National Park Service
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Natural Resource Stewardship and Science

Status of Climate and Water Resources at Guadalupe Mountains National Park

Water Year 2018

Natural Resource Report NPS/CHDN/NRR—2020/2132

ON THE COVER

Storm clouds at Guadalupe Mountains National Park. Photo Credit: NPS\C. Filippone

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Water Year 2018

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Contents

Figures

Tables

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

heleocrene: spring type that emerges into a wetlands

limnocrene: spring type that emerges as a pool

non-native: a plant or animal that occurs outside of its native or natural range

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 body of water

springbrook: a spring-fed stream

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

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

Abbreviations

bgs: below ground surface
ft: feet
in: inch
m: meter

Executive Summary

Climate and hydrology are major drivers of 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 springs at Guadalupe Mountains 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 below normal (1981–2010) for Guadalupe Mountains NP: 58% of normal for the Pinery Remote Automated Weather Station (RAWS) and 42% of normal for the Dog Canyon RAWS. Precipitation at the Dog Canyon RAWS is likely underrepresented due to missing data. A majority of the WY2018 total rain occurred from July through September (68–88% at the four RAWS). Temperatures at the Pinery RAWS were greater than normal for the whole year, up to 8.8°F warmer than normal. The reconnaissance drought index indicates that WY2018 was slightly wetter at the Guadalupe Peak RAWS and drier at the Pinery RAWS compared to the average for the period of record.

Monitoring equipment was replaced at three groundwater wells in April 2018. Signal Peak Well water level was 1141.22 ft below ground surface (bgs) at the end of WY2018, indicating a decline of 8.92 ft since monitoring began in WY2010, and 11.32 ft since the well was installed in 1978. Lemonade Well water level was 29.22 ft bgs at the end of WY2017, 0.54 ft lower than in WY2017. Lemonade Well water level has been relatively stable over the monitoring period, except when nearby pumping or leaking pipes temporarily impacted groundwater levels. PX Well water level was 278.98 ft bgs at the end of WY2018, indicating a decline of 4.91 ft since monitoring began in WY2010.

Five of the six monitored springs had surface water present when visited in WY2018. Four of the springs had obligate/facultative wetland plants, and two springs had invasive non-native plants. Although overall (median) disturbance ratings were low, each spring showed some sort of natural or anthropogenic disturbance.

Acknowledgments

We thank Superintendent Eric Brunnemann, Chief of Resource Stewardship and Science Dr. Mike Medrano, Geologist Dr. Jonena Hearst and the staff of Guadalupe Mountains NP for their onsite support of the monitoring effort. Dr. Hearst provided valuable edits and review of this report. Colleen Filippone oversaw the groundwater monitoring effort and collaborated with Dr. Hearst. Brandon Gottung, Timothy Pine, Megan Podolinsky, Susan Singley, and Henry Whitenack assisted with the springs data collection and processing. Mark Isley, Kristen Bonebrake, Heidi Sosinski, Melissa Powell, and other network staff led the management and posting of all data products. Mike Tercek developed the Climate Analyzer website (www.climateanalyzer.org) that was used for all climate data analysis.

1 Introduction

Climate and hydrology are major drivers of ecosystems. They dramatically shape ecosystem structure and function, particularly in arid and semi-arid ecosystems. Understanding changes in climate, groundwater, and water quality is central to assessing the condition of park biota and key cultural resources. This document summarizes climate and water resource conditions for water year (WY) 2018 (October 2017–September 2018) at Guadalupe Mountains National Park (NP) in west Texas, adjacent to the New Mexico border. 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 data while other complementary information is harvested from publically available sources. For details on the monitoring protocols, please see the Chihuahuan Desert Network website (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." Here we compare weather data for WY2018 to the 30-year climate normal (1981–2010).

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 climate of the Guadalupe Mountains as cool arid (Peel et al. 2007).

Guadalupe Mountains NP has four Remote Automated Weather Stations (RAWS) (Figure 2-1). The Guadelupe (sic) Peak RAWS (GDBT2) is at an elevation of 7,755 ft (2,364 m) and has been in operation since 2003. The Dog Canyon RAWS (DGCT2) is at 6,262 ft (1910 m) and has been in operation since 2010. The Pinery RAWS (PSGT2) is at 5,381 ft (1,640 m) and has been in operation since 2001. The PX Well RAWS is at 3,873 ft (1,180 m) and has been in operation since 2010. The station data were obtained from Climate Analyzer (Walking Shadow Ecology 2019a; 2019b; 2019c; 2019d), a website that allows users to make on-demand tables and graphs with data from weather stations that are updated daily (Walking Shadow Ecology 2019e). Previously, the National Park Service operated two National Oceanic and Atmospheric Administration (NOAA) Cooperative Observer Program (COOP)

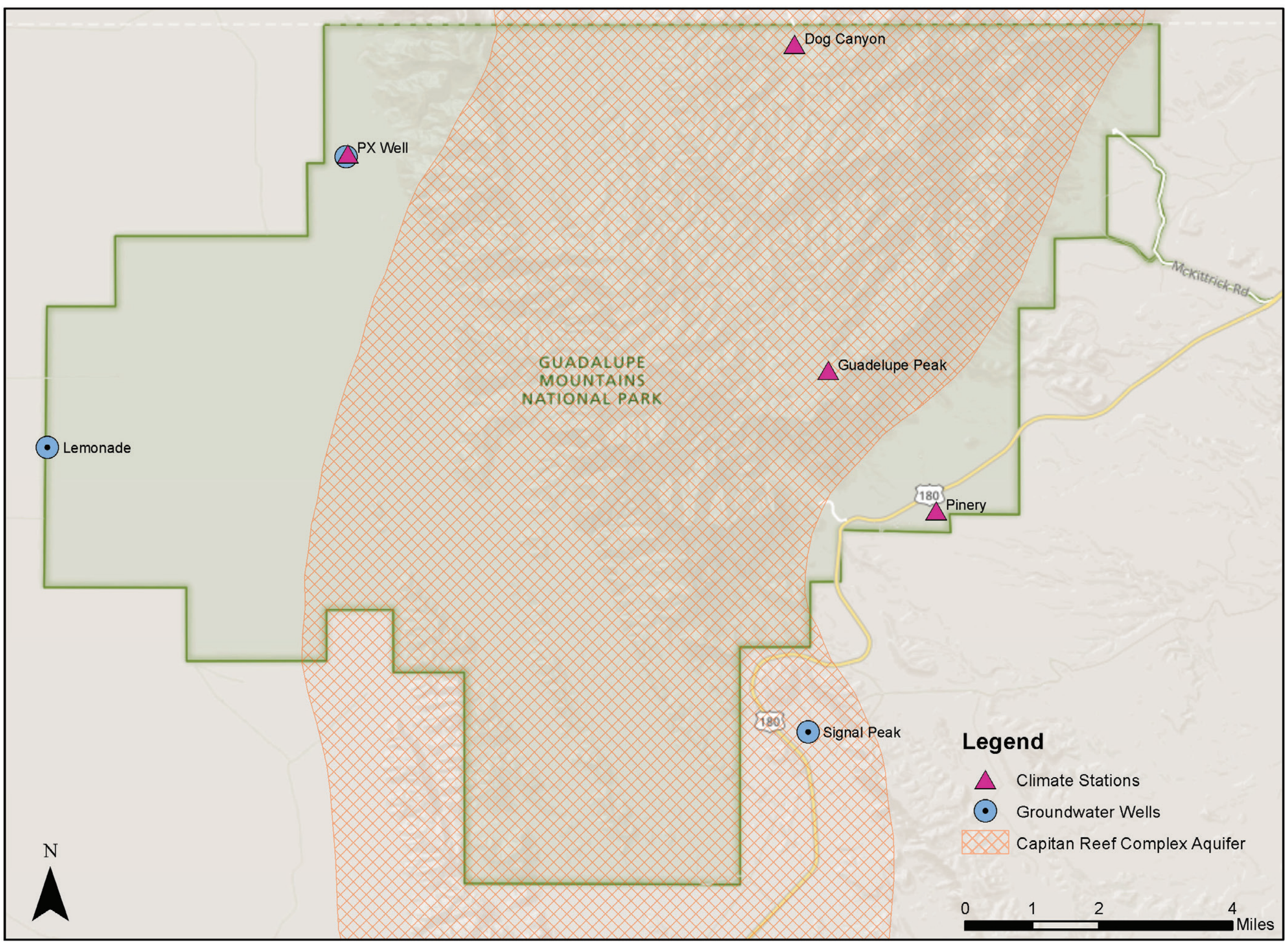

Figure 2-1. Climate stations and monitoring groundwater monitoring wells at Guadalupe Mountains National Park

weather stations: Pine Springs (#417044) and Dog Canyon (#412485). Historical data from these stations provides 1981–2010 climate normal for two of the stations: precipitation and monthly maximum and minimum temperatures for the Pinery RAWS and only precipitation for the Dog Canyon RAWS (Arguez et al. 2010).

2.2 Results and discussion

Data quality during WY2018 was excellent at all stations, except at Dog Canyon, which had missing values on 36 days (January 30–March 6, 2018). Only Pinery RAWS and Dog Canyon RAWS WY2018 data is compared to the climate normals (see above), but data from all stations is provided for understanding the weather in WY2018.

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

Overall, annual precipitation in WY2018 was below normal for Guadalupe Mountains NP: 58% of normal for Pinery (10.37 in vs. 17.97 in) and 42% of normal for Dog Canyon (8.99 in vs. 21.24 in). Precipitation at Dog Canyon is likely underrepresented due to missing data.

2.2.1.1 Cool season (October–March)

Both Pinery and Dog Canyon received less than half the normal rainfall (33% or 3.87 in below normal, and 39% or 2.82 in below normal, respectively) for the fall and winter of WY2018. Only January rainfall at Dog Canyon was near normal; all other months (October, November, December, February, and March) were substantially below normal (Figure 2-2). Monthly precipitation totals in WY2018 were less than 0.55 in for all stations during the cool season (Figure 2-3). Notably, only 0.01 in was recorded at the Guadelupe Peak RAWS in January and March (data for February were insufficient).

Mean monthly minimum and maximum air temperatures at the Pinery RAWS were warmer than normal, up to 7.8°F above normal in November (Figure 2-4). Mean monthly maximum temperatures were highest at PX Well and decreased as station elevation increased (Figure 2-5). The mean monthly minimum temperatures were slightly more variable.

2.2.1.2 Warm season (April–September)

Precipitation in the spring and summer was higher at both the Pinery RAWS and Dog Canyon RAWS, but still substantially below normal (69% or 3.73 in below normal, and 43% or 8.74 in below normal, respectively). Both stations had precipitation totals higher than normal in September, and also in July at Pinery RAWS. All other warm season months (April, May, June, and August) received ≤58% of normal rainfall. Minimal rainfall fell across the park in April and May. A majority of total rain during WY2018 occurred July–September (68–88%). Mean monthly minimum and maximum air temperatures at the Pinery station were warmer than normal, up to 8.8°F above normal in May. Mean monthly maximum and minimum temperatures decreased with increasing elevation.

2.2.2 Reconnaissance Drought Index

Reconnaissance drought index (RDI; Tsakiris and Vengelis 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 Guadelupe Peak RAWS indicated that WY2018 was the fourth consecutive year with wetter conditions compared to the average for WY2004 through WY2018 (Figure 2-6). The RDI at the Pinery RAWS indicated drier conditions in WY2018 based on the average for WY2002 through WY2018 from the perspective of precipitation and evaporative demand (Figure 2-7). The RDI was not calculated for the Dog Canyon RAWS and PX Well RAWS due to their limited monitoring record.

2.2.3 Extreme weather events

Stochastic events, such as unusually intense precipitation events, may be as important to understanding ecological patterns as long-term climate averages are. High air temperatures are a defining feature of warm deserts (Strahler 2013); however, extreme heat events can also have important consequences for Chihuahuan Desert and Arizona-New Mexico Mountains ecoregions in Texas. For example, sustained warm temperatures increase evapotranspiration rates. Extreme precipitation events can also cause localized flooding and erosion events, enhance or inhibit plant productivity and reproduction, and modify animal behavior (Sumner 1988).

The frequency of extremely warms days (>91°F, 95th percentile of 1981–2010 data) was more than twice the normal frequency (36 vs. 17.4 ± 1.6 days). Fewer extremely cold days (<23°F, 5th percentile of 1981–2010 data) than normal occurred in WY2018 (10 vs. 16.1 ± 1.6 days). Each station had up to four

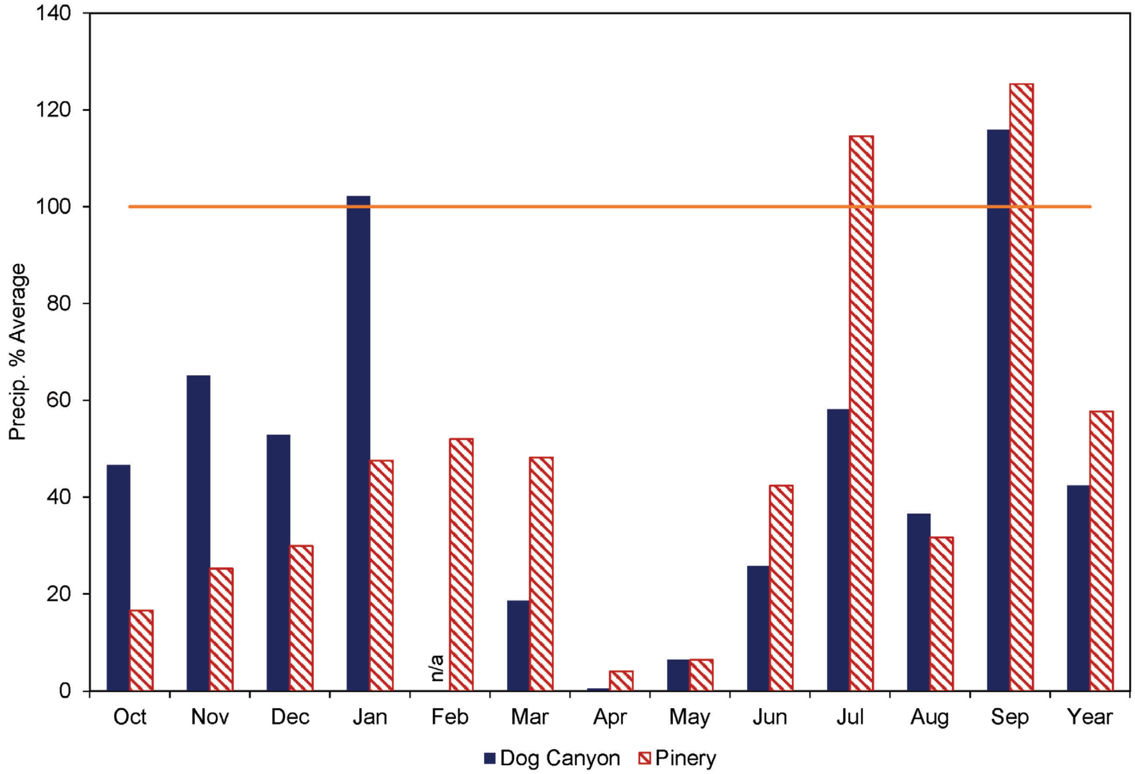

Figure 2-2. Departures from 30-year (1981–2010) normal monthly precipitation at the Dog Canyon and Pinery RAWS, Guadalupe Mountains NP, water year 2018 (October 2017–September 2018). "n/a" = insufficient data to generate reliable data.

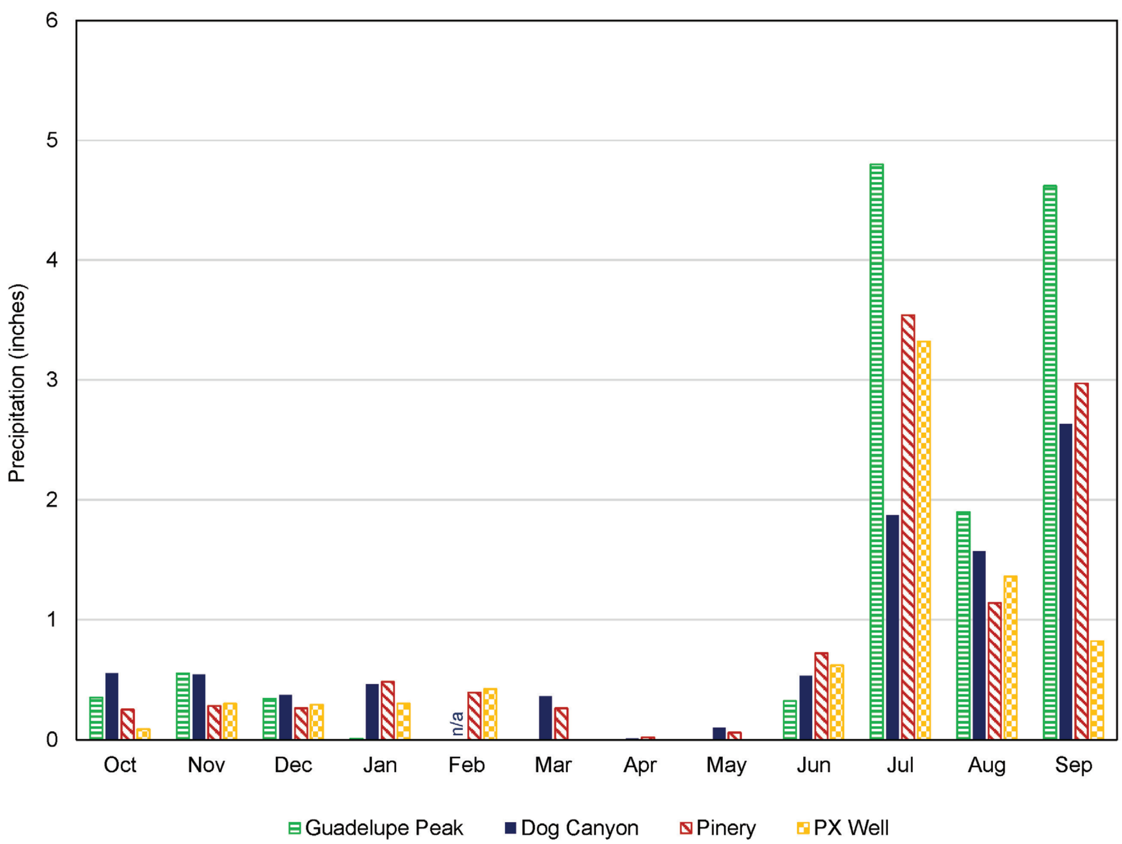

Figure 2-3. Monthly precipitation for Guadalupe Mountains NP, water year 2018 (October 2017–September 2018). "n/a" = insufficient data to generate reliable data.

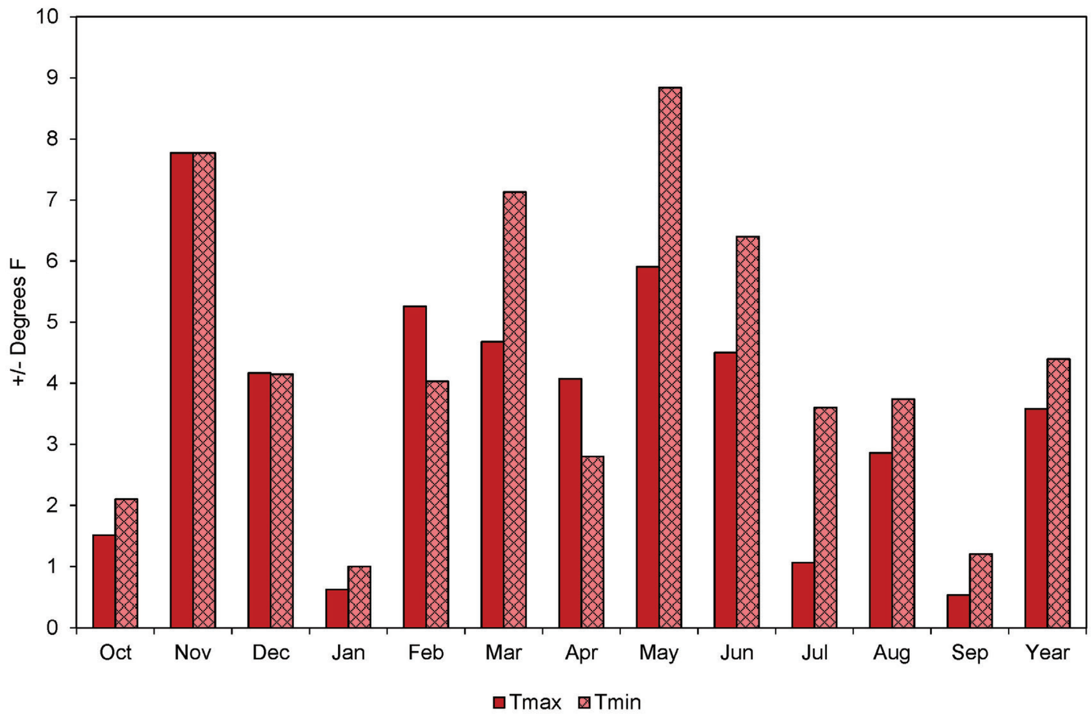

Figure 2-4. Departures from 30-year (1981–2010) normal monthly minimum and maximum air temperatures at the Pinery climate station, Guadalupe Mountains NP, water year 2018 (October 2017–September 2018).

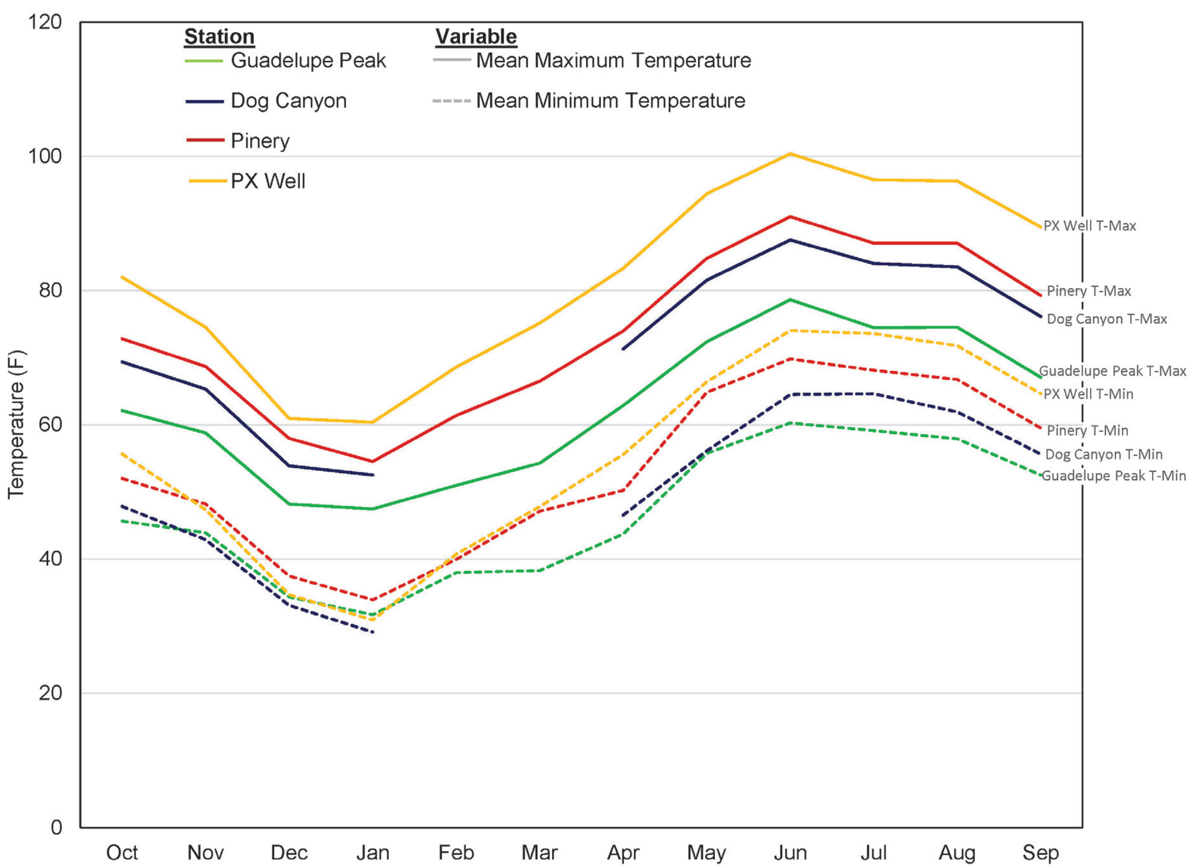

Figure 2-5. Mean monthly minimum and maximum air temperatures for Guadalupe Mountains NP, water year 2018 (October 2017–September 2018).

days with extreme precipitation of one inch or more. The Pinery station had two days with extreme precipitation, compared to the mean of 3.2 days for 1981–2010. These extreme events occurred on July 7 (1.12 in) and September 18 (1.70 in). The Guadelupe Peak station recorded extreme precipitation on July 10 (1.14 in), July 31 (1.04 in), August 19 (1.14 in), and September 18 (1.29 in). The Dog Canyon RAWS and PX Well RAWS each had a single large precipitation day: August 8 (1.03 in) and July 26 (1.47 in), respectively.

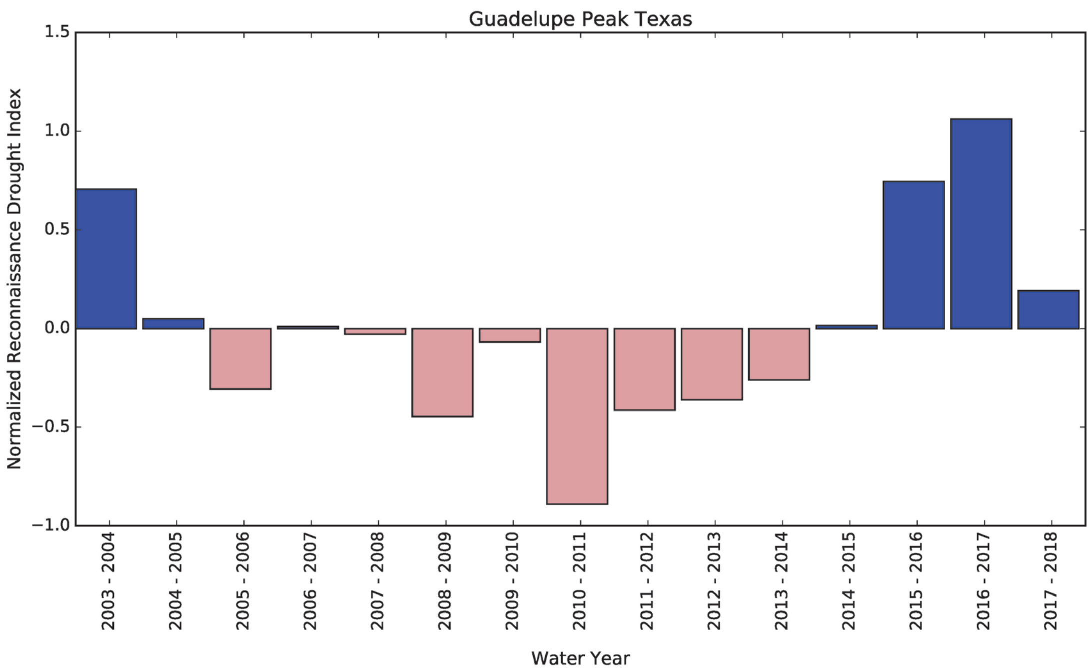

Figure 2-6. Reconnaissance drought index (RDI), Guadelupe (sic) Peak RAWS, Guadalupe Mountains NP, water years 2004–2018. Graphic generated by climateanalyzer.org (Walking Shadow Ecology 2019a).

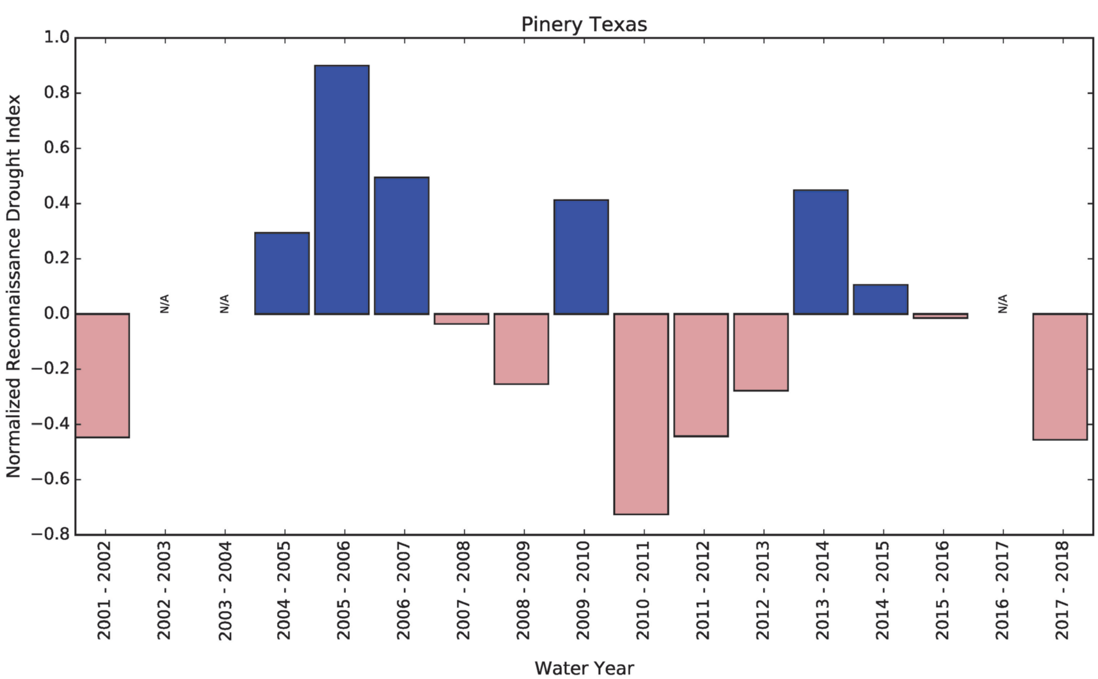

Figure 2-7. Reconnaissance drought index (RDI), Pinery RAWS, Guadalupe Mountains NP, water years 2002–2018. "n/a" = insufficient data to generate reliable data. Graphic generated by climateanalyzer.org (Walking Shadow Ecology 2019c).

3 Groundwater

3.1 Background

Groundwater is one of the most critical natural resources of the American Southwest, providing drinking water, irrigating crops, and sustaining rivers, streams, and springs throughout the region. Groundwater is closely linked to long-term precipitation and surface waters, as ephemeral flows sink below ground to reappear months, years, decades, or even centuries later as perennial and intermittent streams and springs. Groundwater also sustains vegetation throughout the region and is the primary source of water for many people in the southwestern United States. Groundwater therefore interacts either directly or indirectly with all key ecosystem features of the Chihuahuan Desert ecoregion (Filippone et al. 2014).

The Capitan Reef Complex aquifer underlies much of the park (Ashworth and Hopkins 1995; Figure 2-1). The aquifer is comprised mostly of dolomite and limestone stratigraphic units with a thickness as much as 2360 ft (719 m) in a 10–14 mile (16–23 km) wide strip. The Capitan Reef Complex formations are also exposed in Guadalupe Mountains NP. Immediately west of and at the base of the Guadalupe Mountains, Quaternary alluvium forms a layer on top of the Capitan Reef Complex (Ashworth 1995). At the furthest west part of the park is the down-faulted Salt Basin, a graben filled with Tertiary and Quaternary alluvium and lacustrine lake deposits (Ashworth 1995). The Bone Spring-Victorio Peak aquifer underlies the Salt Basin and Dell Valley, a residential and agricultural area west of the park. The Bone Spring-Victorio Peak aquifer is hydraulically connected throughout the Salt Basin (Ashworth 1995). Water level changes in the Bone Spring-Victorio Peak aquifer have the potential to impact the unique ecology of the Salt Basin dunes.

The Capitan Reef Complex aquifer is primarily recharged through precipitation. Infiltration can occur diffusely through overlaying sediments, or the karst geology can cause concentrated recharge (Weeks et al. 2008; Angle 2001). The Bone Spring-Victorio Peak aquifer is primarily recharged by downward seepage from the Sacramento River, with additional contributions from the irrigation return flow and infiltration on the Diablo Plateau (Ashworth 1995). Groundwater discharge generally occurs through evaporation, flow to adjacent aquifers, and pumping. Historically, most groundwater withdrawals from the Bone Spring-Victorio Peak aquifer west of the park were for agricultural irrigation and, to lesser extent, the public water supply for Dell City (Ashworth and Hopkins 1995). Withdrawals from the Capitan Reef Complex aquifer east of the park have been used for oil reservoir flooding (Ashworth and Hopkins 1995).

Potential impacts to groundwater in and adjacent to Guadalupe Mountains NP include oil and gas production and development for municipal uses. Increasing oil and gas production may affect groundwater quantity and quality (Weeks et al. 2008). The Far West Texas Water Plan includes a multifaceted strategy to support the increasing population of El Paso. Starting in 2060, groundwater may be withdrawn from the Bone Spring-Victorio Peak aquifer in Dell City and exported to El Paso (Far West Texas Water Planning Group 2016). This groundwater will require desalination, and the effluent water from the desalination process will be mixed with untreated water and released to disposal wells (FWTPG 2016). It is unclear how these new and changing impacts to groundwater near Guadalupe Mountains NP will affect groundwater and springs within its boundary.

3.1.1 Methods and monitoring wells

Three wells are monitored at Guadalupe Mountains NP by NPS regional, network and/or park staff (Figure 2-1). Data are collected manually every quarter and every six hours by pressure transducers. The Signal Peak Well (Texas Water Development Board TWDB #4710201) is located on a NPS-owned parcel of land outside the legislated park boundary. The Signal Peak Well is 1,240 ft deep and is completed in the Capitan Reef Complex aquifer (TWDB 2019). Lemonade Well (TWDB #4808904) is 51 ft deep and located on the west side of the park. It is completed in shallow alluvium of Salt Flat. PX Well (TWDB #4701201) is a 300-ft deep well completed in Quaternary alluvial fan sediments at the base of the Guadalupe Mountains (TWDB 2019). Monitoring at these wells began in 2010 at the request of park staff and following the recommendations of the Water Resource Division (Martin 2009).

3.2 Results

Water level data are not available for approximately the first half of WY2018 due to equipment failure. New pressure transducers were installed at the three wells on April 9, 2018.

Depth to water at Signal Peak Well on April 9, 2018, was 1140.30 ft below ground surface (bgs; Figure 3-1). Water level declined throughout the rest of WY2018, with the lowest water level of the monitoring record on September 26, 2018, at 1141.22 ft bgs. This indicates a decline of 8.92 ft since monitoring began in WY2010, and 11.32 feet since the well was installed in 1978 (TWDB 2019). Water level at the Signal Peak Well has generally shown a downward trend over the monitoring record with the exceptions of a manual measurement on November 6, 2013, and a separate increase starting in late September 2014. The latter increase may be in response to a multi-day rain event and subsequent flooding in September 2014. Over an 18-day period, 15.41 in of precipitation fell, exceeding the 20-day 50-year return interval (14.6 in; NOAA 2019).

Depth to water at Lemonade Well on April 9, 2018, was 28.38 ft bgs (Figure 3-2). In May, the water level dropped approximately 1.4 ft and then increased 0.5 ft. This step down and step up is unusual in the record and its cause is unclear. However, from June to the end of WY2018, the water level remained relatively static, ending at 29.22 ft bgs, 0.54 ft lower than the manual measurement in WY2017. The water level in Lemonade Well has been variable over the monitoring record due to nearby groundwater pumping and leaking pipes (C. Filippone, pers. comm.). However, excluding these periods, water levels have been relatively static, only varying within a range of approximately 1.5 ft. The largest increase occurred in September and October 2013 following a 4.76-in rain event recorded at the PX Well RAWS.

Depth to water at PX Well on April 9, 2018, was 278.40 ft bgs (Figure 3-3). Water level continued to decline throughout the rest of WY2018, with the lowest water level of the monitoring record on September 26, 2018, at 278.98 ft bgs. This indicates a net decline of 4.91 ft since monitoring began in WY2010. Water levels in PX Well demonstrate seasonal variability: stable or slightly increasing water levels in fall and winter, followed by declining water levels in spring and summer, creating an overall downward trend.

Water level in the three wells were within 80 ft of elevation for the entire monitoring period (Figure 3-4). The aquifers that the three wells are completed in are hydraulically connected, but they also show localized responses to withdrawals and recharge, as observed in Lemonade and Signal Peak wells.

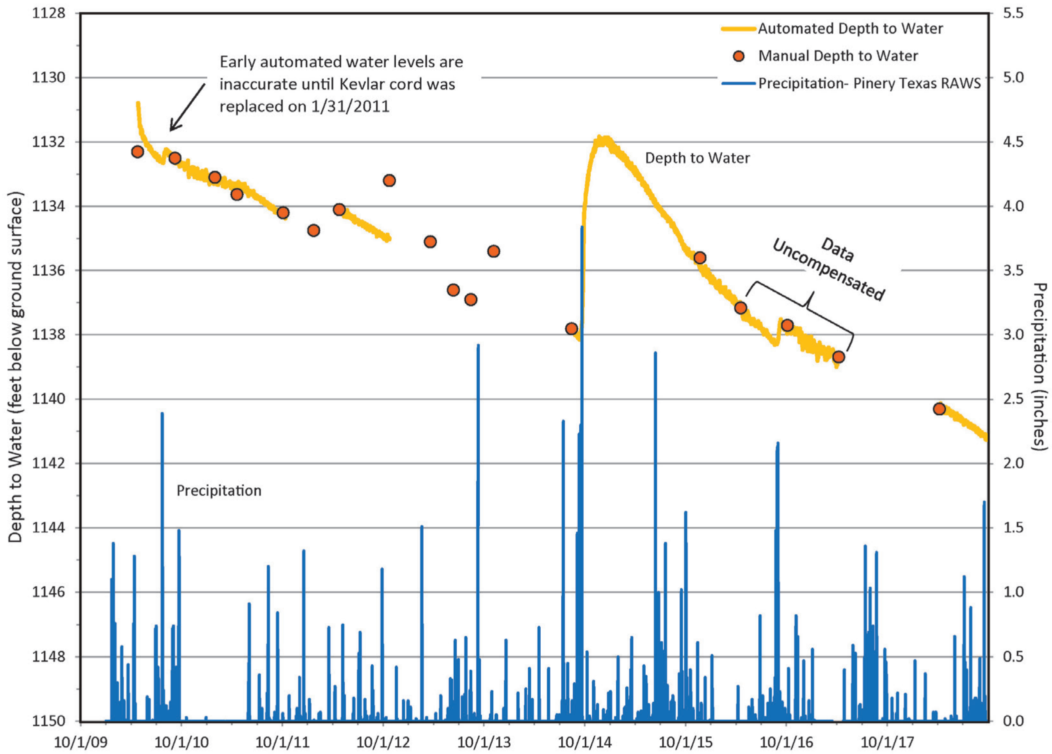

Figure 3-1. Depth to water below ground surface (bgs) at Signal Peak Well with daily precipitation from the Pinery RAWS, water years 2010–-2018, Guadalupe Mountains NP

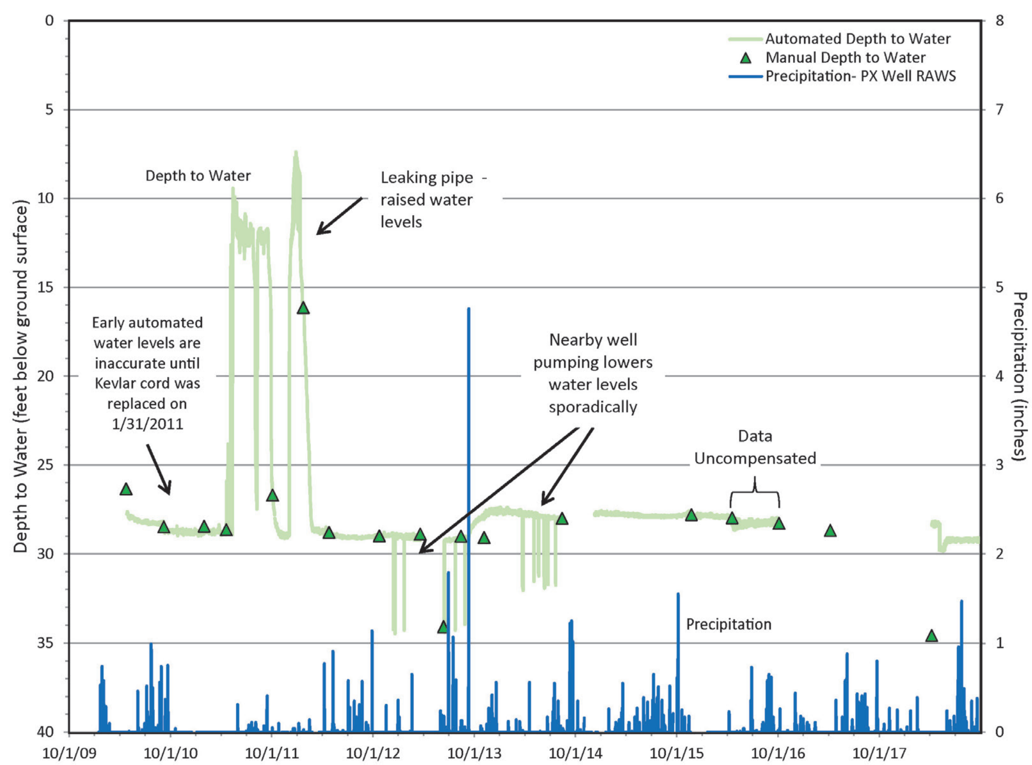

Figure 3-2. Depth to water below ground surface (bgs) at Lemonade Well with daily precipitation from the PX Well RAWS, water years 2010–-2018, Guadalupe Mountains NP

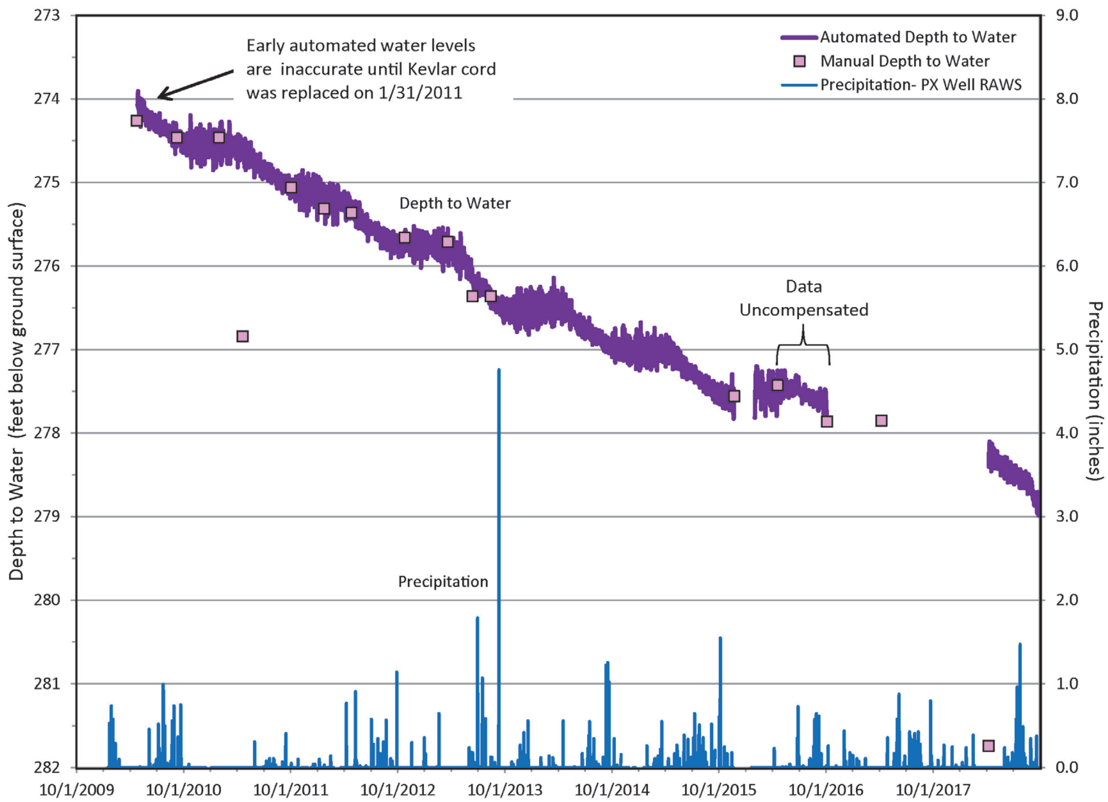

Figure 3-3. Depth to water below ground surface (bgs) at PX Well with daily precipitation from the PX Well RAWS, water years 2010–-2018, Guadalupe Mountains NP

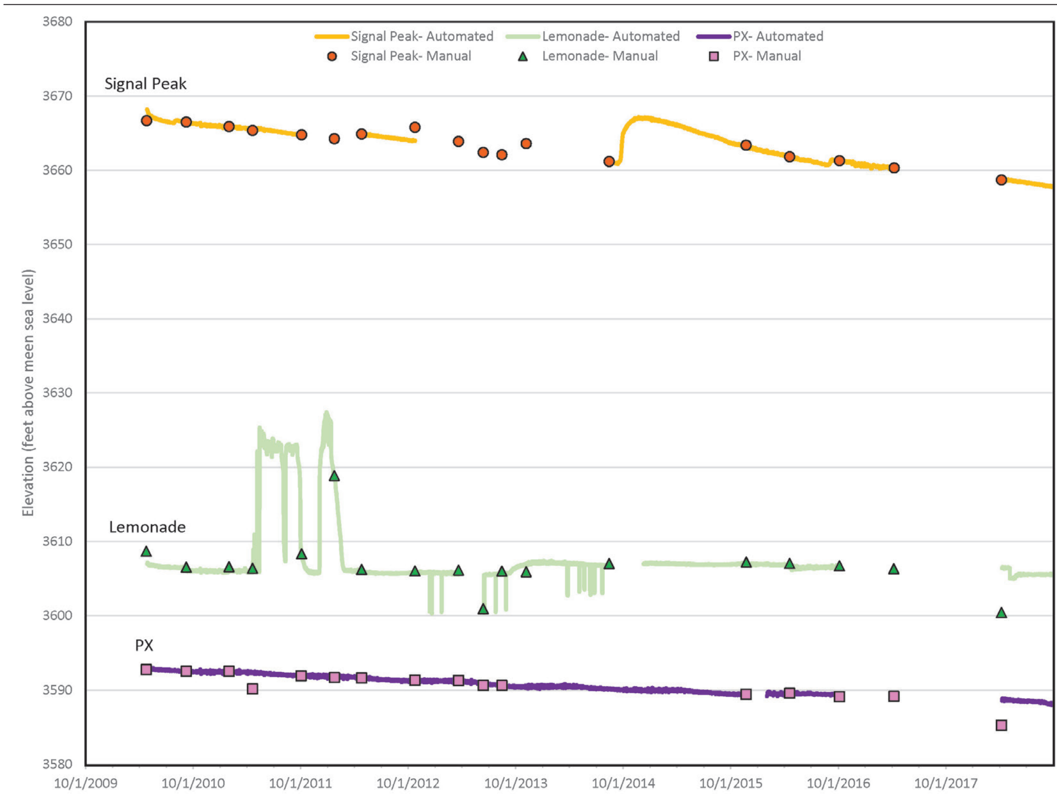

Figure 3-4. Water level elevation at three groundwater monitoring wells, water years 2010–2018, Guadalupe Mountains NP

4 Springs

4.1 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 biota at springs include reduced water availability when drying occurs, water temperature extremes (e.g., 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 threat to springs in the American Southwest, with expected increases in air temperatures, reductions in precipitation, increases in evaporation rates, increases in drought frequency, and increases in 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).

4.2 Methods

Chihuahuan Desert Network springs monitoring in WY2018 focused on five "sentinel sites" (McIntyre et al. 2018): Bone, Dog Canyon, Guadalupe, Sharp Rock, and Smith springs. The "sentinel sites" design is similar to a judgmental design. Statistical inference provided by this design is limited to each individual spring monitored over time. The springs sampled in Guadalupe Mountains NP may change in the future.

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 Guadalupe Mountains NP during WY2018 is extracted from the protocol (McIntyre et al. 2018) and presented below. See McIntyre et al. (2018) for additional details.

4.2.1 Site characterization

The site characterization module is a modification of the inventory methods developed for the Mojave Desert Network (Sada and Pohlmann 2006). In Chihuahuan Desert Network springs, 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, site description, and vegetation community description. See the springs monitoring protocol for details (McIntyre et al. 2018). This module was completed at Guadalupe Mountains NP in 2018 and data will be recollected in 2023. This report presents a highly condensed and edited version of the information collected in the site characterization module.

4.2.2 Site condition

The site condition module is based on inventory methods developed for the Mojave Desert Network (Sada and 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 disturbances and the level of stress on vegetation and soils in spring ecosystems (Sada and Pohlmann 2006). Types of natural disturbance that are 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 the 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).

4.2.3 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 on consecutive days (first day in sequence is marked as dry). 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 100 m; 328 ft), width, and depth of water present, and is assessed using techniques for standing water (e.g., limnocrene springs, heleocrene springs, and some tinajas) and for flowing water (e.g., rheocrene springs and some tinajas).

4.2.4 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 concentrations of major ions with a photometer (YSI 9500) (McIntyre et al. 2018).

4.3 Results and discussion

4.3.1 Bone Spring

4.3.1.1 Site characterization and visit information

Bone Spring (Figure 4-1) is as a rheochrene spring (a spring that emerges as a flowing stream) in a larger drainage. It was visited on March 24, 2018. The spring emerges between two medium boulders as a small trickle among maidenhair ferns (*Adiantum* sp). The cool and clear flow spills into a plunge pool, the first of many interspersed along the springbrook (of which the first 100 m (328 ft) were measured per the protocol). Most of the pools range from a surface area of 2 m^2 (21.5 ft^2) to 4 m^2 (43.1 ft^2) and a depth of 0.5 m (1.6 ft) to 1.0 m (3.3 ft). The substrate is dominated

Figure 4-1. Bone Spring orifice, Guadalupe Mountains NP, March 2018

by boulders with gravel deposits present in flatter sections of the system. Some areas of the springbrook are incised and there is evidence that runoff events in the drainage affect the overall system.

4.3.1.2 Site condition

Disturbance surveys resulted in a mean and median value of 1 = undisturbed for both anthropogenic and natural disturbances. There was moderate evidence of contemporary human or wildlife use based on social trails along the springbrook and moderate historical human use of the spring. There was slight disturbance from flooding.

The crew observed six obligate/facultative wetland plants: horsetail (*Equisetum* sp.), cattail (Typhaceae family), cottonwood (*Populus* sp.), tamarisk (*Tamarix* sp.), mule-fat (*Baccharis salicifolia*), and maidenhair fern (*Adiantum* sp.). One to five individuals of two invasive non-native plant species were observed: horehound (*Marrubium vulgare*) and saltcedar (*Tamarix ramosissima*). No invasive non-native wildlife (bullfrogs or crayfish) were observed.

4.3.1.3 Water quantity

Temperature sensors indicated that the spring was dry for the majority of the sampled period (March–October 2018; Figure 4-2). The spring was not visited until April 2018, so there was no sensor deployed for the first half of the water year. Discharge from orifice A was estimated at 6.0 ± 0.1 L/min (1.6 gal/min). The channel length was not measured, but was estimated to be 200–500 m (656–1640 ft). The first 100 m (328 ft) had a mean wetted width of 147.2 cm (4.8 ft) and mean depth of 5.3 cm (2.1 in).

4.3.1.4 Water quality

In 2018, core water quality (Table 4-1) and water chemistry (Table 4-2) were measured at orifice A. We do not report values for dissolved oxygen because the instrument did not pass its post-calibration check.

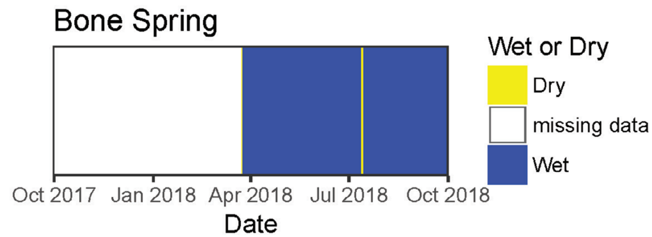

Figure 4-2. Estimated wet/dry days at Bone Spring, Guadalupe Mountains NP, WY2018

4.3.2 Dog Canyon Spring

4.3.2.1 Site characterization and visit information

Dog Canyon Spring was classified as limnocrene (a spring that emerges as a pool) during the March 22, 2018 visit. The spring emerges as a cool, clear, confined pool on the southern edge of an active drainage channel. This pool is roughly 3.5 x 2.8 m (11.5 x 9.2 ft) in size and fluctuates around 1.0 m (3.3 ft) deep. The pool is filled with 50–90 cm (1.6–3.0 ft) of leaf litter with approximately 20 cm (0.7 ft) of clear water on top where all water quality measurements were taken. The northwest corner has a small outlet, but appears to be wetted due to trampling versus outflow from the pool.

4.3.2.2 Site condition

Disturbance surveys resulted in a mean value of 2 = slightly disturbed for anthropogenic disturbance, and 1 = undisturbed for natural disturbance. The median for both was 1 = undisturbed. There was moderate evidence of contemporary human use. High disturbance was noted for historical human use and flow modification categories. Game trails represent the only natural disturbance, with deer observed at the site.

Table 4-1. Water quality data for Bone Spring at Guadalupe Mountains 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	11:40	14.6	8.15	1063.0	689.0	Partial Sun

Table 4-2. Water chemistry data for Bone Spring at Guadalupe Mountains NP, WY2018. All results in mg/L

Sampling Location	Orifice(s)	Alkalinity	Calcium	Chloride	Magnesium	Potassium	Sulfate
1	A	205	70	19	95	0.8	260

No wetland plants, invasive non-native plants, or invasive non-native wildlife (crayfish or bullfrogs) were observed during the visit.

3.3.2.3 Water quantity
Temperature sensors indicated that the spring was wetted until early July and was generally dry for the remainder of the water year (Figure 4-3). The sensor was found approximately 0.3 m (1 ft) above the water in 2019, and the dry readings in the last quarter of WY2018 may not represent actual conditions. Sensors were not deployed in 2017 and there are no data available from October 2017 to March 2018. Discharge was not measurable in this limnocrene system. Due to the inaccessibility of the pool, the crew measured a single length and width to roughly estimate the size of this rectangular pool: length was 288 cm (9.4 ft) and width was 350 cm (11.5 ft).

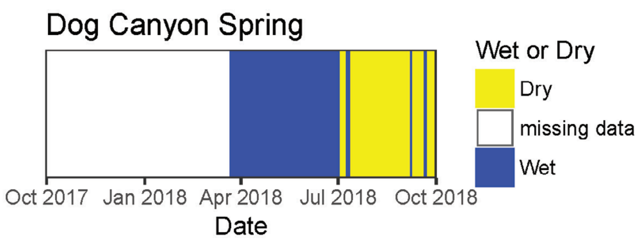

Figure 4-3. Estimated wet/dry days at Dog Canyon Spring, Guadalupe Mountains NP, WY2018

4.3.2.4 Water quality
In 2018, core water quality (Table 4-3) and water chemistry (Table 4-4) were measured at orifice A.

4.3.3 Guadalupe Spring

4.3.3.1 Site characterization and visit information
The crew visited Guadalupe Spring (Figure 4-4), a rheocrene spring, on March 23, 2018. The spring emerges as a trickle underneath a dense patch of Apache plume (*Fallugia paradoxa*). This trickle continues downslope in a small channel that is intermittently widened by trampling in the wetted area. The downstream channel becomes increasingly incised and interspersed with small pools, with the largest measuring 1.0 x 2.0 m (3.2 x 6.6 ft). The springbrook drops several meters (feet) down multiple maidenhair fern (*Adiantum* sp.)-covered slopes. The final section of the springbrook is wider and with surface water more dispersed among wetland obligate plants. The spring terminates more than 100 m downstream from the orifice.

4.3.3.2 Site condition
Disturbance surveys resulted in a median and mean value of 1 = undisturbed for both anthropogenic and natural disturbances. There was minimal evidence of historical human use and flow modification. Wildlife trampling and beds along the spring length were the only natural disturbances observed.

The crew observed four obligate/facultative wetland plants: horsetail (*Equisetum* sp.), sedge (*Carex* sp.), mule-fat (*Baccharis salicifolia*), and maidenhair fern (*Adiantum* sp.). One invasive non-native plant, bermudagrass (*Cynodon dactylon*) was noted in scattered patches. No invasive non-native animals (bullfrogs or crayfish) were observed.

4.3.3.3 Water quantity
Temperature sensors indicated that the spring was wetted for the majority of the sampled interval (October 2017–May 2018) with drying events in the spring (Figure 4-5). Data from the latter half of the year are missing due to sensor failure. Discharge from orifice A was estimated at 19.9 ± 0.4 L/min (5.3 ± 0.1 L/min). The channel length was not measured but was estimated to be 200–500 m (656–1640 ft). The first 100 m (328 ft) had a mean wetted width of 76.6 cm (2.5 ft) and mean depth of 1.8 cm (0.1 ft).

Table 4-3. Water quality data for Dog Canyon Spring at Guadalupe Mountains 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	08:58	6.7	5.30	7.64	598.7	389.4	shade

Table 4-4. Water chemistry data for Dog Canyon Spring at Guadalupe Mountains NP, WY2018. All results in mg/L

Sampling Location	Orifice(s)	Alkalinity	Calcium	Chloride	Magnesium	Potassium	Sulfate
1	A	310	46	5	45	0.4	2

Figure 4-4. Guadalupe Spring orifice A, Guadalupe Mountains NP, March 2018

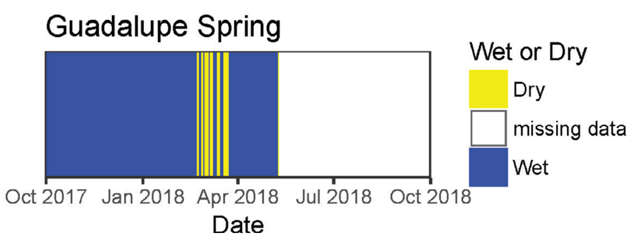

Figure 4-5. Estimated wet/dry days at Guadalupe Spring, Guadalupe Mountains NP, WY2018

4.3.3.4 Water quality

In 2018, core water quality (Table 4-5) and water chemistry (Table 4-6) were measured at two locations: at orifice A and at a pour-off approximately 50 m (164 ft) downstream.

4.3.4 Sharp Rock Spring

4.3.4.1 Site characterization and visit information

At the time of the visit on March 25, 2018, the spring orifice was completely dry, as was most of the downstream channel (Figure 4-6). A few small depressions in the bedrock contained water and leaf litter, but it is unclear if this was from rain the previous night or from past seepage. Some evidence of past seepage is present on the bedrock slab at the orifice and on the bedrock channel downslope.

4.3.4.2 Site condition

Disturbance surveys resulted in a mean value of 1 = undisturbed for anthropogenic and 1.5 = slightly disturbed for natural disturbance. The median for both natural and anthropogenic disturbances was 1 = undisturbed. There was an apparent lack of surface water at the spring site and many dead trees had fallen over the channel. Due to the dominant substrate of bedrock, potential disturbances were difficult to discern.

The crew did not observe any wetland plants, invasive non-native plants, or invasive non-native animals (bullfrogs or crayfish) at this site.

4.3.4.3 Water quantity

Temperature sensors were not deployed due to concern about sensor loss so there is no data on wet/

Table 4-5. Water Quality data for Guadalupe Spring at Guadalupe Mountains 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	14:30	19.6	7.19	7.66	759.0	494.0	Shade
2	A	14:40	16.8	7.65	8.14	711.0	461.5	Partial

Table 4-6. Water Chemistry data for Guadalupe Spring at Guadalupe Mountains NP, WY2018. All results in mg/L

Sampling Location	Orifice(s)	Alkalinity	Calcium	Chloride	Magnesium	Potassium	Sulfate
1	A	235	110	12	50	1.3	128
2	A	245	76	15	50	1.5	145

Figure 4-6. Sharp Rock Spring orifice, Guadalupe Mountains NP, March 2018

Figure 4-7. Smith Spring orifice A, Guadalupe Mountains NP, March 2018

dry periods. There was no surface water available for discharge or wetted extent measurements.

4.3.4.4 Water quality
No core water quality or water chemistry was measured in 2018 due to a lack of surface water.

4.3.5 Smith Spring

4.3.5.1 Site characterization and visit information
Smith Spring (Figure 4-7) was classified as a rheocrene spring on March 25, 2018. The spring emerges from a boulder pile within an oak- and madrone-forested drainage. Orifice A creates a cool and clear pool. Orifice B emerges from a scoured channel as a shallow flow. These orifices combine to create a mostly straight-running stream characterized by a pool and drop profile. The cool and clear flow is limited to the channel and pools, which are lined with large boulders and occasional eroded banks stabilized by tree roots. Downstream, the channel narrows to 20–30 cm (0.65–0.98 ft) into a chute that spills into the largest pool of the system (6.0 x 5.5 x 1.5 m; 20 x 18 x 5 ft). At the downstream end of the pool, the channel splits into two. The left channel is larger and was measured as the main channel. It continues under a fence and reaches a width of more than 1.0 m (3.3 ft) where the Smith Spring Trail crosses it. The last portion of the stream returns to a series of wide plunge pools. The entire springbrook extends 100–200 m (328–656 ft) downstream from the orifice.

4.3.5.2 Site condition
Disturbance surveys resulted in a mean value of 2 = slightly disturbed for anthropogenic disturbance and 1 = undisturbed for natural disturbance. The median for both natural and anthropogenic disturbances was 1 = undisturbed. High visitation, including a designated trail and social (and/or wildlife) trails around the site, led to a rating of highly disturbed for contemporary human use and hiking trails. Wildlife may also use these trails, but it was difficult for the crew to discern.

The crew observed two obligate/facultative wetland plant genera: sedge (*Carex* sp.) and maidenhair fern (*Adiantum* sp.). No invasive non-native plants or animals (crayfish or bullfrogs) were noted.

4.3.5.3 Water quantity

The temperature sensor indicated that the spring was wetted for the entirety of the sampled period (October 2017–April 2018). The sensor failed on April 28, 2018, and the one dry day estimated was near that failure and may not indicate actual conditions (Figure 4-8). Discharge was measured at three locations. Discharge was 101.2 ± 1.8 L/min (26.7 ± 0.5 gal/min) at 2.5 m (3.2 ft) downstream of orifice A, and 65.4 ± 1.8 L/min (17.3 ± 0.5 gal/min) at 2.5 m (8.2 ft) downstream from orifice B. Approximately 35 m (114 ft) downstream of orifice A, which is downstream of where flow from the two orifices join, discharge was 138.8 ± 2.1 L/min (36.7 ± 0.6 gal/min). The first 100 m (328 ft) of the springbrook had a mean wetted width of 140 cm (55.1 in) and mean depth of 3.6 cm (1.4 in).

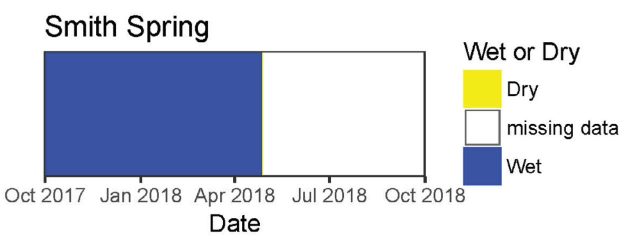

Figure 4-8. Estimated wet/dry days at Smith Spring, Guadalupe Mountains NP, WY2018

4.3.5.4 Water quality

In 2018, core water quality (Table 4-7) and water chemistry (Table 4-8) were measured at each orifice.

4.3.6 Upper Pine Spring

4.3.6.1 Site characterization and visit information

Upper Pine spring (Figure 4-9) was classified as a rheocrene spring and was visited on March 23, 2018. The discharge is spring-dominated, emerging from two orifices. Orifice A begins near the left bank of the drainage and forms a cool, clear pool (approximately 0.5 x 2.7 m; 1.6 x 8.9 ft) with a silty substrate. It then narrows into a small channel with small boulders for approximately 4 m (13 ft). Orifice B emerges approximately 4 m (13 ft) from orifice A as a cool and clear trickle from below a small boulder. Orifice B flows into an approximately 1.0 x 1.5-m (3.2 x 0.9-ft) pool with a thick algae mat. There is no discernable discharge from this pool and it does not connect to the main channel. The narrow channel from orifice A continues to a 4.0 x 2.0 x 0.5-m (13.1 x 6.6 x 1.6-ft) pool with 60% algae cover and a silty substrate. The springbrook then constricts again before forming another 1.5 x 3.0-m (4.9 x 9.8-ft) pool next to an alligator juniper (*Juniperus deppeana*). The substrate here ranges from silt to cobble and boulders. Leaf litter from surrounding trees accumulate where rocks have decelerated the flow in the channel. Downstream, the brook narrows again and then forms a 6.0 x 1.0-m (19.6 x 3.2-ft) pool that is 0.25 m (0.82 ft) deep and has a silty substrate. The brook narrows once again to flow over rocks and vegetation debris before pouring over a travertine slide into a shallow terminal pool.

4.3.6.2 Site condition

Disturbance surveys resulted in a mean and median value of 1 = undisturbed for both anthropogenic and natural disturbances. There was moderate disturbance due to historical human use and flow

Table 4-7. Water quality data for Smith Spring at Guadalupe Mountains 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	08:34	15.1	6.98	7.28	534.6	347.1	Shade
2	B	08:38	14.7	6.90	7.29	533.1	346.5	Shade

Table 4-8. Water chemistry data for Smith Spring at Guadalupe Mountains NP, WY2018. All results in mg/L

Sampling Location	Orifice(s)	Alkalinity	Calcium	Chloride	Magnesium	Potassium	Sulfate
1	A	275	64	9	80	0.3	2
2	B	290	48	4	27	0.6	7

Figure 4-9. Upper Pine Spring orifice A, Guadalupe Mountains NP, March 2018

modification. The crew also noted slight evidence of drying, fire, and non-livestock (wildlife) use.

The crew observed three obligate/facultative wetland plant genera and one family: spikerush (*Eleocharis* sp.), bluestem (*Andropogon* sp.), maidenhair fern (*Adiantum* sp.), and sedge (Cyperaceae family). No invasive non-native plants or wildlife (bullfrogs or crayfish) were observed.

4.3.6.3 Water quantity

The temperature sensors indicated that the spring was wetted throughout WY2018 (Figure 4-10). Discharge from orifice A was estimated at 1.2 ± 0.02 L/min (0.3 ± 0.005 gal/min). Discharge from orifice B was not estimated. The 73-m (240-ft) springbrook had a mean wetted width of 65.2 cm (2.1 ft) and mean depth of 8.2 cm (0.3 ft).

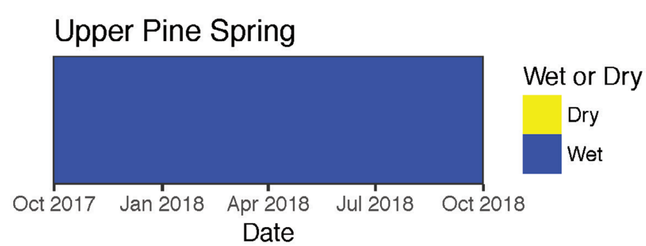

Figure 4-10. Estimated wet/dry days at Upper Pine Spring, Guadalupe Mountains NP, WY2018

4.3.6.4 Water quality

In 2018, core water quality (Table 5-9) and water chemistry (Table 5-10) were measured at each orifice, totaling two samples.

Table 4-9. Water quality data for Upper Pine Spring at Guadalupe Mountains 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	08:46	14.8	6.32	7.31	512.9	333.5	Shade
2	B	08:50	14.8	6.57	7.33	518.0	336.7	Shade

Table 4-10. Water chemistry data for Upper Pine Spring at Guadalupe Mountains NP, WY2018. All results in mg/L

Sampling Location	Orifice(s)	Alkalinity	Calcium	Chloride	Magnesium	Potassium	Sulfate
1	A	275	56	64	195	1.2	3
2	B	265	58	12	90	0.4	5

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