National Park Service
U.S. Department of the Interior

Natural Resource Stewardship and Science

Status of Climate and Water Resources at Big Bend National Park

Water Year 2019

Natural Resource Data Series NPS/CHDN/NRR—2022/2446

ON THE COVER
Rain showers at Big Bend National Park.
Photography by NPS.

Status of Climate and Water Resources at Big Bend National Park

Water Year 2019

Natural Resource Report NPS/CHDN/NRR—2022/2446

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September 2022

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:

Raymond, K., L. Palacios, and E. Gwilliam. 2022. Status of climate and water resources at Big Bend National Park: Water year 2019. Natural Resource Report NPS/CHDN/NRR—2022/2446. National Park Service, Fort Collins, Colorado. https://doi.org/10.36967/2294267.

NPS 155/184147, September 2022

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Glossary

anthropogenic: caused by human activities

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

bgs: below ground surface

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

ft: feet

hanging garden: spring emerging horizontally along a geologic contact, usually accompanied by vegetation

helocrene: spring emerging as a low-gradient wetland

limnocrene: spring type that emerges as a pool

m: meter

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

specific conductivity: a measure of how well water can 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

Executive Summary

Climate

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 resources. This report combines data collected on climate, groundwater, and springs at Big Bend National Park (NP) to provide an integrated look at climate and water conditions during water year (WY) 2019 (October 2018–September 2019). However, this report does not address the Rio Grande or its tributaries.

Annual precipitation was higher than normal (1981–2010) for Big Bend NP at four of the five National Oceanic and Atmospheric Administration Cooperative Observer Program weather stations: 111% of normal for Chisos Basin, 122% of normal for Panther Junction, 155% of normal for Persimmon Gap, and 124% of normal for Rio Grande Village. Castolon had 88% of normal annual precipitation. All five stations had higher than normal rainfall in October and December, while rainfall totals were substantially below normal at all stations in November, February, and March. Monthly precipitation totals for April through September were more variable from station to station. Mean monthly maximum air temperatures were below normal in the fall months, with Panther Junction as much as 7.5°F below normal in October. Monthly temperatures from January through July were more variable. Temperatures in August and September were warmer than normal at every station, up to +9.4°F at Rio Grande Village and +8.7°F at Chisos Basin in July. The reconnaissance drought index values indicate generally wetter conditions (based on precipitation and evaporative demand) at Chisos Basin since WY2016 and at Panther Junction and Persimmon Gap since WY2015, except for WY2017.

Groundwater

This report presents the manual and automatic groundwater monitoring results at nine wells. Five wells had their highest water level in or just before WY2019: Panther Junction #10 peaked at 99.94 ft below ground surface (bgs) in September 2018, Contractor's Well peaked at 31.43 ft bgs in November 2018, T-3 peaked at 65.39 ft bgs in December 2018, K-Bar #6 Observation Well peaked at 77.78 ft bgs in February 2019, and K-Bar #7 Observation Well peaked at 43.18 ft bgs in February 2019. This was likely in response to above normal rainfall in the later summer and fall 2018.

The other monitoring wells did not directly track within-season precipitation. The last measurement at Gallery Well in WY2019 was 18.60 ft bgs. Gallery Well is located 120 feet from the river and closely tracked the Rio Grande stage, generally increasing in late summer or early fall following higher flow events. Water levels in Gambusia Well were consistently very shallow, though the manual well measurement collected in April was 4.25 ft bgs—relatively high for the monitoring record—and occurred outside the normal peak period of later summer and early fall. The last manual measurement taken at TH-10 in WY2019 was 34.80 ft bgs, only 0.45 ft higher than the earliest measurement in 1967, consistent with the lack of directional change in groundwater at this location, and apparently decoupled from within-season precipitation patterns. The last water level reading in WY2019 at Oak Springs #1 was 59.91 ft bgs, indicating an overall decrease of 26.08 ft since the well was dug in 1989.

Springs

The Southwest Network Collaboration (SWNC) collects data on sentinel springs annually in the late winter and early spring following the network springs monitoring protocol. In WY2019, 18 sentinel site springs were visited at Big Bend NP (February 21, 2019–March 09, 2019). Most springs had relatively few indications of natural and anthropogenic disturbances. Natural disturbances included recent flooding, drying, and wildlife use. Anthropogenic disturbances included flow modifications (e.g., springboxes), hiking trails, and contemporary human use. Crews observed one to seven facultative/obligate wetland plant taxa and zero to three invasive non-native species at each spring. Across the springs, crews observed eight non-native plant species: Bermudagrass (*Cynodon dactylon*; 7 springs), Lehmann lovegrass (*Eragrostis lehmanniana*; 4 springs), horehound (*Marrubium vulgare*; 1 spring), tree tobacco (*Nicotiana glauca*; 1 spring), annual rabbitsfoot grass (*Polypogon*

monspeliensis; 2 springs), common sowthistle (*Sonchus oleraceus*; 4 springs), five-stamen tamarisk (*Tamarix chinensis*; 3 springs), and saltcedar (*T. ramosissima*; 1 spring).

During WY2019, temperature sensors were deployed at all 18 of the Big Bend NP sentinel springs to assess the persistence (hydroperiod) of the spring, or the period the spring has surface water. Temperature sensors were lost at Lorn Spring and failed at three other springs during WY2019. All recovered sensors indicated that the 17 springs with data had surface water for some part of WY2019. For the 15 springs with temperature loggers that functioned for the entirety of WY2019, all had water at least 60% of the water year and seven had water all year. Discharge was measured at 15 springs and ranged from < 1 L/min to 61 L/min. Cattail Falls had the highest discharge at 61 L/min and ten springs had discharge < 10 L/min. Water quality and chemistry parameters were collected at each spring. More data are required to develop reference points for assessing current water quality status and trends in springs.

Acknowledgments

We thank Superintendent Bob Krumenaker, former Chief of Resource Management David Larson, cartographer Marie Landis, former hydrologist Jeff Bennet, and the staff of Big Bend NP for their onsite support of the monitoring effort. Megan Podolinsky, Brandon Gottung, Timothy Pine, Susan Singley, Kristina Fahey, Lindsay Smythe, Henry Whitenack, Deb Manley, Meredith Dennis, and Stephanie Latimer conducted the springs and groundwater data collection and processing. Mark Isley, Henry Whitenack, Helen Thomas, Heidi Sosinski, Melissa Powell, and other network staff led the data management. 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, groundwater, and springs monitoring results for water year (WY) 2019 (October 2018–September 2019) at Big Bend National Park (NP) in southwest Texas, adjacent to the Mexico border. However, this report does not address the Rio Grande or its tributaries. Detailed analyses of trends will follow in subsequent reports as the period of record warrants such assessments. Some of the information in this report is from Chihuahuan Desert Inventory & Monitoring Network monitoring data and data collected and managed by Big Bend NP staff, while other complementary information is harvested from publicly available sources. For details on the springs monitoring protocol, please see the Chihuahuan Desert Network website (www.nps.gov/im/chdn/protocols.htm).

Big Bend National Park. NPS/JENNETTE-JURADO

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 WY2019 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 Big Bend NP as cool semi-arid (Peel et al. 2007).

Big Bend NP has twelve climate stations: five National Oceanic and Atmospheric Administration (NOAA) Cooperative Observer Program (COOP) weather stations, four Remote Automated Weather Stations (RAWS), two West Texas Mesonet (WTMN) stations, and one Climate Reference Network (CRN) station (Table 2-1; Figure 2-1). The station data were obtained from Climate Analyzer (Walking Shadow Ecology 2020a, b, c, d, e, f, g, h), a website that allows users to make on-demand tables and graphs with data from weather stations that are updated daily (Walking Shadow Ecology 2020i). The COOP stations have the largest data records and are used for all analyses in this report. Historical data from the COOP stations provide 1981–2010 climate normals: precipitation and monthly maximum and minimum temperatures (Arguez et al. 2010).

Table 2-1. Climate station metadata, Big Bend NP. Only data from COOP stations are included in this report.

Type	Name	NWSLI	Type	Latitude	Longitude	Elevation (ft)	Elevation (m)	Years in Operation	Days Missing Data in WY2019
COOP	Castolon*	CSLT2	COOP	29.134440	-103.515000	2170	661	1947, 1961–1965, 1980–2013, 2015–Present	43
	Chisos Basin*	BBPT2	COOP	29.270280	-103.300280	5300	1615	1943–Present	49
	Panther Junction*	PAJT2	COOP	29.327220	-103.206110	3740	1140	1955–Present	11
	Persimmon Gap *	PNGT2	COOP	29.660280	-103.173610	2870	875	1952,1967, 1982–Present	15
	Rio Grande Village*	RGVT2	COOP	29.185300	-102.962200	1857	566	2006–Present	15
CRN	Panther Junction 2N	PNJT2	CRN	29.205400	-103.124000	3494	1065	2010–Present	0
RAWS	Bibe RGV Texas	RGET2	RAWS	29.185800	-102.963000	1860	567	2016–Present	0
	Big Bend QD 1	TS645	RAWS	29.593283	-103.262483	2839	865	2009, 2011–Present	2
	Chisos Basin Texas	CSBT2	RAWS	29.266667	-103.300000	5400	1646	2000–Present	0
	Panther Junction Texas	PJNT2	RAWS	29.316667	-103.208300	3750	1143	2003–Present	0
WTMN	Castolon 1NW	CTLT2	WTMN	29.145920	-103.527170	2175	663	2019–Present	186
	Persimmon Gap BBNP	PGPT2	WTMN	29.660300	-103.175100	2869	874	2013–Present	16

* Station data used for the analysis in this report.

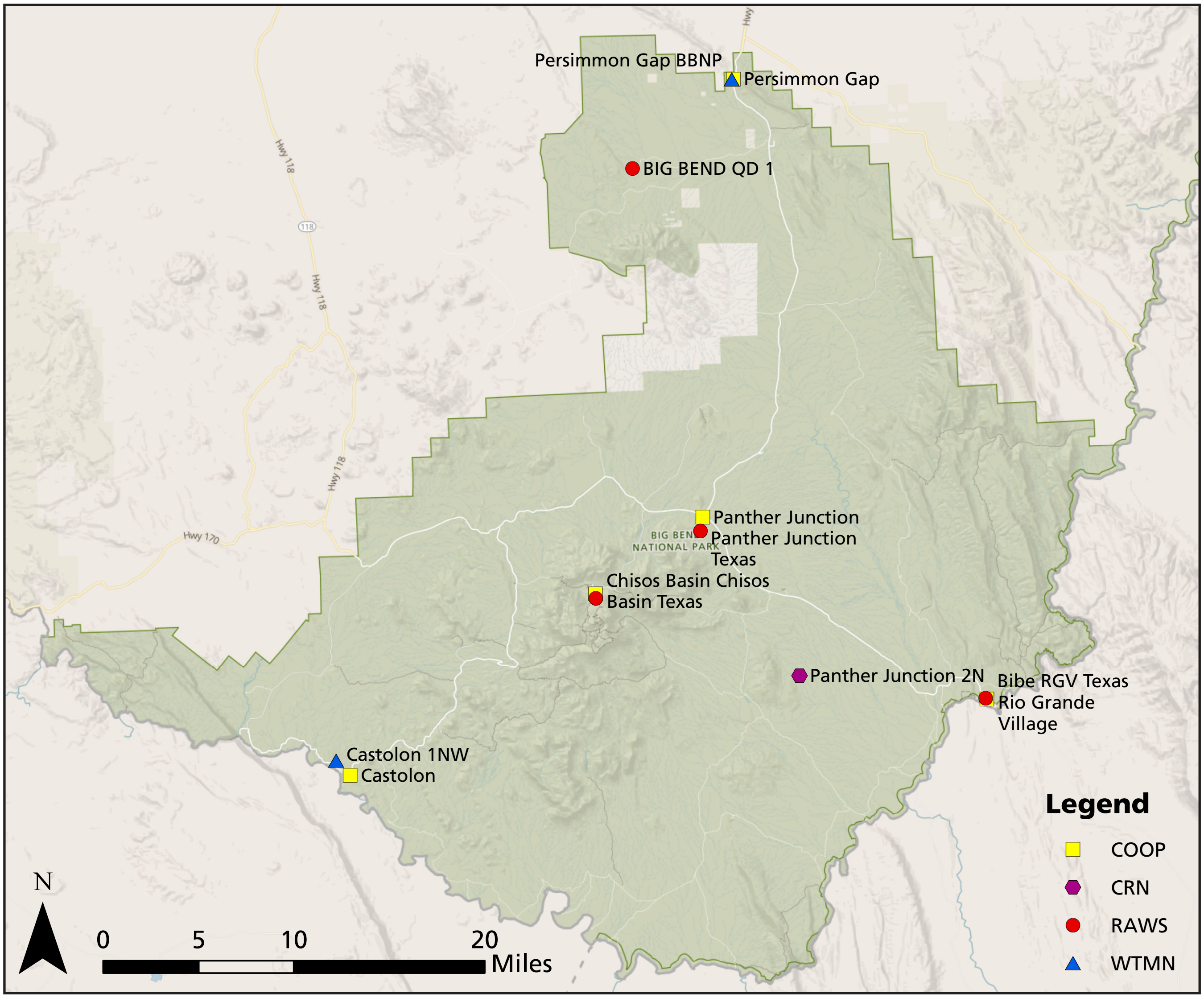

Figure 2-1. Climate stations at Big Bend NP. COOP = National Weather Service Cooperative Observer Program station. CRN = Climate Reference Network. RAWS = Interagency Remote Automated Weather Station. WTMN = West Texas Mesonet. Only data from COOP stations were included in this report.

2.2 Results and Discussion

Data quality during WY2019 was variable: between 11 and 49 days of data were missing depending on the COOP station, in part due to the 2018–2019 government shutdown. Temperature data were estimated based on available data for December at all COOP stations, and in October and March for the Castolon COOP station. July temperatures are missing for Chisos Basin. Precipitation data were estimated for missing days based on the available data and co-located weather stations in December for all COOP stations and in July and August at the Chisos Basin COOP station.

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

Overall, annual precipitation in WY2019 was higher than normal for Big Bend NP, with the exception of Castolon, which was lower: 88% of normal for Castolon (9.56 in. vs. 10.85 in.), 111% of normal for Chisos Basin (21.44 in. vs. 19.36 in.), 122% of normal for Panther Junction (16.82 in. vs. 13.76 in.), 155% of normal for Persimmon Gap (17.67 in. vs. 11.39 in.), and 124% of normal for Rio Grande Village (15.86 in. vs. 12.77 in.).

Cool Season (October–March)

Precipitation in the fall and winter of WY2019 was higher than normal at all five COOP stations: Castolon (4.03 in., 131% of normal), Chisos Basin (6.56 in., 136% of normal), Panther Junction (5.35 in., 137% of normal), Persimmon Gap (5.05 in., 172% of normal) and Rio Grande Village (6.30 in., 172% of normal). The increased rainfall was concentrated in October and December at all five COOP stations (Figure 2-2). In October, Rio Grande Village received 4.49 in. (359% of the normal 1.25 in.). In December, Castolon received 1.35 in. (435% of the normal 0.31 in.; Figure 2-3). Rainfall totals were substantially below normal at all stations in November, February, and March, with no rain or only trace amounts recorded for some of these months.

Mean monthly maximum temperatures were below normal in the fall months, with Panther Junction experiencing up to 7.5°F below normal in October (Figure 2-4). Mean monthly maximum temperatures were more variable in the winter months, ranging from 2.5°F below normal to 4.0°F above normal. Mean monthly minimum temperatures were generally above normal in the fall and winter, except in November at all stations and in January at Castolon and Chisos Basin. In WY2019, mean monthly maximum temperatures were the highest at the two low elevation stations along the Rio Grande (Castolon and Rio Grande Village), and maximum temperatures were lowest at the high elevation station at Chisos Basin (Figure 2-5). Mean monthly minimum temperatures were slightly more variable.

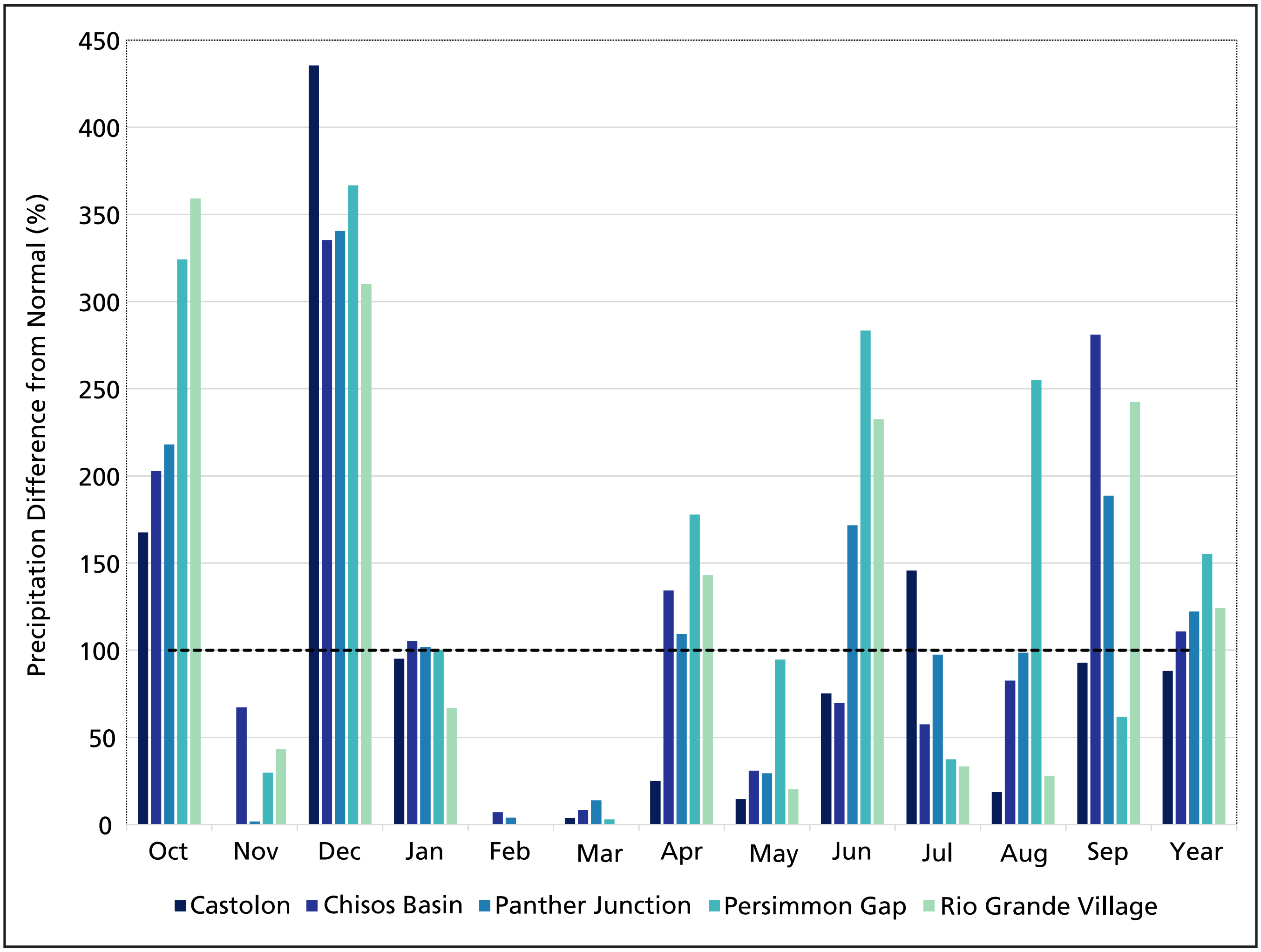

Figure 2-2. Departures from 30-year (1981–2010) normal precipitation at five COOP weather stations, Big Bend NP, WY2019 (October 2018–September 2019). Precipitation may be underrepresented due to missing data in December for all COOP stations and July and August for Chisos Basin.

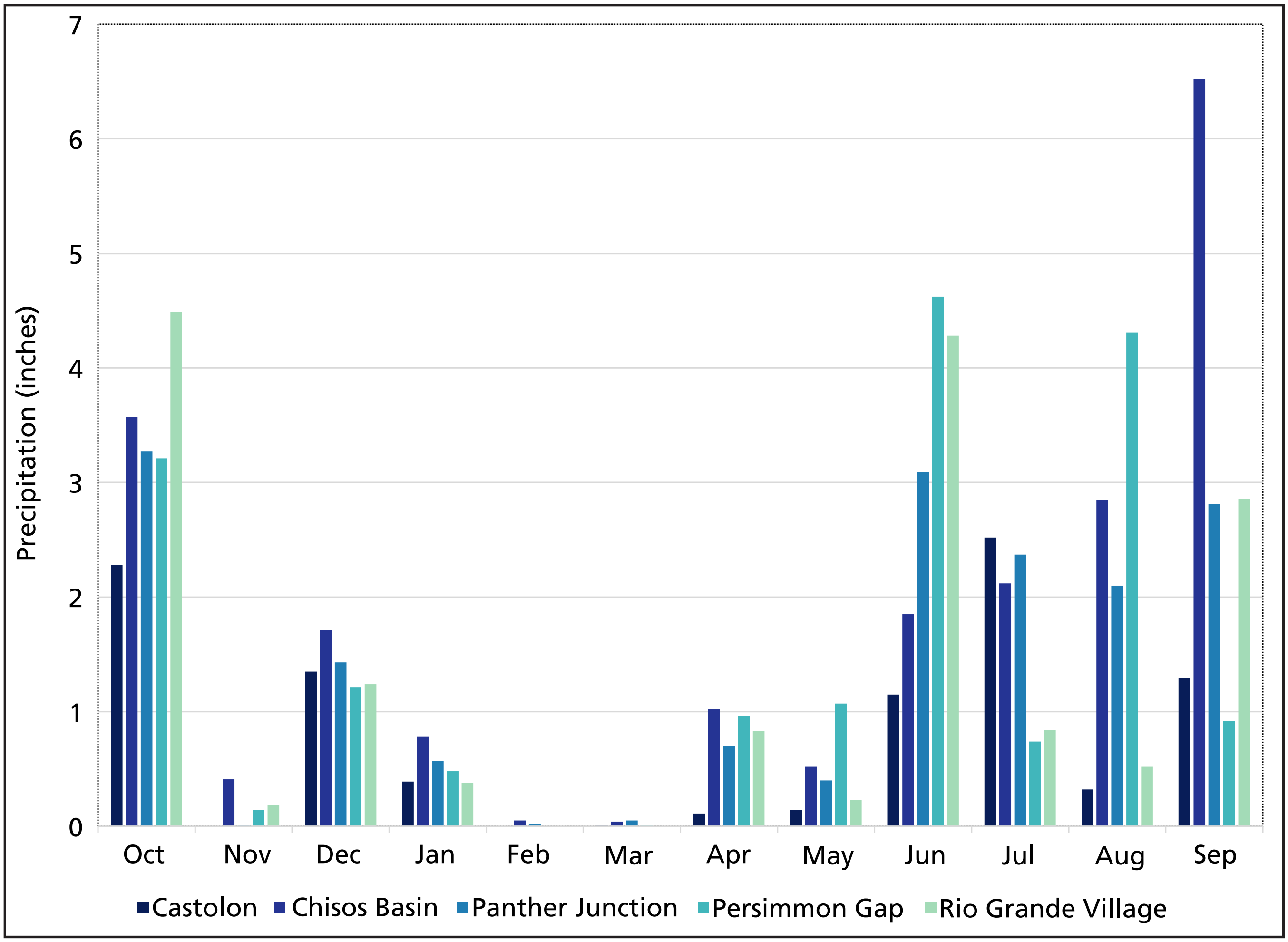

Figure 2-3. Monthly precipitation at five COOP weather stations, Big Bend NP, WY2019 (October 2018–September 2019). Precipitation may be underrepresented due to missing data in December for all COOP stations and July and August for Chisos Basin.

Warm Season (April–September)

Precipitation in the spring and summer was lower than normal at Castolon (5.53 inches, 71% of normal), and higher than normal at Chisos Basin (14.88 in., 102% of normal), Panther Junction (11.47 in., 116% of normal), Persimmon Gap (12.62 in., 149% of normal) and Rio Grande Village (9.56 in., 105% of normal). Monthly precipitation compared to normal was variable across the stations. Normally July is the wettest month at all stations, followed by August, but in WY2019, July was only the wettest month for Castolon (2.52 in.). June was the wettest month at Panther Junction (3.09 in.), Persimmon Gap (4.62 in.) and Rio Grande Village (4.28 in.), and September was the wettest month for Chisos Basin (6.52 in.).

Mean monthly minimum and maximum temperatures were variable April through July, relative to normal (3.5°F below normal to 5.8°F above normal). Temperatures in August and September were above normal at every station, up to 9.4°F above normal at Rio Grande Village and 8.7°F above normal at Chisos Basin.

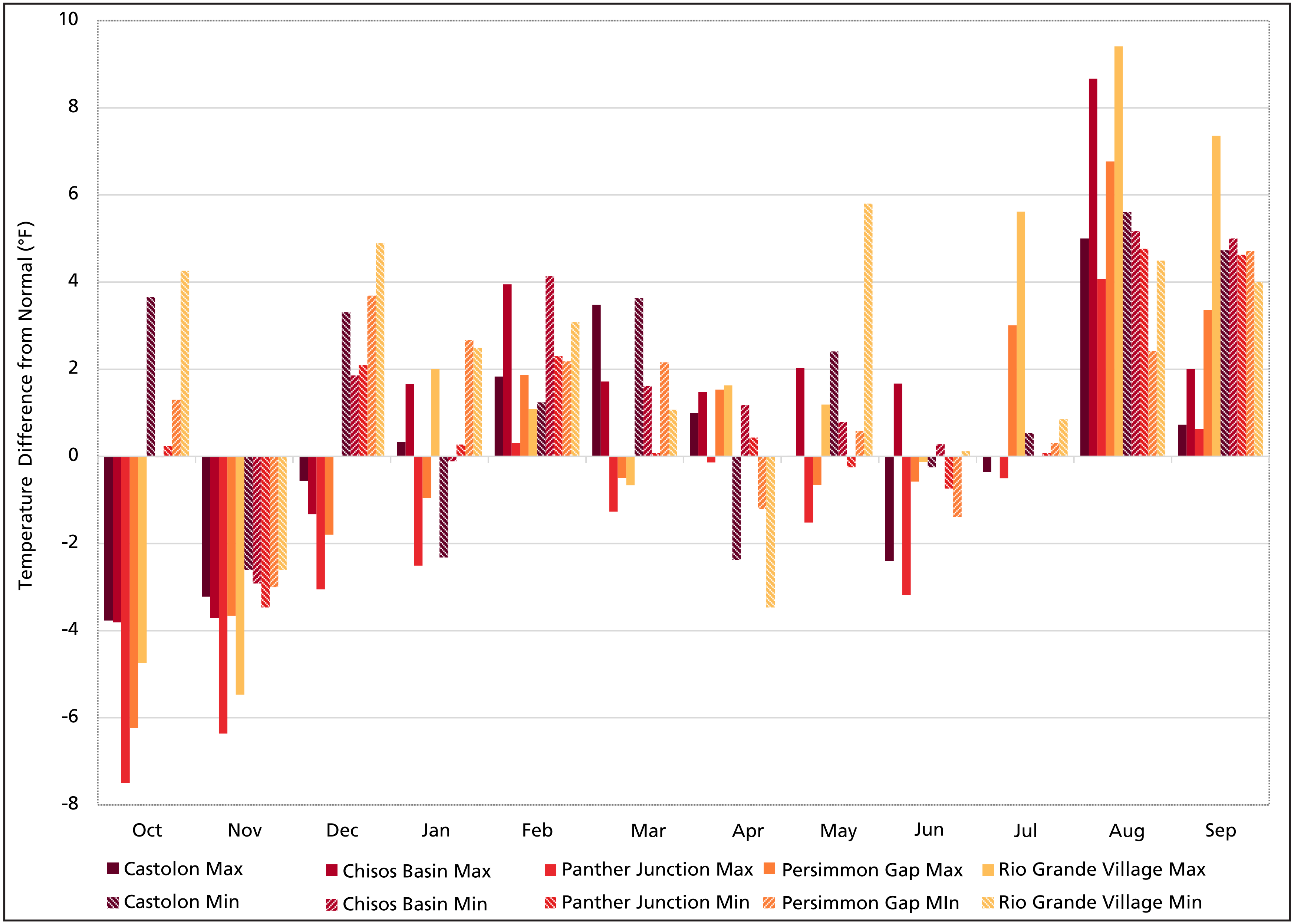

Figure 2-4. Departures from 30-year (1981–2010) normal minimum and maximum air temperatures at five Cooperative Observer Program weather stations, Big Bend NP, WY2019 (October 2018–September 2019). Temperature is estimated based on available data in December for all COOP stations; October, February, and March for Castolon, and August for Chisos Basin. July temperatures are missing for Chisos Basin.

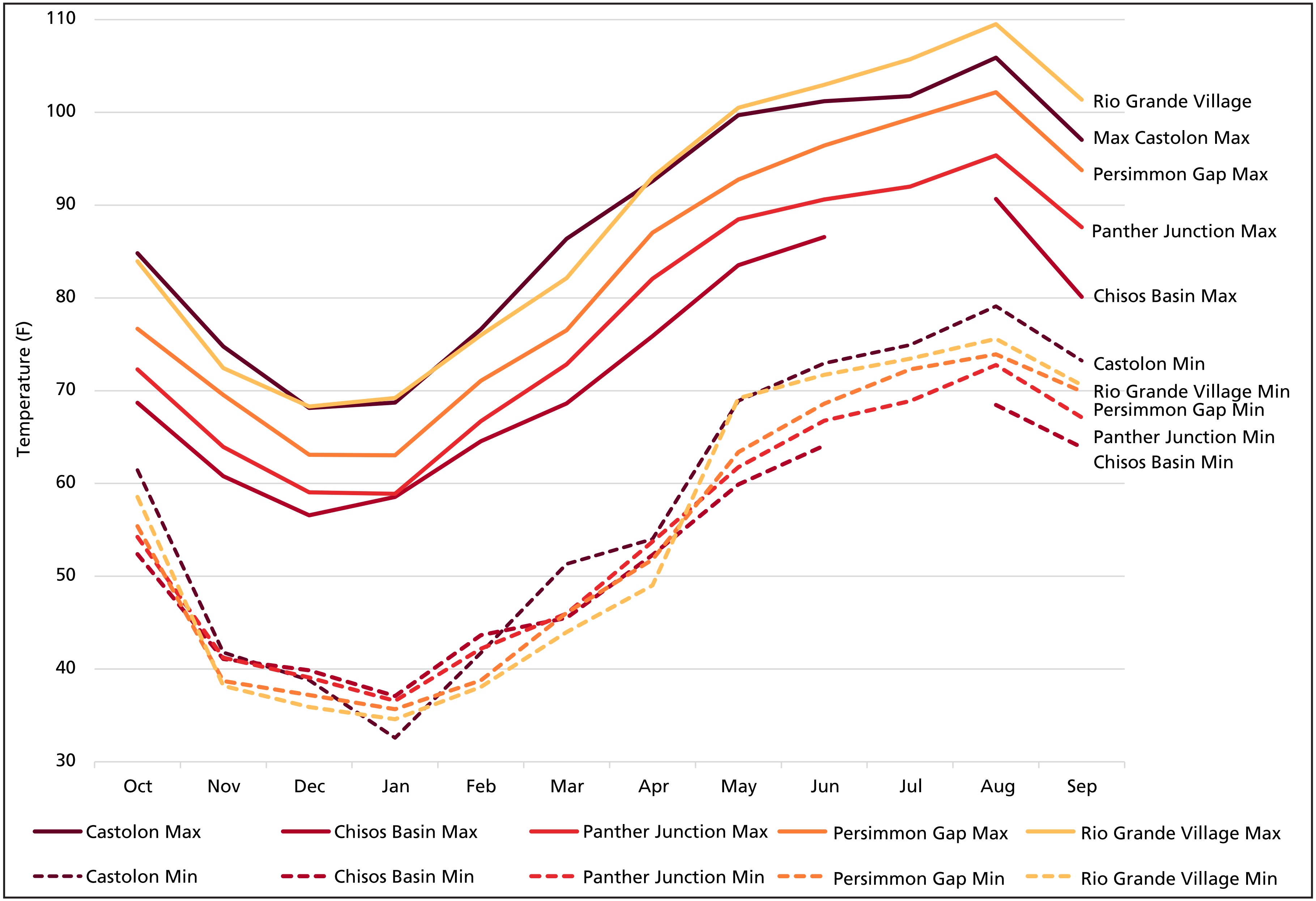

Figure 2-5. Mean monthly minimum and maximum air temperatures at six weather stations, Big Bend NP, WY2019 (October 2018–September 2019). Temperature is estimated based on available data in December for all COOP stations; October, February, and March for Castolon, and August for Chisos Basin. July temperatures are missing for Chisos Basin.

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 RDIs indicate generally wetter conditions (based on precipitation and evaporative demand) at Chisos Basin since WY2016, and at Panther Junction and Persimmon Gap since WY2015 , except for WY2017 at all three locations (Figures 2-6 through 2-8). The RDI for WY2019 could not be calculated for Chisos Basin and Persimmon Gap; however, above normal precipitation and warmer conditions likely indicate a near normal RDI. The five-year moving mean of total annual precipitation (water year) at Chisos Basin, Panther Junction, and Persimmon Gap indicate a recovery in WY2019, following a 6 to 8-year precipitation deficit (Figures 2-9 through 2-11). The RDI and five-year moving mean of total annual precipitation were not calculated for Castolon and Rio Grande Village due to large gaps in the monitoring record.

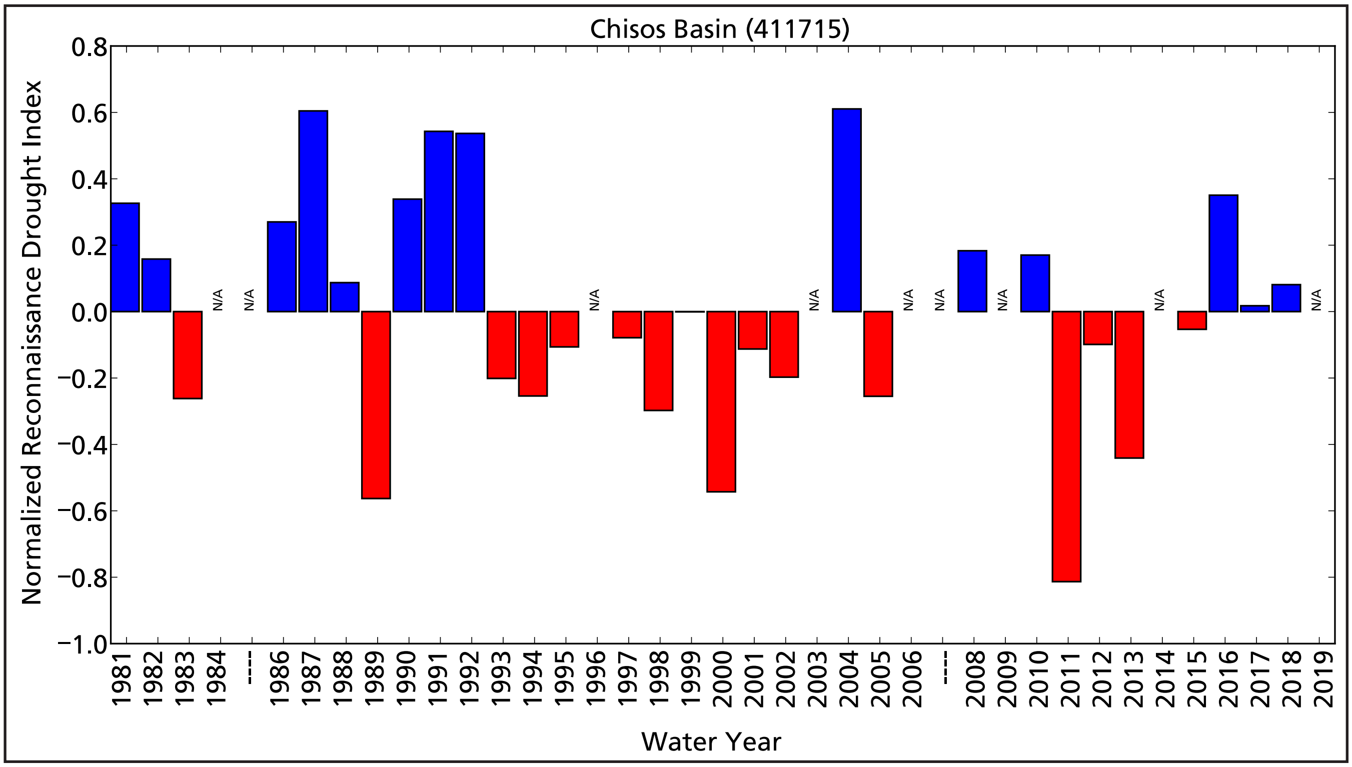

Figure 2-6. Reconnaissance drought index (RDI), Chisos Basin COOP, Big Bend NP, water years 1981–2019. n/a = insufficient data to generate reliable data. Graphics generated by climateanalyzer.org (Walking Shadow Ecology 2020b).

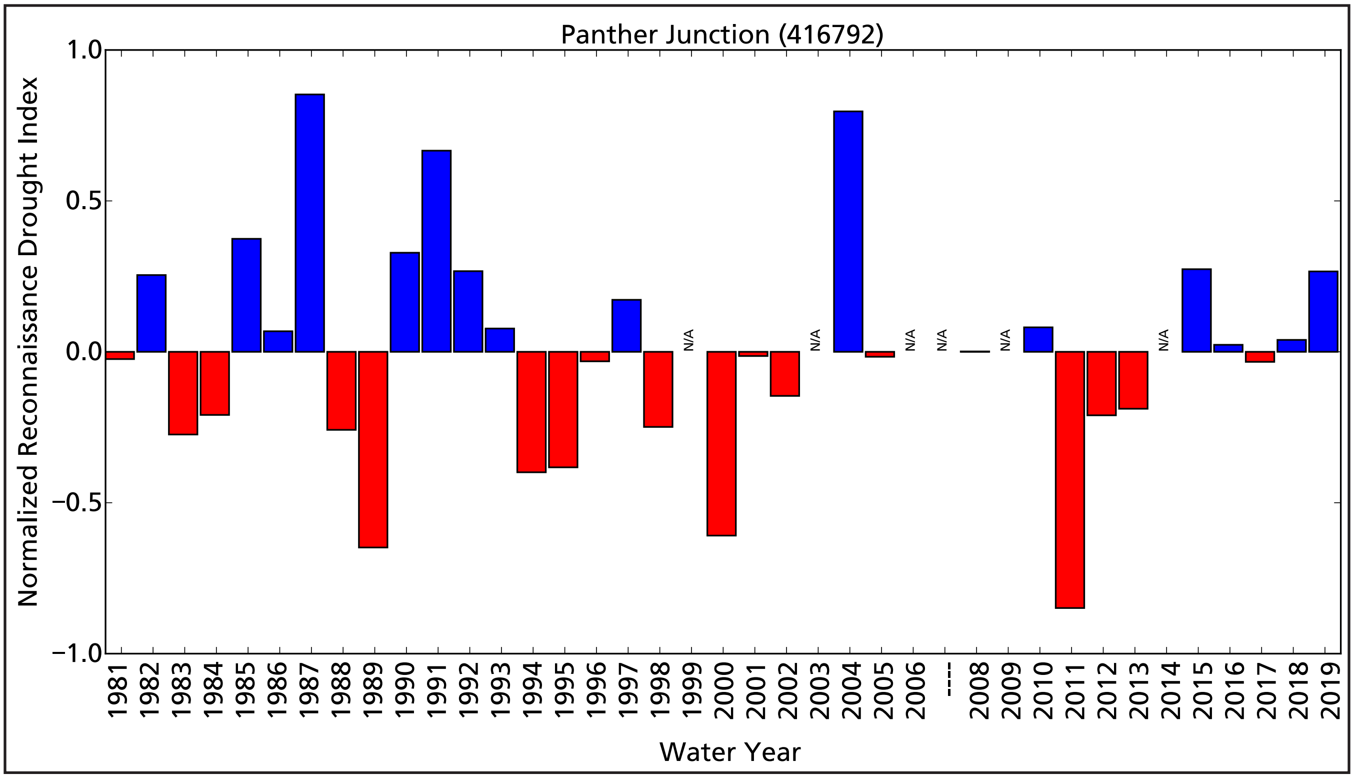

Figure 2-7. Reconnaissance drought index (RDI), Panther Junction COOP, Big Bend NP, water years 1981–2019. n/a = insufficient data to generate reliable data. Graphics generated by climateanalyzer.org (Walking Shadow Ecology 2020d).

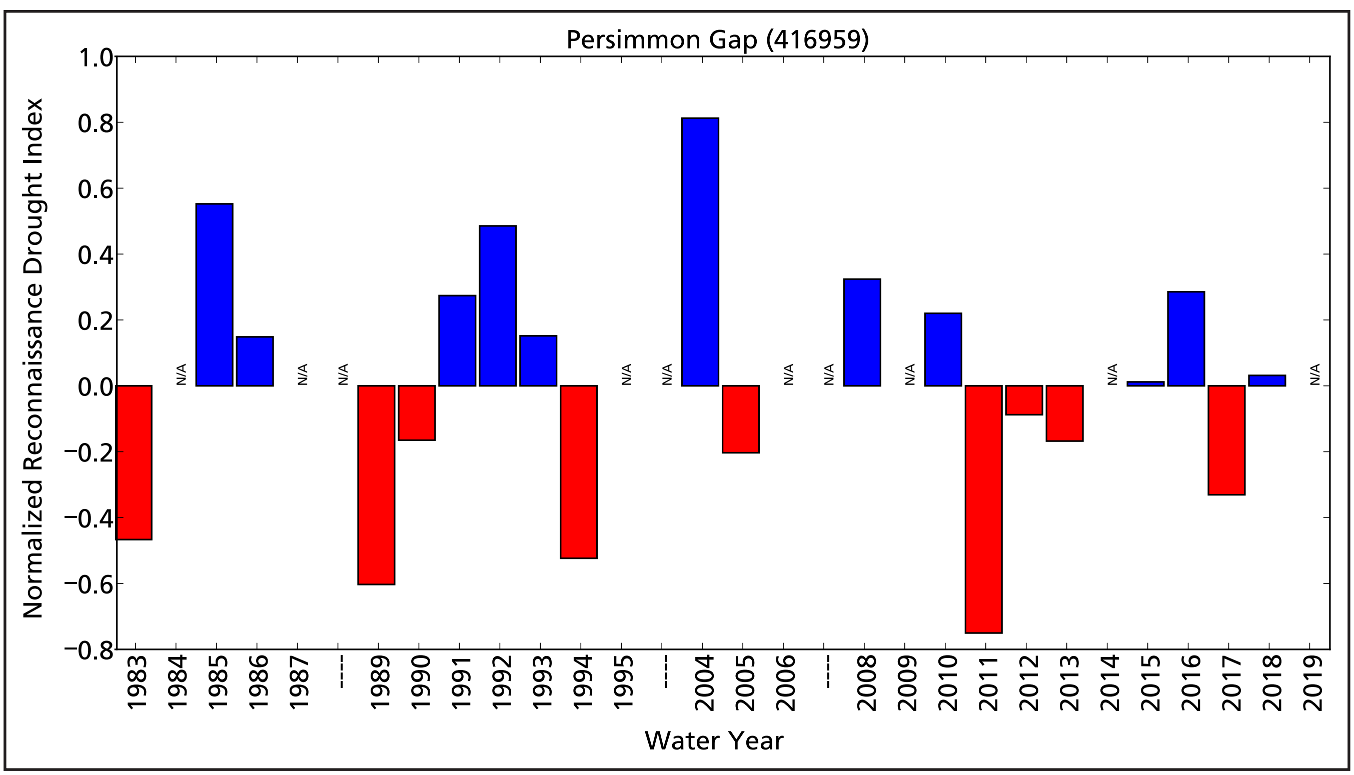

Figure 2-8. Reconnaissance drought index (RDI), Persimmon Gap COOP, Big Bend NP, water years 1982–2019. n/a = insufficient data to generate reliable data. Graphics generated by climateanalyzer.org (Walking Shadow Ecology 2020f).

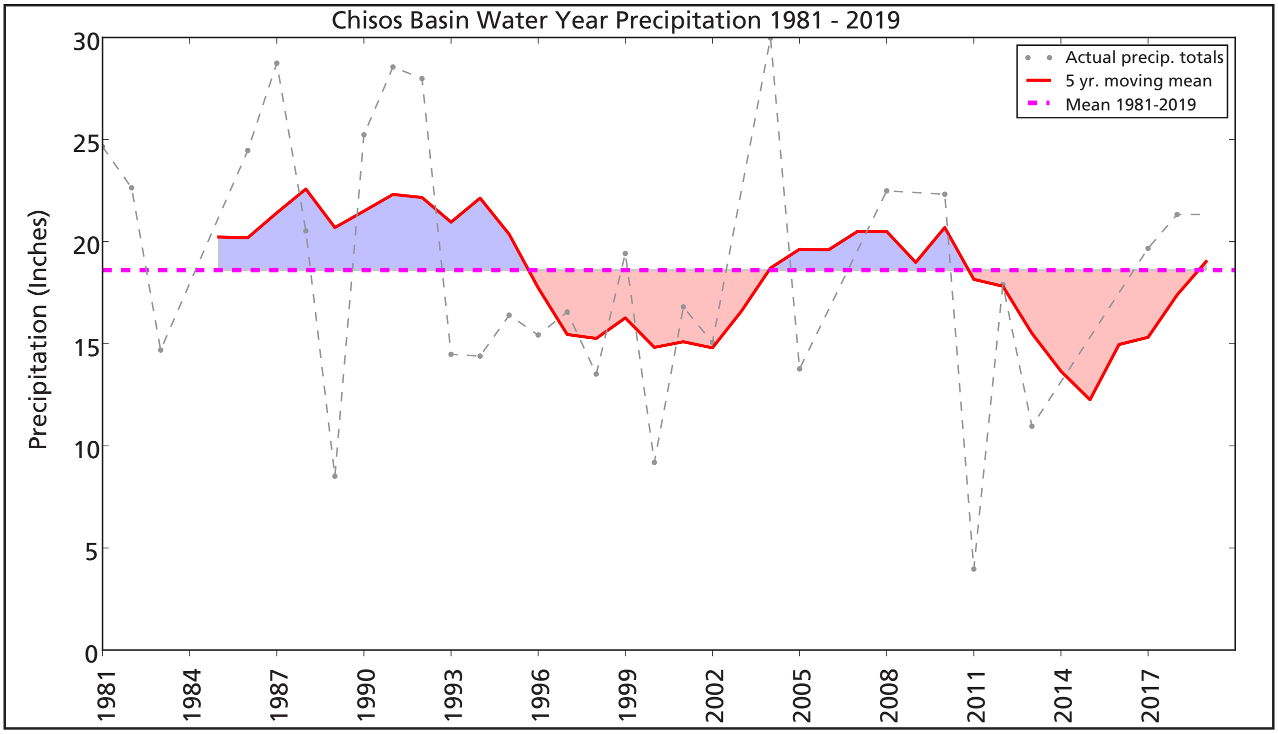

Figure 2-9. Five-year moving mean of annual precipitation at Chisos Basin, Big Bend NP, 1981–2019 (solid line)—based on a time series with 25.6% (10 of 39) missing values and includes the current year and previous four years. Fields above (in blue) and below (in red) the mean (thick, straight, dashed line) represent water surpluses and deficits, respectively. Dots on the thin, dashed line represent actual precipitation totals and missing years are linearly interpolated. Graphic generated by climateanalyzer.org (Walking Shadow Ecology 2020b).

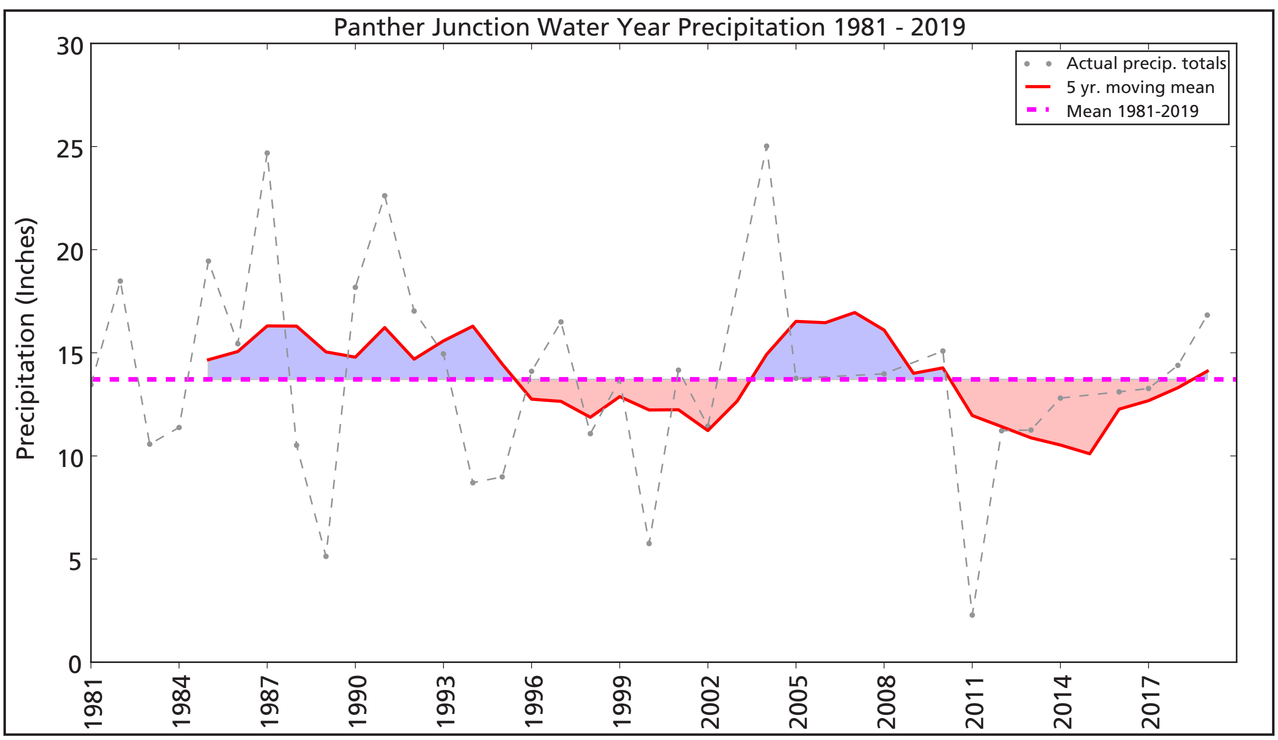

Figure 2-10. Five-year moving mean of annual precipitation at Panther Junction, Big Bend NP, 1981–2019 (solid line)—based on a time series with 12.8% (5 of 39) missing values and includes the current year and previous four years. Fields above (in blue) and below (in red) the mean (thick, straight, dashed line) represent water surpluses and deficits, respectively. Dots on the thin, dashed line represent actual precipitation totals and missing years are linearly interpolated. Graphic generated by climateanalyzer.org (Walking Shadow Ecology 2020d).

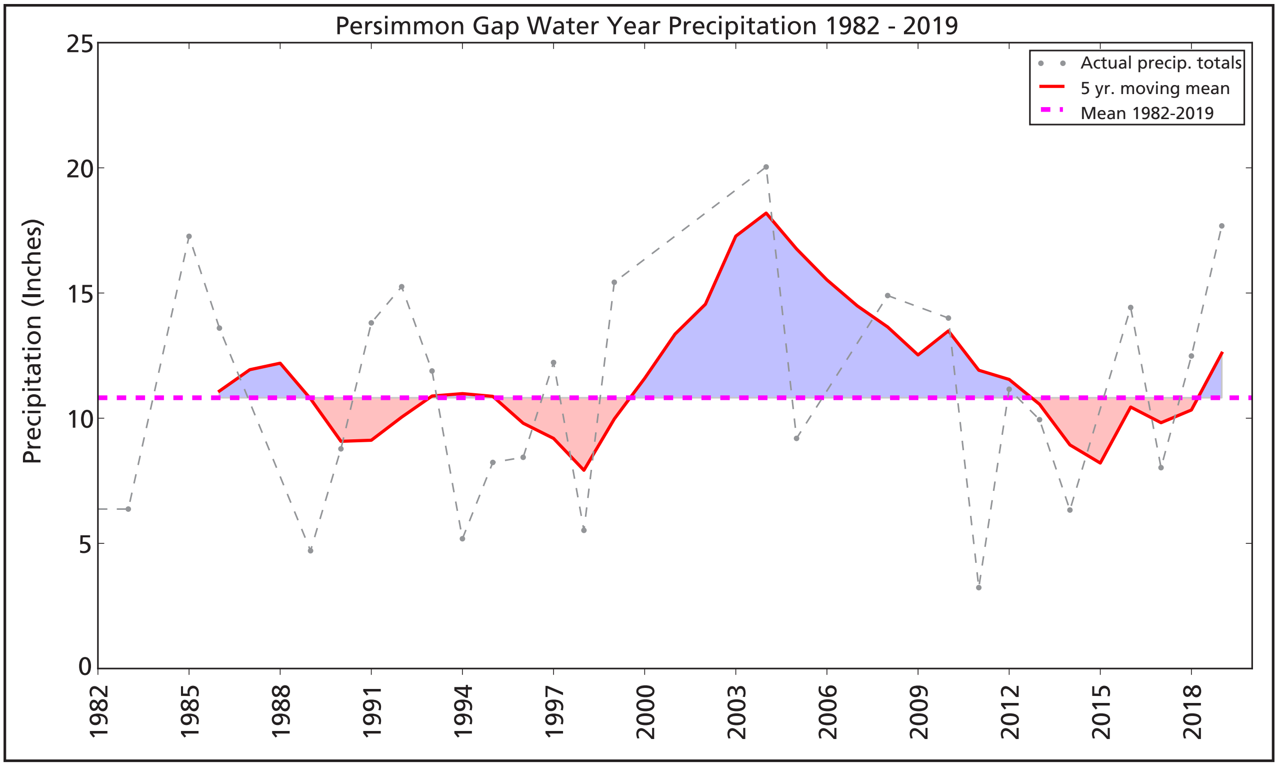

Figure 2-11. Five-year moving mean of annual precipitation at Persimmon Gap, Big Bend NP, 1982–2019 (solid line)—based on a time series with 31.6% (12 of 38) missing values and includes the current year and previous four years. Fields above (in blue) and below (in red) the mean (thick, straight, dashed line) represent water surpluses and deficits, respectively. Dots on the thin, dashed line represent actual precipitation totals and missing years are linearly interpolated. Graphic generated by climateanalyzer.org (Walking Shadow Ecology 2020f).

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 ecosystems. For example, sustained warm temperatures increase evapotranspiration rates, decreasing the availability of water for plants and wildlife. Extreme precipitation events can also cause localized flooding and erosion events, enhance or inhibit plant productivity and reproduction, and modify animal behavior (Sumner 1988). We define extreme weather events as follows: "extremely warm days" are days with maximum temperatures that exceed the 95th percentile of 1981–2010 data (P_{95}); "extremely cold days" are days with minimum temperatures that do not reach the 5th percentile of 1981–2010 data (P_5); "extreme storm events" are days with > 1 in. of precipitation.

Extreme events in WY2019 are summarized in Table 2-2. Temperatures were milder in WY2019 at Castolon and Panther Junction; each had fewer extreme warm and cold days than normal. However, extreme cold days may be underestimated due to missing temperature data in December. The high elevation Chisos Basin had more extreme warm days and fewer extreme cold days compared to normal. Castolon recorded no extreme precipitation events in WY2019. However, daily rainfall totals exceeded 0.90 in. on three days. The number of days with precipitation > 1 in. at Chisos Basin, Panther Junction, and Persimmon Gap were within one day of the average frequency.

Table 2-2. Summary of extreme temperature and precipitation events, Big Bend NP. Extreme temperature and precipitation events were not calculated for the Rio Grande Village COOP station due to the limited data record. n/a= not applicable due to missing data in the historic record. P95 is the 95th percentile and P5 is the 5th percentile.

Type of Extreme Event	Description	Castolon	Chisos Basin	Panther Junction	Persimmon Gap
Extremely Warm Days	P_{95} Temperature (1981–2010)	108°F	89°F	98°F	n/a
	Days > Temp P_{95}: 1981–2010 normal (mean ± standard error)	12.3 ± 1.8	23.4 ± 2.1	22.8 ± 2.5	n/a
	Days > Temp P_{95}: WY2019	9	30	7	n/a
Extremely Cold Days	P_5 Temperature (1981–2010)	30°F	30°F	30°F	n/a
	Days < Temp P_5: 1981–2010 normal (mean ± standard error)	17.2 ± 1.8	18.1 ± 1.5	17.8 ± 1.1	n/a
	Days < Temp P_5: WY2019	15	9	13	n/a
Extreme Storm Events	Days >1 in. Precipitation: 1991–2010 normal (mean ± standard error)	1.8 ± 0.30	4.2 ± 0.56	2.7 ± 0.29	2.5 ± 0.53
	Days >1 in. Precipitation: WY2019	0	5	3	3
	Dates with >1 in. Precipitation: WY2019	–	10/24/2018 (1.02 in) 12/8/2018 (1.14 in) 8/29/2019 (1.66 in) 9/21/2019 (1.90 in) 9/22/2019 (1.25 in)	12/8/2018 (1.02 in) 7/4/2019 (1.29 in) 9/21/2019 (1.36 in)	6/18/2019 (1.05 in) 8/24/2019 (1.20 in) 8/28/2019 (1.67 in)

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).

Big Bend NP has a complex geologic history that drives the current groundwater conditions. During the Paleocene and Cretaceous periods, the park was relatively flat and covered by ocean waters, resulting in the deposition of marine sediments. These sedimentary rocks were then folded and faulted during the Laramide orogeny, approximately 80 to 47 million years ago (Bohannon 2011). This led into a period of several volcanic eruptions 48 to 27 million years ago and intervening periods of erosion, creating interbedded volcanic-sedimentary units (Chastain-Howley 2001). Starting 23 million years ago, tectonic extension characteristic of the Basin and Range province caused faulting and uplifting (Bohannon 2011). Erosion during the Quaternary period then filled in the basins, creating the mountain and valley topography characteristic of Big Bend NP today. Aquifers at Big Bend NP exist in three main geologic units: Cretaceous sedimentary, Tertiary volcanic, and Quaternary alluvium.

The Cretaceous sedimentary units are composed of limestone, sandstone, and shale created through marine deposition and later continental deposition (Baker and Buszka 1993; Turner et al. 2011). The Cretaceous sedimentary units underlie most of the park, only outcropping where overlying layers have eroded away. Some of the Cretaceous units provide the most reliable water supplies for the park, discharging water to springs and seeps and contributing substantial groundwater inflows to the Rio Grande River (MacNish et al. 1996). Groundwater discharge is variable year to year and is dependent on recharge (Porter et al. 2009).

Groundwater in the Tertiary volcanic units occupies the interflow zones: the rubble below lava flow layers and the fractures and crevices in the upper portion of lava flows created by rapid cooling of lava. These porous zones are generally separated by denser material that cooled more slowly. Some of the individual aquifers are discrete and others are hydraulically connected where fractures and faults are located (Chastain-Howley 2001). Recharge of the Tertiary volcanic units occurs through direct infiltration of rainfall through fractures, generally recharging the aquifers quickly (Porter et al. 2009). Streams may also lose water to this aquifer through infiltration into fractures (Chastain-Howley 2001). Discharge occurs primarily at springs that are often located at fractures.

Quaternary alluvium and colluvium overlay Tertiary and Cretaceous bedrock in many low elevation parts of the park (Baker and Buszka 1993). Aquifers in the Quaternary alluvium are limited to areas adjacent to wetted streams, and the alluvium further from streams tends to be unsaturated (Tony Fallin 1990). Water in the alluvium generally runs toward and parallel to the streams. The Quaternary alluvium aquifers are recharged through precipitation and spring flow into the streams. Discharge occurs through evapotranspiration in the riparian areas and conveyance downstream.

3.2 Methods and Monitoring Wells

Big Bend NP has 111 known groundwater wells. Nine wells are currently monitored using a combination of manual and automated methods: eight by Big Bend NP staff and one by the Texas Water Development Board (TWDB; Table 3-1). Big Bend NP began automated monitoring in 2012 following a park generated protocol. Data collection frequency is variable (every 15 minutes to six hours using pressure transducers), and manual measurements are conducted at least annually.

Table 3-1. Summary of groundwater monitoring wells at Big Bend NP.

Area of Park	Well Name	Well ID	Well Use	Elevation (ft amsl)	Total Depth (ft)	Year Completed	Formation
Rio Grande	Gallery Well	7352909*	Irrigation	2126 .0	26	1969	Rio Grande Alluvium/ Cretaceous - Aguja
Rio Grande	Gambusia Well	7249508*	Observation	1855 .0	283	1984	Cretaceous - Santa Elena
Chisos Basin	Contractor's Well	7346705*	Test	3753.0	234	1971	unknown
Chisos Basin	Oak Springs #1/ TB-5	7346702	Test	4165.0	118	1989	Tertiary – Intrusive Igneous
Panther Junction	K-Bar #6 Observation Well/ Panther Junction #6 Observation Well	7347508*	Observation	3498.0	165	1983	Tertiary - Chisos
Panther Junction	K-Bar #7 Observation Well	7347511*	Observation	3460.0	130	1984	Tertiary - Chisos
Panther Junction	Panther Junction #10	7347404	Test	3880 .0	620	2006	Tertiary - Chisos
Panther Junction	T-3/ Well 37	7347101*	Test	3617.2	136 (blocked)	1964	Tertiary - Chisos
Panther Junction	TH-10/ I-50	7347201*	Test	3466 .0	445	1967	Cretaceous - Aguja

*Well is not registered with the Texas Water Development Board (TWDB) system and Well ID was not assigned by the TWDB.

TWDB automated measurements at Panther Junction #10 (73-47-404) occur on day 5, 10, 15, 20, 25, and 30 of each month. Data for Panther Junction #10 is available at http://www.twdb.texas.gov/groundwater/data/gwdbrpt.asp(TWDB 2020). Data used for this section are considered preliminary. Caution should be exercised when interpreting the results.

The height of the measuring points above ground surface at some of the park's wells may not have been recorded accurately. Actually depth to water and elevation measurements may be slightly different, but the patterns and trends in groundwater level are unaffected.

3.2.1 Rio Grande Wells

Gallery Well is located near Castolon, approximately 100 yds downstream of the confluence of Blue Creek with the Rio Grande, and is the only monitoring well completed in alluvium. Water level and quality in the well fluctuates in response to the stage of the Rio Grande River (Martin 2000). However, the underlaying Aguja formation may also be discharging water to alluvium (Martin 2000; NPS 1996).

Gambusia Well is in the Rio Grande Village area, 0.30 miles from the current channel of the Rio Grande. It was drilled approximately 30 m northwest of the Gambusia refuge pond, on a low terrace just above the Rio Grande floodplain (NPS 1996; NPS 2011). This well is completed in the Lower Cretaceous Santa Elena Formation, likely accessing the same source as nearby springs. This aquifer is recharged through faults in an outcrop of the same formation, approximately three miles north of the Rio Grande Village at elevations greater than 3000 ft (Shanks et al. 2008).

3.2.2 Panther Junction Wells

Five monitoring wells are in the Panther Junction Area, where a shallow geologic contact occurs between Upper Cretaceous units and the Lower Tertiary Chisos Formation. TH-10 is the northernmost well, located east of a northwest to southeast anticline. TH-10 is completed in the Upper Cretaceous Aguja formation, overlain by intermediate alluvial deposits (NPS 1996; NPS 2011). T-3, K-Bar #6 Observation Well, and K-Bar #7 Observation Well lie between the fault to the west and the anticline to the east. These wells access the Tertiary Chisos Formation. Panther Junction #10 is west of the fault and accesses a different unit of the Tertiary Chisos Formation. Water produced from

Panther Junction #10 is a mix of *young* water (from recent precipitation) and water older than 50 years (Shanks et al. 2008). Water from the K-Bar area is primarily older than 50 years (Shanks et al. 2008).

3.3.3 Chisos Basin Wells

Oak Springs #1 (TB-5) is in the Chisos Basin Area. This was a test well drilled to locate the source of water to Oak Spring. It is 280 ft north of Oak Spring and the wellhead is approximately 85 ft above the Oak Spring outlet (Baker and Buszka 1993). The park identifies the well as being completed in instrusive igeneous rock (Big Bend NP written communication, 2019); however, the geology may be more complex as the Oak Spring area landslide deposits overlay the Chisos Formation, and intrusive igneous rocks are exposed at the nearby Window pouroff. However, when the well was drilled, the lithology was considered more similar to the Aguja Formation than the Chisos Formation (Baker and Buszka 1993). The Oak Spring aquifer is 60% *old* water, which is recharged from high in the Chisos Mountains through fractures, and 40% *young* water (Shanks et al. 2008). The *young* water is from rain that quickly infiltrates through a layer of landslide deposits, composed of rhyolite boulder field of intrusive and volcanic rock origin (Baker and Buszka 1993).

The geology of Contractor's Well is unknown. It is located near outcrops of the Upper Cretaceous Blacks Peaks Formation and the Tertiary Chisos Formation and may be completed in either formation (NPS 2011). Monitoring comments routinely note "rusty water" in the well, which indicates iron in the well and possibly iron bacteria.

3.3 Results and Discussion

Water levels were higher in WY2019 in the Panther Junction area wells and well T-3, compared to the earliest measurement for each well. In contrast, water levels in the Chisos Basin area wells and wells in or near the Rio Grande floodplain showed no change since monitoring began (Table 3-2).

3.3.1 Rio Grande Wells

Water levels in Gallery Well are shallow due to its proximity to the Rio Grande (Figure 3-1). Gallery Well, located 120 ft from the river, tracks closely with the Rio Grande stage (Figure 3-2). Well levels often increase in late summer or early fall, following higher flow events. The last manual measurement at Gallery Well in WY2019 was 18.60 ft below ground surface (bgs), relatively low compared to the historic range. This measurement was taken during a period of base flow conditions in the Rio Grande and shows the impact of the river stage on the well levels.

Table 3-2. Groundwater monitoring results in water year 2019, Big Bend NP.

Area of Park	Well Name	Depth to Water WY2019 (ft bgs)	Elevation WY2019 (ft amsl)	Elevation Change Since Earliest Measurement (± ft (WY of earliest measurement))	Minimum Depth to Water for the Monitoring Record (ft bgs (WY observed))	Maximum Depth to Water for the Monitoring Record (ft bgs (WY observed))
Rio Grande	Gallery Well	18.60	2107.40	-7.08 (1969)	10.52 (1969)	20.52 (2002)
Rio Grande	Gambusia Well[a]	4.25	1850.75	-0.25 (1984)	4.00 (1984)	6.46 (2016)
Panther Junction	K-Bar #6 Observation Well/ Panther Junction #6 Observation Well	80.54	3417.46	+37.67 (2000)	77.30 (2019)	130.07 (2014)
Panther Junction	K-Bar #7 Observation Well	43.26	3416.74	+30.33 (1984)	42.73 (2019)	90.89 (2007)
Panther Junction	Panther Junction #10[b]	129.86	3757.14	+31.64 (2006)	99.94 (2018)	174.23 (2008)
Panther Junction	T-3/ Well 37	78.39	3538.81	+29.77 (1965)	65.98 (2019)	108.16 (1965)
Panther Junction	TH-10/ I-50	35.13	3430.87	+0.45 (1968)	30.93 (1975)	43.73 (2014)
Chisos Basin	Contractor's Well	41.50	3711.50	0.00 (1971)	31.43 (2019)	44.69 (2015)
Chisos Basin	Oak Springs #1/ TB-5	59.91	4105.09	-26.08 (1989)	33.83 (1989)	61.09 (2017)

[a] Depth to water measurements at Gambusia are feet below the measuring point instead of below ground surface.

[b] Based on the mean water level for the water year

Water levels in Gambusia Well are consistently very shallow. Gambusia Well has demonstrated a less than 2.5-ft range over the monitoring record, with a maximum recorded depth to water of only 6.46 ft bgs. The consistent water level is likely regulated by nearby springs, more than the proximity to the river. Gambusia Well does track the Rio Grande stage; however, the signal is weaker compared to Gallery Well (Figure 3-3). The manual well measurement collected in April WY2019 was 4.25 ft bgs, which is high for the monitoring record, and occurs outside the normal peak period of later summer and early fall.

3.3.2 Panther Junction Wells

Water level elevation in K-Bar #6 Observation Well was within five feet of K-Bar #7 Observation Well for the entire monitoring record due to the two wells being completed in the same aquifer and in close vicinity, 0.45 miles apart (Figures 3-1 and 3-4). Water levels in both wells sharply increased starting in September 2018 and continued until March 2019. Both wells reached their highest recorded water level in February 2019, 77.30 ft bgs for K-Bar #6 Observation Well and 42.73 ft bgs for K-Bar #7 Observation Well. This increase was likely in response to a 3.46-in. rainstorm on 9/2/2018, equivalent to a 10 to 25-year rain event. September, October and December of 2018 were wetter than normal, likely contributing to the steady increase in groundwater. The only other substantial increase in water level occurred May 2014 through December 2015. This period included the largest rain event in the last decade, 3.70 in. on 11/5/2014.

T-3 water level is generally 130 ft higher in elevation than the K-Bar #6 and K-Bar #7 observation wells (Figures 3-1 and 3-4). Over the past decade, groundwater increases and decreases in T-3 have been similar to the K-Bar #6 and #7 observation wells. T-3 also increased in fall 2018 in response to higher-than-normal precipitation. It peaked on 12/31/2018 at 65.98 ft bgs, the highest water level of the monitoring record.

TH-10 is also in the Panther Junction area, but its water level has been very consistent over the past decade and does not appear to be influenced by rain events (Figures 3-1 and 3-4). TH-10 has varied 12.8 ft over the entire monitoring record. The last manual measurement taken in WY2019 was 35.13 ft bgs, 0.45 ft higher than the earliest measurement in 1967, indicating no obvious trend.

Panther Junction #10 is this most variable of the monitoring wells (Figures 3-1 and 3-5). This variability appears to be driven by precipitation, indicating rapid infiltration through the fractured volcanic rock. A nearby fault may also be an infiltration pathway. The increases in water level are temporary as the water likely infiltrates to deeper aquifers. Panther Junction #10 recorded its highest water level, 99.94 ft bgs, in September 2018, in response to the large storm event on 9/2/2018. This peak occurred months earlier than the peaks at the K-Bar # 6 and #7 observation wells. This difference is due to the rapid infiltration at Panther Junction #10 and delayed recharge at K-Bar #6 and #7 observation wells.

3.3.3 Chisos Basin Wells

Contractor’s Well shows a strong relationship with precipitation (Figure 3-5). This indicates that Contractor’s Well may be completed in the Chisos formation, which is highly fractured allowing for rapid infiltration. The response to precipitation is more muted at Contractor’s Well compared to Panther Junction #10, which may be due to differences in hydraulic connectivity in each locality. In November 2018, Contractor’s Well reached its highest recorded water level, 31.43 ft bgs.

Water levels at Oak Springs #1 have varied only 4.16 ft over the past nine years (Figure 3-6). This appears to indicate relatively consistent water levels with no direct response to precipitation. However, the water level has decreased by 26.08 ft since the well was dug in 1989, with most of that decline occurring prior to the start of routine monitoring in water year 2011.

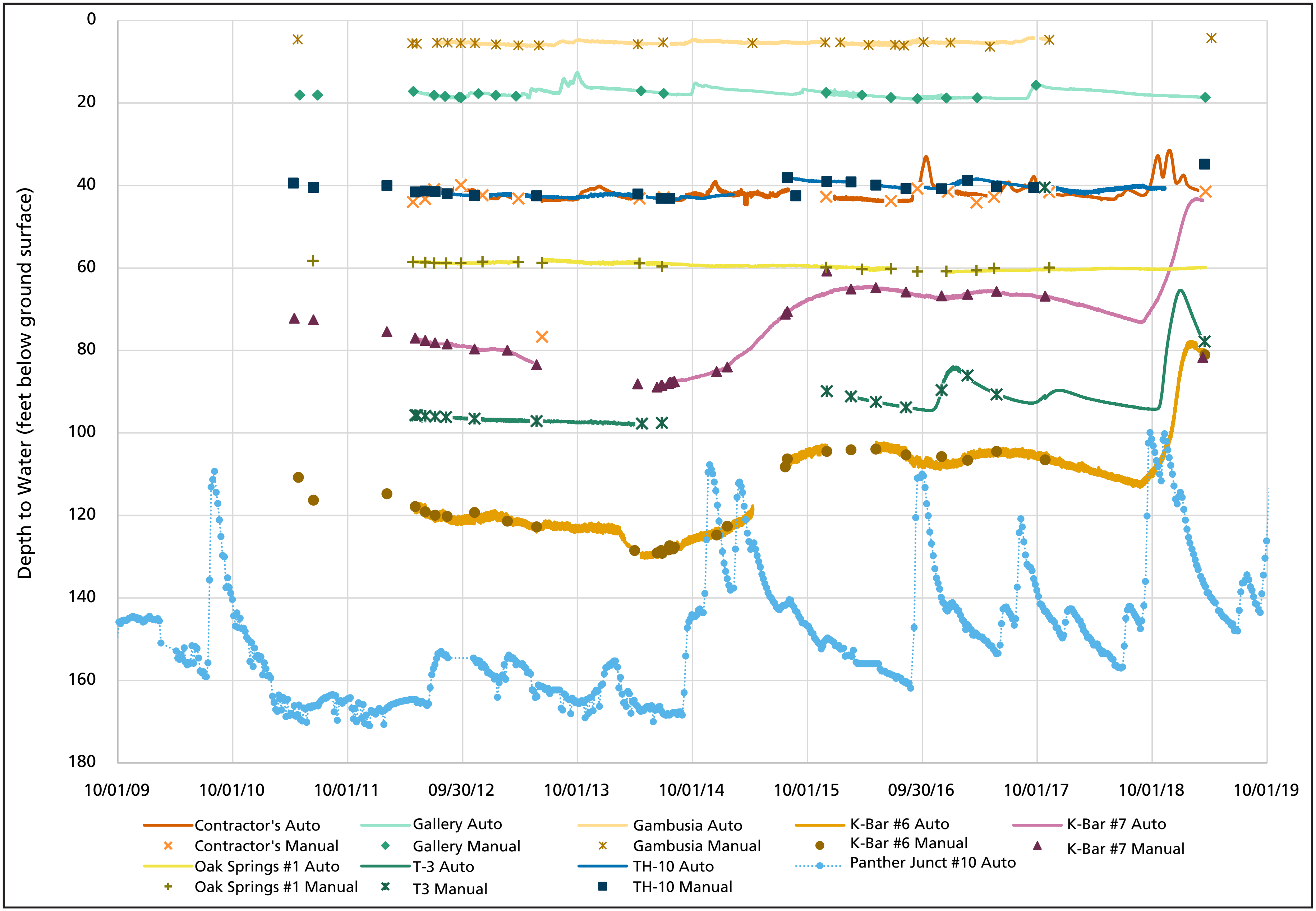

Figure 3-1. Depth to water below ground surface at nine monitoring wells, water years 2010–2019, Big Bend NP. Depth to water measurements at Gambusia are feet below the measuring point instead of below ground surface.

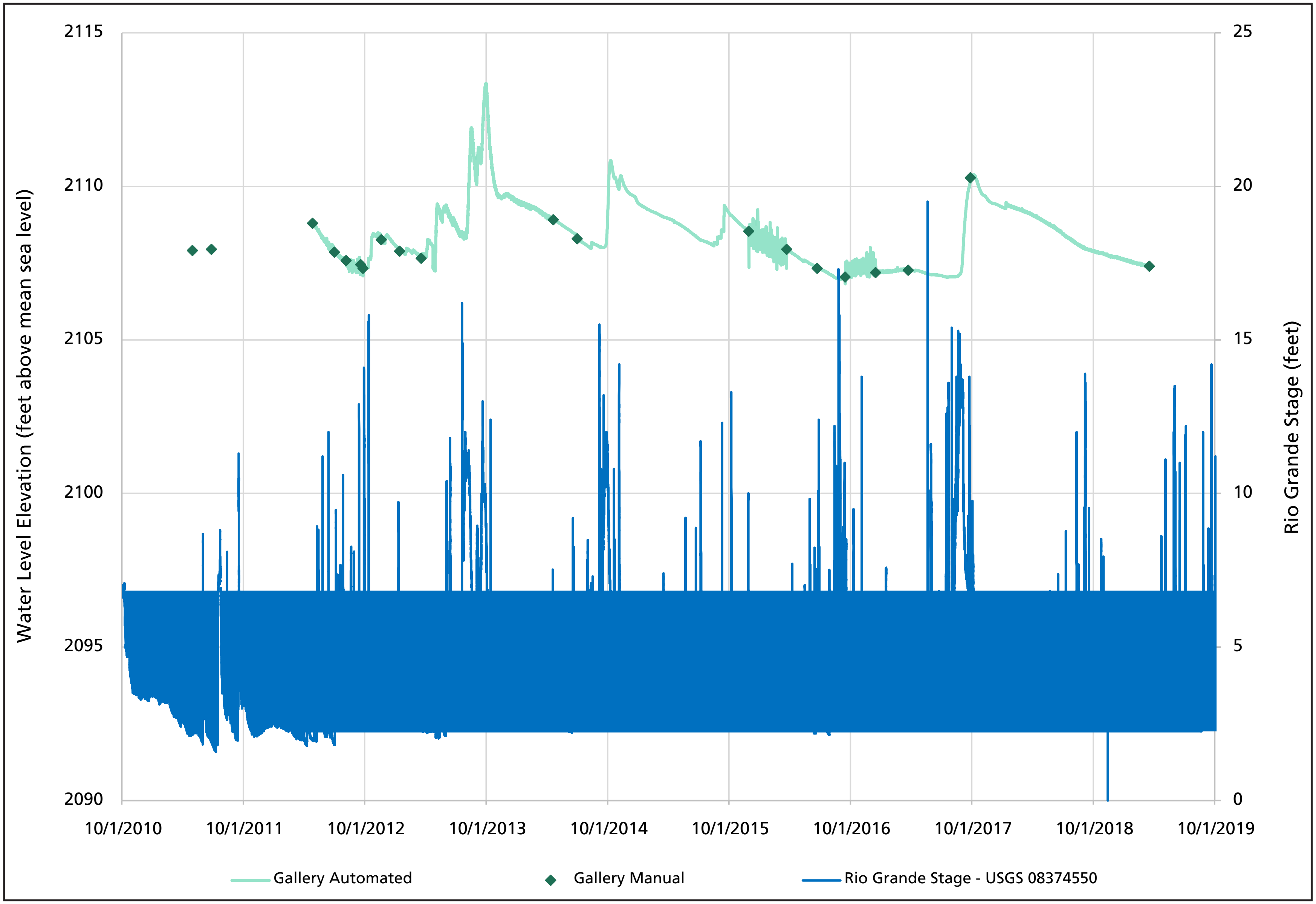

Figure 3-2. Water level elevation at Gallery Well with Rio Grande stage at Castolon, USGS gage 08374550, water years 2011–2019, Big Bend NP.

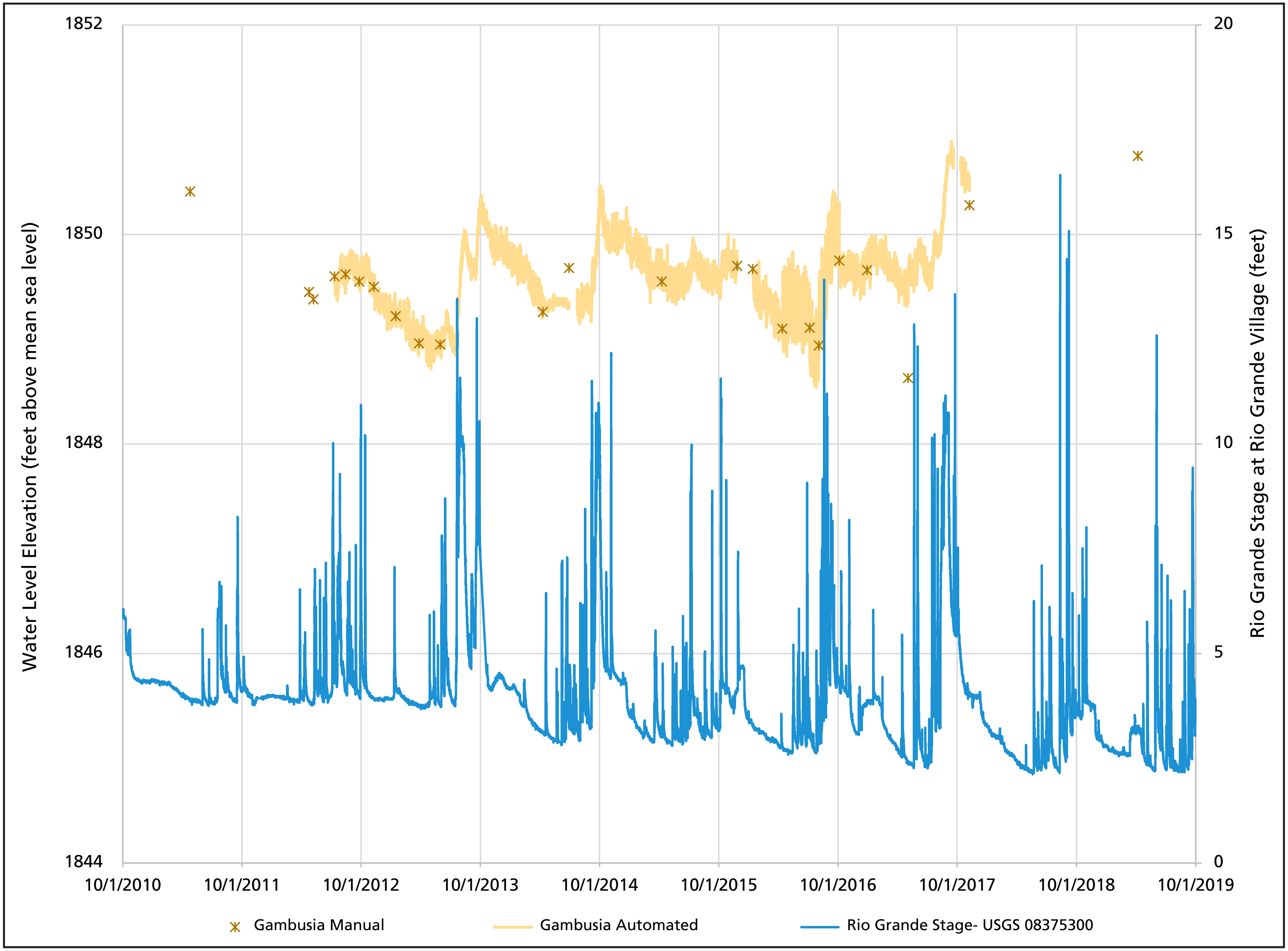

Figure 3-3. Water level elevation at Gambusia Well with Rio Grande stage at Rio Grande Village, USGS gage 08375300, water years 2011–2019, Big Bend NP.

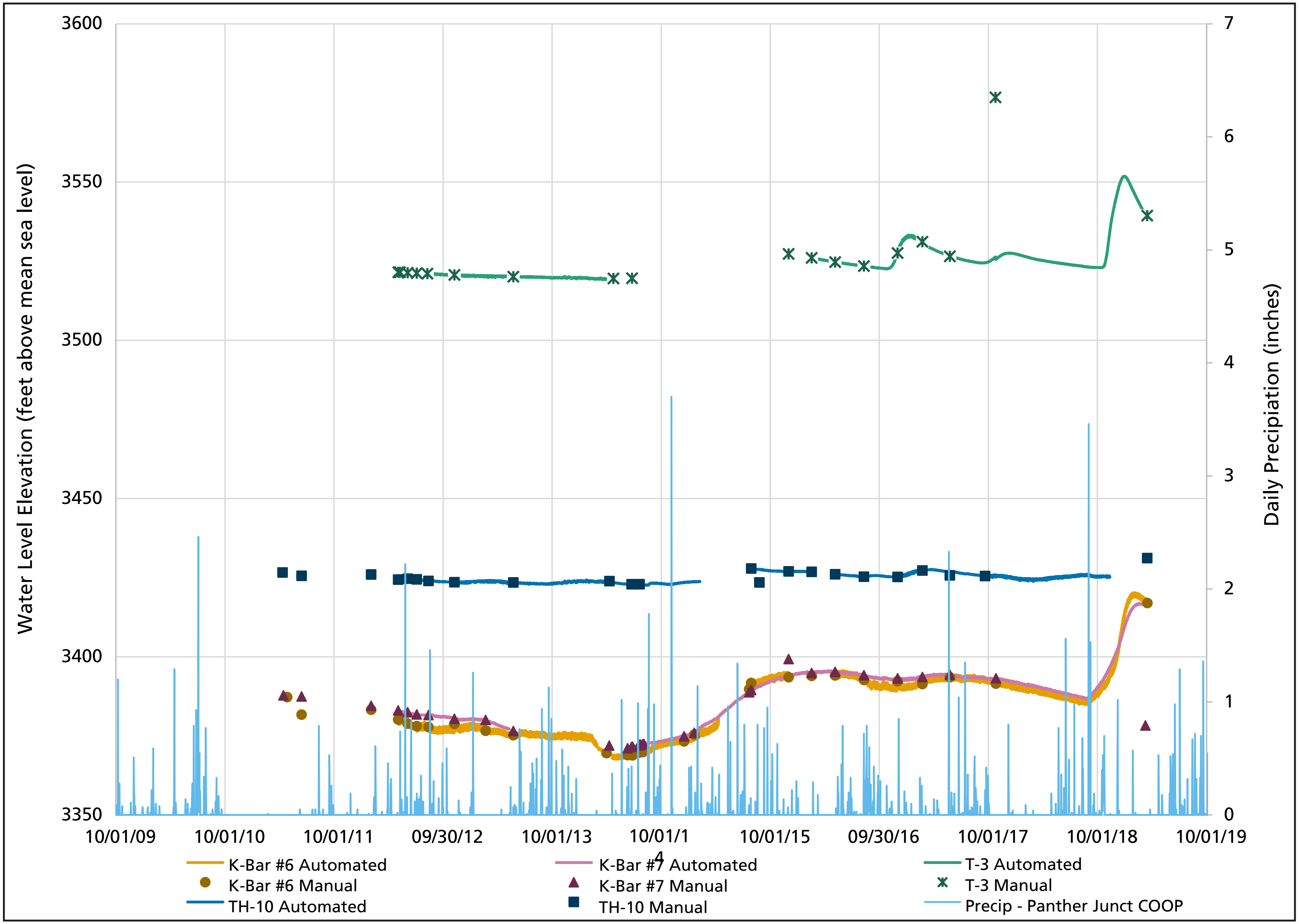

Figure 3-4. Water level elevation at K-Bar #6 Observation Well, K-Bar #7 Observation Well, T-3, and TH-10 with daily precipitation from the Panther Junction COOP station, water years 2011–2019, Big Bend NP.

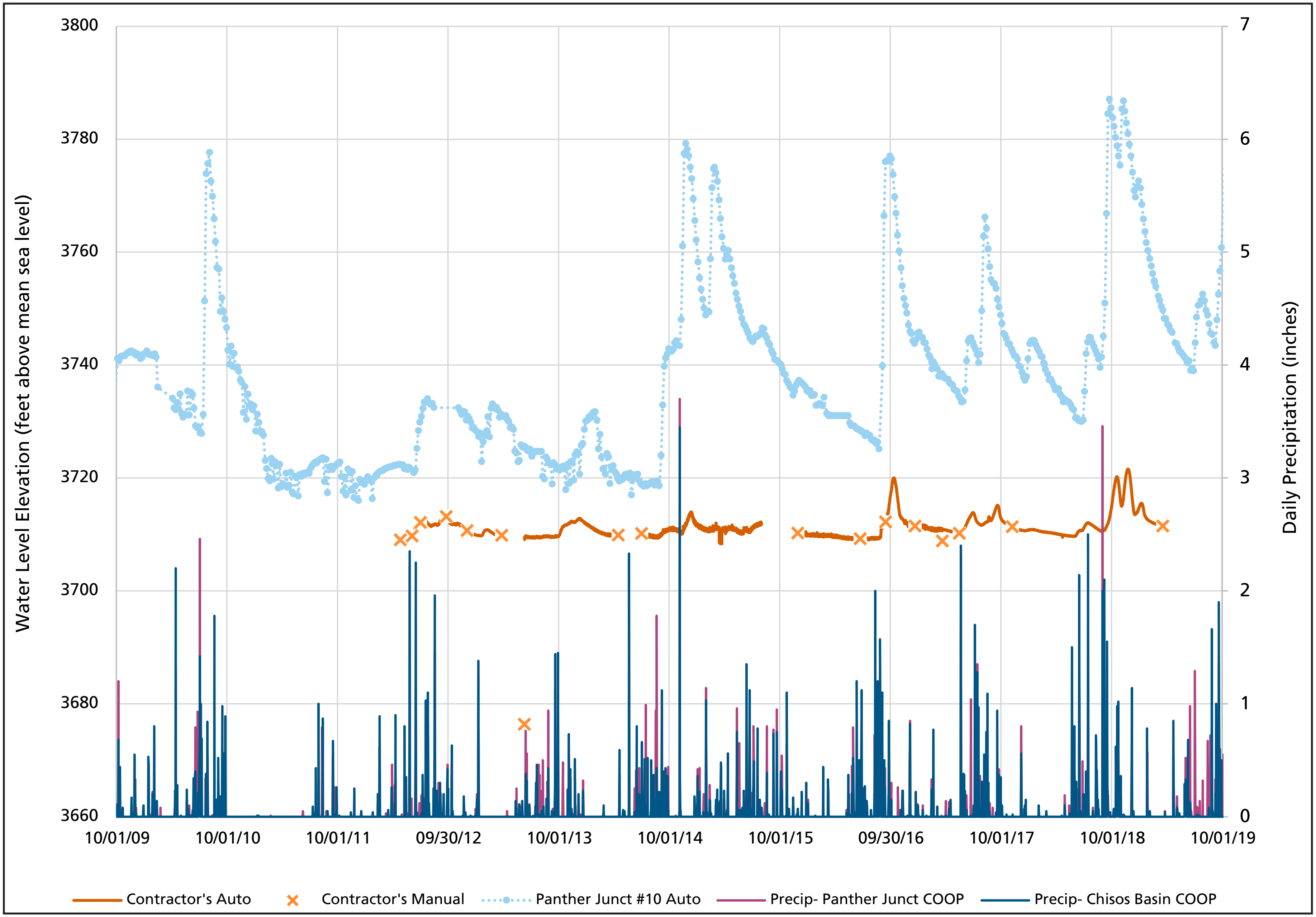

Figure 3-5. Water level elevation at Contractor's Well and Panther Junction #10 with daily precipitation from the Panther Junction and Chisos Basin COOP stations, water years 2011–2019, Big Bend NP.

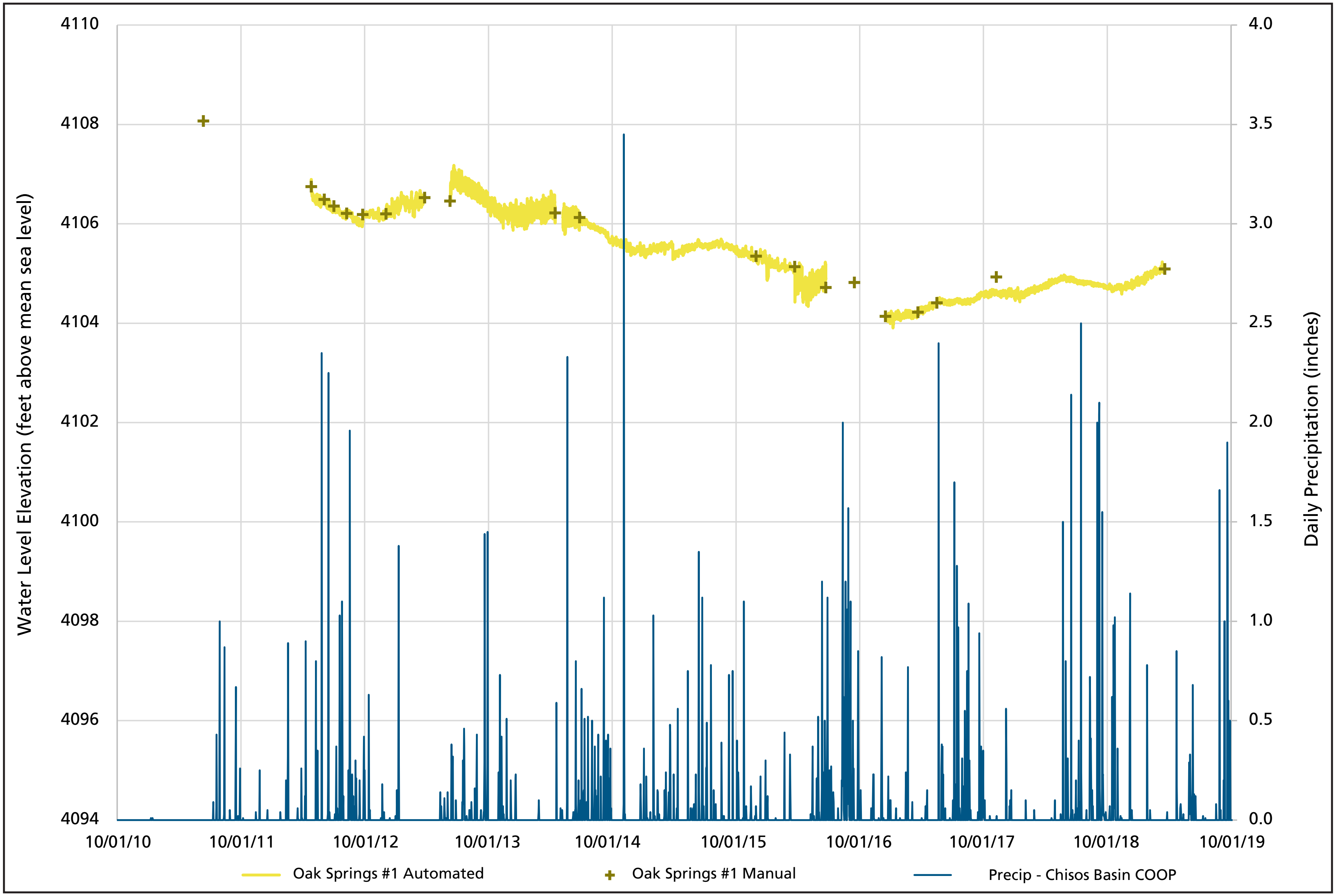

Figure 3-6. Water level elevation at Oak Springs #1 with daily precipitation from the Chisos Basin COOP station, water years 2011-2019, Big Bend NP.

4 Springs

4.1 Background

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

Common stressors to springs biota include reduced water availability (drying), water-temperature extremes (freezing, high temperatures), reduced light penetration (due to turbidity), and biochemical conditions outside the usual *environmental envelope* for a given site (Sada 2013a, b). Climate change is an emerging impact on springs in the American Southwest. Anticipated changes include increased air temperatures, evaporation rates, drought intensity, extreme rainfall and heat events, and potentially reduced precipitation in the winter and spring (Hayhoe et al. 2018). These changes may cause springs to experience reduced flow (Grimm et al. 1997; Weissinger et al. 2016) or even go dry (Comer et al. 2012; Dekker and Hughson 2014), which may disrupt ecological functions and reduce species diversity (Garfin et al. 2013).

4.2 Methods

The Chihuahuan Desert Network monitoring included eighteen *sentinel sites* (sites chosen based on representativeness or other criteria) in WY2019: Bois D'Arc Spring, Cattail Falls, Chilicotal Spring Complex, De La Ho Spring, Government Spring, Grapevine Spring, Lorn Spring, Lower Croton Spring, Mule Ears Spring, Painted Hills Spring, Peña Spring 1, Red Ass Spring, Rough Spring B, Screwbean Spring, Shelf Spring, Solis Spring, Tiptoe Spring, and Water Boy Tinaja. This sample design allows us to detect change and measure trend in selected parameters at a given spring site over time. It does not provide statistical inference across the park (McIntyre et al. 2018).

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. A brief description of the data collection methodologies is presented below. See McIntyre and others (2018) for additional details.

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

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

Spring	Site Condition, Water Quantity, and Water Quality	Site Characterization
Bois D’Arc Spring	24-Feb-2019	WY2018
Cattail Falls	25-Feb-2019	WY2018
Chilicotal Spring Complex	21-Feb-2019	WY2018/2019
De La Ho Spring	07-Mar-2019	WY2018
Government Spring	09-Mar-2019	WY2019
Grapevine Spring	23-Feb-2019	WY2018
Lorn Spring	23-Feb-2019	WY2019
Lower Croton Spring	26-Feb-2019	WY2018
Mule Ears Spring	07-Mar-2019	WY2018
Painted Hills Spring	26-Feb-2019	WY2018
Peña Spring 1	08-Mar-2019	WY2018
Red Ass Spring	24-Feb-2019	WY2018
Rough Spring B	26-Feb-2019	WY2018
Screwbean Spring	22-Feb-2019	WY2018
Shelf Spring	22-Feb-2019	WY2018
Solis Spring	23-Feb-2019	WY2018
Tiptoe Spring	26-Feb-2019	WY2019
Water Boy Tinaja	24-Feb-2019	WY2018

4.2.1 Site Characterization

The site characterization module is a modification of the inventory methods developed for the Mojave Desert Network (Sada and Pohlmann 2006). This module is completed once every five years, or after significant events, and provides context for interpreting change in the other modules. Data collected for this module include spring type and characterization, GPS locations, a site diagram and description, and a vegetation-community description. See McIntyre et al. (2018) for additional details. This module was completed for springs at Big Bend NP from WY2018 to WY2019. Data will be recollected in WY2023. This report presents a

condensed version of the information collected in the site characterization module.

4.2.2 Site Condition

The site condition module is based on inventory methods developed for the Mojave Desert Network (Sada and Pohlmann 2006). It contains four subsections: disturbance, photopoints, obligate/facultative wetland plants, and invasive, non-native plants and wildlife (McIntyre et al. 2018). The disturbance assessment is a categorical measure of 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 (e.g., evidence of campsites, fire rings, or trash). An "other" category is also included for both natural and anthropogenic disturbances. Magnitude of each disturbance on the spring is classified on a scale of 1–4, where 1 = undisturbed, 2 = slightly disturbed, 3 = moderately disturbed, and 4 = highly disturbed (Sada and Pohlmann 2006). Results are reported as mean and median across all categories, with individual values >1 described in the text. Photographs are taken from designated photopoints to show the spring and its landscape context. We note the presence of a suite of obligate or facultative wetland plants during each visit using a picklist that identifies plants to the family, genus, or species level. Presence and density of invasive, non-native plants are recorded, with a goal of identifying them to the species level, and we also record the presence of bullfrogs and crayfish (potentially non-native, invasive wildlife).

4.2.3 Water Quantity

The water quantity module provides information on spring persistence, discharge, and wetted extent. We estimate the persistence of surface water at springs by analyzing the variance of temperature measurements taken by electronic data recorders every one to two hours (Anderson et al. 2015). A sensor placed at or near the orifice (or in the deepest-possible part of a pool) is utilized to estimate presence of water. Because water mediates variation in diurnal temperatures, data from a submerged sensor will show less daily variation than data from an exposed sensor (Anderson et al. 2015). Days are marked as "wet" (water present) when the daily variance is less than 20°C on consecutive days (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. A timed sample of water volume estimates the system's surface discharge. Wetted extent provides information about the length (up to 100 m), width, and depth of water present. It is assessed using a technique for either standing water (e.g., limnocrene and heleocrene springs and some tinajas) or 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 include water temperature, pH, specific conductivity, dissolved oxygen, and total dissolved solids. Discrete samples of these parameters are collected with a multiparameter meter (YSI Professional Plus) and a dissolved oxygen meter (YSI ProODO) deployed on-site. Water chemistry is assessed by collecting surface water samples and estimating the concentration of major ions with a photometer (YSI 9500) in the field.

4.3 Bois D'Arc Spring

The WY2019 visit to Bois D'Arc occurred on February 24, 2019. The site characterization module was most recently collected in WY2018.

4.3.1 Site Characterization

Bois D'Arc Spring (Figure 4-1) is a rheochrene spring (a spring that emerges as a flowing stream). In 2018, Orifice A emerged in a canyon as a small algae-filled pool which quickly disappeared under a gravel bar. Downstream, a monkeyflower-laden (*Mimulus* sp.) channel reemerged with nearly imperceptible flow and minimal surface water. The channel continued as intermittent pooled emergences, damp gravel and bedrock areas, and dried sections filled in with sand and vegetation such as whitebrush (*Aloysia gratissima*). In 2019, the crew found an additional pool about 40 m upstream of Orifice A. This new pool was designated Orifice B.

4.3.2 Site Condition

The mean and median values for anthropengenic and natural disturbances were 1.0 (undisturbed).

Figure 4-1. Bois D'Arc Spring, Orifice A (sampling location 1), Big Bend NP, February 2019.

The crew observed one obligate/facultative wetland plant family and two genera: rush family (Juncaceae), monkeyflower (*Mimulus* sp.), and mule-fat (*Baccharis salicifolia*). The invasive Lehmann lovegrass (*Eragrostis lehmanniana*) was noted in scattered patches. No bullfrogs or crayfish were observed.

4.3.3 Water Quantity

Temperature sensors indicated the spring was wetted for the majority of WY2019 (Figure 4-2), with dry periods in late spring/early summer. During the WY2019 visit, discharge from Orifice B was estimated at 7.8 ± 0.3 L/min (2.1 ± 0.1 gal/min). Channel length was not measured but was estimated to be 100–200 m (328.1–656.2 ft). Wetted extent of Bois D'Arc Spring was surveyed with the flowing water method and width and depth within the first 100 m averaged 110.5 cm (43.5 in.) and 2.0 cm (0.8 in.), respectively.

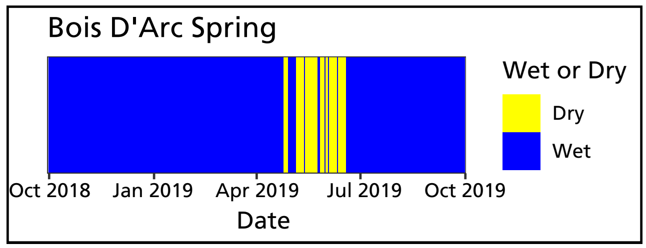

Figure 4-2. Estimated wet/dry days at Bois D'Arc Spring, Big Bend NP, WY2019.

4.3.4 Water Quality

In WY2019, core water quality (Table 4-2) and water chemistry (Table 4-3) were measured at the pool of Orifice A (sampling location 1) and a small pool (Orifice B, sampling location 4) approximately 40 m (~131 ft) upstream of Orifice A.

Table 4-2. Water quality data for Bois D'Arc Spring, Big Bend NP, WY2019.

Sampling Location	Orifice(s)	Sample Time	Temperature (°C)	Dissolved Oxygen (mg/L)	pH	Specific Conductivity (µS/cm)	Total Dissolved Solids (mg/L)	Exposure
1	A	10:45	15.6	18.17	8.52	413.1	268.5	Sun
4	B	11:02	16.7	16.70	8.84	489.7	318.5	Sun

Table 4-3. Water chemistry data for Bois D'Arc Spring, Big Bend NP, WY2019.

Sampling Location	Orifice(s)	Alkalinity (mg/L)	Calcium (mg/L)	Chloride (mg/L)	Magnesium (mg/L)	Potassium (mg/L)	Sulfate (mg/L)
1	A	155	42	12	6	0.0	29
4	B	280	56	0	7	1.4	0

Figure 4-3. Cattail Falls, Orifice A (sampling location 1), Big Bend NP, February 2019.

4.4 Cattail Falls

The WY2019 visit to Cattail Falls occurred on February 25, 2019. The site characterization module was most recently collected in WY2018.

4.4.1 Site Characterization

Cattail Falls (Figure 4-3) is a rheochrene spring (a spring that emerges as a flowing stream). In 2018, it began above a large pour off (Orifice A) followed by a series of plunge pools, which gradually trickled into a graveled and vegetated area. This dispersed flow, mostly subsurface, fed a series of long, channelized pools. Orifice B fed the second half of this system. It emerged as a hanging garden and collected into a series of pools separated by large boulders. Water from both orifices was cool and clear, with algal growth in the more stagnant pools. The dominant substrate ranged from gravel to cobble dispersed among large boulders and bedrock.

4.4.2 Site Condition

The mean anthropogenic disturbance value was 1.78 (slightly disturbed) and the mean natural disturbance value was 1.3 (undisturbed). Median values for both disturbance categories were 1.0 (undisturbed). The spring is heavily used by visitors; social trails and polished rock surfaces were noted throughout the area. Recent flooding caused the sensor cable to twist and deposited gravel into the pour-off pool.

We observed two obligate/facultative wetland plant families and three genera: rush family (Juncaceae), cattail family (Typhaceae), bluestem (*Andropogon* sp.), maidenhair fern (*Adiantum* sp.), and mule-fat (*Baccharis salicifolia*). No invasive plants, bullfrogs, or crayfish were observed.

4.4.3 Water Quantity

Temperature sensors indicated that the spring was wetted for the entirety of 2019 (Figure 4-4). Discharge was estimated at 61.0 ± 1.7 L/min. The wetted extent of Cattail Falls was surveyed as a flowing spring with a channel length of 98.1 m (321.9 ft). Width and depth averaged 352.6 cm (138.8 in.) and 16.3 cm (6.4 in.), respectively.

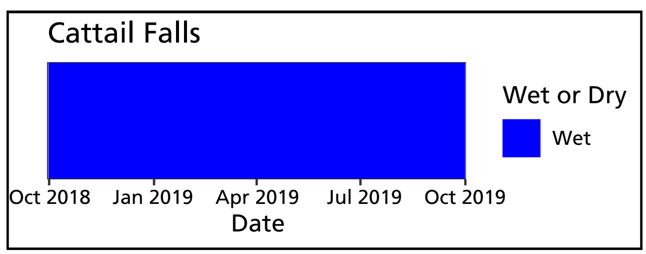

Figure 4-4. Estimated wet/dry days at Cattail Falls, Big Bend NP, WY2019.

4.4.4 Water Quality

In 2019, core water quality (Table 4-4) and water chemistry (Table 4-5) were measured at a pool directly below a pour-off (Orifice A, sampling location 1) and a small pool at the base of a hanging garden (Orifice B, sampling location 2).

Table 4-4. Water quality data for Cattail Falls, Big Bend NP, WY2019.

Sampling Location	Orifice(s)	Sample Time	Temperature (°C)	Dissolved Oxygen (mg/L)	pH	Specific Conductivity (µS/cm)	Total Dissolved Solids (mg/L)	Exposure
1	A	08:04	9.7	8.49	7.80	318.4	206.7	Shade
2	B	08:13	19.4	3.19	7.28	526.6	342.6	Shade

Table 4-5. Water chemistry data for Cattail Falls, Big Bend NP, WY2019.

Sampling Location	Orifice(s)	Alkalinity (mg/L)	Calcium (mg/L)	Chloride (mg/L)	Magnesium (mg/L)	Potassium (mg/L)	Sulfate (mg/L)
1	A	65	34	27	9	1.9	75
2	B	195	66	not detected	not detected	1.5	110

4.5 Chilicotal Spring Complex

The WY2019 visit to Chilicotal Spring Complex occurred on February 21, 2019. The site characterization module was most recently collected in WY2018/2019.

4.5.1 Site Characterization

Chilicotal Spring Complex (Figure 4-5) is a rheochrene spring (a spring that emerges as a flowing stream). It likely originated near the large, lone cottonwood, flowing in an intermittently wet and unmeasurable channel. Orifice A emerged as cool, clear water under a dense sumac (*Rhus* sp.) community. The brook was covered with leaf litter and twigs and trickled into a wider marsh interlaced with sedge (*Carex* sp.) and in 2018, flatsedge (*Cyperus* sp.). After the marsh an almost heleocrene system emerged with sporadic cattail (*Typha* sp.) and a large willow (*Salix* sp.) growing in a pool lined with downed litter. The pool constricted to a channel where downed willow (*Salix* sp.) and Baccharis (*Baccharis* sp.) created a seeping earthen dam.

4.5.2 Site Condition

The mean anthropogenic disturbance value was 1.0 (undisturbed) and the mean natural disturbance value was 1.3 (undisturbed). Median values for both disturbance categories were 1.0 (undisturbed). Salt crusts downstream of the orifice indicated drying. The crew also noted slight windthrow disturbance.

Figure 4-5. Chilicotal Spring Complex, Orifice A (sampling location 1), Big Bend NP, February 2019.

The crew observed two obligate/facultative wetland plant families and four genera: rush family (Juncaceae), cattail family (Typhaceae), cottonwood (*Populus* sp.), mule-fat (*Baccharis salicifolia*), tamarisk (*Tamarix* sp.), and willow (*Salix* sp.). The crew also observed two invasive plants: Bermudagrass (*Cynodon dactylon*) in evenly distributed patches and five-stamen tamarisk (*Tamarix chinensis*) in scattered patches. No bullfrogs or crayfish were observed.

4.5.3 Water Quantity

Temperature sensors indicated that the spring was wetted for the first half of the sample period and sporadically throughout the second half (Figure 4-6). However, the crew did not note drying upon collection of the sensor in February 2020. Discharge was estimated at 11.1 ± 0.2 L/min. Chilicotal Spring Complex was surveyed as a flowing spring with a channel length of 24.9 m (81.7 ft). Width and depth averaged 524.4 cm (206.5 in.) and 21.4 cm (8.4 in.), respectively.

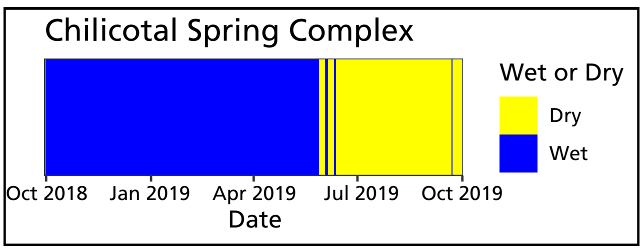

Figure 4-6. Estimated wet/dry days at Chilicotal Spring Complex, Big Bend NP, WY2019.

4.5.4 Water Quality

In 2019, core water quality (Table 4-6) and water chemistry (Table 4-7) were measured at the large, shallow Orifice A pool (sampling location 1).

4.6 De La Ho Spring

The WY2019 visit to De La Ho Spring occurred on March 7, 2019. The site characterization module was most recently collected in WY2018.

4.6.1 Site Characterization

De La Ho Spring (Figure 4-7) emerged as a historically manufactured limnocrene spring (emerges as a pool) within a large, braided ephemeral wash. The orifice was situated on the upstream end of a densely vegetated pool of stagnant water. The pool was surrounded by significant amounts of woody debris with a perimeter thicket of mesquite (*Prosopis* sp.), desert-thorn (*Lycium* sp.), and acacia (*Acacia*, *Vachellia*, or *Senegalia* sp.). There was one outlet at a large willow (*Salix* sp.) that created a short channel with no discernable flow. The water was cool and clear; however, the upstream end of the pool had a soft silty substrate that was easily disturbed. The rest of the pool had a mixed substrate of silt, sand, and leaves.

4.6.2 Site Condition

The mean anthropogenic disturbance value was 1.3 (undisturbed) and the mean natural disturbance value was 1.4 (undisturbed). Median values for both disturbance categories were 1.0 (undisturbed). There was evidence of wildlife use and an animal carcass was found on the bank. Many trees had fallen over the site, though not recently, indicating high windthrow disturbance.

The crew observed one obligate/facultative wetland plant family and two genera: rush family (Juncaceae), mule-fat (*Baccharis salicifolia*), and willow (*Salix* sp.). Invasive common sowthistle (*Sonchus oleraceus*) was

Table 4-6. Water quality data for Chilicotal Spring Complex, Big Bend NP, WY2019.

Sampling Location	Orifice(s)	Sample Time	Temperature (°C)	Dissolved Oxygen (mg/L)	pH	Specific Conductivity (µS/cm)	Total Dissolved Solids (mg/L)	Exposure
1	A	09:12	15.0	7.08	7.66	343.5	223.0	Shade

Table 4-7. Water chemistry data for Chilicotal Spring Complex, Big Bend NP, WY2019.

Sampling Location	Orifice(s)	Alkalinity (mg/L)	Calcium (mg/L)	Chloride (mg/L)	Magnesium (mg/L)	Potassium (mg/L)	Sulfate (mg/L)
1	A	140	26	18	9	0.2	4

Figure 4-7. De La Ho Spring, Orifice A (sampling location 1), Big Bend NP, March 2019.

noted in the first density class, 1–5 individuals, and tree tobacco (*Nicotiana glauca*) was noted in scattered patches. No bullfrogs or crayfish were observed.

4.6.3 Water Quantity

Temperature sensors indicated that the spring was wetted for the entirety of the sampled period (Figure 4-8). Discharge could not be measured. De La Ho Spring was surveyed as a non-flowing spring with an average length, width, and depth of 751.3 cm (295.8 in.), 421.3 cm (165.9 in.), and 14.7 cm (5.8 in.), respectively.

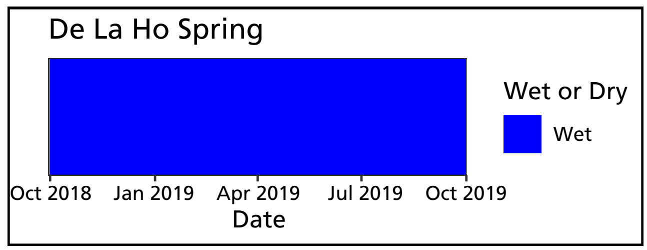

Figure 4-8. Estimated wet/dry days at De La Ho Spring, Big Bend NP, WY2019.

4.6.4 Water Quality

In 2019, core water quality (Table 4-8) and water chemistry (Table 4-9) were measured at the deepest part of the pool that could be reached from the edge (Orifice A, sampling location 1).

Table 4-8. Water quality data for De La Ho Spring, Big Bend NP, WY2019.

Sampling Location	Orifice(s)	Sample Time	Temperature (°C)	Dissolved Oxygen (mg/L)	pH	Specific Conductivity (µS/cm)	Total Dissolved Solids (mg/L)	Exposure
1	A	13:29	21.5	16.69	8.89	582.0	377.0	Partial

Table 4-9. Water chemistry data for De La Ho Spring, Big Bend NP, WY2019.

Sampling Location	Orifice(s)	Alkalinity (mg/L)	Calcium (mg/L)	Chloride (mg/L)	Magnesium (mg/L)	Potassium (mg/L)	Sulfate (mg/L)
1	A	185	22	9	1	3.8	77

Figure 4-9. Government Spring springbox (sampling location 1), Big Bend NP, March 2019.

4.7 Government Spring

The WY2019 visit to Government Spring occurred on March 9, 2019. The site characterization module was most recently collected in WY2019.

4.7.1Site Characterization

Government Spring (Figure 4-9) is a springbox that drains into a limnocrene pool. The water was warm and clear with no discharge from the springbox outflow piping. Downstream, a small pool contained cool and clear water with significant detritus over silt and gravel. There was no visible connection between the springbox and the pool.

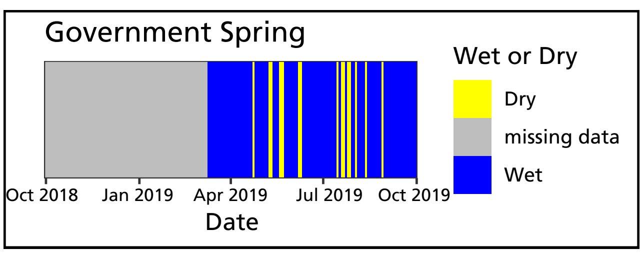

Figure 4-10. Estimated wet/dry days at Government Spring, Big Bend NP, WY2019.

4.7.2 Site Condition

The mean anthropogenic disturbance value was 2.0 (slightly disturbed) and the mean natural disturbance value was 1.1 (undisturbed). Median values for both disturbance categories were 1.0 (undisturbed). A well-used trail leads directly to the site. Vegetation had been recently planted and trimmed. A pipe, wall, and trough were noted downstream of the pool and springbox. Wildlife use was masked by the high amount of human disturbance, but scat and tracks were noted in some areas.

The crew observed two obligate/facultative wetland plant genera: mule-fat (*Baccharis salicifolia*) and cottonwood (*Populus* sp.). Three invasive species were detected: 1–5 individual common sowthistle (*Sonchus oleraceus*) and scattered patches of Bermudagrass (*Cynodon dactylon*) and horehound (*Marrubium vulgare*). No crayfish or bullfrogs were observed.

4.7.3 Water Quantity

Temperature sensors indicated that the spring was wetted for the majority of the sampled period (Figure 4-10). The spring was not visited to deploy the temperature sensor in 2018; there are no data from October 2018 to March 2019. Discharge could not be measured at this site. The pool at Government Spring was surveyed as a non-flowing spring with an average length, width, and depth of 652.3 cm (256.8 in.), 401.3 cm (158.0 in.), and 11.0 cm (4.3 in.), respectively.

4.7.4 Water Quality

In 2019, core water quality (Table 4-10) and water chemistry (Table 4-11) were measured inside of the springbox (Orifice A, sampling location 1) and on the northwest edge of the pool (Orifice B, sampling location 2). Three measurements were taken within springboxes.

Table 4-10. Water quality data for Government Spring, Big Bend NP, WY2019.

Sampling Location	Orifice(s)	Sample Time	Temperature (°C)	Dissolved Oxygen (mg/L)	pH	Specific Conductivity (µS/cm)	Total Dissolved Solids (mg/L)	Exposure
1	A	07:49	19.1	2.51	7.68	229.9	149.5	Shade
1	A	07:50	19.1	2.20	7.52	230.4	149.5	Shade
1	A	07:50	19.2	2.28	7.40	230.5	149.5	Shade
2	B	08:34	12.1	1.64	7.05	370.4	240.5	Partial

Table 4-11. Water chemistry data for Government Spring, Big Bend NP, WY2019.

Sampling Location	Orifice(s)	Alkalinity (mg/L)	Calcium (mg/L)	Chloride (mg/L)	Magnesium (mg/L)	Potassium (mg/L)	Sulfate (mg/L)
1	A	100	24	8	10	1.2	8
2	B	175	32	not detected	9	0.0	not detected

4.8 Grapevine Spring

The WY2019 visit to Grapevine Spring occurred on February 23, 2019. The site characterization module was most recently collected in WY2018.

4.8.1 Site Characterization

Grapevine Spring (Figure 4-11) is a rheochrene spring (a spring that emerges as a flowing stream). Orifice A was a clear, deep pool originating in a steep undercut centered in a wash. The pool flowed into a narrow, braided main channel carpeted with spikerush (*Eleocharis* sp.) and baccharis (*Baccharis* sp.) The cool and clear flow meandered down the wash over a silt and clay substrate. Downstream, Orifice B was a small, pooled upwelling, which flowed into a narrow channel separate from the Orifice A flow. Vegetation differed strongly from the upland vegetation on the banks and surrounding uplands.

4.8.2 Site Condition

The mean anthropogenic disturbance value was 1.0 (undisturbed) and the mean natural disturbance value was 1.4 (undisturbed). Median values for both disturbance categories were 1.0 (undisturbed). The crew noted slight natural disturbance from recent flooding, wildlife use, and windthrow.

Figure 4-11. Grapevine Spring, Orifice A (sampling location 1), Big Bend NP, February 2019.

The crew observed one obligate/facultative wetland plant family and five genera: cattail family (Typhaceae), bluestem (*Andropogon* sp.), maidenhair fern (*Adiantum* sp.), mule-fat (*Baccharis salicifolia*), spikerush (*Eleocharis* sp.), and willow (*Salix* sp.). No invasive plants, bullfrogs, or crayfish were observed.

4.8.3 Water Quantity

Temperature sensors were retrieved and deployed during this survey. Sensors indicated that the spring was wetted for the entirety of the sampled period (Figure 4-12). Discharge was estimated at 3.2 ± 0.1 L/min. Grapevine Spring was surveyed as a flowing spring with a channel length of 47.0 m (154.2 ft). Width and depth averaged 54.4 cm (21.4 in.) and 2.4 cm (0.9 in.), respectively.

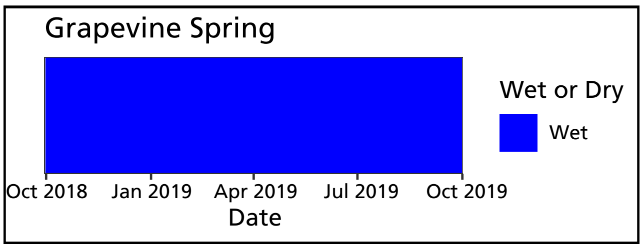

Figure 4-12. Estimated wet/dry days at Grapevine Spring, Big Bend NP, WY2019.

4.8.4 Water Quality

In 2019, core water quality (Table 4-12) and water chemistry (Table 4-13) were measured at two locations. The first water quality sample was measured at 25, 50, and 75% of the width of the large, shallow area approximately 2 m downstream of Orifice A (sampling location 1). This location was the first upstream location that was safe to sample. One water chemistry sample was obtained from the center of the pool. The second sampling location was in the middle of the orifice B pool (sampling location 2).

4.9 Lorn Spring

The WY2019 visit to Lorn Spring occurred on February 23, 2019. The site characterization module was most recently collected in WY2019.

4.9.1 Site Characterization

Lorn Spring (Figure 4-13) is a hanging garden. Orifice A emerged from a cliff as a moist maidenhair fern (*Adiantum* sp.) covered area. Water from here slowly dripped to collect in a small, silty pool. Orifice B emerged to the west, separated from Orifice A by a dry gap. Travertine deposits indicated this may have been previously wetted. Orifice B was wider with visibly dripping flow collecting into another silty pool. Water from both orifices was cool and clear. Macroinvertebrates were present in both pools, though pool A had a considerable amount more.

4.9.2 Site Condition

The mean anthropogenic disturbance value was 1.0 (undisturbed) and the mean natural disturbance value was 1.3 (undisturbed). Median values for both disturbance categories were 1.0. The crew noted slight disturbance due to recent flooding and wildlife.

Table 4-12. Water quality data for Grapevine Spring, Big Bend NP, WY2019.

Sampling Location	Orifice(s)	Sample Time	Temperature (°C)	Dissolved Oxygen (mg/L)	pH	Specific Conductivity (µS/cm)	Total Dissolved Solids (mg/L)	Exposure
1	A	07:59	16.4	3.82	7.47	604.0	390.0	Partial
1	A	08:01	16.2	4.92	7.44	602.0	390.0	Partial
1	A	08:02	16.5	3.64	7.36	610.0	396.5	Partial
2	B	08:06	14.5	2.32	7.36	599.1	389.4	Partial

Table 4-13. Water chemistry data for Grapevine Spring, Big Bend NP, WY2019.

Sampling Location	Orifice(s)	Alkalinity (mg/L)	Calcium (mg/L)	Chloride (mg/L)	Magnesium (mg/L)	Potassium (mg/L)	Sulfate (mg/L)
1	A	245	74	48	7	0.8	40
2	B	230	74	31	not detected	0.1	38

Figure 4-13. Lorn Spring, sampling location 1 (a pool below Orifice A), Big Bend NP, February 2019.

The crew observed two obligate/facultative wetland plant genera: maidenhair fern (*Adiantum* sp.) and mule-fat (*Baccharis salicifolia*). Invasive Lehmann lovegrass (*Eragrostis lehmanniana*) was observed in scattered patches. No bullfrogs or crayfish were observed.

4.9.3 Water Quantity

Temperature sensors were lost. Therefore, there is no information on persistence. Discharge from Orifice B was estimated at 0.6 ± 0.01 L/min. Lorn Spring was surveyed as a non-flowing spring. Orifice A averaged 122.0 cm (48.0 in.), 62.3 cm (24.5 in.), and 9.0 cm (3.5 in.) in length, width and depth, respectively. Orifice B had an average length, width, and depth of 196.3 cm (77.3 in.), 79.7 cm (31.4 in.), and 7.7 cm (3.0 in.), respectively.

4.9.4 Water Quality

In 2019, core water quality (Table 4-14) and water chemistry (Table 4-15) were measured in the center of the southeast pool below the Orifice A hanging garden (sampling location 1) and in the deepest part of the pool under Orifice B where water drips from vegetation (sampling location 2).

Table 4-14. Water quality data for Lorn Spring, Big Bend NP, WY2019.

Sampling Location	Orifice(s)	Sample Time	Temperature (°C)	Dissolved Oxygen (mg/L)	pH	Specific Conductivity (µS/cm)	Total Dissolved Solids (mg/L)	Exposure
1	A	11:58	10.2	9.48	8.11	1797.0	1170.0	Shade
2	B	11:57	11.6	9.57	8.36	1797.0	1170.0	Shade

Table 4-15. Water chemistry data for Lorn Spring, Big Bend NP, WY2019.

Sampling Location	Orifice(s)	Alkalinity (mg/L)	Calcium (mg/L)	Chloride (mg/L)	Magnesium (mg/L)	Potassium (mg/L)	Sulfate (mg/L)
1	A	155	115	60	22	1.7	60
2	B	255	28	92	23	2.8	65

Figure 4-14. Lower Croton Spring, sampling location 1 (along the edge of the heleocrene pool), Big Bend NP, February 2019.

4.10 Lower Croton Spring

The WY2019 visit to Lower Croton Spring occurred on February 26, 2019. The site characterization module was most recently collected in WY2018.

4.10.1 Site Characterization

Lower Croton Spring (Figure 4-14)is a heleocrene system (emerges in a diffuse fashion). The main pool was large and surrounded by a ring of salt precipitate. It contained a dense stand of cattails (*Typha* sp.) and drained into a narrow downslope channel, which slowly flowed towards a second wetted pool. The water was mostly clear, though an oily film was on top of some of the pools between the cattails.

4.10.2 Site Condition

The mean anthropogenic disturbance value was 2.1 (slightly disturbed) and the mean natural disturbance value was 1.3 (undisturbed). Median values for both disturbance categories were 1.0 (undisturbed). A well-used hiking trail and cairns lead directly to the site, causing moderate disturbance. Historical disturbance was assessed as severe. Many wildlife tracks were observed.

The crew observed two obligate/facultative wetland plant families, two genera, and one species: cattail family (Typhaceae), rush family (Juncaceae), mule-fat (*Baccharis salicifolia*), rabbitsfoot grass (*Polypogon* sp.) and sedge (*Carex* sp.). Three invasive species were detected: scattered patches of annual rabbitsfoot grass (*Polypogon monspeliensis*) and common sowthistle (*Sonchus oleraceus*) and evenly distributed patches of bermudagrass (*Cynodon dactylon*). No crayfish or bullfrogs were observed.

4.10.3 Water Quantity

Sensors indicated that the spring was wetted for most of the sampled period (Figure 4-15). The sensor deployed in WY2018 was found outside of the water during the sampling event of March 2019, causing an overestimation of dry days early in WY2019. Discharge could not be measured at this site. Lower Croton Spring was surveyed as a non-flowing spring with an average length, width, and depth of 1835.7 cm (722.7 in.), 1347.0 cm (530.3 in.) and 6.7 cm (2.6 in.), respectively.

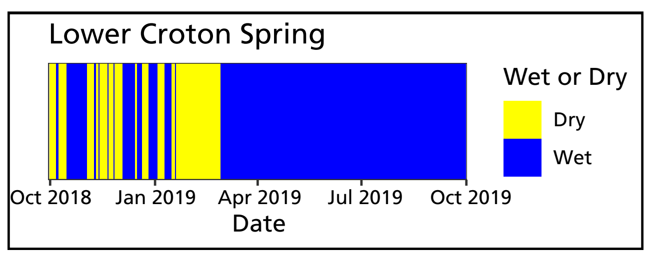

Figure 4-15. Estimated wet/dry days at Lower Croton Spring, Big Bend NP, WY2019.

4.10.4 Water Quality

In 2019, core water quality (Table 4-16) and water chemistry (Table 4-17) were measured in the murky pool on the edge of the heleocrene system (sampling location 1).

Table 4-16. Water quality data for Lower Croton Spring, Big Bend NP, WY2019.

Sampling Location	Orifice(s)	Sample Time	Temperature (°C)	Dissolved Oxygen (mg/L)	pH	Specific Conductivity (µS/cm)	Total Dissolved Solids (mg/L)	Exposure
1	A	13:40	17.4	0.36	7.28	1861.0	1209.0	Shade

Table 4-17. Water chemistry data for Lower Croton Spring, Big Bend NP, WY2019.

Sampling Location	Orifice(s)	Alkalinity (mg/L)	Calcium (mg/L)	Chloride (mg/L)	Magnesium (mg/L)	Potassium (mg/L)	Sulfate (mg/L)
1	A	500	36	57	32	2.4	390

4.11 Mule Ears Spring

The WY2019 visit to Mule Ears Spring occurred on March 7, 2019. The site characterization module was most recently collected in WY2018.

4.11.1 Site Characterization

Mule Ears Spring (Figure 4-16) is a hanging garden that feeds into a large pool and continues as a rheochrene system (a spring that emerges as a flowing stream). Orifice A water collected in a pool among boulders at the base of a travertine slide. It continued flowing into a channel joined by additional water seeps from the wall. Orifice B emerged from under maidenhair fern (*Adiantum* sp.) and filled a pool occupied with cattail (*Typha* sp.) before joining the main channel. The warm, clear water then flowed intermittently underground for the remainder of the brook length. The dominant substrate was a sand and gravel mix and travertine near the orifices.

4.11.2 Site Condition

The mean anthropogenic disturbance value was 1.4 (slightly disturbed) and the mean natural disturbance value was 1.1 (undisturbed). Median values for both disturbance categories were 1.0 (undisturbed). Mule Ears trail is a high-traffic trail, which leads to the bottom half of the springbrook. There were various social trails and rock wear. Possible javelina tunnels were noted, though impossible to distinguish from wildlife use.

The crew observed two obligate/facultative wetland plant families and four genera: cattail family (Typhaceae), rush family (Juncaceae), bluestem (*Andropogon* sp.), maidenhair fern (*Adiantum* sp.), mule-fat (*Baccharis salicifolia*) and spikerush (*Eleocharis* sp.). Scattered patches of invasive bermudagrass (*Cynodon dactylon*) and common sowthistle (*Sonchus oleraceus*) were noted. No bullfrogs or crayfish were observed.

Figure 4-16. Mule Ears Spring, Orifice A (sampling location 1), Big Bend NP, March 2019.

4.11.3 Water Quantity

Temperature sensors were retrieved and deployed during this survey. Sensors indicated that the spring was wetted for the entirety of the sampled period (Figure 4-17). Discharge from Orifice A was estimated at 13.7 ± 0.4 L/min. Discharge from Orifice B was estimated at 1.5 ± 0.1 L/min. Mule Ears Spring was surveyed as a flowing spring with a channel length of 23.0 m (75.5 ft). Width and depth averaged 136.0 cm (53.5 in.) and 12.1 cm (4.8 in.), respectively.

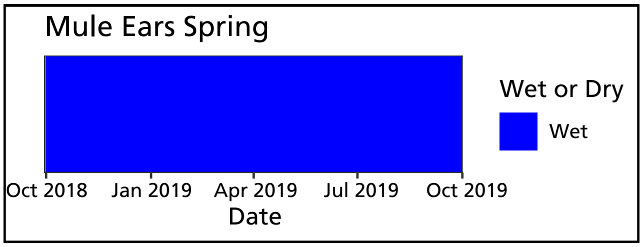

Figure 4-17. Estimated wet/dry days at Mule Ears Spring, Big Bend NP, WY2019.

4.11.4 Water Quality

In 2019, core water quality (Table 4-18) and water chemistry (Table 4-19) were measured at the small pool at the base of the Orifice A hanging garden (sampling location 1) and in a small pool approximately 7 m (23.0 ft) downstream (sampling location 2).

4.12 Painted Hills Spring

The WY2019 visit to Painted Hills Spring occurred on February 26, 2019. The site characterization module was most recently collected in WY2018.

4.12.1 Site Characterization

Painted Hills Spring (Figure 4-18) is a rheochrene spring (a spring that emerges as a flowing stream). The spring emerged from under a gravel bar and root. Water had collected in two small pools which did not appear to have any outflow. Water seeped from a seam just downstream and flowed over bedrock in a dispersed fashion. The channel was not well defined as most of the flow is on bedrock. There were several other instances where water or dampness was present within 200 m (656.2 ft) .

4.12.2 Site Condition

The mean anthropogenic disturbance value was 1.1 (undisturbed) and the mean natural disturbance value was 1.3 (undisturbed). Median values for both disturbance categories were 1.00 (undisturbed). The crew observed slight disturbances from feral animals, recent flooding, and drying.

The crew observed three obligate/facultative wetland plant genera: cottonwood (*Populus* sp.), flatsedge (*Cyperus* sp.) and mule-fat (*Baccharis salicifolia*). Invasive plants were noted, including evenly distributed patches of Bermudagrass (*Cynodon dactylon*) and scattered patches of Lehmann lovegrass (*Eragrostis lehmanniana*). No crayfish or bullfrogs were observed.

Table 4-18. Water quality data for Mule Ears Spring, Big Bend NP, WY2019.

Sampling Location	Orifice(s)	Sample Time	Temperature (°C)	Dissolved Oxygen (mg/L)	pH	Specific Conductivity (µS/cm)	Total Dissolved Solids (mg/L)	Exposure
1	A	08:07	20.6	2.72	7.52	626.0	409.5	Partial
2	B	08:21	17.3	1.07	7.47	632.0	409.4	Shade

Table 4-19. Water chemistry data for Mule Ears Spring, Big Bend NP, WY2019.

Sampling Location	Orifice(s)	Alkalinity (mg/L)	Calcium (mg/L)	Chloride (mg/L)	Magnesium (mg/L)	Potassium (mg/L)	Sulfate (mg/L)
1	A	260	68	15	5	1.7	22
2	B	300	70	15	5	1.5	3

Figure 4-18. Painted Hills Spring, sampling location 1 (a pool below Orifice A), Big Bend NP, February 2019.

4.12.3 Water Quantity

Temperature sensors indicated that the spring was wetted for most days until May (Figure 4-19) when the spring may have been dry or the water was too shallow to mediate temperature variation; we interpreted it as dry. Discharge could not be measured at this site. Painted Hills Spring was surveyed as a flowing spring with a channel length of 13.7 m (45.0 ft). Width and depth averaged 23.9 cm (9.4 in.) and 0.4 cm (0.2 in.), respectively.

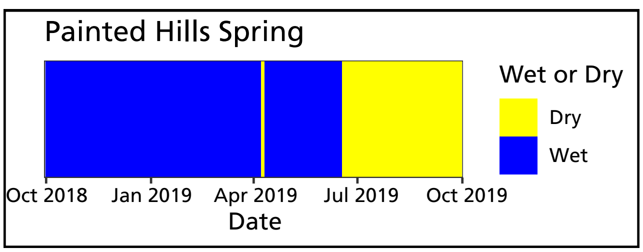

Figure 4-19. Estimated wet/dry days at Painted Hills Spring, Big Bend NP, WY2019.

4.12.4 Water Quality

In 2019, core water quality (Table 4-20) and water chemistry (Table 4-21) were measured at the first pool downstream of the orifice (sampling location 1).

4.13 Peña Spring 1

The WY2019 visit to Peña Spring 1 occurred on March 8, 2019. The site characterization module was most recently collected in WY2018.

4.13.1 Site Characterization

Peña Spring 1 (Figure 4-20) is a rheochrene spring (a spring that emerges as a flowing stream). Water emerged in a mat of spikerush (*Eleocharis* sp.) just downstream of several large willows (*Salix* sp.). Orifice A was a pool under a downed tree which flowed into a narrow channel of silt, organic matter, and pebbles. The water was cool and clear and filled with leaf litter. The channel curved with

Table 4-20. Water quality data for Painted Hills Spring, Big Bend NP, WY2019.

Sampling Location	Orifice(s)	Sample Time	Temperature (°C)	Dissolved Oxygen (mg/L)	pH	Specific Conductivity (µS/cm)	Total Dissolved Solids (mg/L)	Exposure
1	A	07:30	9.6	4.10	7.77	1451.0	942.5	Sun

Table 4-21. Water chemistry data for Painted Hills Spring, Big Bend NP, WY2019.

Sampling Location	Orifice(s)	Alkalinity (mg/L)	Calcium (mg/L)	Chloride (mg/L)	Magnesium (mg/L)	Potassium (mg/L)	Sulfate (mg/L)
1	A	510	34	81	14	2.0	190

Figure 4-20. Peña Spring 1, sampling location 1 (a pool below Orifice A), Big Bend NP, March 2019.

imperceptible flow, although some water seemed to be flowing under collapsed bank sediment. The stream continued in a densely vegetated channel over detritus and a spongy substrate before it was joined by a small hanging garden, considered Orifice B.

4.13.2 Site Condition

The mean anthropogenic disturbance value was 1.0 (undisturbed) and the mean natural disturbance value was 1.4 (undisturbed). Median values for both disturbance categories were 1.0 (undisturbed). Wildlife has caused significant disturbance to this site. There are many tracks and game trails along the springbrook causing extensive widening of the channel and erosion of the banks.

The crew observed six obligate/facultative wetland plant species or genera: bluestem (*Andropogon* sp.), maidenhair fern (*Adiantum* sp.), mule-fat (*Baccharis salicifolia*), sneezeweed (*Helenium* sp.), spikerush (*Eleocharis* sp.) and willow (*Salix* sp.). No invasive plants, bullfrogs, or crayfish were observed.

4.13.3 Water Quantity

Temperature sensors indicated that the spring was wetted for the entire sampled period (Figure 4-21). Discharge from Orifice A was estimated at 5.0 ± 0.1 L/min. Discharge from Orifice C was estimated at 1.4 ± 0.1 L/min. Peña Spring 1 was surveyed as a flowing spring with a channel length of 100–200 m (328.1–656.2 ft). Width and depth for the first 14.4 m (47.2 ft) averaged 130.0 cm (51.2 in.) and 4.6 cm (1.8 in.), respectively. The remainder of the channel was too heavily vegetated and easily disturbed to effectively sample.

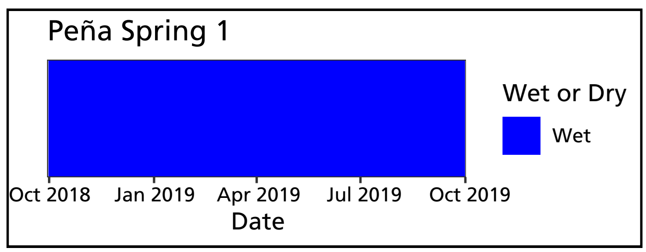

Figure 4-21. Estimated wet/dry days at Peña Spring 1, Big Bend NP, WY2019.

4.13.4 Water Quality

In 2019, core water quality (Table 4-22) and water chemistry (Table 4-23) were measured at the first pool downstream of Orifice A (sampling location 1), in a small pool at Orifice B above the hanging garden (sampling location 2), and in the main channel approximately 5 m downstream of Orifice C (sampling location 3).

Table 4-22. Water quality data for Peña Spring 1, Big Bend NP, WY2019.

Sampling Location	Orifice(s)	Sample Time	Temperature (°C)	Dissolved Oxygen (mg/L)	pH	Specific Conductivity (µS/cm)	Total Dissolved Solids (mg/L)	Exposure
1	A	08:31	19.6	0.72	7.12	917.0	598.0	Partial
2	B	08:41	15.8	7.95	7.76	830.0	539.5	Sun
3	C	10:40	18.8	1.92	7.30	845.0	546.0	Sun

Table 4-23. Water chemistry data for Peña Spring 1, Big Bend NP, WY2019.

Sampling Location	Orifice(s)	Alkalinity (mg/L)	Calcium (mg/L)	Chloride (mg/L)	Magnesium (mg/L)	Potassium (mg/L)	Sulfate (mg/L)
1	A	340	76	25	9	1.0	128
2	B	270	42	15	9	1.3	132
3	C	275	58	27	7	1.4	132

4.14 Red Ass Spring

The WY2019 visit to Red Ass Spring occurred on February 24, 2019. The site characterization module was most recently collected in WY2018.

4.14.1 Site Characterization

Red Ass Spring (Figure 4-22) is a rheochrene spring (a spring that emerges as a flowing stream). Orifice A emerged into a murky, algae-covered, stagnant pool within a drainage. Discharge was visible slightly downstream in the sand and silt dominated channel. Salt deposits coated the ground on either side of the flow. Two other orifices were present within 200 m (656.2 ft), including a previously sampled site, Red Ass A.

4.14.2 Site Condition

The mean anthropogenic disturbance value was 1.3 (undisturbed) and the mean natural disturbance value was 1.3 (undisturbed). Median values for both disturbance categories were 1.0 (undisturbed). Contemporary use was indicated with several sets of boot prints. The crew noted slight disturbance from drying and wildlife use.

Figure 4-22. Red Ass Spring, sampling location 1 (a pool below Orifice A), Big Bend NP, February 2019.

The crew observed one obligate/facultative wetland plant families and three genera: rush family (Juncaceae), cottonwood (*Populus* sp.), flatsedge (*Cyperus* sp.), and spikerush (*Eleocharis* sp.). Invasive Bermudagrass (*Cynodon dactylon*) was present in the 1–5 individual density class. No crayfish or bullfrogs observed.

4.14.3 Water Quantity

Temperature sensors indicated that the spring was wetted for the majority of the sampled period but dry (or very shallow) during the summer (Figure 4-23). Discharge from Orifice A was measured at 1.0 ± < 0.1 L/min. Red Ass Spring was surveyed as a flowing spring with a channel length of 12.9 m (42.2 ft). Width and depth averaged 44.9 cm (17.7 in.) and 1.1 cm (0.4 in.), respectively.

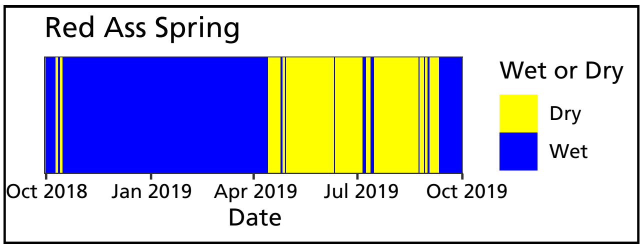

Figure 4-23. Estimated wet/dry days at Red Ass Spring, Big Bend NP, WY2019.

4.14.4 Water Quality

In 2019, core water quality (Table 4-24) and water chemistry (Table 4-25) were measured at the first pool downstream of the orifice (sampling location 1).

4.15 Rough Spring B

4.15.1 Site Characterization

Rough Spring B (Figure 4-24) is a rheochrene spring (a spring that emerges as a flowing stream). The spring was located at the bottom of a bedrock ravine. Orifice A emerged from under a small pour-off and dirt overhang among mule-fat (*Baccharis salicifolia*) and poison oak (*Toxicodendron* sp.). It flowed in an incised channel and then laminarly over bedrock into a small pool dammed by a gravel deposit. From this pool, a small algae-clogged springbrook continued intermittently to the wetted terminus. Flow was generally cool and clear, though detritus was present and dirtied the water in stagnant areas.

4.15.2 Site Condition

The mean anthropogenic disturbance value was 1.1 (undisturbed) and the mean natural disturbance value was 1.1 (undisturbed). Median values for both disturbance categories were 1.0 (undisturbed). Footprints and cairns were observed on the hike to the spring. Game trails were present at the site.

The crew observed two obligate/facultative wetland plant families, four genera, and one species: cattail family (Typhaceae), rush family (Juncaceae), monkeyflower (*Mimulus* sp.), mule-fat (*Baccharis salicifolia*), rabbitsfoot grass (*Polypogon* sp.), sedge (*Carex* sp.), spikerush (*Eleocharis* sp.). Three invasive species were noted in scattered patches: annual rabbitsfoot grass (*Polypogon monspeliensis*), Bermudagrass (*Cynodon dactylon*) and Lehmann lovegrass (*Eragrostis lehmanniana*). No bullfrogs or crayfish were observed.

Table 4-24. Water quality data for Red Ass Spring, Big Bend NP, WY2019.

Sampling Location	Orifice(s)	Sample Time	Temperature (°C)	Dissolved Oxygen (mg/L)	pH	Specific Conductivity (µS/cm)	Total Dissolved Solids (mg/L)	Exposure
1	A	09:30	13.7	3.24	7.46	806.0	526.5	Sun

Table 4-25. Water chemistry data for Red Ass Spring, Big Bend NP, WY2019.

Sampling Location	Orifice(s)	Alkalinity (mg/L)	Calcium (mg/L)	Chloride (mg/L)	Magnesium (mg/L)	Potassium (mg/L)	Sulfate (mg/L)
1	A	310	54	59	3	0.5	67

Figure 4-24. Rough Spring B, sampling location 1 (an incised channel below Orifice A), Big Bend NP, February 2019.

4.15.3 Water Quantity

Temperature sensors indicated that the spring was wetted for most of the sampled period (Figure 4-25). Discharge from Orifice A and Orifice B were estimated at 22.3 ± 0.5 L/min and 6.4 ± 0.4 L/min, respectively. Rough Spring B was surveyed as a flowing spring with a channel length of 82.4 m (270.3 ft). Width and depth averaged 93.8 cm (36.9 in.) and 2.2 cm (0.9 in.), respectively.

4.15.4 Water Quality

In 2019, core water quality (Table 4-26) and water chemistry (Table 4-27) were measured close to Orifice A in an incised channel (sampling location 1) and Orifice B, a small pool approximately 30 m (98.4 ft) upstream of Orifice A (sampling location 4).

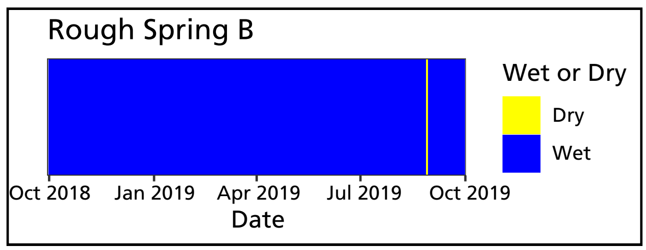

Figure 4-25. Estimated wet/dry days at Rough Spring B, Big Bend NP, WY2019.

Table 4-26. Water quality data for Rough Spring B, Big Bend NP, WY2019.

Sampling Location	Orifice(s)	Sample Time	Temperature (°C)	Dissolved Oxygen (mg/L)	pH	Specific Conductivity (µS/cm)	Total Dissolved Solids (mg/L)	Exposure
1	A	08:27	16.2	1.82	7.54	658.0	429.0	Shade
4	B	08:36	11.9	2.09	6.88	691.0	443.5	Partial

Table 4-27. Water chemistry data for Rough Spring B, Big Bend NP, WY2019.

Sampling Location	Orifice(s)	Alkalinity (mg/L)	Calcium (mg/L)	Chloride (mg/L)	Magnesium (mg/L)	Potassium (mg/L)	Sulfate (mg/L)
1	A	280	70	16	13	0.5	67
4	B	290	64	14	17	0.3	59

Figure 4-26. Screwbean Spring, sampling location 1 (a pool below Orifice A), Big Bend NP, February 2019.

4.16 Screwbean Spring

The WY2019 visit to Screwbean Spring occurred on February 22, 2019. The site characterization module was most recently collected in WY2018.

4.16.1 Site Characterization

Screwbean Spring (Figure 4-26) is a heleocrene complex (emerges in a diffuse fashion). The spring was located on an abandoned floodplain of an active, channelized wash. The system emerged as a series of orifices that collected and formed a wetted area dense with vegetation. Orifice A was the most upstream and the furthest orifice from the wash. It emerged in a trampled pool and trickled down an eroded channel then dispersed into a wider, braided flow. Orifice B was northeast and surfaced as an imperceptible trickle of water under a large mesquite (*Prosopis* sp.). This collected in a series of pools separated by alkali sacaton (*Sporobolus airoides*) grass clumps. The surface water did not connect to the water from Orifice A, although muddy silt between the areas and salt crust indicated the entire area may have been previously wetted. Orifice C emerged from bedrock to the south. This short stream had flow that was too low to measure and ended in the alkali sacaton field before reaching the flow from Orifice A. Downstream of the site, water emerged from a side bank of the wash, most likely the combined flows of all orifices on the floodplain. A dense mesquite (*Prosopis* sp.) stand, tamarisk (*Tamarix* sp.), and grasses and wetland species indicated water is usually present year-round to support them.

4.16.2 Site Condition

The mean anthropogenic disturbance value was 1.0 (undisturbed) and the mean natural disturbance value was 1.3 (undisturbed). Median values for both disturbance categories were 1.0 (undisturbed). Drying was the only noted disturbance.

The crew observed one obligate/facultative wetland plant family and four genera: cattail family (Typhaceae), bluestem (*Andropogon* sp.), sedge (*Carex* sp.), spikerush (*Eleocharis* sp.), and tamarisk (*Tamarix* sp.). Invasive five-stamen tamarisk (*Tamarix chinensis*) was noted in the 1–5 individual density class. No crayfish or bullfrogs were observed.

4.16.3 Water Quantity

Temperature sensors indicated that the spring was wetted for the entirety of the sampled period (Figure 4-27). Discharge from Orifice A was estimated at 4.3 ± 0.1 L/min. Screwbean Spring was surveyed as a non-flowing spring with an average length and width of 3425.0 cm (1348.4 in.), 1235.8 cm (486.5 in.), respectively. Depth was not measured because the measurements would not accurately represent the patchy extent of surface water.

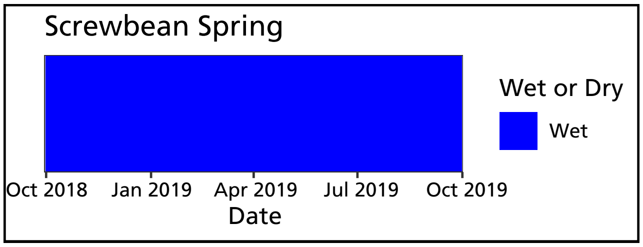

Figure 4-27. Estimated wet/dry days at Screwbean Spring, Big Bend NP, WY2019.

4.16.4 Water Quality

In 2019, core water quality (Table 4-28) and water chemistry (Table 4-29) were measured at four locations: the first pool large enough to measure downstream of Orifice A (sampling location 1); the largest pool downstream of Orifice B (sampling location 2); the first pool large enough to measure downstream of Orifice C (sampling location 3); and a downwash of Orifice C at the base of a small bedrock shelf (Orifice D, sampling location 6).

4.17 Shelf Spring

The WY2019 visit to Shelf Spring occurred on February 22, 2019. The site characterization module was most recently collected in WY2018.

4.17.1 Site Characterization

Shelf Spring (Figure 4-28) is a hanging garden complex. The spring emerged from under a long, overhanging bedrock shelf along a steep-sided drainage among the gravelly bentonite hills. Orifice A occurred near the base of the wall and trickled from maidenhair fern (*Adiantum* sp.) into silty substrate at the base. A small downstream channel emerged from under boulders and silty substrate, which flowed intermittently under mule-fat (*Baccharis salicifolia*) shrubs and down a small pour-off, flowing until the terminus. The flow was cool and clear and only filled with algae toward the end of the reach in a pool.

4.17.2 Site Condition

The mean anthropogenic disturbance value was 1.1 (undisturbed) and the mean natural disturbance value was 1.5 (undisturbed). Median values for both disturbance categories were 1.0 (undisturbed). There

Table 4-28. Water quality data for Screwbean Spring, Big Bend NP, WY2019.

Sampling Location	Orifice(s)	Sample Time	Temperature (°C)	Dissolved Oxygen (mg/L)	pH	Specific Conductivity (µS/cm)	Total Dissolved Solids (mg/L)	Exposure
1	A	08:26	18.4	4.07	7.93	2006.0	1306.5	Partial
2	B	08:37	10.9	1.61	7.67	2958.0	1924.0	Partial
3	C	08:45	12.2	13.90	8.59	2542.0	1651.0	Sun
6	D	09:14	14.9	11.13	8.44	2760.0	1794.0	Partial

Table 4-29. Water chemistry data for Screwbean Spring, Big Bend NP, WY2019.

Sampling Location	Orifice(s)	Alkalinity (mg/L)	Calcium (mg/L)	Chloride (mg/L)	Magnesium (mg/L)	Potassium (mg/L)	Sulfate (mg/L)
1	A	275	26	87	7	1.2	190
2	B	340	36	41	8	0.6	175
3	C	230	12	75	5	not detected	185
6	D	360	24	62	4	0.0	180

Figure 4-28. Shelf Spring, sampling location 1 (a pool below Orifice A), Big Bend NP, February 2019.

was slight disturbance from historical human use, drying, and wildlife. Recent flooding caused moderate disturbance.

The crew observed three obligate/facultative wetland plant genera and one species: bluestem (*Andropogon* sp.), maidenhair fern (*Adiantum* sp.), mule-fat (*Baccharis salicifolia*), and spikerush (*Eleocharis* sp.). No invasive plants, crayfish, or bullfrogs were observed.

4.17.3 Water Quantity

Temperature sensors indicated that the spring was wetted for the majority of the sampled period (Figure 29). The sensor deployed in WY2018 could not be located for retrieval, resulting in missing data from October 2018 to March 2019. Discharge could not be measured due to low flow. Shelf Spring was surveyed as a flowing spring with a channel length of 30.7 m (100.7 ft). Width and depth averaged 39.0 cm (15. 4 in.) and 0.89 cm (0.3 in.), respectively.

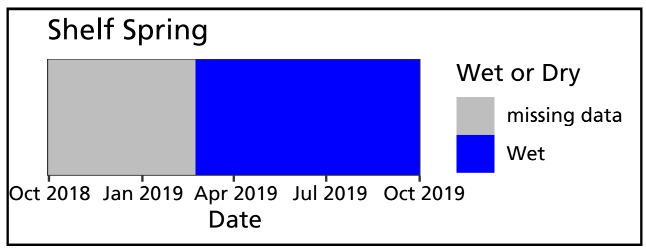

Figure 4-29. Estimated wet/dry days at Shelf Spring, Big Bend NP, WY2019.

4.17.4 Water Quality

In 2019, core water quality (Table 4-30) and water chemistry (Table 4-31) were measured at the first pool downstream of Orifice A (sampling location 1).

Table 4-30. Water quality data for Shelf Spring, Big Bend NP, WY2019.

Sampling Location	Orifice(s)	Sample Time	Temperature (°C)	Dissolved Oxygen (mg/L)	pH	Specific Conductivity (µS/cm)	Total Dissolved Solids (mg/L)	Exposure
1	A	10:00	20.4	4.07	7.49	551.0	357.5	Shade

Table 4-31. Water chemistry data for Shelf Spring, Big Bend NP, WY2019.

Sampling Location	Orifice(s)	Alkalinity (mg/L)	Calcium (mg/L)	Chloride (mg/L)	Magnesium (mg/L)	Potassium (mg/L)	Sulfate (mg/L)
1	A	195	38	21	13	2.3	41

4.18 Solis Spring

The WY2019 visit to Solis Spring occurred on February 23, 2019. The site characterization module was most recently collected in WY2018.

4.18.1 Site Characterization

Solis Spring (Figure 4-30) is a rheochrene spring (a spring that emerges as a flowing stream). Orifice A, which supported several cattail (*Typha* sp.), emerged in a series of small stagnant pools. Orifice B emerged next to a small overhang, creating a small pool, which discharged a low flow into a narrow channel down the hillside. Orifice C emerged in a patch of dropseed (*Sporobolus* sp.) and flowed into a few small, silty puddles before terminating down the hill. The entire area surrounding Solis Spring showed a salty crust indicative of drying. Flow was so low it was nearly imperceptible in the silt-dominated channel. Water from all three orifices emerged clear though a deep silty substrate causing frequent murkiness in disturbed areas.

4.18.2 Site Condition

The mean anthropogenic disturbance value was 1.1 (undisturbed) and the mean natural disturbance value was 1.3 (undisturbed). Median values for both disturbance categories were 1.0 (undisturbed). The crew noted slight disturbance from historical human use and moderate disturbance from drying.

The crew observed one obligate/facultative wetland plant family and two genera: cattail family (Typhaceae), spikerush (*Eleocharis* sp.), and tamarisk (*Tamarix* sp.). The invasive five-stamen tamarisk (*Tamarix chinensis*) was observed in the 1–5 plant density class. No crayfish or bullfrogs were observed.

4.18.3 Water Quantity

Temperature sensors indicated that the spring was wetted for the entirety of the sampled period (Figure 4-31). Discharge could not be measured due to low flow. Solis Spring was surveyed as a flowing spring with a channel length of 32.5 m (106.7 ft). Width and depth averaged 52.3 cm (20.6 in.) and 0.1 cm (< 0.1 in.), respectively.

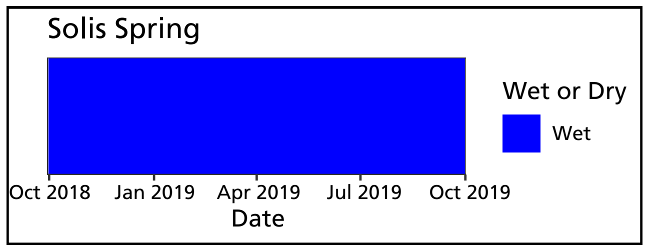

Figure 4-31. Estimated wet/dry days at Solis Spring, Big Bend NP, WY2019.

4.18.4 Water Quality

In 2019, core water quality (Table 4-32) and water chemistry (Table 4-33) were measured at the first pool downstream of the orifice (sampling location 1) and in the pool below a soil overhang (sampling location 2).

Figure 4-30. Solis Spring, sampling location 1 (a pool below Orifice A), Big Bend NP, February 2019.

Table 4-32. Water quality data for Solis Spring, Big Bend NP, WY2019.

Sampling Location	Orifice(s)	Sample Time	Temperature (°C)	Dissolved Oxygen (mg/L)	pH	Specific Conductivity (µS/cm)	Total Dissolved Solids (mg/L)	Exposure
1	A	09:40	15.4	1.63	7.82	3770.0	2450.5	Sun
2	B	09:57	15.6	8.59	8.42	3006.0	1956.5	Sun

Table 4-33. Water chemistry data for Solis Spring, Big Bend NP, WY2019.

Sampling Location	Orifice(s)	Alkalinity (mg/L)	Calcium (mg/L)	Chloride (mg/L)	Magnesium (mg/L)	Potassium (mg/L)	Sulfate (mg/L)
1	A	350	34	105	6	1.9	180
2	B	400	24	83	not detected	2.3	55

4.19 Tiptoe Spring

The WY2019 visit to Tiptoe Spring occurred on February 26, 2019. The site characterization module was most recently collected in WY2019.

4.19.1 Site Characterization

Tiptoe Spring (Figure 4-32) is a rheochrene spring (a spring that emerges as a flowing stream) in a small drainage. Orifice B emerged as stagnant water in a series of terraced pools with no apparent flow. Downstream from here was a steep drop containing the only discernable flow of the spring reach. After this drop, the water joined Orifice A, significantly increasing the water volume and widening the channel. Here the water was covered in a thick mat of algae. Downstream, the channel continued as a series of wetted patches with minimal standing water.

4.19.2 Site Condition

The mean anthropogenic disturbance value was 1.0 (undisturbed) and the mean natural disturbance value was 1.8 (slightly disturbed). Median values for both disturbance categories were 1.0 (undisturbed). Recent flooding caused significant disturbance to the site. The crew also noted slight disturbance due to drying and moderate disturbance caused by wildlife.

The crew observed one obligate/facultative wetland plant family and two genera: rush family (Juncaceae), spikerush (*Eleocharis* sp.), and tamarisk (*Tamarix* sp.). The tamarisk was identified as invasive saltcedar (*Tamarix ramosissima*) and noted in the 1–5 individual density class. No crayfish or bullfrogs were observed.

Figure 4-32. Tiptoe Spring, sampling location 5 (discharge sampling location), Big Bend NP, February 2019.

Table 4-34. Water quality data for Tiptoe Spring, Big Bend NP, WY2019.

Sampling Location	Orifice(s)	Sample Time	Temperature (°C)	Dissolved Oxygen (mg/L)	pH	Specific Conductivity (µS/cm)	Total Dissolved Solids (mg/L)	Exposure
1	A	12:32	24.7	9.37	8.14	892.0	578.5	Sun
4	B	12:48	19.8	2.43	7.69	927.0	604.5	Sun

Table 4-35. Water chemistry data for Tiptoe Spring, Big Bend NP, WY2019.

Sampling Location	Orifice(s)	Alkalinity (mg/L)	Calcium (mg/L)	Chloride (mg/L)	Magnesium (mg/L)	Potassium (mg/L)	Sulfate (mg/L)
1	A	310	24	2	not detected	1.3	106
4	B	330	20	11	5	0.6	80

4.19.3 Water Quantity

Temperature sensors indicated that the spring was wetted for the majority of the sampled period, particularly in the first half of the water year (Figure 4-33). Discharge from Orifice A was estimated at 0.4 ± < 0.1 L/min. Tiptoe Spring was surveyed as a flowing spring with a channel length of 75.2 m (246.7 ft). Width and depth averaged 29.7 cm (11.7 in.) and 2.2 cm (0.9 in.), respectively.

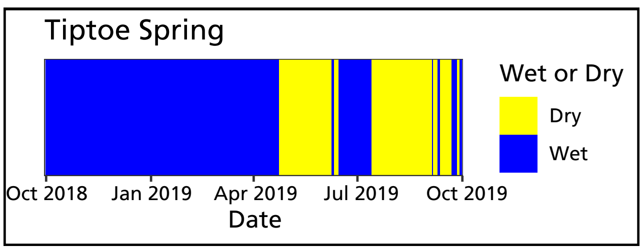

Figure 4-33. Estimated wet/dry days at Tiptoe Spring, Big Bend NP, WY2019.

4.19.4 Water Quality

In 2019, core water quality (Table 4-34) and water chemistry (Table 4-35) were measured at the Orifice A pool (sampling location 1) and the Orifice B pool (sampling location 4).

4.20 Waterboy Tinaja

The WY2019 visit to Waterboy Tinaja occurred on February 24, 2019. The site characterization module was most recently collected in WY2018.

4.20.1 Site Characterization

Water Boy Tinaja (Figure 4-34), a tinaja and a small pool, is in a rock basin of a bedrock canyon. Orifice A emerged from a narrow laminar flow on bedrock from the channel above the pool. The green, clear outflow continued in a bedrock channel, pooling intermittently in flatter areas. Large clumps of grass lined the northwest edge and a small amount of algae existed on the shallow north edge of the pool.

4.20.2 Site Condition

The mean anthropogenic disturbance value was 1.1 (undisturbed) and the mean natural disturbance value was 1.1 (undisturbed). Median values for both disturbance categories were 1.0 (undisturbed). There was debris from recent flooding. Signs of wildlife were not present at the tinaja but were observed on the hike into the spring.

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

4.20.3 Water Quantity

Temperature sensors indicated that the spring was wetted for most of the sampled period (Figure 4-35). Discharge from Orifice A was estimated at 23.0 ± 0.8 L/min. Waterboy Tinaja was surveyed as a non-flowing spring with an average length, width, and depth of 565.7 cm (222.7 in.), 487.3 cm (191.9 in.) and 90.8 cm (35.7 in.), respectively.

4.20.4 Water Quality

In 2019, core water quality (Table 4-36) and water chemistry (Table 4-37) were measured at the center of the tinaja (sampling location 1) at four depths. Although the pH values reported in Table 4-36 match the field datasheets, we suspect that the 3.48 and 3.68 values are erroneous (samples in previous water years are all in the 8 range).

Figure 4-34. Waterboy Tinaja, Orifice A (sampling location 1), Big Bend NP, February 2019.

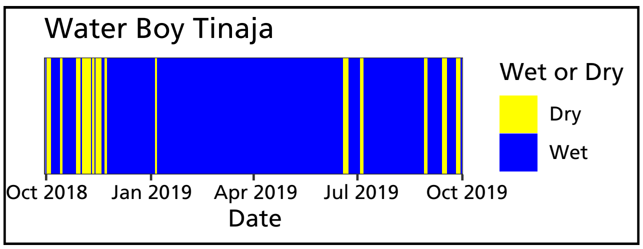

Figure 4-35. Estimated wet/dry days at Waterboy Tinaja, Big Bend NP, WY2019.

Table 4-36. Water quality data for Waterboy Tinaja, Big Bend NP, WY2019.

Sampling Location	Orifice(s)	Sample Time	Temperature (°C)	Dissolved Oxygen (mg/L)	pH*	Specific Conductivity (µS/cm)	Total Dissolved Solids (mg/L)	Exposure
1 (surface)	A	08:14	5.1	10.80	3.48	33.6	217.10	Sun
1 (1/3 depth)	A	08:15	5.0	10.76	8.66	33.7	213.70	Sun
1 (2/3 depth)	A	08:16	5.0	10.80	3.68	33.9	217.10	Sun
1 (bottom)	A	08:17	5.2	10.53	8.66	33.0	216.45	Sun

* pH values of 3.48 and 3.68 are likely erroneous (samples in previous water years are all in the 8 range).

Table 4-37. Water chemistry data for Waterboy Tinaja, Big Bend NP, WY2019.

Sampling Location	Orifice(s)	Alkalinity (mg/L)	Calcium (mg/L)	Chloride (mg/L)	Magnesium (mg/L)	Potassium (mg/L)	Sulfate (mg/L)
1	A	125	32	20	50	0.1	27

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NPS 155/184147, September 2022

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