



Status of Climate and Water Resources at Gila Cliff Dwellings National Monument

Water Year 2018

Natural Resource Report NPS/SODN/NRR—2019/2001



ON THE COVER

Stream habitat monitoring on the West Fork of the Gila River, Gila Cliff Dwellings National Monument. NPS photo.

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Prepared by

Evan L. Gwilliam¹

Laura Palacios¹

Kara Raymond²

¹Sonoran Desert Network

National Park Service

12661 E. Broadway Blvd.

Tucson, AZ 85748

²Southern Arizona Office

3636 N. Central Ave., Suite 410

Phoenix, AZ 85012

Editing and Design

Alice Wondrak Biel

Sonoran Desert Network

National Park Service

12661 E. Broadway Blvd.

Tucson, AZ 85748

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 Gila Cliff Dwellings National Monument: Water year 2018. Natural Resource Report NPS/SODN/NRR—2019/2001. National Park Service, Fort Collins, Colorado.

Contents

Figures v

Tables vii

Executive Summary ix

Acknowledgements xi

1 Introduction 1

2 Climate.....3

 2.1 Background and methods 3

 2.2 Results and discussion 4

3 Springs 7

 3.1 Background 7

 3.2 Methods.....7

 3.3 Results and discussion 8

4 Surface Water.....13

 4.1 Background 13

 4.2 Methods.....14

 4.3 Results and discussion 16

5 Literature Cited 25

Appendices 27

 Appendix A. Detection Limits and Methods for Nutrient Analysis 27

 Appendix B. Macroinvertebrate Taxa 29

Figures

Figure 2-1. Aridity index vs. elevation of selected southwestern national parks, including Gila Cliff Dwellings National Monument 3

Figure 2-2. Departures from 30-year (1981–2010) normal minimum and maximum air temperature and precipitation for water year 2018, Gila Cliff Dwellings National Monument 4

Figure 2-3. Climogram for water year 2018, Gila Cliff Dwellings National Monument..... 5

Figure 2-4. Reconnaissance drought index (RDI), Gila Cliff Dwellings National Monument, water years 1981–2018..... 5

Figure 2-5. Five-year moving mean of annual precipitation, Gila Cliff Dwellings National Monument, water years 1981–2018..... 6

Figure 3-1. Cliff Dweller Canyon Spring looking downstream to orifice, Gila Cliff Dwellings National Monument, June 2018. 8

Figure 3-2. Hubbard’s Bog, Gila Cliff Dwellings National Monument, June 2018..... 9

Figure 3-3. Cliff Dweller Canyon Spring looking upstream from orifice, Gila Cliff Dwellings National Monument, May 2011..... 9

Figure 3-4. Cliff Dweller Canyon Spring looking upstream from orifice, Gila Cliff Dwellings National Monument, June 2018. 9

Figure 3-5. Estimated wet/dry days at Cliff Dweller Canyon Spring, Gila Cliff Dwellings National Monument, WY2018. 10

Figure 3-6. Estimated wet/dry days at Hubbard’s Bog, Gila Cliff Dwellings National Monument, WY2018..... 10

Figure 4-1. Sampling locations on the West Fork Gila River, Gila Cliff Dwelling National Monument.. 13

Figure 4-2. Location of the radar gauge at Gila Cliff Dwellings National Monument..... 14

Figure 4-3. West Fork of the Gila River hydrograph (from USGS 09430010). 16

Figure 4-4. Hydrologic season (as defined in NPS 1998) and annual mean discharge statistics for the West Fork Gila River, water years 2017 and 2018..... 17

Figure 4-5. Seasonal variability in continuous data for (A) water temperature, (B) specific conductivity, (C) pH, and (D) dissolved oxygen concentration, West Fork Gila River, WY2018..... 19

Figure 4-6. New Mexico Stream Condition Index scores, West Fork Gila River, WY2012–2018..... 23

Tables

Table 3-1. Water-quality data for springs at Gila Cliff Dwellings National Monument, WY2018.	11
Table 3-2. Water-chemistry data (mg/L) for springs at Gila Cliff Dwellings National Monument, WY2018.	11
Table 4-1. Sampling dates, West Fork Gila River, WY2018.	17
Table 4-2. Discrete data summary for core water-quality parameters, West Fork Gila River, WY2018..	18
Table 4-3. Sonde deployment date and number of samples collected, West Fork Gila River, WY2018.	18
Table 4-4. Results (mg/L) from nutrient sampling, West Fork Gila River, WY2018.	21
Table 4-5. Results (mg/L) from biological condition sampling, West Fork Gila River, WY2018.....	21
Table 4-6. Results (mg/L) from metal and metalloids (dissolved) sampling, West Fork Gila River, WY2018.	21
Table 4-7. Results (mg/L) from metal and metalloids (total) sampling, West Fork Gila River, WY2018.	21
Table 4-8. Results (mg/L) from suspended and total sediment sampling, West Fork Gila River, WY2018.	22
Table 4-9. Results (mg/L) from general and inorganic sampling, West Fork Gila River, WY2018.	22
Table A-1. Detection limits and methods for nutrient analysis, West Fork Gila River, Gila Cliff Dwellings National Monument, WY2018.	28
Table B-1. Macroinvertebrate taxa collected at the index reach on the West Fork Gila River, Gila Cliff Dwellings National Monument, WY2018.	29

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 Gila Cliff Dwellings 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 hotter and drier than normal at Gila Cliff Dwellings National Monument. Overall annual precipitation was 70.7% of normal, based on a 30-year record (1981–2010). In the fall and winter, all months except February received only 0–28% of normal rainfall. The park received 88% of normal precipitation in spring and summer. Mean monthly maximum temperatures were all higher than normal—especially November, which averaged 10.6°F higher than normal. Mean monthly minimum temperatures were more variable. The reconnaissance drought index indicates that WY2018 returned to drier conditions after three wetter-than-average years.

Two springs are monitored at the monument. Both had surface water present and flowing when visited in WY2018 and showed little sign of change or disturbance.

This was the second water year of data for USGS stream gage 09430010. The U.S. Geological Survey maintains the equipment for this gage, and also collects and manages its data. The hydrograph for WY2018 was typical of the Upper Gila Basin, with peak streamflow occurring from February to early April. The largest flow event occurred in late February. Snowmelt and late winter storms made crucial contributions to the hydrologic season. The median value for the winter season (48.7 cfs) was about 60% greater than the spring median value (30.2 cfs) and more than 10 times the summer value (4.49 cfs).

There were 248 discrete analyses of water samples collected from the West Fork Gila River index site in WY2018. Of these samples, 94 were associated with New Mexico surface-water criteria. There were no exceedances of New Mexico state water-quality standards noted in these samples, for a compliance rate of 100%.

Macroinvertebrates were collected to provide data for compliance with the New Mexico biological standards. In WY2018, the index reach scored 50.14 on the New Mexico integrated biological index, putting it in the “fair” category. This index reach has been sampled with the same methods since WY2012. The index value has been near the upper 25th percentile each year—even after major fires in the monument watershed (2011–2012). These results show the resilience of the macroinvertebrate community, and the ability of the stream reach to recover after postfire flows of debris and ash.

Acknowledgements

We thank the superintendent, staff, and volunteers of Gila Cliff Dwellings National Monument for their on-site support of the monitoring effort. Greg Goodrum, Taylor Hubbard, Misa Kupkova, David Máck, Terezia Machová, Kate McNicholas, and Victor Sementelli assisted with data collection and processing. Kristen Bonebrake led the management and posting of all data products. Macroinvertebrate identifications were completed by the Utah State University BugLab. TestAmerica (Arizona) processed the water-chemistry samples. Andy Hubbard contributed to this report.

1 Introduction

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

September 2018) at Gila Cliff Dwellings National Monument (NM), a small (216-ha) National Park Service unit in southwestern New Mexico. 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 visit 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.

Gila Cliff Dwellings NM has had a nearby National Oceanic and Atmospheric Ad-

ministration Cooperative Observer Program (COOP) weather station (GILA HOT SPRINGS #0293530) since 1957. This station provides a reliable, long-term climate dataset. We used this data source for all subsequent analyses. The monument has also hosted a Remote Automated Weather Station (RAWS) since 1998. Both stations are accessible through the Climate Analyzer. See the SODN climate monitoring protocol (Hubbard et al. in prep) for details on methods and data handling.

An Aridity Index (UNEP 1992), based on the long-term average annual precipitation relative to the average annual potential evapotranspiration, can be a useful tool for contrasting the local climate of national parks (Figure 2-1). Used globally to classify climate zones, aridity index seeks to answer the question “How dry is dry?” (Tsakiris and Vangelis 2005). Using the period of record (1957–present), the climate of Gila Cliff Dwellings NM is classified as semi-arid.

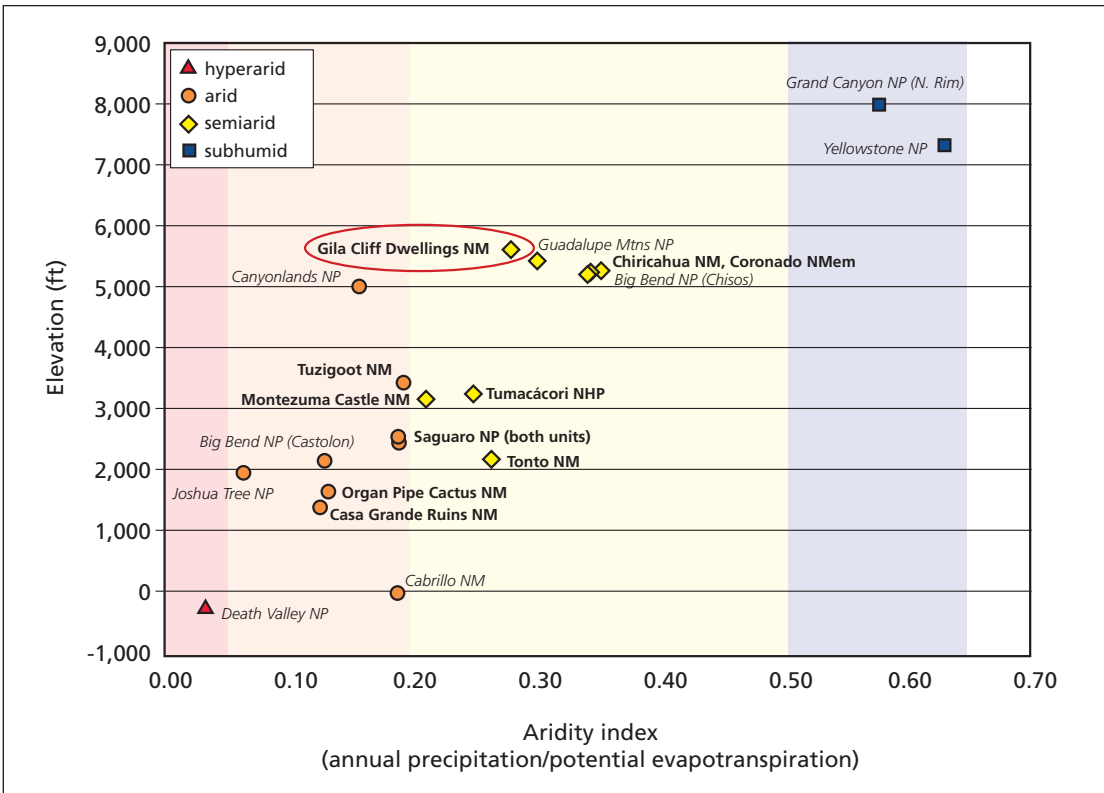


Figure 2-1. Aridity index vs. elevation of selected southwestern national parks, including Gila Cliff Dwellings National Monument. Figure from Hubbard and others (in prep).

2.2 Results and discussion

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

Data quality during WY2017 was excellent, with missing values on only two days. Overall annual precipitation was 70.7% of normal for Gila Cliff Dwellings NM (11.50" vs 16.26").

2.2.1.1 Cool season (October–March)

Overall precipitation was less half of normal (46% or -3.60") for the fall and winter of WY2018 (Figure 2-2). Total rainfall in February was 2.21", over double normal (Figure 2-3). All other months were substantially drier, receiving 0–28% of normal rainfall. Mean monthly maximum temperatures were all higher than normal (+2.2–10.6°F). November showed the largest increase, while the late winter months were more moderate. Mean monthly minimum temperatures were much more variable ($\pm 3.7^{\circ}\text{F}$).

2.2.1.2 Warm season (April–September)

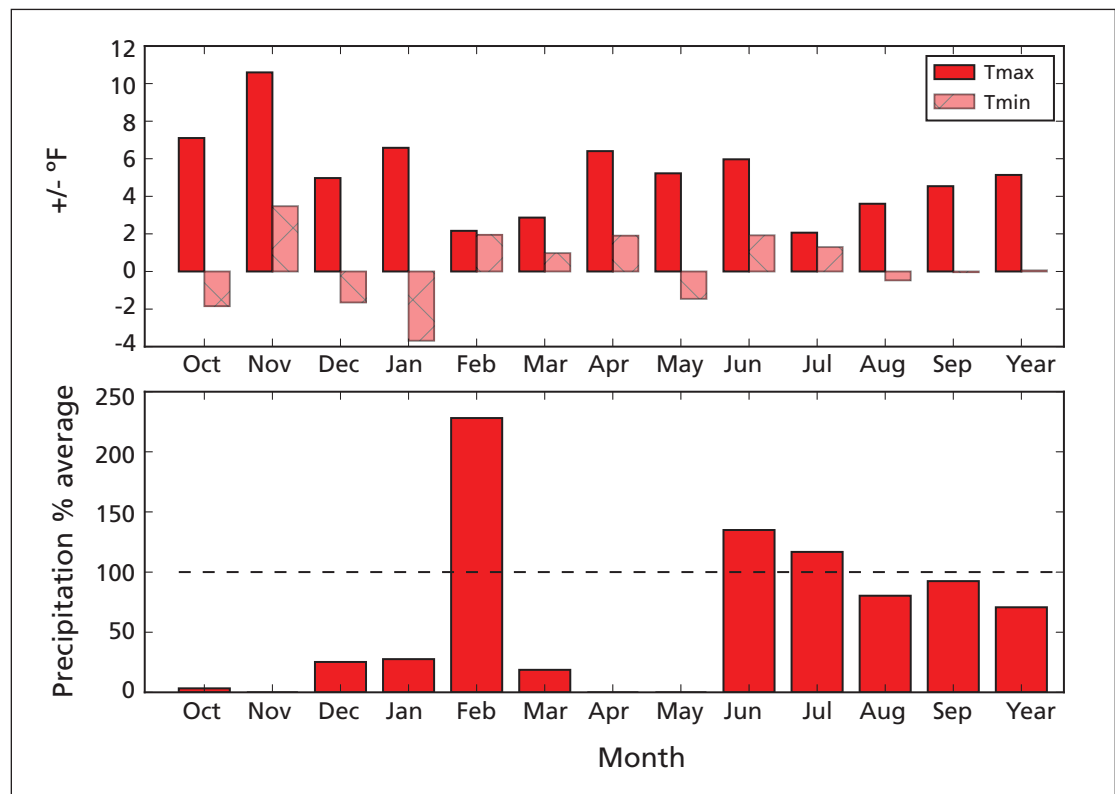
Overall precipitation was less than normal (88%, 1.16") for the spring and summer months in WY2018. No rainfall occurred in

April and May, but June through September had near or above-normal precipitation. Similar to the cool season, mean monthly maximum temperatures were all higher than normal (+2.1–6.4°F), and the mean monthly minimum temperatures were variable and close to normal ($\pm 1.9^{\circ}\text{F}$).

2.2.2 Reconnaissance Drought Index

Reconnaissance drought index (Tsakiris and Vangelis 2005) provides a measure of drought severity and extent relative to the long-term climate based on the ratio of average precipitation to average potential evapotranspiration over shorter periods of time (seasons to years). The reconnaissance drought index for Gila Cliff Dwellings NM reflects the extended regional drought since 2000 (Figure 2-4). Water years 2015–2017 demonstrated a limited recovery, but WY2018 returned to below-average (1981–2018) conditions from the perspective of both precipitation and evaporative demand. The five-year moving mean of total annual precipitation from years 1981–2018 (Figure 2-5) suggests that there is still a slight multi-year precipitation surplus.

Figure 2-2. Departures from 30-year (1981–2010) normal minimum and maximum air temperature and precipitation for water year 2018, Gila Cliff Dwellings National Monument. Graphics generated by climateanalyzer.org.



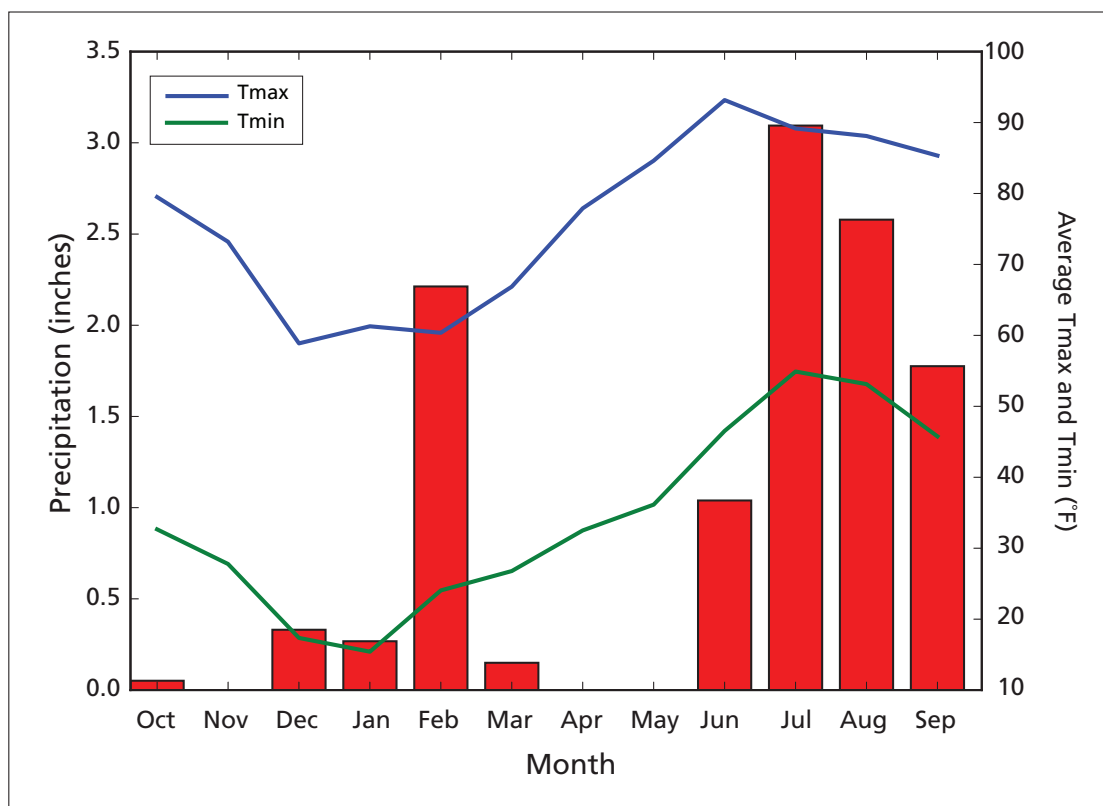


Figure 2-3. Climogram for water year 2018, Gila Cliff Dwellings National Monument. Graphics generated by climateanalyzer.org.

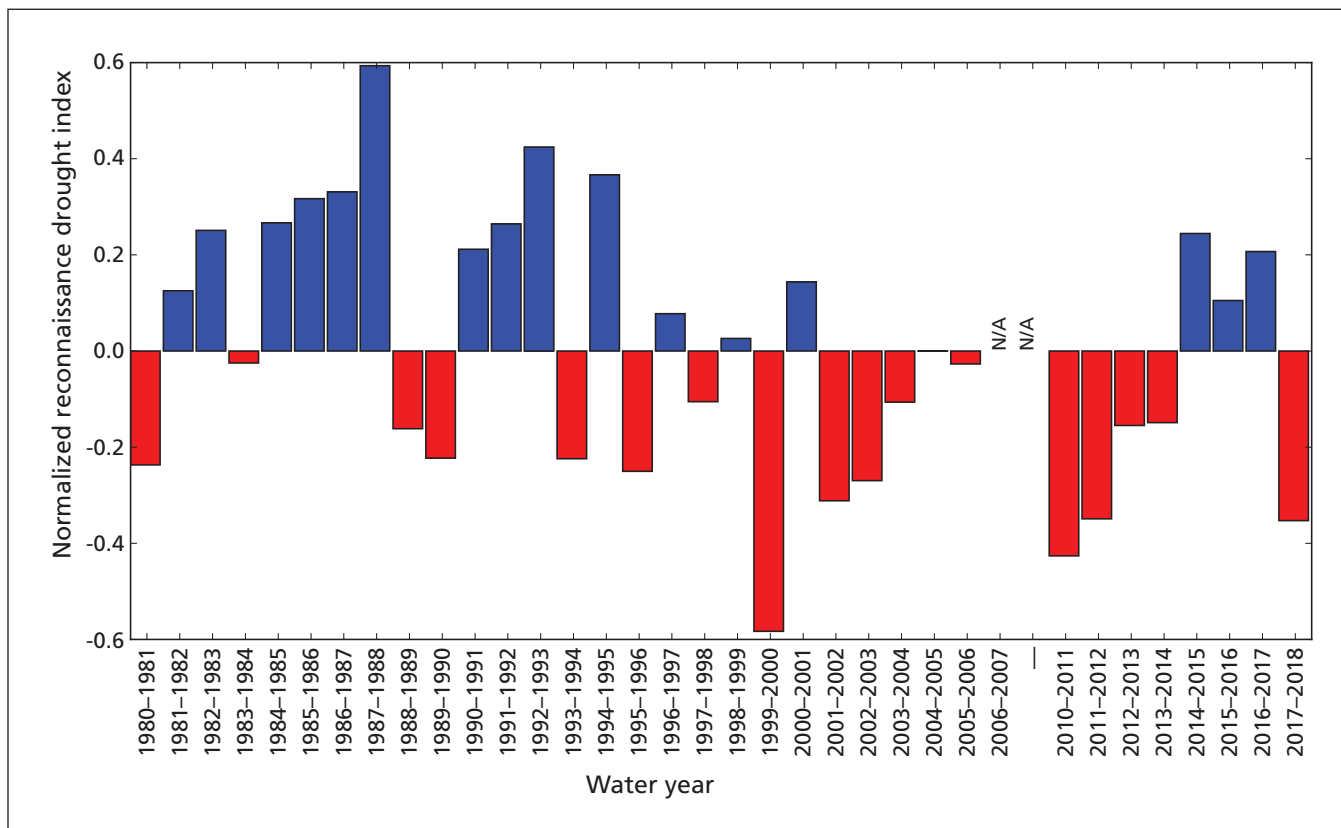


Figure 2-4. Reconnaissance drought index (RDI), Gila Cliff Dwellings National Monument, water years 1981-2018. "N/A" = insufficient data to generate reliable RDI estimates. The station was abandoned from 2007 to 2010. Graphics generated by climateanalyzer.org.

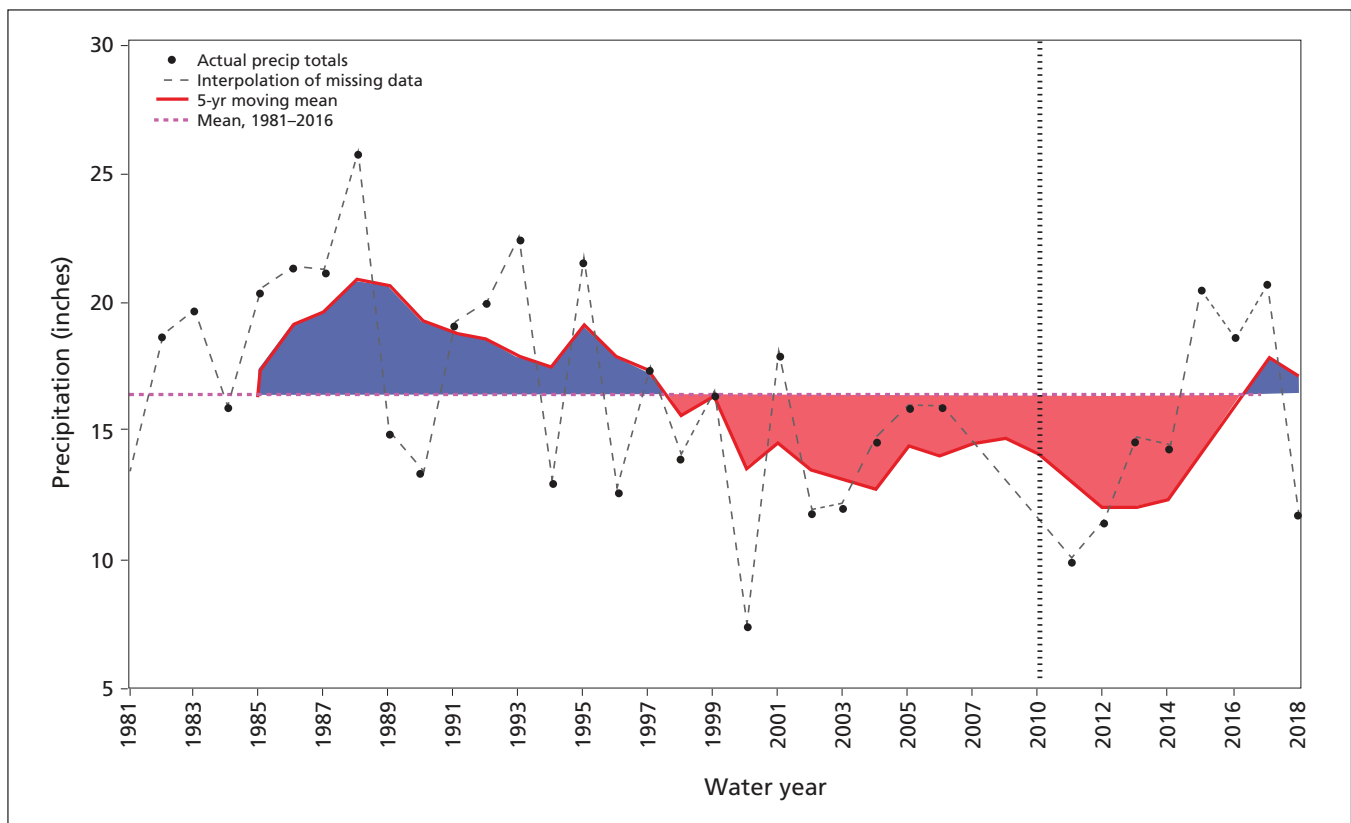


Figure 2-5. Five-year moving mean of annual precipitation, Gila Cliff Dwellings National Monument, water years 1981–2018. The moving mean (solid red line) is based on a timeseries with 8.1% (3 of 37) missing values, and includes the current year and previous four years. Blue and red fields represent water surplus and deficit. Missing years are linearly interpolated (dashed grey lines). The station was abandoned from WY2007 to 2010. Graphics generated by climateanalyzer.org.

2.2.3 Extreme weather events

Stochastic events, such as air-temperature extremes and unusually intense precipitation events, may be as important to understanding ecological patterns as long-term climate averages are. Although high air temperatures are a defining feature of warm deserts, extreme frost events also have important consequences for Arizona–New Mexico Mountains ecosystems. In particular, sustained low air temperatures can limit plant productivity and cause mortality in some species (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 ($<13^{\circ}\text{F}$, 5th percentile of 1981–2010 data) occurred 37% more frequently in WY2018 than normal (27 vs. 19.7 ± 1.9 days), and were of a longer duration (3 consecutive days vs. 2.1 ± 0.1 days). No days remained below 32°F all day. There were no extreme precipitation events ($>1"$) in WY2018, compared to 2.3 days for 1981–2010). The largest event occurred on August 3 ($0.90"$).

3 Springs

3.1 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).

3.2 Methods

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

3.2.1 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 Gila Cliff Dwellings National Monument in 2017 and will be recollected in 2022.

3.2.2 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, photo points, 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 was 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 were taken from designated photo points to show the spring and its landscape context. The presence of a suite of obligate or facultative wetland plants was noted during each visit using a checklist. The presence and density of invasive non-native plants, by species, was recorded during each visit. The presence of invasive non-native aquatic wildlife species was also recorded.

3.2.3 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 was 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 measured 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.

3.2.4 Water quality

Water-quality monitoring measures core water-quality parameters and water chemistry. Core parameters sampled by SODN included water temperature, pH, specific conductivity, dissolved oxygen, and total dissolved solids. Discrete samples of these parameters were 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).

3.3 Results and discussion

3.3.1 Site characterization

Cliff Dweller Canyon Spring (Figure 3-1) is a rheocrene spring dominated by groundwater and surface flow. The spring emerges near a large bedrock wall as a still pool below a boulder. The flow immediately becomes a channelized springbrook, terminating as subsurface flow downstream. The shallow, narrow springbrook is interrupted by scattered pools and small, braided sections. The channel substrate is sand, gravel, and small cobble, with patches of bedrock. The water is uniformly cold and clear, even in pools where flow loses velocity. There does not appear to be surface flow upstream of where the spring emerges from the bed of the ephemeral stream.

Hubbard's Bog (Figure 3-2) is a rheocrene spring dominated by groundwater and



Figure 3-1. Cliff Dweller Canyon Spring looking downstream to orifice, Gila Cliff Dwellings National Monument, June 2018.

surface flow. The spring emerges in the canyon bottom as a small channel with no obvious flow. It continues downstream as a low-flow springbrook with occasional small pools. Beyond the sampled extent, the channel continues intermittently downstream, though never exhibiting the volume of water, length of channel, or density of riparian vegetation found at the emergence site. Though rarely flowing, the water is cool and clear throughout. The drainage is characterized as primarily a low-angle silt and gravel streambed with occasional boulders and frequent snags. The channel is very narrow. The drainage upstream of the orifice does not appear to contain flowing surface water. Steep canyon backslopes emerge immediately, with no obvious riparian character. Disturbance caused by the 2011 Miller Fire is notable in the form of sedimentation and downed trees.

3.3.1.1 Site condition

At *Cliff Dweller Canyon Spring*, disturbance surveys resulted in a median value of 1 = undisturbed for both anthropogenic and natural disturbance. There was no indication of disturbance noted at the site.



Figure 3-2. Hubbard's Bog, Gila Cliff Dwellings National Monument, June 2018.

Photos appear to show little difference in condition between the sample of water year 2018 and the inventory performed in 2011 (Figure 3-3 and Figure 3-4). The crew did not observe any facultative/obligate plants, invasive plants, or invasive animals during this sample.



Figure 3-3. Cliff Dweller Canyon Spring looking upstream from orifice, Gila Cliff Dwellings National Monument, May 2011.



Figure 3-4. Cliff Dweller Canyon Spring looking upstream from orifice, Gila Cliff Dwellings National Monument, June 2018.

At *Hubbard’s Bog*, disturbance surveys resulted in a median value of 1 = undisturbed for both anthropogenic and natural disturbance. The crew noted that overall the site appeared to be dryer than previous visits; the orifice had moved eight meters downstream from when pilot sampling was done in 2017. Unidentified animal tracks were observed at the site. The crew observed four obligate/ facultative wetland plant genera/ species and one family: monkeyflower (*Mimulus* sp.), spikerush (*Eleocharis* sp.), fowl mannagrass (*Glyceria striata*), willow (*Salix* sp.), and rush (Juncaceae family). Invasive woolly mullein (*Verbascum thaspus*), common across the monument, was noted in scattered patches throughout the springbrook. No invasive wildlife was observed.

3.3.1.2 Water quantity

At *Cliff Dweller Canyon Spring*, temperature sensors indicated the spring was wetted

throughout WY2018 (Figure 3-5). Discharge from the orifice was estimated at 3.6 ± 0.02 liters/second. Channel length was greater than the sample extent of 100 meters. Width and depth averaged 58.1 and 1.6 centimeters, respectively.

At *Hubbard’s Bog*, temperature sensors indicated the spring was wetted throughout WY2018 (Figure 3-6). Discharge from the orifice was estimated at 0.41 ± 0.05 liters/second. Channel length was 33 meters. Width and depth averaged 57.6 and 4.6 centimeters, respectively.

3.3.1.3 Water quality

In 2018, water quality (Table 3-1) and water chemistry (Table 3-2) were measured slightly downstream of the orifices at both springs. The results fell in the expected ranges at both sites.

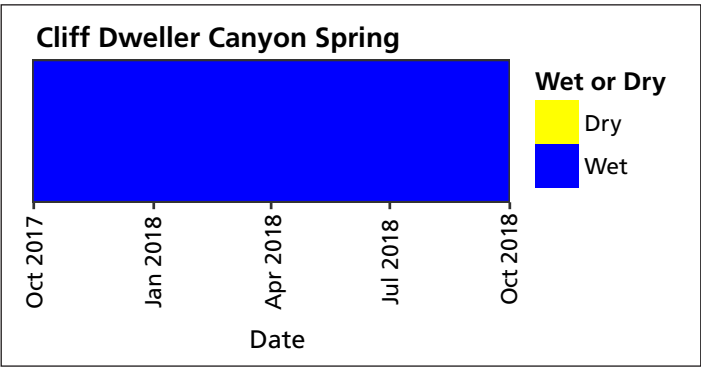


Figure 3-5. Estimated wet/dry days at Cliff Dweller Canyon Spring, Gila Cliff Dwellings National Monument, WY2018.

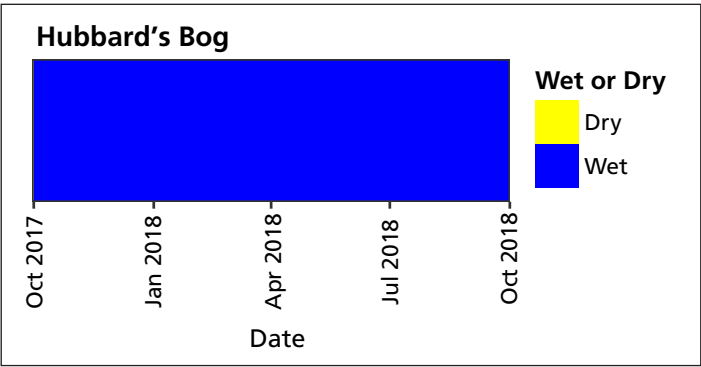


Figure 3-6. Estimated wet/dry days at Hubbard’s Bog, Gila Cliff Dwellings National Monument, WY2018.

Table 3-1. Water-quality data for springs at Gila Cliff Dwellings National Monument, WY2018.

Sampling location	Orifice(s)	Sample time	Temperature (°C)	Dissolved oxygen (mg/L)	pH	Specific conductivity (µS/cm)	Total dissolved solids (mg/L)	Exposure
Cliff Dweller Canyon Spring	A	08:45	12.5	5.27	7.00	207.00	134.55	Shade
Hubbard's Bog	A	10:04	13.4	5.52	7.39	221.50	143.65	Shade

Table 3-2. Water-chemistry data (mg/L) for springs at Gila Cliff Dwellings National Monument, WY2018.

Sampling location	Orifice(s)	Alkalinity	Calcium	Chloride	Magnesium	Potassium	Sulfate
Cliff Dweller Canyon Spring	A	85.0	32.0	0.0	8.0	ND ¹	ND ¹
Hubbard's Bog	A	105.0	28.0	0.0	9.0	0.3	4.0

¹Values were below detectable limits of photometer.

4 Surface Water

4.1 Background

The West Fork Gila River, which crosses the northeastern portion of Gila Cliff Dwellings NM, is a high-quality, mountainous stream. Located in the Gila Wilderness, its watershed is nearly devoid of residential, agricultural, and industrial land use. Visitor impacts are minimal. Consequently, this small (120-mi²) watershed is more subject to natural stressors than anthropogenic disturbances.

The impacts of natural stressors vary temporally and spatially. The headwaters region of the Gila River has been in a nearly continuous drought since approximately 2000 (see Section 2.2.2). This has resulted in decreased streamflow in the West Fork Gila River, which sometimes runs dry near the park's eastern boundary. This area is also prone to flooding. Inside the park, the narrow floodplain is bounded by canyon walls that act as

a bottleneck, increasing the destructive force of high floodwaters. This was demonstrated in 2008, when a large rain-on-snow event carved a new stream channel. This event also caused economic damage when camp facilities and a bridge providing access to the monument were washed out, resulting in necessary repairs and reduced visitation.

In July 2012, the Whitewater-Baldy Fire burned in the watershed of the Gila Wilderness. Impacts of this fire have included aquatic habitat degradation, establishment of invasive exotic plants, and potential future flooding and channel change.

In WY2018, Sonoran Desert Network (SODN) staff made four sampling visits to the West Fork Gila River at Gila Cliff Dwellings NM. Water-quality monitoring occurred at the pedestrian bridge near the park's eastern boundary (Figure 4-1).

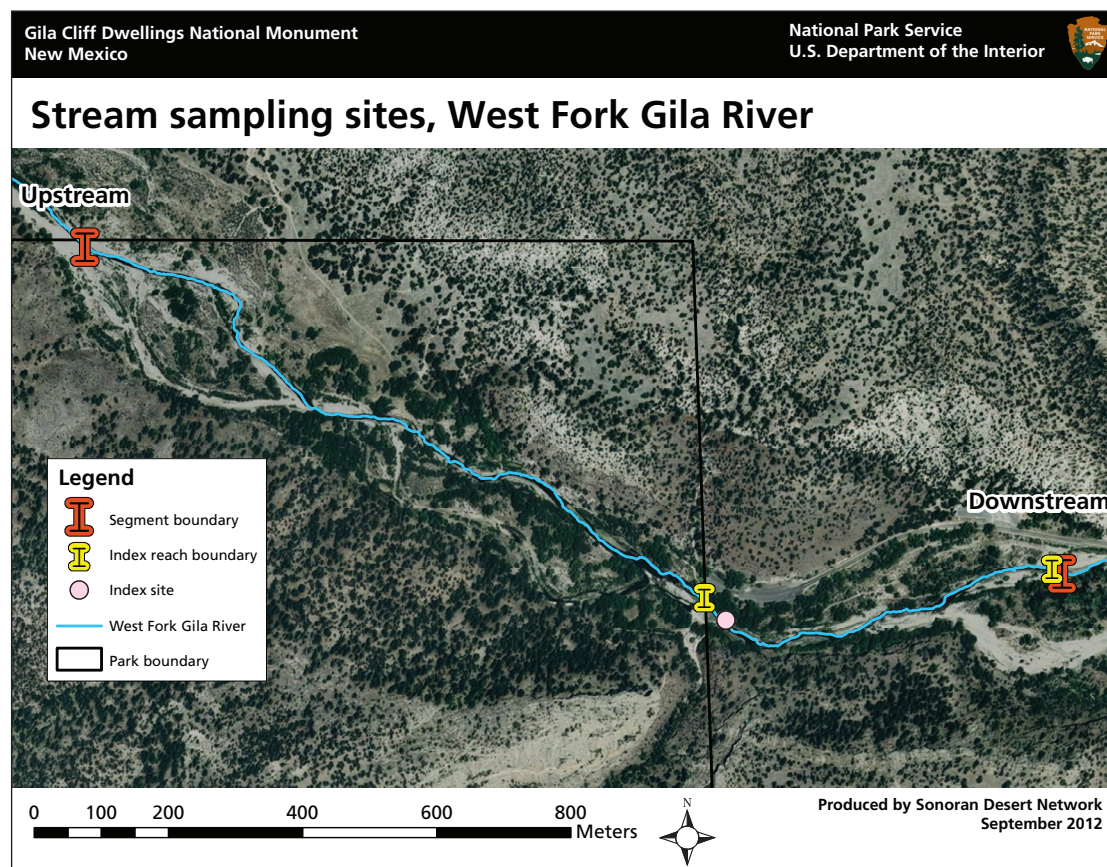


Figure 4-1. Sampling locations on the West Fork Gila River, Gila Cliff Dwelling National Monument. Water quality and water quantity are collected at the index point. Macroinvertebrates are collected in the index reach.

4.2 Methods

A brief description of data collection and processing methodologies for stream sampling at Gila Cliff Dwellings NM is presented below. Detailed descriptions of these procedures are available in the network's streams monitoring protocol (Gwilliam et al. 2018).

Sampling is conducted at the West Fork Gila River index site (for water quality, quantity, and discharge), and at the index reach (macroinvertebrates). The index site is located adjacent to the visitor contact station. The index reach is located downstream of the contact station (see Figure 4-1).

4.2.1 Water-quality core parameters

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

- On arrival at the site, a multi-parameter meter (YSI Professional Plus) is calibrated and deployed in a well-mixed part of the stream channel, logging tem-

perature, pH, specific conductivity, and dissolved oxygen data at one-minute intervals. The meter is left in the stream for the entire visit.

- Turbidity samples are collected and analyzed within one hour using a portable turbidimeter (HACH 2100P).
- Discharge is measured using a FlowTracker Acoustic Doppler Velocimeter.

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

4.2.2 Water quality samples

During each site visit, water samples are collected in a three-liter Nalgene sample collection bottle, following non-isokinetic sampling methods as described in the National Field Manual for the Collection of Water Quality Data (USGS 2006). We transfer the sample water to bottles for analysis of bacteria, turbidity, metals, and other constituents. The sample water is filtered and/or treated as required, kept on ice, and dropped off at the contract laboratory. For WY2018, that lab was TestAmerica in Phoenix, Arizona.

4.2.3 Water quantity data

In WY2017, SODN partnered with the U.S. Geological Survey (USGS) to install a stream gage (USGS 09430010) at the SODN index point. The USGS Las Cruces Field Office operates this gage following all USGS methods (Sauer and Turnipseed 2010, Turnipseed and Sauer 2010, Kenney 2010). This station uses a radar water-level telemetry system to measure water quantity at Gila Cliff Dwellings NM. A Waterlog radar gage is mounted to the bottom of the footbridge across the West Fork Gila River (Figure 4-2). Every 15 minutes, the gage sends a pulse of electromagnetic energy down toward the surface of the river and measures the reflected energy to determine the distance from the radar to the water surface (Sauer and Turnipseed

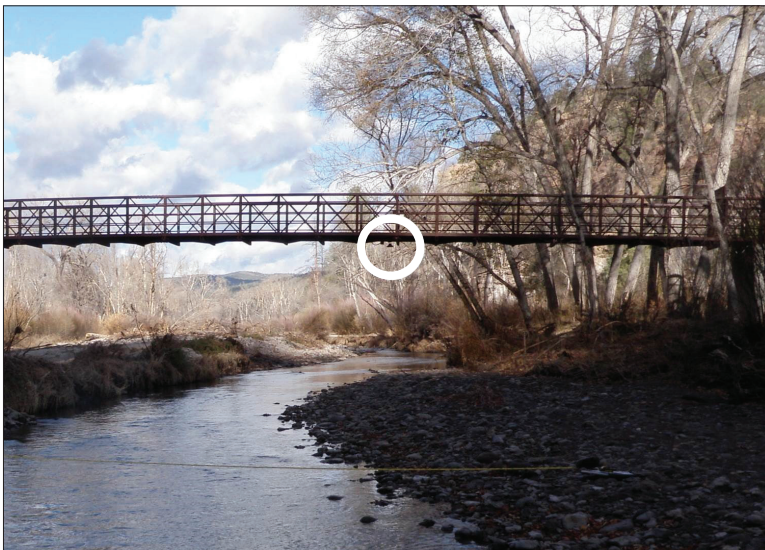


Figure 4-2. Location of the radar gauge at Gila Cliff Dwellings National Monument. The radar emitter (center of white circle) is not stationed over the center of the stream due to channel movement.

2010), thereby measuring the elevation of the water. This instrument is attached to a Waterlog data recorder and a Sutron telemetry system using the National Weather Service GOES satellite system. This allows for remote real-time access and logging of water-level data (Sauer and Turnipseed 2010). These real-time data are available at the Climate Analyzer website.

4.2.4 *Aquatic macroinvertebrates and habitat*

To ensure compatibility of monitoring samples, SODN macroinvertebrate sample collection coincides with the index period used by the New Mexico Environment Department. The sampling period for warmwater streams is August 15–November 15 (Jacobi et al. 2006).

The index reach at Gila Cliff Dwellings NM is 570 meters long, starting upstream of the park’s western boundary and continuing onto U.S. Forest Service land. The reach contains 11 equally spaced transects. At each transect, we measure wetted width, water depth, velocity, and canopy cover; estimate substrate size, bank erosion (using the Rosgen Bank Erosion Hazard Index), and diversity of aquatic habitat; and complete a bank-erosion hazard index. Two types of samples are collected:

- A quantitative sample is collected from four targeted riffle habitats to provide data on organism abundance. Using a kicknet with a 0.3-meter opening for one minute, a total of 12 replicate samples are collected from a 0.09-m² area. At each habitat, we also measure

depth, velocity, particle size, and particle embeddedness. This method is comparable to the methods used by the State of New Mexico.

- A reach-wide qualitative sample is collected to develop a comprehensive list of species present in the reach. Using dip- and kicknets, samples are collected from all habitat types within the reach during a one-hour collection period, proportionally allocated by habitat type, and compiled into one composite sample.

Aquatic macroinvertebrate samples are sent to the National Aquatic Monitoring Center (BugLab), a Bureau of Land Management laboratory at Utah State University in Logan, Utah. There, a taxonomist certified by the North American Benthological Society identifies all aquatic macroinvertebrates to the lowest taxonomic level possible.

4.2.5 *Data handling and analysis*

All data on water quality and quantity are stored on the SODN server. This report includes all discrete water-quality data collected except for turbidity, coliform, and *E. coli* samples, for which the mean of the triplicate samples are presented. For total coliforms and *E. coli* samples, most probable numbers (MPN/100 mL) are reported (IDEXX 2018). The continuous multi-parameter sonde measurements are presented with the minimum, first quartile, median, third quartile, and maximum to demonstrate variability. When applicable, this report compares SODN water-quality data against the State of New Mexico water-quality standards (NMAC 2013) and notes any exceedances.

4.3 Results and discussion

4.3.1 Water quantity

The USGS and SODN have partnered with Gila Cliff Dwellings NM to operate a stream gage at the West Fork Gila River index site (USGS 09430010). In WY2017, the USGS took over the management of this gage, maintaining the equipment collecting and managing the data. The hydrograph for WY2018 (Figure 4-3) was typical of the Upper Gila Basin (NPS 1998), with peak streamflow occurring during late February to early April, corresponding to snowmelt in the watershed.

The largest flow event occurred in late February 2018 (see Figure 4-3). It was likely an event of 100–150 cfs (cubic feet per second) that resulted in water approaching, but not overtopping, the stream banks. This type of flow event (and those large enough to push water levels over the stream banks) are important for the maintenance of stream geo-

morphology and the movement of organic material through the system (Rosgen 1996).

4.3.1.1 Mean daily discharge and seasonal statistics

Mean annual discharge at the park's index station in WY2018 was 10.17 cfs (SD 8.98); the median was 9.1 cfs. This was 3 cfs less than the median discharge for WY2017 (12.6 cfs; Goodrum et al. 2019). The median values for the hydrologic seasons* (Figure 4-4) illustrate the importance of snowmelt and late-winter storms to annual discharge totals. Median discharge for the winter season (48.7 cfs) was about 60% greater than the spring median value (30.2 cfs) and over ten times the summer value (4.49 cfs). Mean seasonal and annual flow were lower than in WY2017, indicating that WY2018 had less discharge than average. In the future, discharge values compared to the gage record will provide valuable insight into the physical and biological processes in the West Fork of the Gila River.

*As defined in NPS (1998), the hydrologic seasons are Summer (July 1–October 31), Winter (November 1–March 14), and Spring (March 15–June 30).

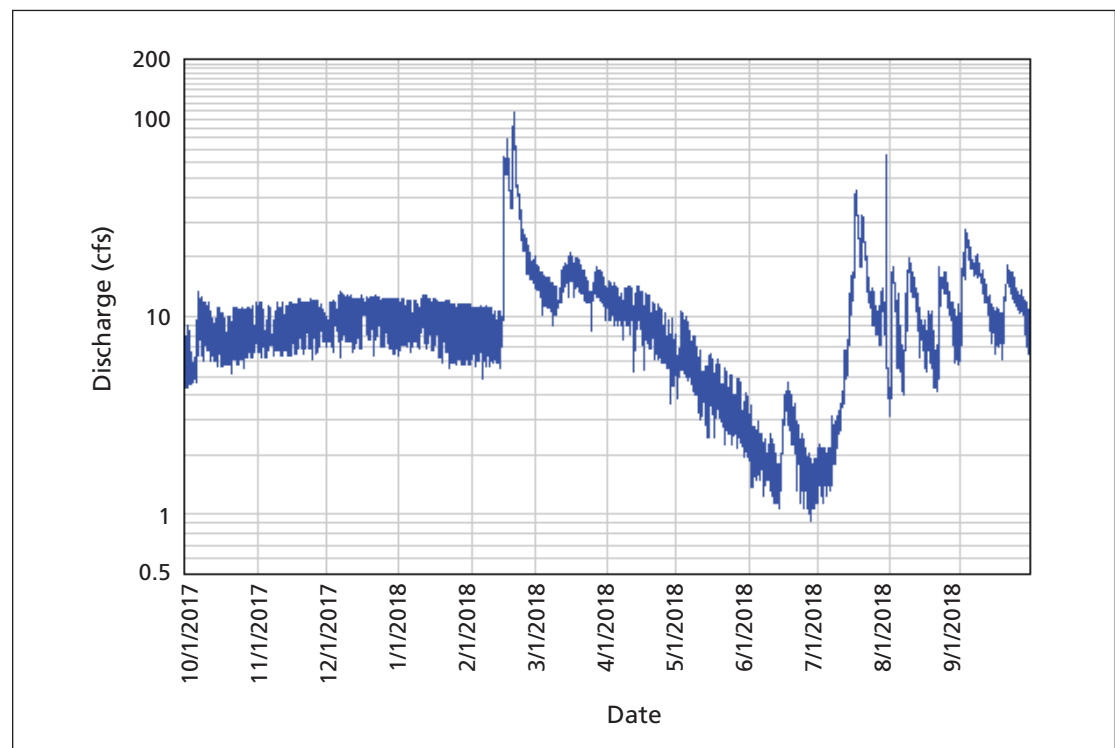


Figure 4-3. West Fork of the Gila River hydrograph (from USGS 09430010).

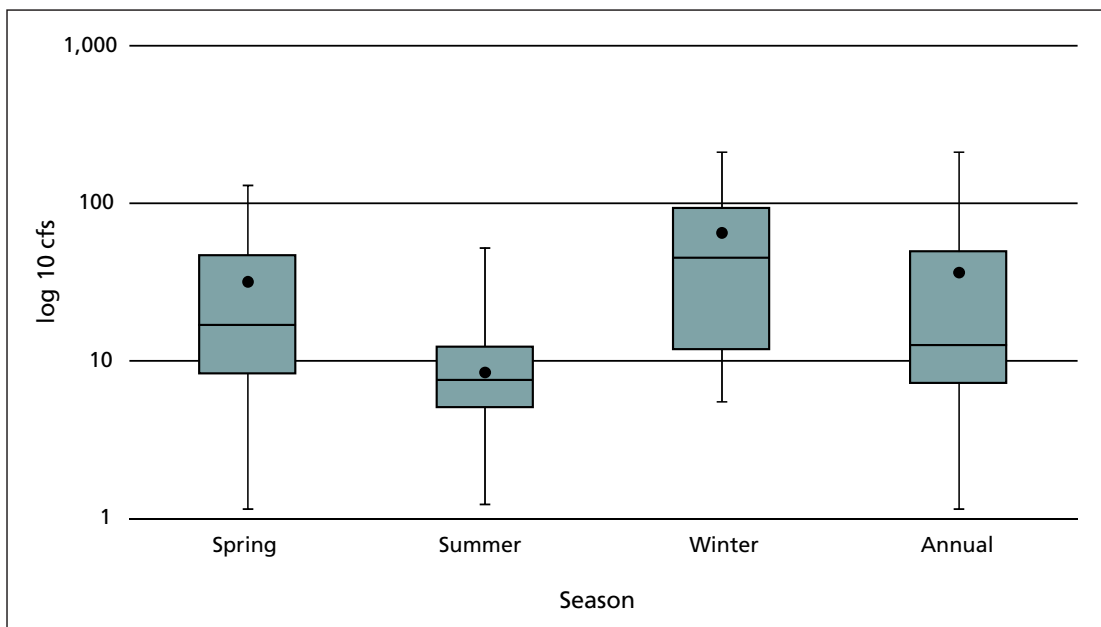


Figure 4-4. Hydrologic season (as defined in NPS 1998) and annual mean discharge statistics for the West Fork Gila River, water years 2017 and 2018. The top whisker is the maximum value for the parameter. The boxes indicate the 25th (bottom of box) to 75th (top of box) percentile of the data, with the line in the middle as the median value. The bottom whisker represents the minimum value. The mean value for WY2018 is indicated by a dot (the variance associated with these mean values are omitted from this graphic for clarity). Please note that the Y axis is measured using a log scale of the discharge (cfs). The statistics were generated from USGS data (USGS 09430010).

4.3.2 Water quality

In WY2018, SODN staff made a total of four sampling visits to the West Fork Gila River index site. Discrete samples were collected in each quarter (Table 4-1). Continuous sampling occurred during deployment periods in quarters 1, 3 and 4. Sampling did not occur in Q2 due to high flow conditions that exceeded safety-protocol prescriptions.

A total of 248 discrete analyses were performed on water samples collected in WY2018. Of these, 94 were associated with state standards. There were no exceedances of New Mexico state water-quality standards noted in these samples, for a compliance rate of 100%. The state standard for water temperature “Beneficial Use” (NMAC 2013) indicates that if the temperature of the stream exceeds 23°C for four hours or more on three consecutive days, this would be an exceedance of the New Mexico state water-quality standard. The water was at or above 23°C for four hours on seven days during the Q4 sonde deployment (see section 4.3.2.1, continuous sampling, below), but none of the seven days included three consecutive days. Thus, the standard was not exceeded.

Table 4-1. Sampling dates, West Fork Gila River, WY2018.

Quarter	Sample date
Q1	10/15/2017
Q2	2/7/2018
Q3	5/2/2018
Q4	8/18/2018

SODN and park staff will continue to watch this parameter in the future.

4.3.2.1 Core parameters

Discrete sampling—. The discrete measurements shown in Table 4-2, made in the field, represent conditions at the West Fork Gila River index site during site visits in WY2018. The results were all within the expected range for a mid-elevation stream in New Mexico.

Continuous sampling—. A logging multi-parameter sonde was deployed for 2–3 weeks during quarters 1, 3, and 4 of WY2018 to collect measurements of temperature, pH, specific conductivity, and

dissolved oxygen at 15-minute intervals (Table 4-3). A total of 5,643 measurements were collected. The sonde was not deployed during the second quarter of WY2018 due to possible high flow conditions during the deployment visit, and concern over possible ice damage to the sonde.

The sonde sampling location is currently at a secondary site, approximately 100 meters downstream from the footbridge. The primary site was located upstream from the footbridge but was abandoned after stream movement stranded the site out of the water.

The results from continuous sampling of core water quality parameters in WY2018 (Figure 4-5) were within what would be expected, with several considerations.

Although the segment of the West Fork Gila River at Gila Cliff Dwellings NM is in the “High Quality Cold Water” beneficial-use category, the park is at the bottom of the elevation range for this group. This leads to possible exceedances of state water-quality standards for core water-quality parameters. For example, in Figure 4-5, the 75% percentile statistic for temperature (20.82°C) in Q4 approached the state temperature standard of 23°C. This indicates that commonly observed water temperatures at the index site frequently approach state standards due to the positioning of the index site (and the park unit) in the landscape.

Table 4-2. Discrete data summary for core water-quality parameters, West Fork Gila River, WY2018.

Parameter	Quarter				New Mexico state standard	
	Q1	Q2	Q3	Q4		
Temperature (°C)	12.5	5.6	12.2	18.3	<23 ¹	Beneficial use
Specific conductivity (µS/cm)	138.6	131.0	133.0	134.0	<400	High quality cold water aquatic life
Turbidity (NTU)	0.65	0.56	0.67	4.20	<10 over background ²	Park-specific
pH	7.08	7.50	7.20	7.01	6.6–8.8	General
Dissolved oxygen concentration (mg/L)	7.27	10.14	8.00	7.59	>6	High quality cold water aquatic life
Discharge	6.82	8.10 ³	6.79	21.98	NS	High quality cold water aquatic life

¹Not to be exceeded for four or more consecutive hours on three or more consecutive days. ²No more than 10 NTU over background (when background is 50 NTU or less), or 20% increase when background is over 50 NTU. ³A direct discharge measurement was not collected due to equipment failure. The discharge measurement was collected from the USGS gage located on the footbridge at Gila Cliff Dwellings National Monument.

Table 4-3. Sonde deployment date and number of samples collected, West Fork Gila River, WY2018.

Quarter	Sample period	# samples
Q1	10/16/2017–11/7/2017	2,011
Q2	No probe deployed	no data
Q3	5/1/2018–5/29/2018	2,688
Q4	7/18/2018–8/8/2018	944

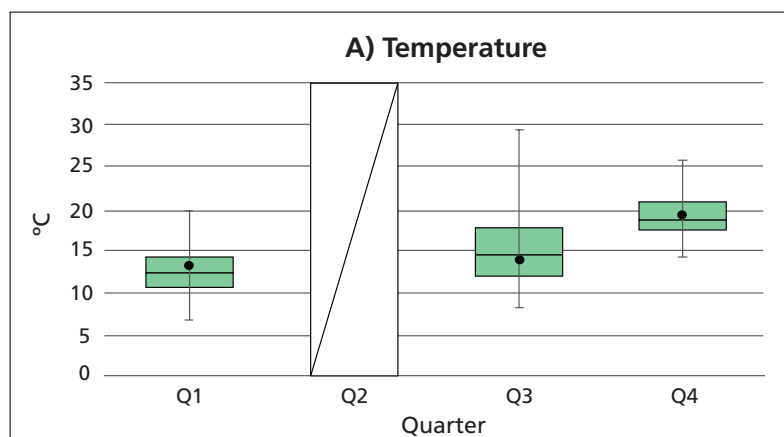
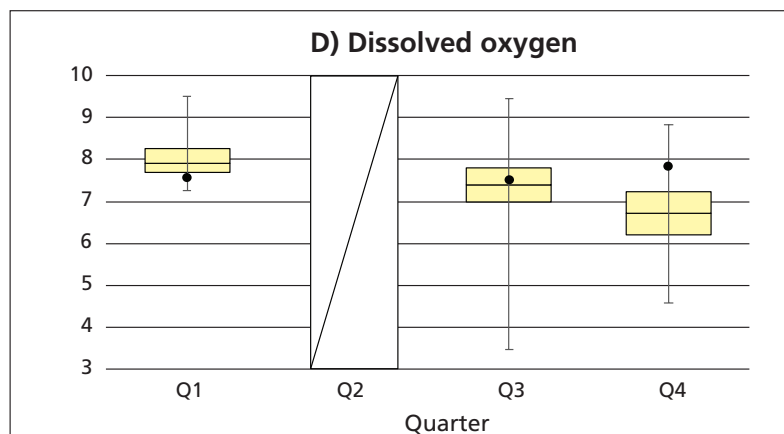
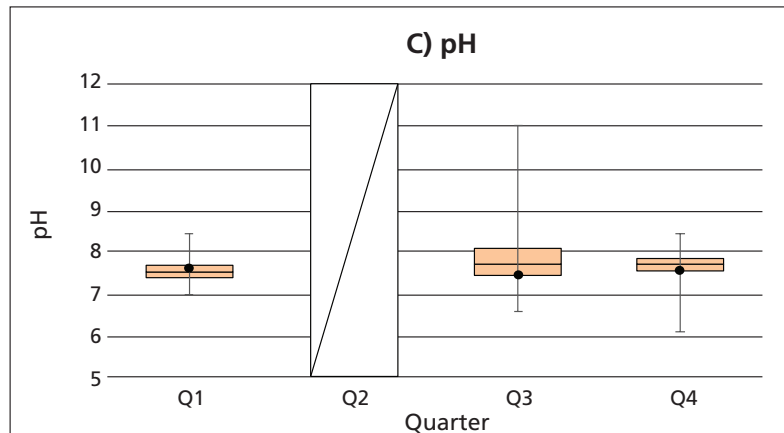
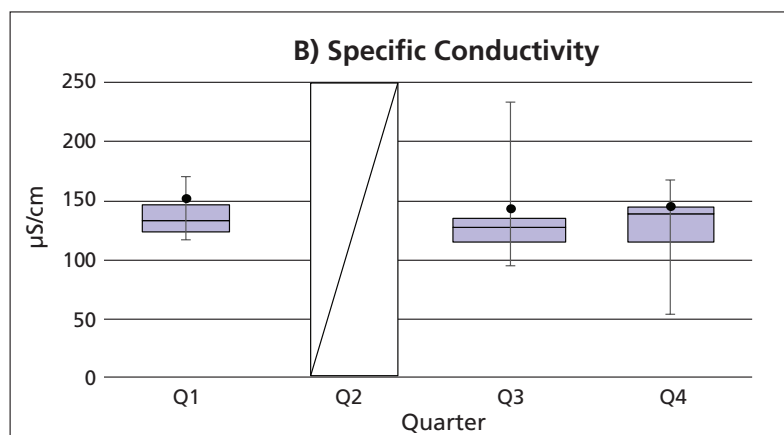


Figure 4-5. Seasonal variability in continuous data for (A) water temperature, (B) specific conductivity, (C) pH, and (D) dissolved oxygen concentration, West Fork Gila River, WY2018. These box-and-whisker graphs display data from water years 2011–2017. The top whisker is the maximum value for the parameter. The boxes indicate the 25th (bottom of box) to 75th (top of box) percentile of the data, with the line in the middle as the median value. The bottom whisker represents the minimum value. The solid black dots mark the median value from WY2018 sampling for each parameter. The sonde was not deployed during Q2.



The main impetus behind the High Quality Cold Water Aquatic Life beneficial-use designation is fishery management, and trout fisheries in particular. Trout are encountered within the monument, but historically in low numbers because of lack of habitat and sub-optimal water temperature (NMAC 2013). In Q4 of WY2018, there were several days during the sonde deployment (7/21, 7/22, 7/28, 8/2, 8/4, 8/5, 8/7) when the water temperature exceeded the state temperature standard for more than four hours. This helps illustrate that the habitat found at the park for trout reproduction is sub-optimal, due to low elevation. As the climate warms and temperature ranges shift, habitat may become unsuitable for trout reproduction.

The median values for core parameters were generally within the expected range (between the 25th and 75th percentile) in WY2018, with the exception of the measurements for dissolved oxygen in Q4 and pH in Q3 (see Figure 4-5). There is no obvious explanation for these anomalies. The median DO value, 7.3 mg/L, is not unusual and may be indicative of the slightly lower water temperature. SODN will continue to consider this value as more data become available.

4.3.2.2 Nutrients

The results from nutrient sampling during WY2018 (nitrate, nitrite, total nitrogen, and Kjeldahl nitrogen) were all below the detection limit of the instrumentation used for analysis (Table 4-4). Please see Appendix A for the detection limits and methods for nutrient analysis.

4.3.2.3 Biological condition

No exceedances were detected for this parameter group, which includes *E. coli* (Table 4-5). SODN data for total coliforms and *E. coli* are expressed as a most probable number (MPN) per 100 mL of stream water, a statistical estimate of the number of bacteria. Although water-quality criteria are expressed as colony-forming units (cfu) per 100 mL (which, unlike MPN, does not assume estimation), the two units are comparable.

The bacterium, *E. coli*, is a naturally occurring member of the biotic community.

It is found in soil, decaying material, and the guts of mammals. It is used as an indicator of contamination of water by human fecal waste.

There have been past exceedances of state *E. coli* standards at the West Fork Gila River index site. However, these exceedances have been attributed to natural sources, mainly beavers and beaver pools directly upstream from the sample site. In WY2018, there were no beaver dams within one kilometer upstream of the sample site.

Only parameters with results are reported. Please note that parameters not reported should not assumed to be zero, but rather below the detection limit of the analytical equipment. They may have been present in very low concentrations.

4.3.2.4 Metals and metalloids

There were no exceedances of state water-quality standards for metals and metalloids in WY2018 (Tables 4-6 and 4-7). Other results were within expected ranges. Only parameters with results are reported. Please note that parameters not reported should not assumed to be zero, but rather below the detection limit of the analytical equipment. They may have been present in very low concentrations.

4.3.2.5 Suspended and total sediment

During WY2018, results for suspended and total sediment fell within the expected range (Table 4-8). Only parameters with results are reported. Please note that parameters not reported should not assumed to be zero, but rather below the detection limit of the analytical equipment. They may have been present in very low concentrations.

4.3.2.6 General water quality and inorganics

During WY2018, results for general water quality and inorganics were within the range of expected values (Table 4-9). Please note that parameters not reported should not assumed to be zero, but rather below the detection limit of the analytical equipment. They may have been present in very low concentrations.

Table 4-4. Results (mg/L) from nutrient sampling, West Fork Gila River, WY2018.

Analyte	Quarter ¹				Method ²	New Mexico state standard	
	Q1	Q2	Q3	Q4		Measure	Beneficial use
Nitrate, Nitrite as N	<0.10	<0.10	<0.10	<0.10	353.2		132
Total Nitrogen	<0.10	<0.10	<0.10	<0.10	calculated		NS ³

¹Parameters reported with a "<" symbol are not assumed to be zero, but rather below the detection limit of the analytical equipment. They may have been present in very low concentrations. ²Eaton and others (2005). ³No Standard.

Table 4-5. Results (mg/L) from biological condition sampling, West Fork Gila River, WY2018.

Analyte	Quarter				Method ¹	New Mexico state standard	
	Q1	Q2	Q3	Q4		Measure	Beneficial use
Total Organic Carbon	NC ²	NC ²	NC ²	2.2	SM 5310B	NS ³	–
<i>E. coli</i> (MPN) ⁴	8.97 ± 1.84	<1.0 ⁵	11.4 ± 4.51	119.4 ± 25.8	SM 9223B	235 (single sample)	Park-specific

¹SM = standard method (Eaton et al. 2005). ²Not Collected. ³No Standard. ⁴Most Probable Number 100 mL. ⁵Parameters reported with a "<" symbol are not assumed to be zero, but rather below the detection limit of the analytical equipment. They may have been present in very low concentrations.

Table 4-6. Results (mg/L) from metal and metalloids (dissolved) sampling, West Fork Gila River, WY2018.

Analyte	Quarter				Method ¹	New Mexico state standard	
	Q1	Q2 ²	Q3	Q4		Measure	Beneficial use
Calcium	15	14	15	14	EPA 200.7	NS ³	NS ³
Magnesium	3	2.8	2.8	3	EPA 200.7	NS ³	NS ³
Manganese	0.013	<0.01 ⁴	<0.01 ⁴	0.01	EPA 200.7/200.8	Calculated ⁵	Aquatic Life - Chronic
SiO ₂ , Silica	29	26	29	29	EPA 200.7	NS ³	NS ³
Sodium	8.3	8.6	8.6	9.4	EPA 200.7	NS ³	NS ³

¹Methods are from Eaton and others (2005). ²Sampling technique affected dissolved metal measurements. This begs further explanation. ³No Standard. ⁴Parameters reported with a "<" symbol are not assumed to be zero, but rather below the detection limit of the analytical equipment. They may have been present in very low concentrations. ⁵Standard calculated using total hardness of sample.

Table 4-7. Results (mg/L) from metal and metalloids (total) sampling, West Fork Gila River, WY2018.

Analyte	Quarter				Method ¹	New Mexico state standard	
	Q1	Q2 ²	Q3	Q4		Measure	Beneficial use
Calcium	15	14	15	15	EPA 200.7/200.7 Rev 4.42	NS ³	NS ³
Magnesium	3	2.8	2.8	3.2	EPA 200.7/200.7 Rev 4.42	NS ³	NS ³
SiO ₂ , Silica	30	26	28	30	EPA 200.7/200.7 Rev 4.42	NS ³	NS ³
Sodium	8.5	8.4	8.3	9.7	EPA 200.7/200.7 Rev 4.42	NS ³	NS ³

¹Methods are from Eaton and others (2005). ²Sampling technique affected dissolved metal measurements. This begs further explanation. ³No Standard.

Table 4-8. Results (mg/L) from suspended and total sediment sampling, West Fork Gila River, WY2018.

Analyte	Quarter				Method ¹	New Mexico state standard
	Q1	Q2	Q3	Q4		
Total dissolved solids	110	100	100	97	SM 2540C	NS ²
Total suspended solids	<4 ³	<4 ³	<4 ³	13	SM 2540D	NS ²

¹Eaton and others (2005). ²No Standard. ³Parameters reported with a "<" symbol are not assumed to be zero, but rather below the detection limit of the analytical equipment. They may have been present in very low concentrations.

Table 4-9. Results (mg/L) from general and inorganic sampling, West Fork Gila River, WY2018.

Analyte	Quarter				Method ¹	New Mexico state standard
	Q1	Q2	Q3	Q4		
Alkalinity as CaCO ₃	63	59	63	61	SM 2320B	NS ²
Bicarbonate Alkalinity as CaCO ₃	63	59	63	61	SM 2320B	NS ²
Fluoride	0.79	0.89	1	0.79	EPA 300.0	NS ²
Total Hardness	49	47	48	50	SM 2340B	NS ²
Anion/Cation Balance	1.9	3.1	1.6	3.6	SM 1030E	NS ²

¹Eaton and others (2005). ²No Standard.

4.3.3 Macroinvertebrates

Macroinvertebrate samples and associated habitat data were collected at the monument on October 16, 2017. A list of taxa collected from the index reach can be found in Appendix B.

The State of New Mexico uses the New Mexico Stream Condition Indices (NMSCI; Jacobi et. al 2006) to meet mandates established by the U.S. Environmental Protection Agency. In WY2018, the index was measured at 50.14 (Figure 4-6). This placed Gila Cliff Dwellings NM in the “Fair” category, falling in the middle 20% of index sites in the “high-elevation small watershed” class.

This index reach has been sampled with the same methods since WY2012. The NMSCI

value has been near the upper 25th percentile each year—even after major fires in the monument watershed (2011–2012). These results show the resilience of the macroinvertebrate community, and the ability of the stream reach to recover after postfire flows of debris and ash.

As noted in Section 4.3.2.1, the monument is at the lower end of its elevation category for water-quality standards. This may influence the park’s NMSCI score, as well. The park’s median index score is 54.4 since WY2011, and the boundary for the “good” rating is 56.70. The value for WY2018 falls within the expected range of values for the index at Gila Cliff Dwellings NM.

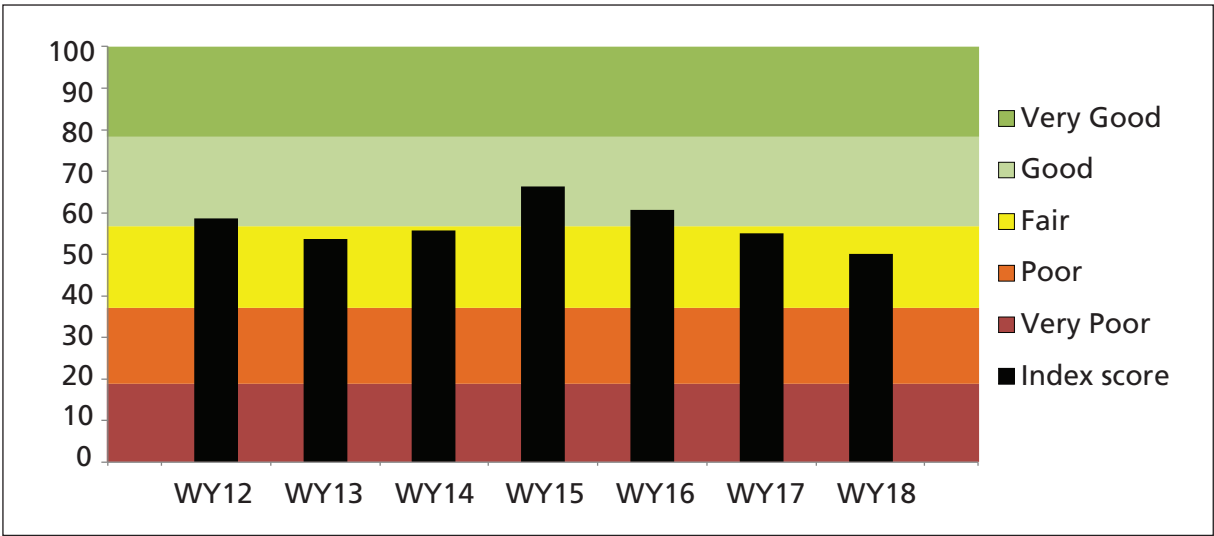


Figure 4-6. New Mexico Stream Condition Index scores, West Fork Gila River, WY2012–2018.

5 Literature Cited

- Comer, P. J., B. Young, K. Schulz, G. Kittel, B. Unnasch, D. Braun, G. Hammerson, L. Smart, H. Hamilton, S. Auer, R. Smyth, and J. Hak. 2012. Climate change vulnerability and adaptation strategies for natural communities: Piloting methods in the Mojave and Sonoran deserts. Report to the U.S. Fish and Wildlife Service. NatureServe, Arlington, Virginia.
- Dekker, F. J., and D. L. Hughson. 2014. Reliability of ephemeral montane springs in Mojave National Preserve, California. *Journal of Arid Environments* 111:61–67.
- Eaton, A. D., L. S. Clesceri, E. W. Rice, and A. E. Greenberg, eds. 2005. Standard methods for the examination of water and wastewater. 21st edition. American Public Health Association, American Water Works Association, Water Environment Federation, American Public Health Association, Washington, D.C.
- Garfin, G., A. Jardine, R. Merideth, M. Black, and S. LeRoy, eds. 2013. Assessment of climate change in the Southwest United States: A report prepared for the National Climate Assessment. A report by the Southwest Climate Alliance. Washington, DC: Island Press.
- Goodrum, G., E. Gwilliam, L. Palacios, and K. Raymond. 2019. Status of climate and water resources at Gila Cliff Dwellings National Monument: Water year 2017. Natural Resource Report NPS/SODN/NRR—2019/1890. National Park Service, Fort Collins, Colorado.
- Grimm, N. B., A. Chacon, C. N. Dahm, S. W. Hostetler, O. T. Lind, P. L. Starkweather, and W. W. Wurtsbaugh. 1997. Sensitivity of aquatic ecosystems to climatic and anthropogenic changes: The basin and range, American Southwest and Mexico. *Hydrological Processes* 11:1023–1041.
- Gwilliam, E., C. McIntyre, A. Hubbard, K. Raymond, K. Bonebrake, and L. Palacios. 2018. Streams monitoring protocol for the Sonoran Desert and Southern Plains networks: Version 1.0. Natural Resource Report NPS/SODN/NRR—2017/1787. National Park Service, Fort Collins, Colorado.
- IDEXX. 2018. IDEXX MPN generator software program, v1.4.4. IDEXX Laboratories, Inc. <https://www.idexx.com/en/water/resources/mpn-generator/>. Accessed 2/5/2018.
- Irwin, R. J. 2008. Draft Part B lite QA/QC Review checklist for aquatic vital sign monitoring protocols and SOPs. National Park Service, Water Resources Division, Fort Collins, Colorado. <https://www.nature.nps.gov/water/vitalsigns/assets/docs/PartBLite.pdf>.
- Jacobi G. Z., M. D. Jacobi, M. T. Barbour, and E. W. Leppo. 2006. Benthic macroinvertebrate stream condition indices for New Mexico wadeable streams. Jacobi and Associates and Tetra Tech, Inc. for New Mexico Environment Department, Surface Water Quality Bureau. Santa Fe, New Mexico.
- Kenney, T. A. 2010. Levels at gaging stations: U.S. Geological Survey Techniques and Methods 3-A19. 60 p.
- McIntyre, C., K. Gallo, E. Gwilliam, J. A. Hubbard, J. Christian K. Bonebrake, G. Goodrum, M. Podolinsky, L. Palacios, B. Cooper and M. Isley. 2018. Springs, seeps, and tinajas monitoring protocol: Chihuahuan and Sonoran Desert Networks. Natural Resource Report NPS/CHDN/NRR—2018/1796. National Park Service, Fort Collins, Colorado.
- Hubbard, J. A., K. Raymond, E. Gwilliam, and M. Tercek. in prep. Climate monitoring protocol for the Sonoran, Chihuahuan, and Southern Plains national parks.
- McIntyre, C., K. Gallo, E. Gwilliam, J. A. Hubbard, J. Christian, K. Bonebrake, G. Goodrum, M. Podolinsky, L. Palacios, B. Cooper, and M. Isley. 2018. Springs, seeps, and tinajas monitoring protocol: Chihuahuan and Sonoran Desert Networks. Natural Resource Report NPS/CHDN/NRR—2018/1796. National Park Service, Fort Collins, Colorado.
- National Park Service (NPS). 1998. Baseline water quality data inventory and analy-

- sis: Gila Cliff Dwellings National Monument. NPS/NRWRD/ NRTR-98/156. National Park Service, Water Resources Division. Fort Collins, Colorado.
- New Mexico Administrative Code (NMAC). 2013. Environmental water quality standards of interstate and intrastate surface waters. Page 48 in New Mexico Water Control Commission, Title 20, Chapter 6, Part 4. <http://164.64.110.239/nmac/parts/title20/20.006.0004.pdf>. Accessed April 11, 2016.
- Rosgen, D. L. 1996. Applied river morphology. Pagosa Springs, Co.: Wildland Hydrology.
- Sada, D. W. 2013a. Environmental and biological characteristics of springs in the Chihuahuan Desert Network of National Parks, with a prioritized assessment of suitability to monitor for effects of climate change. Unpublished report to U.S. National Park Service, Chihuahuan Desert Inventory and Monitoring Network, Las Cruces, New Mexico.
- Sada, D. W. 2013b. Environmental and biological characteristics of springs in the Sonoran Desert Network of National Parks, with an assessment of suitability to monitor for effects of climate change. Unpublished report to U.S. National Park Service, Chihuahuan Desert Inventory and Monitoring Network, Las Cruces, New Mexico.
- Sada, D. W., E. Fleischman, and D. D. Murphy. 2005. Associations among spring-dependent aquatic assemblages and environmental and land use gradients in a Mojave Desert mountain range. *Diversity and Distributions* 11:91–99.
- Sada, D. W., and K. F. Pohlmann. 2006. DRAFT U.S. National Park Service Mojave Inventory and Monitoring Network spring survey protocols: Level I and II. Unpublished Report, Desert Research Institute, Reno and Las Vegas, Nevada.
- Sauer, V. B., and D. P. Turnipseed. 2010. Stage measurement at gaging stations. U.S. Geological Survey techniques and methods, book 3, chapter A7. <http://pubs.usgs.gov/tm/tm3-a7/>.
- Strahler, A. H. 2013. *Introducing physical geography*. 6th edition. Hoboken, N.J.: Wiley.
- Tsakiris, G., and H. Vangelis. 2005. Establishing a drought index incorporating evapotranspiration. *European Water* 9/10:3–11.
- Turner, R. M., R. H. Webb, J. E. Bowers, and J. R. Hastings. 2003. *The changing mile revisited*. Tucson: University of Arizona Press.
- Turnipseed, D. P., and V. B. Sauer. 2010. Discharge measurements at gaging stations. U.S. Geological Survey techniques and methods, book 3, chapter A8. <https://pubs.usgs.gov/tm/tm3-a8/>.
- U.S. Geological Survey (USGS). 2006. National field manual for the collection of water-quality data. <https://water.usgs.gov/owq/FieldManual/>.
- United Nations Environment Programme (UNEP). 1992. *World atlas of desertification*. London: Edward Arnold.
- Weissinger, R., T. E. Philippi, and D. Thoma. 2016. Linking climate to changing discharge at springs in Arches National Park, Utah, USA. *Ecosphere* 7:e01491.

Appendix A. Detection Limits and Methods for Nutrient Analysis

Table A-1. Detection limits and methods for nutrient analysis, West Fork Gila River, Gila Cliff Dwellings National Monument, WY2018.

Analyte	Detection limit	Units	Method
Acidity	10.00	mg/L	SM 2310B
Alkalinity as CaCO ₃	5.00	mg/L	SM 2320B
Aluminum	0.10	mg/L	200.7 Rev 4.4
Ammonia	0.10	mg/L	350.1
Anion/Cation Balance	N.A.	%	SM 1030E
Antimony	2.00	ug/L	200.8
Arsenic	5.00	ug/L	200.8
Barium	1.00	ug/L	200.8
Beryllium	1.00	ug/L	200.8
Bicarbonate Alkalinity as CaCO ₃	5.00	mg/L	SM 2320B
Biochemical Oxygen Demand	2.00	mg/L	SM5210B
Boron	0.10	mg/L	200.7 Rev 4.4
Cadmium	1.00	ug/L	200.8
Calcium	0.20	mg/L	200.7 Rev 4.4
Carbonate Alkalinity as CaCO ₃	5.00	mg/L	SM 2320B
Chloride	3.00	mg/L	300.0
Chromium	3.00	ug/L	200.8
Copper	2.00	ug/L	200.8
Cyanide, Total	0.01	mg/L	SM 4500 CN E
Dis Aluminum	0.10	mg/L	200.7
Dis Antimony	2.00	ug/L	200.8
Dis Arsenic	5.00	ug/L	200.8
Dis Barium	1.00	ug/L	200.8
Dis Beryllium	1.00	ug/L	200.8
Dis Boron	0.10	mg/L	200.7
Dis Cadmium	1.00	ug/L	200.8
Dis Calcium	0.20	mg/L	200.7
Dis Chromium	3.00	ug/L	200.8
Dis Copper	2.00	ug/L	200.8
Dis Iron	0.10	mg/L	200.7
Dis Lead	1.00	ug/L	200.8
Dis Magnesium	0.20	mg/L	200.7
Dis Manganese	2.00	ug/L	200.8
Dis Mercury	0.00	mg/L	245.1
Dis Molybdenum	2.00	ug/L	200.8
Dis Nickel	2.00	ug/L	200.8
Dis Phosphorus	3.00	mg/L	200.7
Dis Potassium	3.00	mg/L	200.7
Dis Selenium	5.00	ug/L	200.8
Dis Silver	1.00	ug/L	200.8
Dis SiO ₂ , Silica	1.10	mg/L	200.7

Table A-1. Detection limits and methods for nutrient analysis, West Fork Gila River, Gila Cliff Dwellings National Monument, WY2018, cont.

Analyte	Detection limit	Units	Method
Dis Sodium	5.00	mg/L	200.7
Dis Thallium	1.00	ug/L	200.8
Dis Uranium	1.00	ug/L	200.8
Dis Zinc	10.00	ug/L	200.8
Fluoride	0.50	mg/L	300.0
Hardness, as CaCO ₃	1.30	mg/L	SM 2340B
Iron	0.10	mg/L	200.7 Rev 4.4
Lead	1.00	ug/L	200.8
Magnesium	0.20	mg/L	200.7 Rev 4.4
Manganese	2.00	ug/L	200.8
Mercury	0.00	mg/L	245.1
Molybdenum	2.00	ug/L	200.8
Nickel	2.00	ug/L	200.8
Nitrate Nitrite as N	0.10	mg/L	353.2
Nitrate, Dissolved	0.50	mg/L	300.0
Nitrite, dissolved	0.50	mg/L	300.0
Nitrogen, Kjeldahl	1.00	mg/L	351.2
Nitrogen, Total	0.10	mg/L	Computed
pH	0.10	SU	SM 4500 H+ B
Phosphorus	3.00	mg/L	200.7 Rev 4.4
Potassium	3.00	mg/L	200.7 Rev 4.4
Selenium	5.00	ug/L	200.8
Silver	1.00	ug/L	200.8
SiO ₂ , Silica	1.10	mg/L	200.7 Rev 4.4
Sodium	5.00	mg/L	200.7 Rev 4.4
Specific Conductance	2.00	umhos/cm	SM 2510B
Sulfate	5.00	mg/L	300.0
Thallium	1.00	ug/L	200.8
Total Dissolved Solids	10.00	mg/L	SM 2540C
Total Organic Carbon	1.00	mg/L	SM 5310B
Total Suspended Solids	4.00	mg/L	SM 2540D
Uranium	1.00	ug/L	200.8
Zinc	10.00	ug/L	200.8

Appendix B. Macroinvertebrate Taxa

This appendix contains a list of all the macroinvertebrate taxa collected at the GICL index reach on the West Fork of the Gila River. It combines the results from all macroinvertebrate sampling at the index site, including the targeted riffles, and the reach-wide samples.

Table B-1. Macroinvertebrate taxa collected at the index reach on the West Fork Gila River, Gila Cliff Dwellings National Monument, WY2018.

Phylum	Class	Order	Family	Genus	Species
Annelida	Clitellata	–	–	–	–
Arthropoda	Arachnida	Trombidiformes	Hygrobatidae	–	–
Arthropoda	Arachnida	Trombidiformes	Lebertiidae	Lebertia	–
Arthropoda	Arachnida	Trombidiformes	Sperchonidae	Sperchon	–
Arthropoda	Arachnida	Trombidiformes	Sperchonidae	Sperchonopsis	–
Arthropoda	Arachnida	Trombidiformes	Torrenticolidae	Torrenticola	–
Arthropoda	Arachnida	Trombidiformes	–	–	–
Arthropoda	Insecta	Coleoptera	Dryopidae	Postelichus	–
Arthropoda	Insecta	Coleoptera	Elmidae	Heterelmis	–
Arthropoda	Insecta	Coleoptera	Elmidae	Microcylloepus	pusillus
Arthropoda	Insecta	Coleoptera	Elmidae	Optioservus	–
Arthropoda	Insecta	Coleoptera	Elmidae	–	–
Arthropoda	Insecta	Coleoptera	Psephenidae	Psephenus	–
Arthropoda	Insecta	Diptera	Ceratopogonidae	Probezzia	–
Arthropoda	Insecta	Diptera	Ceratopogonidae	–	–
Arthropoda	Insecta	Diptera	Chironomidae	–	–
Arthropoda	Insecta	Diptera	Empididae	Hemerodromia	–
Arthropoda	Insecta	Diptera	Empididae	Wiedemannia	–
Arthropoda	Insecta	Diptera	Empididae	–	–
Arthropoda	Insecta	Diptera	Psychodidae	Maruina	–
Arthropoda	Insecta	Diptera	Simuliidae	Simulium	–
Arthropoda	Insecta	Diptera	Simuliidae	–	–
Arthropoda	Insecta	Diptera	Tabanidae	Tabanus	–
Arthropoda	Insecta	Diptera	Tipulidae	Tipula	–
Arthropoda	Insecta	Diptera	Tipulidae	–	–
Arthropoda	Insecta	Ephemeroptera	Baetidae	Acentrella	–
Arthropoda	Insecta	Ephemeroptera	Baetidae	Baetis	–
Arthropoda	Insecta	Ephemeroptera	Ephemerellidae	–	–
Arthropoda	Insecta	Ephemeroptera	Heptageniidae	Epeorus	–
Arthropoda	Insecta	Ephemeroptera	Leptohyphidae	Leptohyphes	–
Arthropoda	Insecta	Ephemeroptera	Leptohyphidae	Tricorythodes	–
Arthropoda	Insecta	Ephemeroptera	Leptohyphidae	–	–
Arthropoda	Insecta	Ephemeroptera	Leptophlebiidae	–	–
Arthropoda	Insecta	Hemiptera	Belostomatidae	–	–
Arthropoda	Insecta	Hemiptera	Corixidae	–	–

Phylum	Class	Order	Family	Genus	Species
Arthropoda	Insecta	Lepidoptera	Crambidae	Petrophila	–
Arthropoda	Insecta	Megaloptera	Corydalidae	Corydalus	cornutus
Arthropoda	Insecta	Odonata	Calopterygidae	Hetaerina	–
Arthropoda	Insecta	Odonata	Coenagrionidae	Argia	–
Arthropoda	Insecta	Odonata	Gomphidae	Progomphus	–
Arthropoda	Insecta	Odonata	Gomphidae	–	–
Arthropoda	Insecta	Odonata	Libellulidae	–	–
Arthropoda	Insecta	Plecoptera	Perlodidae	Isogenoides	–
Arthropoda	Insecta	Plecoptera		–	–
Arthropoda	Insecta	Trichoptera	Helicopsychidae	Helicopsyche	–
Arthropoda	Insecta	Trichoptera	Hydrobiosidae	Atopsyche	–
Arthropoda	Insecta	Trichoptera	Hydropsychidae	Cheumatopsyche	–
Arthropoda	Insecta	Trichoptera	Hydropsychidae	Hydropsyche	–
Arthropoda	Insecta	Trichoptera	Hydropsychidae	–	–
Arthropoda	Insecta	Trichoptera	Hydroptilidae	Hydroptila	–
Arthropoda	Insecta	Trichoptera	Hydroptilidae	Leucotrichia	–
Arthropoda	Insecta	Trichoptera	Hydroptilidae	–	–
Arthropoda	Insecta	Trichoptera	Leptoceridae	Nectopsyche	–
Arthropoda	Insecta	Trichoptera	Leptoceridae	Oecetis	–
Arthropoda	Insecta	Trichoptera	Rhyacophilidae	Rhyacophila	–

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