comer et al. 2012, Dekker and Hughson 2014), which may disrupt ecological functions and reduce species diversity (Garfin et al. 2013).

4.2 Methods

The Sonoran Desert Network monitored nine “sentinel sites” (sites chosen based on representativeness or other criteria) at the Southeast Arizona group of parks in WY2019: Garfield Spring, Newton Cave Seep, Shake Spring, Silver Spur Spring, Fern Grotto, Blue Waterfall #2, Sparkes Spring, Apache Spring, and Lower Mine Spring (Table 4-1). This sampling design allows us to detect change and measure trend in selected parameters at a given spring site over time. It does not provide statistical inference across a park (McIntyre et al. 2018).

The Sonoran Desert Network monitors a suite of vital signs and parameters organized into four modules: site characterization, site condition, water quantity, and water quality. A brief description of data-collection methods is presented below. See McIntyre and others (2018) for additional details.

Data for the site-condition, water-quantity, and water-quality modules are collected annually (see Table 4-1), except for the persistence parameter (within the water-quantity module). Data on this parameter span the entire water year when possible. Data for the site-characterization module are collected every five years.

Table 4-1. Springs-monitoring dates, by module, for the most recent sampling period, Southeast Arizona units.

Park	Spring	Site condition, water quantity, and water quality	Site characterization
Chiricahua NM	Garfield Spring	April 17, 2019	WY2017
Chiricahua NM	Newton Cave Seep	April 18, 2019	WY2017
Chiricahua NM	Shake Spring	May 28, 2019	WY2017
Chiricahua NM	Silver Spur Spring	May 29, 2019	WY2017
Coronado NMem	Blue Waterfall #2	April 19, 2019	WY2017
Coronado NMem	Fern Grotto	April 20, 2019	WY2017
Coronado NMem	Sparkes Spring	April 19, 2019	WY2017
Fort Bowie NHS	Apache Spring	April 21, 2019	WY2017
Fort Bowie NHS	Lower Mine Spring	April 21, 2019	WY2017

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. It provides context for interpreting change in the other modules. Data collected for this module include spring type and characterization, GPS locations, a site diagram and site description, and a vegetation-community description. See McIntyre and others (2018) for additional details. This module was completed for springs at Chiricahua NM, Coronado NMem, and Fort Bowie NHS in WY2017. Data will be re-collected in WY2022. This report presents a condensed version of the information collected in the site-characterization module.

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 non-native plants and wildlife (McIntyre et al. 2018).

The disturbance assessment is a categorical measure of anthropogenic and natural disturbance and the level of stress on vegetation and soils in spring ecosystems (Sada and Pohlmann 2006). Types of anthropogenic disturbance include roads and off-highway vehicle trails, hiking trails, livestock, feral animals, removal of invasive non-native plants, flow modification, and contemporary human use (e.g., evidence of campsites, fire rings, or trash). Types of natural disturbance evaluated include flooding, drying, fire, wildlife, windthrow of trees and shrubs, beaver activity, and insect infestations. An “other” category is also included for both natural and anthropogenic disturbances. 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 (Sada and Pohlmann 2006). Results are reported as mean and median across all categories, with individual values of >1 described in the text.

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 picklist that identifies plants to the family, genus, or species level. The presence and density of invasive non-native plants is also recorded, with a goal of identifying them to the species level. The presence of bullfrogs and crayfish (potentially invasive non-native wildlife) is also recorded.

4.2.3 Water quantity

The water-quantity module provides information on spring persistence, discharge, and wetted extent. We estimate the persistence of surface water at springs by analyzing the variance of temperature measurements taken by electronic data recorders every one or two hours (Anderson et al. 2015). A sensor placed at or near the orifice (or in the deepest-possible part of a pool) is used to estimate presence of water. Because water mediates variation in diurnal temperatures, data from a submerged sensor will show less daily variation than data from an exposed sensor (Anderson et al. 2015). Days are marked as “wet” (water present) when the daily variance is less than 20°C on consecutive days. This method can yield both false wet and false dry estimates, and quality control/quality assurance procedures are yet to be developed.

A timed sample of water volume estimates the system’s surface discharge. Wetted extent provides information about the length (up to 100 m), width, and depth of water present. It is assessed using a technique for either standing water (e.g., limnocrone and heleocrone springs and some tinajas) or flowing water (e.g., rheocrone springs and some tinajas).

4.2.4 Water quality

Baseline water-quality monitoring includes core water-quality parameters and water chemistry. Core parameters 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) and a dissolved-oxygen meter (YSI ProODO) deployed on-site. Water chemistry is assessed by collecting surface water sample(s) and estimating the concentration of major ions with a photometer (YSI 9500) in the field.

4.3 Results

4.3.1 Chiricahua National Monument

4.3.1.1 Garfield Spring

Site characterization—. Garfield Spring (Figure 4-1) is a rheocrene spring (a spring that emerges as a flowing stream) on a north-facing backslope. When characterized in WY2017, orifice A emerged as a small pool adjacent to a tree-root overhang. The pool immediately transitioned to a narrow, intermittent springbrook with cool, clear water.

Site condition—. Disturbance surveys estimated a mean of 1.1 (undisturbed) for anthropogenic and 1.13 (undisturbed) for natural disturbance. Median values for both disturbance categories were 1 (undisturbed). A hiking trail leads to the site. Despite the ease of access, the spring was minimally impacted, with no extensive trampling, erosion, or trash. There was evidence of some wildlife grazing, resulting in little impact.

The crew observed one obligate/facultative wetland plant: sedge (*Carex* sp.). No invasive plants, crayfish or bullfrogs were observed.

Water quantity—. Temperature sensors indicated the spring was wetted for the entirety of the water year (Figure 4-2). Discharge from orifice A was estimated at 0.5 ± 0.5 L/minute. The wetted extent of Garfield Spring was surveyed as a flowing spring with a channel length of 121.4 feet (37 m). Width and depth averaged 18.9" (47.9 cm) $\times$ 0.2" (0.5 cm).

Water quality—. In 2019, core water quality (Table 4-2) and water chemistry (Table 4-3) were measured at orifice A (sampling location 1).



Figure 4-1. Garfield Spring, sampling location 1, orifice A, Chiricahua National Monument, April 2019.

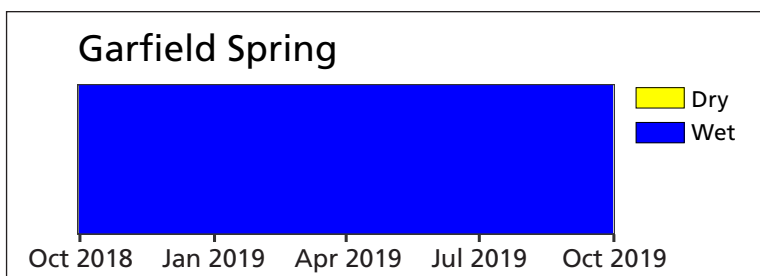


Figure 4-2. Estimated wet/dry days at Garfield Spring, Chiricahua National Monument, WY2019.

Table 4-2. Water-quality data for Garfield Spring, Chiricahua National Monument, WY2019.

Sampling location	Orifice	Sample time	Temperature (°C)	Dissolved oxygen (mg/L)	pH	Specific conductivity (µS/cm)	Total dissolved solids (mg/L)	Exposure
1	A	10:55	11.9	3.92	7.25	184.6	119.6	Shade

Table 4-3. Water-chemistry data for Garfield Spring, Chiricahua National Monument, WY2019.

Sampling location	Orifice	Alkalinity (mg/L)	Calcium (mg/L)	Chloride (mg/L)	Magnesium (mg/L)	Potassium (mg/L)	Sulfate (mg/L)
1	A	80	16	3	9	1.5	1



Figure 4-3. Newton Cave Seep, sampling location 1, orifice A, Chiricahua National Monument, April 2019.

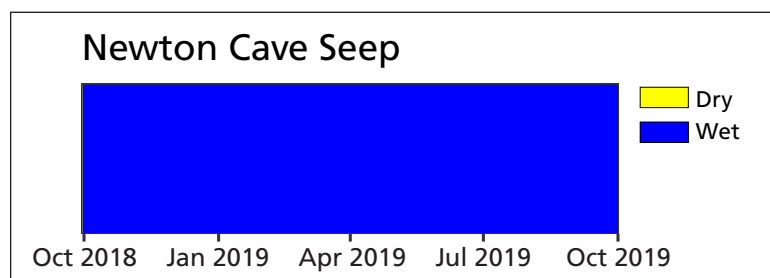


Figure 4-4. Estimated wet/dry days at Newton Cave Seep, Chiricahua National Monument, WY2019.

4.3.1.2 Newton Cave Seep

Site characterization—. Newton Cave Seep emerges at the base of an east-facing cliff (Figure 4-3). When characterized in WY2017, its spring type was not certain. There was an approximately 3.3 × 6.6 × 16.4-foot (1 × 2 × 5-m) overhang above substrate of primarily sand and small gravel. The orifice itself was a small area of moist sand with moss lining the bedrock wall. Directly out from the orifice there were a few oak trees that were noticeably greener and denser than the surrounding upland community.

Site condition—. Disturbance surveys estimated a mean of 1.1 (undisturbed) for anthropogenic and 1.38 (undisturbed) for natural disturbance. Median values for both disturbance categories were 1 (undisturbed). The spring orifice was moist, but drying was recorded as a moderate disturbance due to a lack of surface water. Deer or other ungulate scat was noted near the spring. The crew observed no obligate/facultative wetland plants, invasive plants, bullfrogs, or crayfish.

Water quantity—. Temperature sensors indicated the spring was wetted for the entirety of the sampled period (Figure 4-4). This may be a false wet reading due to the burial of the sensor housing. Discharge and wetted extent could not be measured due to a lack of surface water. The spring was still considered wetted due to the moisture present in the surface substrate.

Water quality—. In WY2019, core water quality and water chemistry were not measured due to a lack of surface water.

4.3.1.3 Shake Spring

Site characterization—. Shake Spring (Figure 4-5) is a rheocrene spring situated in a west-facing drainage. When characterized in WY2017, there were multiple orifices that exuded clear water. Orifice A was chosen as a monitoring site due to its proximity to an historic spring box and likeliness to be repeatable. The orifice is an exudence underneath a large, car-sized boulder approximately 16.5 feet (5 m) from the spring box. The small springbrook was braided throughout the channel. The channel was dominated by boulders of equal size distribution (0.8–13.4 ft/256–4,096 mm) and contained smaller amounts of sand and gravel.

Site condition—. Disturbance surveys estimated a mean of 1.4 (undisturbed) for anthropogenic and 1.25 (undisturbed) for natural disturbance. Median values for both disturbance categories were 1 (undisturbed). An historic springbox is located directly next to the road. Recent fires and flooding caused a new emergence 65.6 feet (20 m) upstream and downed trees in the channel.

The crew observed two obligate/facultative wetland plant families and four genera: sedge family (Cyperaceae), rush family (Juncaceae), horsetail (*Equisetum* sp.), sedge (*Carex* sp.), sycamore (*Platanus* sp.), and willow (*Salix* sp.). Two invasive plants were noted at Shake Spring with 1–5 individuals: common mullein (*Verbascum thapsus*) and spiny sowthistle (*Sonchus asper*). No bullfrogs or crayfish were observed.

Water quantity—. Temperature sensors indicated the spring was wetted for the entirety of the water year (Figure 4-6). Discharge from orifice A was estimated at 7.6 ± 0.2 L/minute. The wetted extent of Shake Spring was surveyed as a flowing spring with a channel length of 304.5 feet (92.8 m). Width and depth averaged 22.1" (56.1 cm) $\times$ 1.2" (3 cm).

Water quality—. In 2019, core water quality (Table 4-4) and water chemistry (Table 4-5) were measured at the first pool downstream of the orifice.



Figure 4-5. Shake Spring, sampling location 1, a pool below orifice A, Chiricahua National Monument, May 2019.

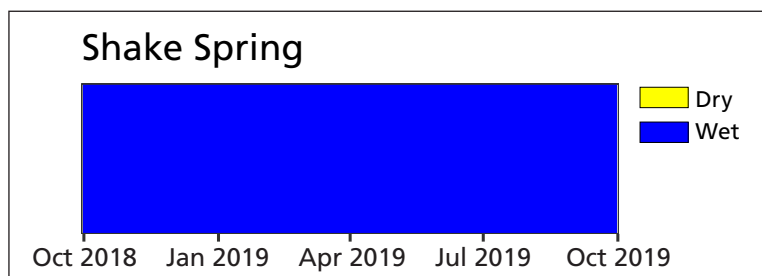


Figure 4-6. Estimated wet/dry days at Shake Spring, Chiricahua National Monument, WY2019.

Table 4-4. Water-quality data for Shake Spring, Chiricahua National Monument, WY2019.

Sampling location	Orifice	Sample time	Temperature (°C)	Dissolved oxygen (mg/L)	pH	Specific conductivity (µS/cm)	Total dissolved solids (mg/L)	Exposure
1	A	11:57	14.6	6.49	7.27	366.3	237.9	Shade

Table 4-5. Water-chemistry data for Shake Spring, Chiricahua National Monument, WY2019.

Sampling location	Orifice	Alkalinity (mg/L)	Calcium (mg/L)	Chloride (mg/L)	Magnesium (mg/L)	Potassium (mg/L)	Sulfate (mg/L)
1	A	135	50	5	9	1.2	32



Figure 4-7. Silver Spur Spring, sampling location 1, orifice A, Chiricahua National Monument, May 2019.

4.3.1.4 Silver Spur Spring

Site characterization—. Silver Spur Spring (Figure 4-7) is a rheocrene spring. When characterized in WY2017, it emerged in a low-slope, west-facing stream bed. The water was clear at emergence (though clogged with algae) and had no discernible flow. The springbrook was occasionally braided but largely a single channel. The substrate was dominated by a mix of sand, gravel, cobble and boulders. Algae is a common, but not ubiquitous, feature of the channel.

Site condition—. Disturbance surveys estimated a mean of 1.2 (undisturbed) for anthropogenic and 1.13 (undisturbed) for natural disturbance. Median values for both disturbance categories were 1 (undisturbed). A well-used hiking trail runs directly into the spring and across the wash, causing slight disturbance. Turkey and deer were both noted in the spring during sampling; trampling and tracks were seen throughout the channel.

The crew observed one obligate/facultative wetland plant family and four species: rush family (Juncaceae), horsetail (*Equisetum* sp.), monkeyflower (*Mimulus* sp.), sedge (*Carex* sp.), and sycamore (*Platanus* sp.). No invasive plants, bullfrogs, or crayfish or were observed.

Water quantity—. Temperature sensors were retrieved and deployed during this survey. Sensors indicated the spring was wetted for the entirety of the sampled period (Figure 4-8). Discharge from orifice A was estimated at $0.05 \pm <0.1$ L/minute. Silver Spur Spring was surveyed as a flowing spring with a channel length of 231.3 feet (70.5 m). Width and depth averaged 46.5" (118.0 cm) × 1.3" (3.2 cm).

Water quality—. In 2019, core water quality (Table 4-6) and water chemistry (Table 4-7) were measured at the first pool downstream of the orifice.

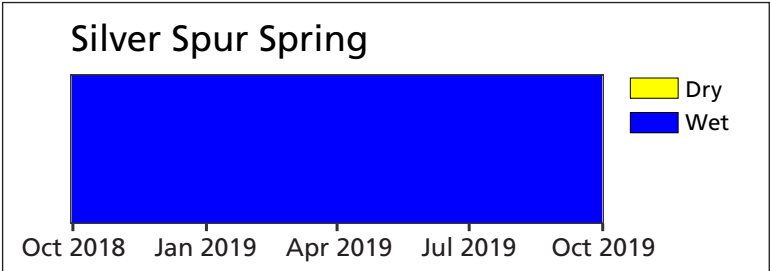


Figure 4-8. Estimated wet/dry days at Silver Spur Spring, Chiricahua National Monument, WY2019.

Table 4-6. Water-quality data for Silver Spur Spring, Chiricahua National Monument, WY2019.

Sampling location	Orifice	Sample time	Temperature (°C)	Dissolved oxygen (mg/L)	pH	Specific conductivity (µS/cm)	Total dissolved solids (mg/L)	Exposure
1	A	07:43	15.4	1.70	6.84	296.1	192.4	Partial

Table 4-7. Water-chemistry data for Silver Spur Spring, Chiricahua National Monument, WY2019.

Sampling location	Orifice	Alkalinity (mg/L)	Calcium (mg/L)	Chloride (mg/L)	Magnesium (mg/L)	Potassium (mg/L)	Sulfate (mg/L)
1	A	130	30	5	8	1.3	14

4.3.2 Coronado National Memorial

4.3.2.1 Blue Waterfall #2

Site characterization—. Blue Waterfall #2 is a rheocrene spring in the bottom of a small drainage (Figure 4-9). When characterized in WY2017, the spring emerged as a small pool below an undeveloped earthen wall, then flowed as a small, shallow spring-brook with several large pour-offs. The substrate was a mix of gravel, bedrock, and significant detritus. The spring emerged directly below an abandoned mine, which likely causes the distinct turquoise coloration of the substrate.



Figure 4-9. Blue Waterfall #2, sampling location 2, Coronado National Memorial, April 2019.

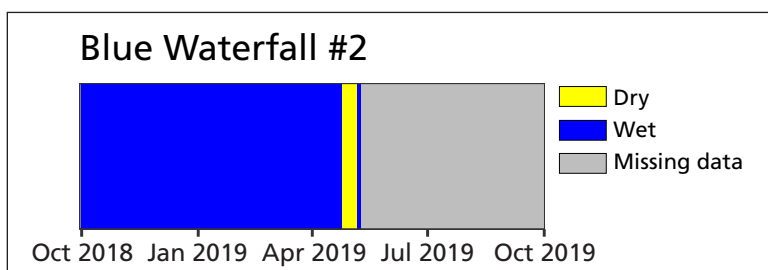


Figure 4-10. Estimated wet/dry days at Blue Waterfall #2, Coronado National Memorial, WY2019.

Site condition—. Disturbance surveys estimated a mean of 1.3 (undisturbed) for anthropogenic and 1.13 (undisturbed) for natural disturbance. Median values for both disturbance categories were 1 (undisturbed). High levels of disturbance were noted from the large tailings pile upstream and the turquoise-blue color of the water. Wildlife trampling and tracks were also noted, causing only slight disturbance.

The crew observed one obligate/facultative wetland plant family and four genera: rush family (Juncaceae), cottonwood (*Populus* sp.), monkeyflower (*Mimulus* sp.), sedge (*Carex* sp.), and spikerush (*Eleocharis* sp.). One invasive plant, Lehmann lovegrass (*Eragrostis lehmanniana*), was noted in scattered patches. No bullfrogs or crayfish were observed.

Water quantity—. Temperature sensors indicated the spring was wetted for the first half of the water year and dry for part of the spring (Figure 4-10). The sensor deployed in WY2019 stopped recording in May 2019. Discharge from orifice A was estimated at 4.2 ± 0.1 L/minute. The wetted extent of Blue Waterfall #2 was surveyed as a flowing spring with a channel length of 101.1 feet (30.8 m). Width and depth averaged 36.1" (91.6 cm) $\times$ 0.4" (1.0 cm).

Water quality—. In 2019, core water quality (Table 4-8) and water chemistry (Table 4-9) were measured at three sampling locations. From upstream to downstream, these locations were: a small, mid-channel dirt and gravel pool (sampling location 1), a pool immediately upstream of the narrow chasm and mine tailings pile (sampling location 4), and a pool downstream of the eponymous, turquoise-colored waterfall (sampling location 2).

Table 4-8. Water-quality data for Blue Waterfall #2, Coronado National Memorial, WY2019.

Sampling location	Orifice	Sample time	Temperature (°C)	Dissolved oxygen (mg/L)	pH	Specific conductivity (µS/cm)	Total dissolved solids (mg/L)	Exposure
1	A	12:51	20.0	2.96	4.21	734.0	474.5	Sun
2	A	12:58	25.4	6.89	7.70	541.0	351.0	Sun
4	A	14:46	18.5	5.32	7.46	347.8	224.9	Sun

Table 4-9. Water-chemistry data for Blue Waterfall #2, Coronado National Memorial, WY2019.

Sampling location	Orifice	Alkalinity (mg/L)	Calcium (mg/L)	Chloride (mg/L)	Magnesium (mg/L)	Potassium (mg/L)	Sulfate (mg/L)
1	A	30	44	Non-detect	5	1.3	185
2	A	80	68	0	22	1.2	155
4	A	90	30	Non-detect	14	0.1	58

4.3.2.2 Fern Grotto

Site characterization—. Fern Grotto is a rheocrene spring in the bed of a small, steep drainage. When characterized in WY2017, orifice A emerged as a small, dirt-walled pool below a large bedrock outcrop. The area surrounding orifice A had dense vegetation and moist soil. The water that emerged was cool and clear, flowing as a low-velocity, often-braided springbrook leading to a bedrock waterfall. At the base of the waterfall pour-off is the eponymous Fern Grotto (Figure 4-11), an impounded alcove wetted through subsurface flow, designated orifice B. A stone impoundment prevented any surface water from joining the channel, which had intermittent pooling but little flow. At 144.4 feet (44 m) from orifice A, the streambrook met a large stonework dam, at the bottom of which a pipe outflow expelled water. The substrate varied throughout the springbrook, from a mix of gravel/silt to bedrock outcrops.

Site condition—. Disturbance surveys estimated a mean of 1.8 (slightly disturbed) for anthropogenic and 1.38 (undisturbed) for natural disturbance. Median values for both disturbance categories were 1 (undisturbed). There were high levels of disturbance from historic human use and flow modification. Trash found on site indicated slight disturbance from contemporary use. The crew



Figure 4-11. Fern Grotto, sampling location 2, orifice B, Coronado National Memorial, April 2019.

noted drying as a slight natural disturbance, as orifice A was smaller than on previous visits, and orifice B was dry. Tracks and trampling showed only slight disturbance by wildlife.

The crew observed two obligate/facultative wetland plants: maidenhair fern (*Adiantum* sp.) and sedge (*Carex* sp.). One invasive plant, Lehmann lovegrass (*Eragrostis lehmanniana*), was noted in scattered patches. No bullfrogs or crayfish were observed.

Water quantity—. Temperature sensors were damaged and could not be down-

loaded, so we did not report information on persistence for WY2019. Discharge from the orifice C pipe outflow was estimated at 1.1 ± 0.02 L/minute. The wetted extent of the outflow was also surveyed as a flowing spring with a channel length of 31.04 feet (9.5 m). Width and depth averaged 5.5" (14.0 cm) $\times$ 0.4" (1.0 cm).

Water quality—. In 2019, core water quality (Table 4-10) and water chemistry (Table 4-11) were measured at three locations: orifice A (sampling location 1), inside Fern Grotto (sampling location 2), and the pipe outflow (sampling location 3).

Table 4-10. Water-quality data for Fern Grotto, Coronado National Memorial, WY2019.

Sampling location	Orifice	Sample time	Temperature (°C)	Dissolved oxygen (mg/L)	pH	Specific conductivity (μS/cm)	Total dissolved solids (mg/L)	Exposure
1	A	11:02	21.9	6.08	7.56	647.0	422.5	Sun
2	B	10:43	17.5	5.41	7.27	671.0	435.5	Shade
3	C	11:19	20.0	6.83	7.12	676.0	442.0	Partial

Table 4-11. Water-chemistry data for Fern Grotto, Coronado National Memorial, WY2019.

Sampling location	Orifice	Alkalinity (mg/L)	Calcium (mg/L)	Chloride (mg/L)	Magnesium (mg/L)	Potassium (mg/L)	Sulfate (mg/L)
1	A	280	120	14	13	0.3	62
2	B	290	150	Not detected	Not detected	Not detected	60
3	C	250	95	5	11	0.4	59

4.3.2.3 Sparkes Spring

Site characterization—. Sparkes Spring (Figure 4-12) is a rheocrene spring that emerges at the base of a bedrock outcrop in a drainage. When characterized in WY2017, orifice A pooled at the base of a small (~3.3-ft/1 m) bedrock pour-off. Subsurface flow reappeared a few meters downstream as a flowing springbrook that surfaced intermittently. While the initial lentic pool was static and algae-choked, the springbrook flowed slowly, with clear, cool water. The channel substrate was largely gravel and dirt, though cobbles and bedrock were common outside the springbrook. The channel had a low-velocity flow, with few locations where surface tension was broken.

Site condition—. Disturbance surveys estimated a mean of 1.2 (undisturbed) for anthropogenic and 1.13 (undisturbed) for natural disturbance. Median values for both disturbance categories were 1 (undisturbed). Earthen dams slightly modified flow. Wildlife caused slight disturbance, as evidenced by trampling and tracks at the site.

The crew observed one obligate/facultative wetland plant family and five genera: Rush family (Juncaceae), monkeyflower (*Mimulus* sp.), mule-fat (*Baccharis salicifolia*), rabbitsfoot grass (*Polypogon* sp.), spikerush (*Eleocharis* sp.), and sycamore (*Platanus* sp.). Two invasive plants were noted at Sparkes Spring: annual rabbitsfoot grass (*Polypogon monspeliensis*) in evenly distributed patches and Lehmann lovegrass (*Eragrostis lehmanniana*) as 1–5 individuals. No bullfrogs or crayfish were observed.

Water quantity—. Temperature sensors indicated the spring was wetted for most of the water year, with scattered dry periods (Figure 4-13). Discharge from orifice A was estimated at 9.3 ± 0.2 L/minute. The wetted extent of Sparkes Spring was assessed as a flowing spring with a channel length of 328.1–656.2 feet (100–200 m). Width and depth averaged 26.8" (68.1 cm) $\times$ 0.9" (2.3 cm) within the first 328.1 feet (100 m).



Figure 4-12. Sparkes Spring, sampling location 1, Coronado National Memorial, April 2019.

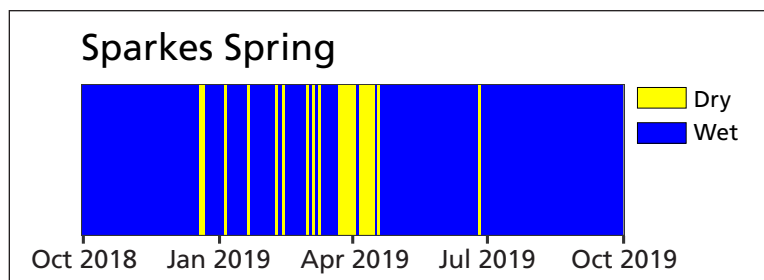


Figure 4-13. Estimated wet/dry days at Sparkes Spring, Coronado National Memorial, WY2019.

Water quality—. In 2019, core water quality (Table 4-12) was measured at the stagnant pool underneath litter at orifice A (sampling location 1) and at the first clear pool downstream of the orifice (sampling location 2). Water chemistry was measured only at the orifice A pool due to the close proximity of the two sampling locations (Table 4-13).

Table 4-12. Water-quality data for Sparkes Spring, Coronado National Memorial, WY2019.

Sampling location	Orifice	Sample time	Temperature (°C)	Dissolved oxygen (mg/L)	pH	Specific conductivity (µS/cm)	Total dissolved solids (mg/L)	Exposure
1	A	10:04	18.7	0.69	6.89	770.0	500.5	Sun
2	A	10:07	17.3	2.48	6.94	767.0	500.5	Partial

Table 4-13. Water-chemistry data for Sparkes Spring, Coronado National Memorial, WY2019.

Sampling location	Orifice	Alkalinity (mg/L)	Calcium (mg/L)	Chloride (mg/L)	Magnesium (mg/L)	Potassium (mg/L)	Sulfate (mg/L)
1	A	300	90	7	23	0.2	52



Figure 4-14. Apache Spring, sampling location 1, orifice A, Fort Bowie National Historic Site, April 2019.

4.3.3 Fort Bowie National Monument

4.3.3.1 Apache Spring

Site characterization—. Apache Spring is a rheocrene spring. When characterized in WY2017, its orifice was an output from a springbox approximately 16.4 feet (5 m) up the channel. Water poured off down a 9.8-foot (3 m), human-made, moss-coated wall into a slender, flowing springbrook (Figure 4-14). The springbrook flowed within constructed walls for 16.4 feet (5 m) before widening to a natural channel for the extent of the springbrook. A second orifice (B) appeared roughly downstream but did not support surface flow into the channel. Orifice B emerged at the base of a velvet ash (*Fraxinus velutina*). The stagnant water was dark, highly turbid, and odiferous. The main springbrook continued past orifice B. The springbrook substrate was dominated by sand, with 20% gravel and occasional boulders. The constant flow from the box created a slow-moving channel of low-turbidity water.

Site condition—. Disturbance surveys estimated a mean of 2.2 (slightly disturbed) for anthropogenic and 1.13 (undisturbed) for natural disturbance. Median values for both disturbance categories were 1 (undisturbed). A hiking trail leads directly to the spring orifice; crews noted evidence of visitor use causing heavy contemporary disturbance.

The spring is also highly impacted by flow modification by the historic springbox. Wildlife use was apparent, with tracks and droppings sighted within the channel.

The crew observed no obligate/facultative wetland plants, invasive plants, bullfrogs, or crayfish.

Water quantity—. Temperature sensors indicated the spring was wetted for the entirety of the water year (Figure 4-15). Discharge from orifice A was estimated at $10.1 \pm$

0.1 L/minute. The wetted extent of Apache Spring was surveyed as a flowing spring with a channel length of 170 feet (51.8 m). Width and depth averaged 29.9" (75.9 cm) $\times$ 0.8" (2.0 cm).

Water quality—. In 2019, core water quality (Table 4-14) and water chemistry (Table 4-15) were measured at the first pool downstream of the main orifice (orifice A, sampling location 1) and a small, stagnant upwelling at the side of the downstream channel (orifice B, sampling location 2).

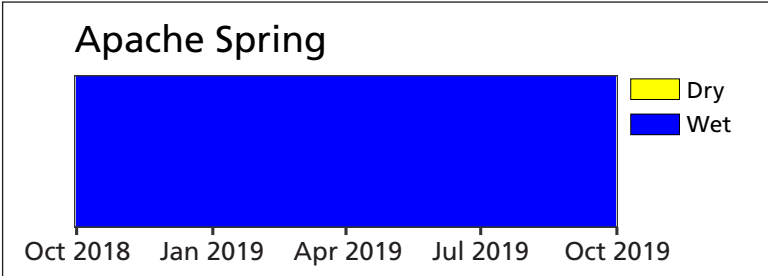


Figure 4-15. Estimated wet/dry days at Apache Spring, Fort Bowie National Historic Site, WY2019.

Table 4-14. Water-quality data for Apache Spring, Fort Bowie National Historic Site, WY2019.

Sampling location	Orifice	Sample time	Temperature (°C)	Dissolved oxygen (mg/L)	pH	Specific conductivity (µS/cm)	Total dissolved solids (mg/L)	Exposure
1	A	10:40	17.2	5.00	7.29	624.0	403.0	Partial
2	B	10:56	15.2	0.85	6.99	422.2	274.3	Partial

Table 4-15. Water-chemistry data for Apache Spring, Fort Bowie National Historic Site, WY2019.

Sampling location	Orifice	Alkalinity (mg/L)	Calcium (mg/L)	Chloride (mg/L)	Magnesium (mg/L)	Potassium (mg/L)	Sulfate (mg/L)
1	A	260	105	8	14	1.0	44
2	B	240	95	2	12	0.6	42



Figure 4-16. Lower Mine Spring, sampling location 1, orifice A springbox, Fort Bowie National Historic Site, April 2019.

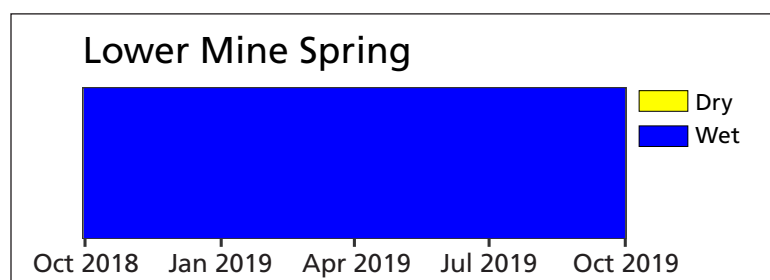


Figure 4-17. Estimated wet/dry days at Lower Mine Spring, Fort Bowie National Historic Site, WY2019.

4.3.3.2 Lower Mine Spring

Site characterization— Lower Mine Spring is a rheocrete spring. Its orifice (Figure 4-16) is a T-shaped springbox that distributes a single inflow to two different outflows. The left side (not included in SODN monitoring) is connected to a secondary springbox that flows out of the park. The right side is considered orifice A, which flows through a 2" (5-cm) pipe to a second outflow (orifice B). The outflow pours over a bedrock outcrop into a channel. When characterized in WY2017, the springbrook was approximately 3.3 feet (1 m) across, with an 80% sand and 20% boulder substrate causing intermittent flow and pooled areas for the entire stretch of visible surface flow. The flow at orifices A and B was clear and consistent, but immediately slowed and became more turbid at the base of the springbrook.

Site condition— Disturbance surveys estimated a mean of 1.8 (slightly disturbed) for anthropogenic and 1.13 (undisturbed) for natural disturbance. Median values for both disturbance categories were 1 (undisturbed). A springbox disrupts any natural flow. Wildlife tracks were noted as a slight disturbance.

The crew observed two obligate/facultative wetland plants: mule-fat (*Baccharis salicifolia*) and sedge (*Carex* sp.). Three invasive plants were noted at Lower Mine Spring in scattered patches: common sowthistle (*Sonchus oleraceus*), Lehmann lovegrass (*Eragrostis lehmanniana*), and red brome (*Bromus rubens*). No bullfrogs or crayfish were observed.

Water quantity— Temperature sensors indicated the spring was wetted for the entirety of the sampled period (Figure 4-17). Discharge from the pipe outflow was estimated at 16.5 ± 0.3 L/minute. The wetted extent of Lower Mine Spring was surveyed as a flowing spring with a channel length of 171.1 feet (52.2 m). Width and depth averaged 37.6" (95.4 cm) $\times$ 1.9" (4.9 cm) within the first 328.1 feet (100 m). Wetted-extent measurements began approximately 26.2 feet (8 m) after the pipe outflow because a steep channel section made measurements unsafe.

Water quality— In 2019, core water quality (Table 4-16) and water chemistry (Table 4-17) were measured in the springbox (sampling location 1) and from the pipe outflow (sampling location 2).

Table 4-16. Water-quality data for Lower Mine Spring, Fort Bowie National Historic Site, WY2019.

Sampling location	Orifice	Sample time	Temperature (°C)	Dissolved oxygen (mg/L)	pH	Specific conductivity (µS/cm)	Total dissolved solids (mg/L)	Exposure
1	A	08:36	17.8	5.38	7.20	533.4	346.5	Sun
2	A,B	08:43	18.3	6.43	7.31	551.5	358.2	Shade

Table 4-17. Water-chemistry data for Lower Mine Spring, Fort Bowie National Historic Site, WY2019.

Sampling location	Orifice	Alkalinity (mg/L)	Calcium (mg/L)	Chloride (mg/L)	Magnesium (mg/L)	Potassium (mg/L)	Sulfate (mg/L)
1	A	260	65	12	22	2.3	37
2	A,B	220	82	7	15	2.1	30

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