



Status of Climate and Water Resources at Carlsbad Caverns National Park

Water Year 2018

Natural Resource Report NPS/CHDN/NRR—2019/2039



ON THE COVER

Rain showers at Carlsbad Caverns National Park. Photo credit: NPSU. Christian

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Data in this report were collected and analyzed using methods based on established, peer-reviewed protocols and were analyzed and interpreted within the guidelines of the protocols.

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Glossary

anthropogenic: caused by human activities

aquifer: an underground layer of rock, sand, etc., containing water

dissolved oxygen (DO): the amount of oxygen in a solution, typically measured as a concentration of milligrams of DO per liter

facultative wetland species: plants usually occurring in wetlands

invasive non-native: a plant or animal that occurs outside of its native or natural range and can cause harm to the environment, people, and/or the economy

limnocrene: spring type that emerges as a pool

obligate wetland species: plants almost always occurring in wetlands

orifice: aboveground emergence of a spring

perennial: persisting for many growing seasons (plant); flowing throughout the year (spring)

pH: a measure of hydrogen ion concentration; a measure of the acidity or alkalinity of a solution

reconnaissance drought index: drought classification based on precipitation and potential evapotranspiration

rheocrene: spring type that emerges as a flowing stream

riparian: associated with the edges of a spring, stream, lake, or river, such as a riparian species, landowner, etc.

specific conductivity: a measure of water's ability to conduct an electrical current

spring: a place where water naturally flows from the ground or rock upon the land to form a stream or into a body of water

total dissolved solids: a measure of the combined content of all inorganic and organic substances contained in a liquid in molecular, ionized, or microgranular suspended form

tinaja: a (generally) small pool in rock basin, can be groundwater-fed

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 and surface water at Carlsbad Caverns National Park (NP) to provide an integrated look at climate and water conditions during water year (WY) 2018 (October 2017–September 2018).

Overall, annual precipitation was 53% of normal in WY2018. Except for a higher than normal rainfall in November, all months had lower than normal rainfall, with six months receiving <50% of normal (1981–2010). Temperatures at Carlsbad Caverns NP were generally warmer than normal, as great as 6.5°F higher than monthly normals. While extreme cold days occurred slightly less frequently, extreme warm days occurred 28% more often. The reconnaissance drought index indicated that WY2018 was a drier than average year.

Six springs were monitored in the park and all had surface water present when visited in WY2018. Although overall (median) disturbance ratings were low, each spring showed some sort of natural or anthropogenic disturbance.

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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, 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 Carlsbad Caverns National Park (NP), a 73 mi² (189 km²) National Park Service unit in

southeastern New Mexico. Detailed analyses of trends will follow in subsequent reports as the period of record warrants such assessments. Some of the information herein is derived from Chihuahuan Desert Inventory & Monitoring Network monitoring, while other complementary information is harvested from publicly available sources. For details on the monitoring protocols, please see the [Chihuahuan Desert website \(https://www.nps.gov/im/chdn/protocols.htm\)](https://www.nps.gov/im/chdn/protocols.htm).

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 (Strahler 2013)—in short, the underpinnings of the natural resources that the National Park Service manages and protects. The updated Köppen Climate Classification System identifies the park’s climate as warm semi-arid (Peel et al. 2007).

Carlsbad Caverns NP has operated a National Oceanic and Atmospheric Administration (NOAA) Cooperative Observer Program (COOP) weather station (Carlsbad Caverns, ID# 291480) since 1935. The record from this station provides a reliable, long-term climate dataset used for the analyses in this report. A Remote Automated Weather Station (RAWS) (Batdraw, BATN5) is also located in the park, 3.0 miles (4.8 km) east of the COOP station and provides supplemental information in this report. This station has been in operation since 1997. The station data were obtained from Climate Analyzer (Walking Shadow Ecology 2019a; Walking Shadow Ecology 2019b), a website that allows users to make on-demand tables and graphs with data from weather stations that are updated daily (Walking Shadow Ecology 2019c).

2.2 Results and discussion

Data quality during WY2018 was good. Only seven days were missing temperature data, and thirteen days were missing precipitation data.

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

Overall annual precipitation was 53% of normal (1981–2010) for Carlsbad Caverns NP (8.40 inches vs 15.72 inches).

2.2.1.1 Cool season (October–March)

Precipitation was substantially below normal (66% or –1.25 inches) for the fall and winter of WY2018. Precipitation in November was 164% of normal, owing primarily to a four-day (November 8–11, 2017) low intensity storm system, totaling 0.90 inches (Figures 2-1 and 2-2). Precipitation in all other months was less than normal. Mean monthly minimum and maximum air temperatures were generally warmer than normal, up to 4.5°F. However, temperatures were slightly cooler than normal in January, and in February, the mean minimum was 3.6°F cooler than normal.

2.2.1.2 Warm season (April–September)

During the spring and summer, precipitation was half of normal (49% or –6.07 inches). However, July precipitation may be underestimated as data are missing for four days, and the nearby RAWS station measured an additional 0.62 inches during that period. August received near normal rainfall, while all other months were substantially below (6–67%) normal. Air temperatures were generally above normal, with May exhibiting the peak deviation; mean maximum and minimum temperatures in May were 5.8°F and 6.5°F degrees above normal. By September, mean temperatures had cooled off slightly.

2.2.2 Reconnaissance Drought Index

Reconnaissance drought index (RDI) (Tsakiris and Vangelis 2005) provides a measure of drought severity and extent relative to the long-term climate based on the ratio of average precipitation to average potential evapotranspiration over shorter periods of time (seasons to years). The RDI at the COOP station could not be generated for several years due to insufficient data (Figure 2-3). The RDI for the RAWS is more complete (Figure 2-4). Both stations indicate that WY2018 was relatively dry compared to the average for Carlsbad Caverns NP (1981–2018 at the COOP station, and 1998–2018 at the RAWS station).

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. High air temperatures are a defining feature of warm deserts (Strahler 2013); however, extreme heat events can also have

Carlsbad Caverns - Water Year 2018 - Departure from 1981 - 2010 Avgs.

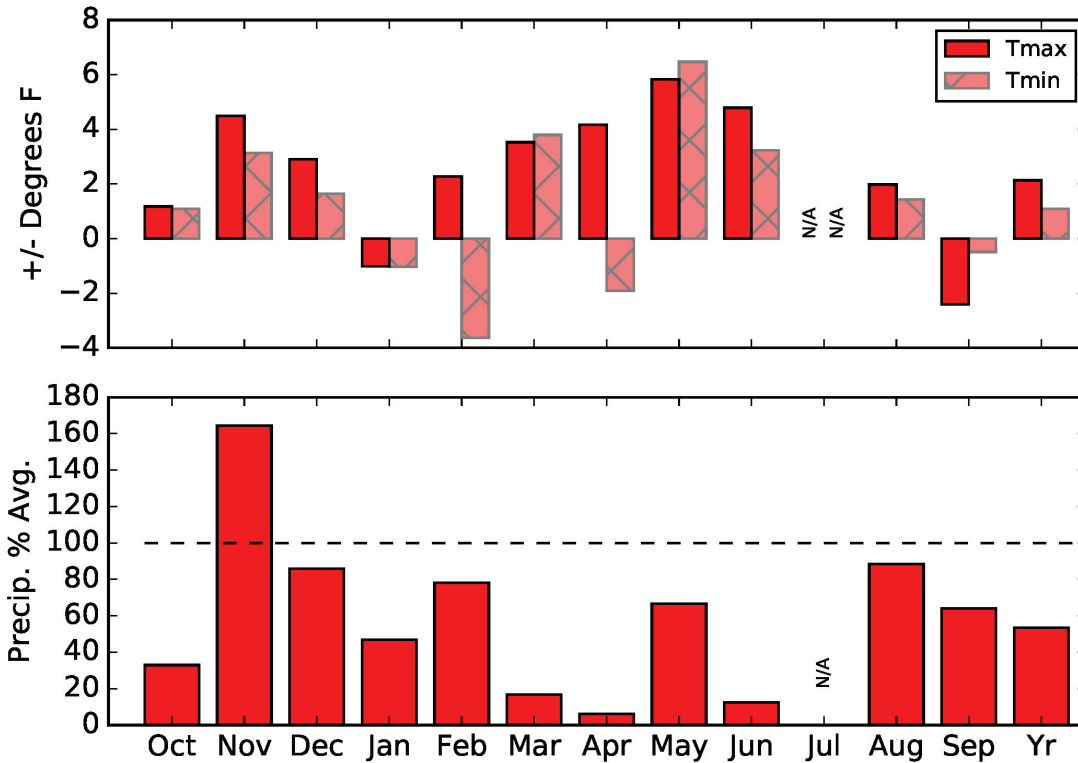


Figure 2-1. Departures from 30-year (1981–2010) normal minimum and maximum air temperature and precipitation, Carlsbad Caverns NP, COOP station, water year 2018. "n/a" = insufficient data to generate reliable data. Graphics generated by climateanalyzer.org (Walking Shadow Ecology 2019a).

Carlsbad Caverns - Water Year Ending 2018

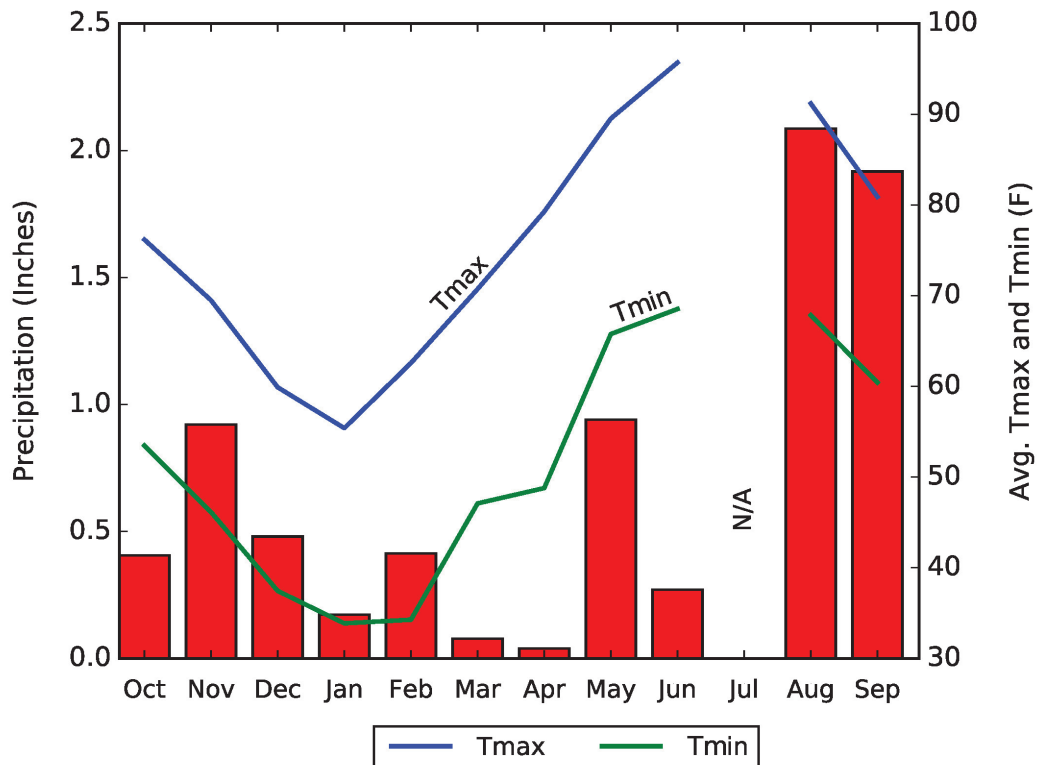


Figure 2-2. Climogram for Carlsbad Caverns NP, COOP station, water year 2018. "n/a" = insufficient data to generate reliable data. Graphic generated by climateanalyzer.org (Walking Shadow Ecology 2019a).

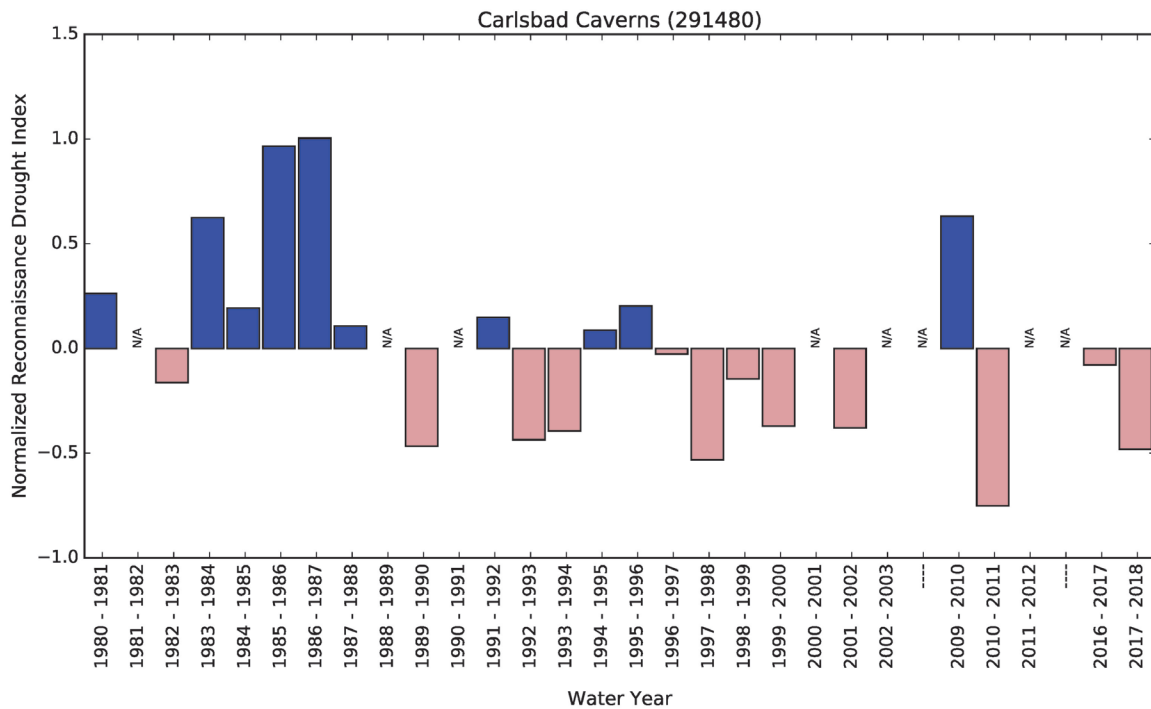


Figure 2-3. Reconnaissance drought index (RDI), Carlsbad Caverns NP, COOP station, water years 1981– 2018. “n/a” = insufficient data to generate reliable RDI estimates. Values above zero (in blue) indicate wetter than average conditions whereas values below zero (in red) indicate dryer than average conditions. The calculations are relative to the time period displayed and different time periods may produce different results. Graphic generated by climateanalyzer.org (Walking Shadow Ecology 2019a).

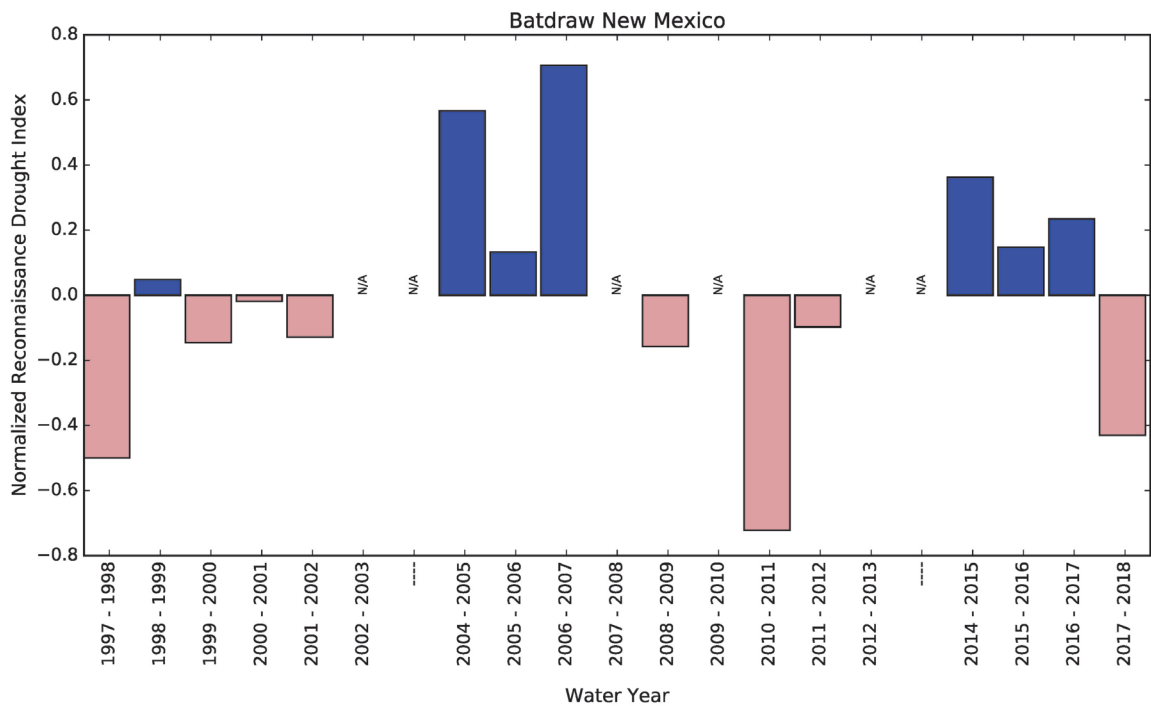


Figure 2-4. Reconnaissance drought index (RDI), Carlsbad Caverns NP, RAWs station, water years 1998– 2018. “n/a” = insufficient data to generate reliable RDI estimates. Values above zero (in blue) indicate wetter than average conditions whereas values below zero (in red) indicate dryer than average conditions. The calculations are relative to the time period displayed and different time periods may produce different results. Graphic generated by climateanalyzer.org (Walking Shadow Ecology 2019a).

important consequences for Chihuahuan Desert and Arizona-New Mexico mountain ecosystems. For example, extreme precipitation events can cause localized flooding and erosion events, spur or inhibit plant productivity and reproduction, and modify animal behavior (Sumner 1988).

Extremely cold days ($<26^{\circ}\text{F}$, 5th percentile of 1981–2010 data) occurred slightly less than normal (17 days vs. 18.9 ± 1.9 days) in WY2018, and were of a similar duration (2.4 consecutive days vs. 2.1 ± 0.1 days). Three days also remained below freezing for

the entire 24-hour period: January 1, January 2, and January 17, 2018.

Extremely warm days ($>96^{\circ}\text{F}$, 95th percentile of 1981–2010 data) occurred 28% more frequently (28 days vs. 21.9 ± 2.6 days) in WY2018, and were of a similar duration (2.3 consecutive days vs. 2.6 ± 0.2 days).

There was one day with extreme precipitation (≥ 1 inch) in WY2018, compared to an average 3.3 days a year for 1981–2010. The single largest precipitation amount occurred on August 19, 2018 (1.00 inches).

3 Springs

3.1 Background

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

Common stressors to springs biota include reduced water availability such as 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, with expected 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 disrupt ecological functions and reduce species diversity (Garfin et al. 2013).

3.2 Methods

The Chihuahuan Desert Network monitoring in WY2018 focused on six “sentinel sites” (McIntyre et al. 2018): Iron Pipe Seep, Oak Spring, Slaughter Pothole, Upper East Grammer Seep, Upper Lechuguilla Spring, and Upper Lowe Ranch Spring. Note that the statistical inference provided by this design is limited to each individual spring monitored over time and that the springs sampled may change.

The Chihuahuan Desert Network monitors a suite of vital signs and parameters organized into four modules: site characterization, site condition, water quantity, and water quality (McIntyre et al. 2018). A brief description of the data collection methodologies followed at Carlsbad Caverns NP during WY2018 is extracted from the protocol (McIntyre et al. 2018) and presented below. See McIntyre et al. (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). The site characterization 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 Carlsbad Caverns NP in 2018 and will be recollected in 2023. This report presents a highly condensed and edited version of the information collected in the site characterization module.

3.2.2 Site condition

The site condition module is based on inventory methods developed for the Mojave Desert Network (Sada and Pohlman 2006) and contains four subsections: disturbance, photo points, obligate/facultative wetland plants, and invasive non-native plants and wildlife (McIntyre et al. 2018). The disturbance assessment is a categorical measure of natural and anthropogenic disturbance and the level of stress on vegetation and soils in spring ecosystems (Sada and Pohlmann 2006). Types of natural disturbance evaluated include flooding, drying, fire, wildlife, windthrow of trees and shrubs, beaver activity, and insect infestations. 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 as evidenced by presence of campsites, fire rings, trash, etc. 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).

3.2.3 Water quantity

The water quantity module provides information on the persistence of springs, spring discharge, and wetted extent (McIntyre et al. 2018). The persistence of surface water at springs is estimated by analyzing the variance of temperature measurements taken every hour by electronic data recorders (Anderson et al. 2015). A sensor placed at or near the orifice is utilized to estimate presence of water as submersion of the sensor mediates diurnal temperature variation (Anderson et al. 2015). Days are marked as “wet” (water present) when the daily variance is less than 20°C. The method can yield both false wet and false

dry estimates, and quality control/quality assurance procedures are yet to be developed. Volumetric discharge calculates the system's surface outflow through a timed sample of water volume. Wetted extent provides information about the length (up to 100m), width, and depth of water present and is assessed using techniques for standing water (e.g., limnocrane springs, heleocone springs, and some tinajas) and for flowing water (e.g., rheocrane springs and some tinajas).

3.2.4 Water quality

Water quality monitoring includes core water quality parameters and water chemistry. Core parameters sampled by the Chihuahuan Desert Network 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 an optical dissolved oxygen meter (YSI ProODO) deployed on-site (McIntyre et al. 2018). Water

chemistry is assessed by collecting a surface water sample(s) and estimating the concentration of major ions with a photometer (YSI 9500) (McIntyre et al. 2018).

3.3 Results and discussion

3.3.1 Iron Pipe Seep

3.3.1.1 Site characterization and visit information

Iron Pipe Seep (Figure 3-1) is a rheocrane spring that was sampled on April 18, 2018. The spring emerges as a small trickle from a 2.5-cm (1-inch) pipe. This flow is cool and clear, and goes into a narrow channel containing seemingly stagnant pools. The substrate is cobble and silt, and the channel is lined by sedges (*Carex* sp.), perennial grasses (including creeping muhly; *Muhlenbergia repens*), and forbs. The channel ends in a 1m (3.3ft) wide by 0.5m (1.6ft) long "pool" which appears to be the result of trampling by feral animals. A somewhat larger remnant pool exists downslope, and was dry during the crew visit.



Figure 3-1. Iron Pipe Seep Orifice, Carlsbad Caverns NP, March 2018

3.3.1.2 Site condition

Disturbance surveys resulted in a median value of 1 = undisturbed for both anthropogenic and natural disturbance. The site was highly disturbed by trampling and bedding of animals, most likely Barbary sheep. It was also considered moderately disturbed due to drying. There is a 3m by 2m (9.8ft by 6.6ft) wallow of cracked mud.

The crew observed one obligate/facultative wetland plant genera and one family: sedge (*Carex* sp.) and rush (Juncaceae family). There were no invasive non-native plants or animals (crayfish or bullfrogs) noted.

3.3.1.3 Water quantity

The temperature sensor indicated that the spring was dry for the majority of the sampling period (April – September 2018; Figure 3-2). However, the sensor was in very shallow water, which may have led to numerous false dry days. Discharge from orifice A was estimated at 0.2 ± 0.0 L/minute (0.05 ± 0.00 gal/minute; all measurements the same). Iron Pipe Seep was measured as a rheocrene system with a channel length of 6.6m (21.7ft). Width and depth averaged 41.7cm (16.4in) and 1.2cm (0.5in), respectively.

3.3.1.4 Water quality

In 2018, core water quality (Table 3-1) and water chemistry (Table 3-2) were measured at the spring orifice.

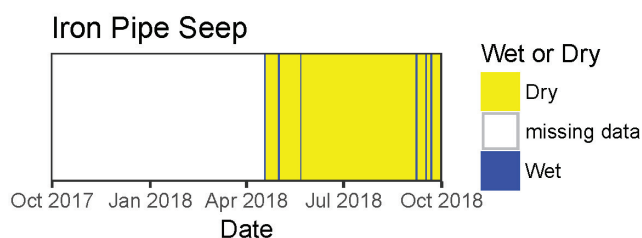


Figure 3-2. Estimated wet/dry days at Iron Pipe Seep

3.3.2 Oak Spring

3.3.2.1 Site characterization and visit information

Oak Spring (Figure 3-3) is a complex rheocrene system with multiple orifices that were sampled on March 12, 2018. Orifice A emerges from a 0.5-m (1.6-ft) bedrock shelf in the center of the main drainage, and flows 1.5m (4.9ft) into a crescent-shaped pool. The water flow then splits, rejoins, and then disappears under a pile of gravel before resurfacing approximately 8m (26.2ft) downstream of orifice A. Orifice B emerges from a 3 – 4 m (9.8 – 13.1ft) rock wall to the south and meets the main channel approximately 8m (26.2 ft) downstream of orifice A. The main gravel-bottomed channel is met 6m (19.7) downstream by additional flow from orifice B. After water from orifice B joins the main channel, surface water disappears under a mat of compacted soil and Bermudagrass (*Cynodon dactylon*). Downstream, there is a mat of large sedge (*Carex* sp.), which is variously wetted. Then two small but distinct channels flow into a large plunge pool filled with cattail (Typhaceae family) on the eastern edge. The pool narrows to a small channel, which disappears into gravel. A third orifice, orifice C, emerges to the north and never joins the main channel. Flow from all orifices is cool and clear with algae/litter in the pools.

3.3.2.2 Site condition

Disturbance surveys resulted in a median value of 1 = undisturbed for both anthropogenic and natural disturbance. Tracks and game trails were observed near the spring causing only slight disturbance. Field crews also noted a shorter intermittent channel, burned snags, and re-sprouts, indicating slight disturbance from fire and drying.

The crew observed two obligate/facultative wetland plant genera and one family: sedge (*Carex*

Table 3-1. Water Quality data for Iron Pipe Seep at Carlsbad Caverns NP, WY2018

Sampling Location	Orifice(s)	Sample time (24 hr)	Temperature (°C)	Dissolved Oxygen (mg/L)	pH	Specific Conductivity (µS/cm)	Total Dissolved Solids (mg/L)	Exposure
1	A	10:42	19.6	4.14	6.92	696.0	455.0	Sun

Table 3-2. Water Chemistry data for Iron Pipe Seep at Carlsbad Caverns NP, WY2018. All results in mg/L

Sampling Location	Orifice(s)	Alkalinity	Calcium	Chloride	Magnesium	Potassium	Sulfate
1	A	320	50	5	48	0.3	7



Figure 3-3. Oak Spring landscape, Carlsbad Caverns NP, March 2018

sp.), maidenhair fern (*Adiantum* sp.), and cattail (Typhaceae family). Two invasive non-native plants were noted at Oak Spring: a matrix of Bermudagrass (*Cynodon dactylon*) and scattered patches of horehound (*Marrubium vulgare*) just downslope of the terminus and farther downstream of the spring in the wash. No invasive, non-native animals (crayfish or bullfrogs) were observed.

3.3.2.3 Water quantity

A temperature sensor was deployed in the plunge pool approximately 35m (115ft) downstream of orifice A and indicated that the pool/spring was wetted for the majority of the sampled period (March – September 2018; Figure 3-4). Discharge from orifice A was estimated at 0.6 ± 0.01 L/minute (0.16 ± 0.003 gal/minute). Oak Spring was assessed as a rheocrene with a channel length of 43.7m (143.4ft). Width and depth averaged 101.0cm (39.8in) and 0.9cm (0.35in) respectively.

3.3.2.4 Water quality

In 2018, core water quality (Table 3-3) and water chemistry (Table 3-4) were measured at each orifice and the plunge pool (sampling location 5), totaling four samples. Values for dissolved oxygen are not reported because the instrument did not pass its post-calibration check.

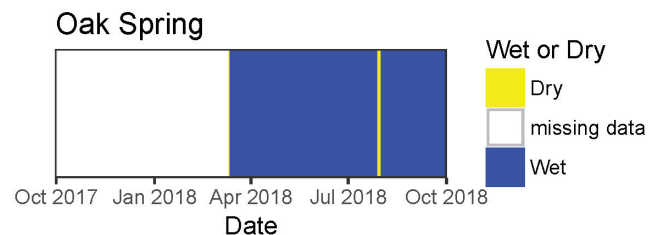


Figure 3-4. Estimated wet/dry days at Oak Spring

Table 3-3. Water Quality data for Oak Spring at Carlsbad Caverns NP, WY2018

Sampling Location	Orifice(s)	Sample time (24 hr)	Temperature (°C)	pH	Specific Conductivity (µS/cm)	Total Dissolved Solids (mg/L)	Exposure
1	A	12:58	15.8	8.12	594.8	386.8	Sun
2	B	13:06	11.3	7.74	570.3	370.5	Shade
3	C	13:34	21.3	8.12	631.0	409.5	Sun
5	A,B	13:50	13.1	7.88	586.0	380.9	Sun

Table 3-4. Water Chemistry data for Oak Spring at Carlsbad Caverns NP, WY2018. All results in mg/L

Sampling Location	Orifice(s)	Alkalinity	Calcium	Chloride	Magnesium	Potassium	Sulfate
1	A	265	58	10	28	0.5	21
2	B	280	58	14	40	0.4	34
3	C	300	62	b.d.l.	31	0.1	24
5	E	295	68	5	33	1.5	2

b.d.l. = below detection limit

3.3.3 Slaughter Pothole

3.3.3.1 Site characterization and visit information

Slaughter Pothole (Figure 3-5) is a tinaja that was sampled on March 26, 2018. The tinaja is entrapped on all sides by bedrock with a 30-degree pouroff to the north/upslope side and a bedrock slab to the south/downslope. Vegetation near the tinaja is limited due to the dominant bedrock substrate, though gravel/soil deposits on the northeast edge of the pool allow for some small forbs and grasses to persist.

3.3.3.2 Site condition

Disturbance surveys resulted in a median value of 1 = undisturbed for both anthropogenic and natural disturbance. A hiking trail passes by the tinaja causing contemporary human visitation; however, the bedrock surface makes disturbance hard to estimate. Crew also noted that the pool is likely used by wildlife, but no disturbance was observed.

The crew observed no wetland plant species at the site. One to five individuals of the invasive non-native plant, mullein (*Verbascum thapsus*) were noted. No crayfish or bullfrogs were observed.

3.3.3.3 Water quantity

A temperature sensor in orifice A indicated that the spring was wetted continuously March 26 through June 6. Although the temperature sensor was found submerged in water, it stopped recording on June

6 and data are missing for the majority of WY2018 (Figure 3-6). Discharge was not measurable with the volumetric technique. The pool at orifice A was assessed as a limnocrone system with an average length of 209.0cm (6.9ft), width of 175.8cm (5.8ft), and average depth of 71.2cm (2.3ft).

3.3.3.4 Water quality

In 2018, core water quality (Table 3-5) and water chemistry (Table 3-6) were measured at orifice A.

3.3.4 Upper East Grammer Seep

3.3.4.1 Site characterization and visit information

Upper East Grammer Seep (Figure 3-7) is a rheochrene spring that was sampled on March 13, 2018. The seep originates from the bottom of a water-carved limestone groove where a prominent horizontal seam seeps with minimal flow. The upstream end of the seam was considered orifice A; however, water seeps at intermittent intervals along the length of the seam, collecting in the groove until the flow becomes perceptible as laminar flow down a steep slide. As the gradient flattens, the flow continues through deposits of silt and gravel until it catches in a large compacted-substrate pool with clear water and significant algae. Another smaller, more stagnant pool occurs downstream of a gravel dam, likely a result of a robust population of muhly grass (*Muhlenbergia* sp.). The flow spreads out through the muhly and becomes subsurface. These braided dry channels



Figure 3-5. Slaughter Pothole pool, Carlsbad Caverns NP, March 2018

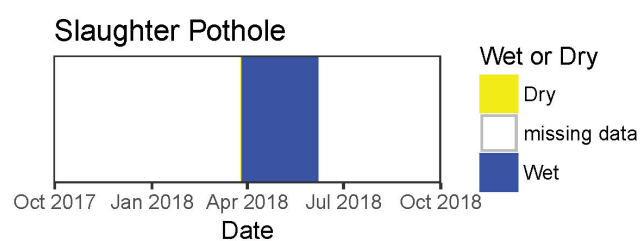


Figure 3-6. Estimated wet/dry days at Slaughter Pothole

Table 3-5. Water Quality data for Slaughter Pothole at Carlsbad Caverns NP, WY2018

Sampling Location	Orifice(s)	Sample time (24 hr)	Temperature (°C)	Dissolved Oxygen (mg/L)	pH	Specific Conductivity (µS/cm)	Total Dissolved Solids (mg/L)	Exposure
1	A	10:26	15.9	10.32	9	271.1	467.1	Shade

Table 3-6. Water Chemistry data for Slaughter Pothole at Carlsbad Caverns NP, WY2018. All results in mg/L

Sampling Location	Orifice(s)	Alkalinity	Calcium	Chloride	Magnesium	Potassium	Sulfate
1	A	135	28	b.d.l.	6	4.5	0

b.d.l. = below detection limit



Figure 3-7. Upper East Grammer Seep orifice A and landscape, Carlsbad Caverns NP, March 2018

merge together to drain down a steep bedrock slide into a litter-covered pool that has a silty substrate and minimal standing water.

3.3.4.2 Site condition

Disturbance surveys resulted in a median value of 1 = undisturbed for both anthropogenic and natural disturbance. There was evidence of substantial animal use at the site. Many game trails, tracks, and animal dugout beds were observed. The crew could not discern if the animal use was from feral Barbary sheep or native wildlife, though deer were observed near the site. Recent flooding has caused slight disturbance, with gravel deposition at the base of the downstream pool.

The crew observed three obligate/facultative wetland plant genera: Sedge (*Carex* sp.), andropogon grass (*Andropogon* sp.), and maidenhair fern (*Adiantum* sp.). The crew noted scattered patches of invasive non-native Bermudagrass (*Cynodon dactylon*) and no invasive, non-native wildlife (crayfish or bullfrogs).

3.3.4.3 Water quantity

A temperature sensor in a pool approximately 19m (62ft) downstream of orifice A indicated that the pool/spring was wetted from March–October 2018 (Figure 3-8). Discharge from orifice A was estimated at 0.9 ± 0.01 L/minute (0.24 ± 0.003 gallons/minute). Upper East Grammer Seep was assessed as a rheocrene system with a channel length of 42.2m (138.5ft). Width and depth averaged 150.0cm (59.1in) and 4.1cm (1.6in), respectively.

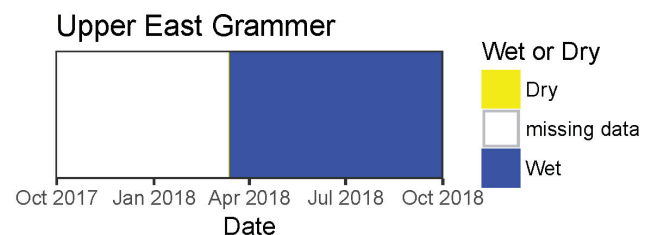


Figure 3-8. Estimated wet/dry days at Upper East Grammer Seep

3.3.4.4 Water quality

In 2018, core water quality (Table 3-7) and water chemistry (Table 3-8) were measured at orifice A.

3.3.5 Upper Lechuguilla Spring

3.3.5.1 Site characterization and visit information

Upper Lechuguilla Spring (Figure 3-9) is a rheochrene spring that was sampled on March 11, 2018. The spring emerges in a drainage as a small algae-covered pool that flows very slowly for approximately 1m (3.3ft) before disappearing as subsurface flow. Dampness and wetland vegetation suggest ephemeral surface water in the channel downstream, leading to a wide bedrock area with pools with algae. Surface water trickles down a 0.5m (1.6ft) drop and terminates. Bedrock is the dominant substrate with silt and some gravel in sections.

3.3.5.2 Site condition

Disturbance surveys resulted in a median value of 1 = undisturbed for both anthropogenic and natural disturbance. Wildlife tracks in the muddy area downslope of channel were the only indication of disturbance.

The crew observed two obligate/facultative wetland plant genera and one family: sedge (*Carex* sp.), spikerush (*Eleocharis* sp.), and rush (Juncaceae family). No invasive, non-native species were noted.

3.3.5.3 Water quantity

Temperature sensors at orifice A indicated that the spring was intermittently wetted from March 2018–October 2018 (Figure 3-10). The sensor was found out of the water in March 2019 and some of the dry days may have been the result of sensor movement, or may be false dry days due to shallow water. Discharge from orifice A was estimated at 0.05 ± 0.004 L/minute (0.01 ± 0.001 gallons/

minute). Upper Lechuguilla Spring was assessed as a rheochrene system with a channel length of 12.8m (42.0ft). Width and depth averaged 48.0cm (18.9in) and 1.4cm (0.6in), respectively.

3.3.5.4 Water quality

In 2018, core water quality (Table 3-9) and water chemistry (Table 3-10) were measured at orifice A.

3.3.6 Upper Lowe Ranch Spring

3.3.6.1 Site characterization and visit information

Upper Lowe Ranch Spring (Figure 3-11) is a rheochrene spring that was sampled on March 12, 2018. The spring emerges as a 6–7m long (19.7–23.0ft) seep along a bedrock shelf and some water collects at the base in a small channel. The flow is very low and almost immediately soaks into the surrounding spongy substrate with sedge (*Cyperaceae* sp.) cover. The northwest side of the seep is the most uphill portion and called orifice A. This small channel flows to meet a small pool where more water joins this pool from the southwest edge of the shelf described previously. The water moves slowly downslope and flows towards the main drainage. The spring eventually spreads out over a flattened area and terminates. Another small pool exists approximately 15m (49.2ft) downslope and another orifice emerges from the hillside to the north, but neither were included in our survey. The substrate is spongy with rooted vegetation and silt.

3.3.6.2 Site condition

Disturbance surveys resulted in a median value of 1 = undisturbed for both anthropogenic and natural disturbance. There was slight disturbance from historical human use. A very distinct trail led to the site, indicating moderate feral animal use and slight native wildlife use. The crew noted that animal

Table 3-7. Water Quality data for Upper East Grammer Seep at Carlsbad Caverns NP, WY2018

Sampling Location	Orifice(s)	Sample time (24 hr)	Temperature (°C)	Dissolved Oxygen (mg/L)	pH	Specific Conductivity (µS/cm)	Total Dissolved Solids (mg/L)	Exposure
1	A	09:02	11.7	7.21	7.85	601.0	390.7	Shade

Table 3-8. Water Chemistry data for Upper East Grammer Seep at Carlsbad Caverns NP, WY2018. All results in mg/L

Sampling Location	Orifice(s)	Alkalinity	Calcium	Chloride	Magnesium	Potassium	Sulfate
1	A	285	42	70	b.d.l.	1.3	38

b.d.l. = below detection limit



Figure 3-9. Upper Lechuguilla Spring orifice, Carlsbad Caverns NP, March 2018

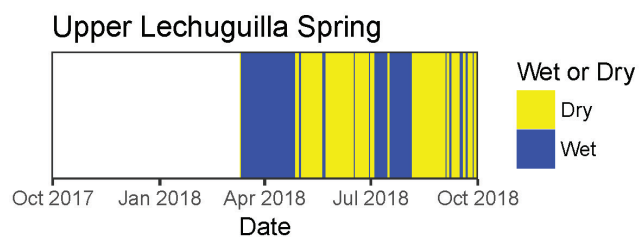


Figure 3-10. Estimated wet/dry days at Upper Lechuguilla Spring

Table 3-9. Water Quality data for Lechuguilla Spring at Carlsbad Caverns NP, WY2018

Sampling Location	Orifice(s)	Sample time (24 hr)	Temperature (°C)	Dissolved Oxygen (mg/L)	pH	Specific Conductivity (µS/cm)	Total Dissolved Solids (mg/L)	Exposure
1	A	11:27	10.9	15.22	7.89	612.3	398.5	Shade

Table 3-10. Water Chemistry data for Lechuguilla Spring at Carlsbad Caverns NP, WY2018. All results in mg/L

Sampling Location	Orifice(s)	Alkalinity	Calcium	Chloride	Magnesium	Potassium	Sulfate
1	A	270	56	6	35	1.2	40

disturbance was likely dominated by Barbary sheep, but may include native wildlife use. The 2011 Loop Fire burned much of the vegetation in the area (rated moderately disturbed), and drying has caused marshy areas of thick riparian vegetation to desiccate (slight disturbance).

The crew observed one obligate/facultative wetland plant genera and one family: spikerush (*Eleocharis* sp.) and sedge (Cyperaceae family). Scattered patches of four invasive non-native plant species were also noted: mullein (*Verbascum thapsus*), Johnsongrass (*Sorghum halepense*), Bermudagrass (*Cynodon dactylon*), and horehound (*Marrubium vulgare*). No



Figure 3-11. Small pool at Upper Lowe Ranch Spring, Carlsbad Caverns NP, April 2018

invasive, non-native wildlife (fish or crayfish) were observed.

3.3.6.3 Water quantity

Temperature sensors in the small pool downstream of orifice A indicated that the pool/spring was wetted throughout the majority of the sampled period, March–October 2018 (Figure 3-12). The shallow depth of water at this site made wet/dry determinations difficult. Discharge was not assessed as the flow was not suitable for volumetric measurements. Upper Lowe Ranch Spring was assessed as a rheocrene system with a channel length of 11.3m (37.1ft). Width and depth averaged 73.3cm (28.9in) and 2.2cm (0.9in) respectively.

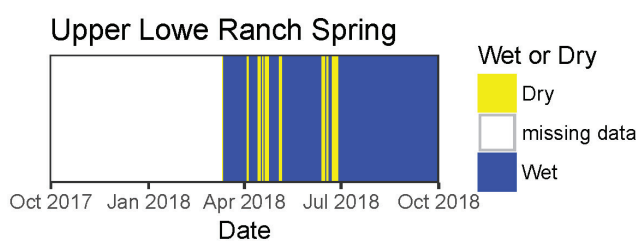


Figure 3-12. Estimated wet/dry days at Upper Lowe Ranch Spring

3.3.6.4 Water quality

In 2018, core water quality (Table 3-11) and water chemistry (Table 3-12) were measured in the small pool downstream of orifice A. We do not report values for dissolved oxygen because the instrument did not pass its post-calibration check.

Table 3-11. Water Quality data for Upper Lowe Ranch Spring at Carlsbad Caverns NP, WY2018

Sampling Location	Orifice(s)	Sample time (24 hr)	Temperature (°C)	pH	Specific Conductivity (µS/cm)	Total Dissolved Solids (mg/L)	Exposure
1	A	08:17	13.0	7.59	563.5	366.0	Shade

Table 3-12. Water Chemistry data for Upper Lowe Ranch Spring at Carlsbad Caverns NP, WY2018. All results in mg/L

Sampling Location	Orifice(s)	Alkalinity	Calcium	Chloride	Magnesium	Potassium	Sulfate
1	A	270	52	6	37	0.0	2

Literature Cited

- Anderson, T. L., J. L. Heemeyer, W. E. Peterman, M. J. Everson, B. H. Ousterhout, D. L. Drake, and R. D. Semlitsch. 2015. Automated analysis of temperature variance to determine inundation state of wetlands. *Wetlands Ecology and Management* 23: 1039-1047.
- 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, VA.
- 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.
- 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.
- 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.
- 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.
- Peel, M. C.; Finlayson, B. L.; McMahon, T. A. 2007. Updated world map of the Köppen–Geiger climate classification. *Hydrol. Earth Syst. Sci.* 11: 1633–1644. Available at <https://www.hydrol-earth-syst-sci.net/11/1633/2007/hess-11-1633-2007.pdf> (accessed 26 June 2019).
- 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. Pohlman. 2006. DRAFT U.S. National Park Service Mojave Inventory and Monitoring Network spring survey protocols: Level I and II. Desert Research Institute, Reno and Las Vegas, Nevada.
- Strahler, A. H. 2013. *Introducing physical geography*. 6th edition. Hoboken, N.J. John Wiley and Sons.
- Sumner, G.N. 1988. *Precipitation: process and analysis*. New York, NY. John Wiley and Sons.

Tsakiris, G., and H. Vangelis. 2005. Establishing a drought index incorporating evapotranspiration. *European Water* 9/10:3–11.

Walking Shadow Ecology. 2019a. Climate Analyzer. Available at <http://www.climateanalyzer.us/coop/carlsbadcaverns> (last accessed 13 August 2019).

Walking Shadow Ecology. 2019a. Climate Analyzer. Available at http://www.climateanalyzer.us/raws/batdraw_raws (last accessed 13 August 2019).

Walking Shadow Ecology. 2019c. Climate Analyzer. Available at <http://www.climateanalyzer.us/about/> (last accessed 31 July 2019).

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.

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