



Status of Climate and Water Resources at Amistad National Recreation Area

Water Year 2018

Natural Resource Report NPS/CHDN/NRR—2019/2006



ON THE COVER

Amistad National Recreation Area. Photo credit: NPS

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Kara Raymond
Southern Arizona Office
National Park Service
3636 N Central Ave #410
Phoenix, AZ 85012

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

Cheryl McIntyre
Chihuahuan Desert Network
National Park Service
3655 Research Dr., Bldg. D
Las Cruces, NM 88003

Editing and Design
Allyson Mathis
Northern Rockies Conservation Cooperative
P.O. Box 2705
Jackson, WY 83001

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Glossary

anthropogenic: caused by human activities

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

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

facultative wetland species: plants usually occurring in wetlands

hanging harden: spring type that emerges horizontally along a cliff

heleocene: spring type that emerges from a wetland

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

limnocene: spring type that emerges as a pool

obligate wetland species: plants almost always occurring in wetlands

orifice: aboveground emergence of a spring

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

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

rheocene: spring type that emerges as a flowing stream

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

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

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

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

Executive Summary

Climate and hydrology are major drivers of ecosystems. They dramatically shape ecosystem structure and function, particularly in arid and semi-arid ecosystems. Understanding changes in climate, groundwater, and springs is central to assessing the condition of park biota and key cultural resources. This report combines data collected on climate, groundwater, and surface water at Amistad National Recreation Area (NRA) to provide an integrated look at climate and water conditions during water year 2018 (October 2017–September 2018).

Overall annual precipitation was 92% of normal. Over half of the annual rainfall occurred in September. Eight of the other months were substantially drier than normal, receiving only 8–53% of normal rainfall. Mean minimum and maximum monthly temperatures were variable compared to the 30-year normal. Extremely warm days occurred 12% less frequently than normal, while there was 35% more extremely cold days. The reconnaissance drought index indicates that WY2018 was slightly drier than normal, following an overall wetter decade. The five-year moving mean of total annual precipitation demonstrates a surplus.

Mean reservoir level in WY2018 was 1089.37 feet above mean sea level, 3.14 feet lower than the mean for WY2017, and 4.29 feet lower than the mean of 1990–2017.

Of the six monitoring wells, water level in four wells increased by as much as 9.29 feet in WY2018 compared to WY2017, and water level in two wells decreased by as much as 5.34 feet. The historic record for three wells indicates that groundwater level has fluctuated with reservoir level. Data collection only began recently at the other three wells.

Four springs were monitored at the recreation area. All had surface water and obligate/facultative wetland vegetation and three had invasive non-native plants present when visited in WY2018.

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We thank Superintendent Chris Ryan, Chief of Interpretation and Resource Management Greg Garetz, Integrated Resources Program Manager Jack Johnson, Biologist Sarah Howard, and the staff of Amistad National Recreation Area for their on-site support of the monitoring effort, including boat rides. Megan Podolinski, Tim Pine, Jack Johnson, Sarah Howard, and Donald Karr collected springs data. Mark Isley, Kristen Bonebrake, Heidi Sosinski, Melissa Powell, and other network staff led the management of all data products. Mike Tercek developed the [Climate Analyzer website \(www.climateanalyzer.org\)](http://www.climateanalyzer.org) that was used for all climate data analysis.

1 Introduction

Climate and hydrology are major drivers of ecosystems. They dramatically shape ecosystem structure and function, particularly in arid and semi-arid ecosystems. Understanding changes in climate, groundwater, and water quality is central to assessing the condition of park biota and key cultural resources. This document summarizes climate and water resource conditions for water year (WY) 2018 (October 2017–September 2018) at Amistad National Recreation Area (NRA), a National Park Service unit in southern Texas along the United

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

2 Climate

2.1 Background and methods

Climate is the suite of characteristic meteorological conditions of the near-surface atmosphere at a given place (Strahler 2013), and is the primary driver of ecological processes on earth. A broader temporal scale (seasons to years) is what distinguishes climate from the instantaneous conditions reflected by the term “weather.”

Climate mediates the fundamental properties of ecological systems, such as soil-water relationships, plant-soil interactions, net primary productivity, the cycling of nutrients and water, and the occurrence, extent, and intensity of disturbances (Strahler 2013) — in short, the underpinnings of the natural resources that the National Park Service manages and protects. The updated Köppen Climate Classification System identifies the park’s climate as warm semi-arid (Peel et al. 2007).

Amistad NRA has operated a National Oceanic and Atmospheric Administration (NOAA) Cooperative Observer Program (COOP) weather station since 1964 (Amistad Dam #410225). This station provides a reliable long-term climate dataset. We used this excellent data source for all subsequent analyses. The station data were obtained from Climate Analyzer (Walking Shadow Ecology 2019a), a website that allows users to make on-demand tables and graphs with data from weather stations that are updated daily (Walking Shadow Ecology 2019b).

2.2 Results and discussion

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

Data quality during WY2018 was excellent, with missing values on only five days. Overall annual precipitation was 92% of normal for Amistad NRA (17.39 inches vs. 18.81 inches; Figure 2-1).

2.2.1.1 Cool season (October–March)

Precipitation was substantially below normal (54% or –2.92 inches) for the fall and winter of WY2018. December is typically the driest month of the year; however, in WY2018, December received 2.5 times the normal rainfall and was the third wettest month of the year (Figures 2-1 and 2-2). Precipitation in February was near normal, while the other fall and winter months received 6–34% of their normal rainfall. Temperatures were variable during the cool

season and mean monthly minimum and maximum air temperatures were $\pm 5^{\circ}\text{F}$ of normal.

2.2.1.2 Warm season (April–September)

Precipitation was greater than normal (112%, +1.5 inches) for the spring and summer months in WY2018 (Figures 2-1 and 2-2). Rainfall in September accounted for over half the annual total for WY2018, and was 3.5 times the normal September precipitation. Residual moisture from Tropical Storm Gordon resulted in seven consecutive days of precipitation, and a second storm system moved through the area a week later. Total precipitation from September 3 through 22 was 9.63 inches, exceeding the 5-year return interval (8.35 inches). Rainfall in August was near normal, while April through July were drier than normal (3–53%). Generally, mean monthly maximum and minimum temperatures were as much as 5°F above normal during May–July. The other months were slightly cooler, with the exception of September. The mean maximum temperature in September was 6.5°F below normal, likely due to increased cloud cover and other impacts of the large low pressure systems that affected the area.

2.2.2 Reconnaissance Drought Index

The reconnaissance drought index (Tsakiris and Vangelis 2005) provides a measure of drought severity and extent relative to the long-term climate based on the ratio of average precipitation to average potential evapotranspiration over short periods of time (seasons to years). The reconnaissance drought index for Amistad NRA indicates that the past decade has been slightly wetter than the average for 1981–2018; however, conditions in WY2018 were marginally drier (Figure 2-3). The five-year moving mean of total annual precipitation (water year) indicated that the park has oscillated between multiyear precipitation surpluses and deficits, with the last five years demonstrating a surplus (Figure 2-4).

2.2.3 Extreme weather events

Stochastic events, such as air-temperature extremes and unusually intense precipitation events, may be as important to understanding ecological patterns as long-term climate averages are. High air temperatures are a defining feature of warm deserts (Strahler 2013); however, extreme heat events can also have important consequences for Chihuahuan Desert, Southern Texas Plains, and Edwards Plateau ecosystems. For

Amistad Dam - Water Year 2018 - Departure from 1981 - 2010 Avgs.

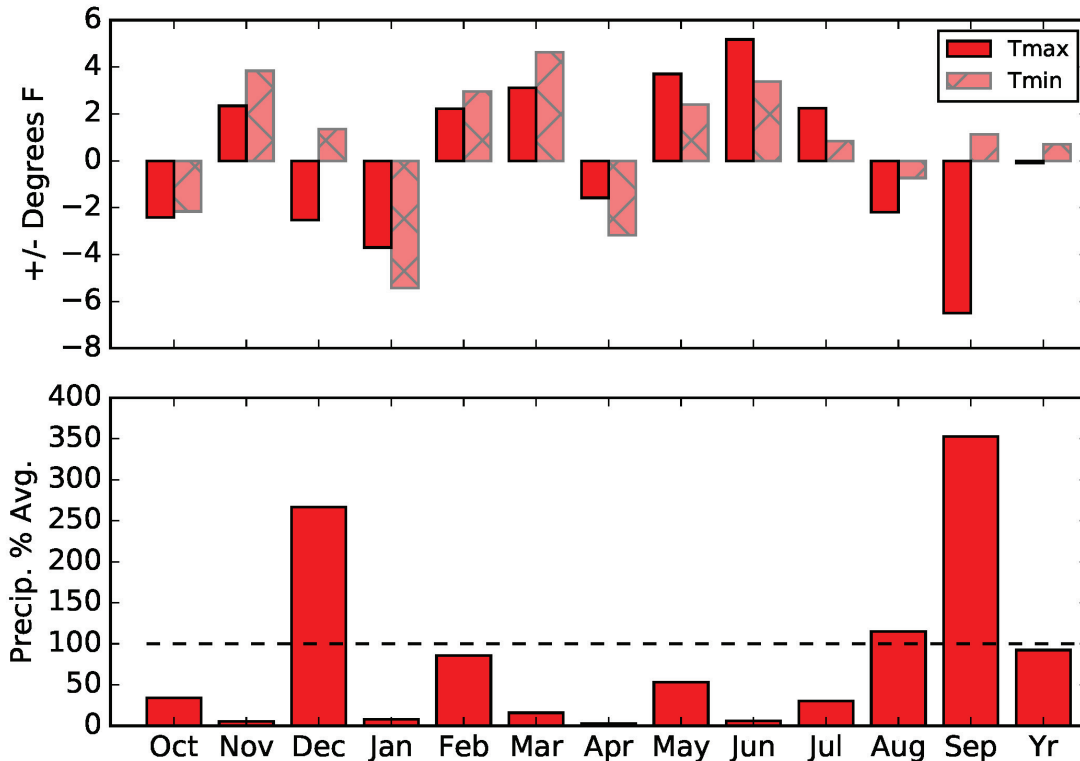


Figure 2-1. Departures from 30-year (1981–2010) normal minimum and maximum air temperature and precipitation, Amistad NRA, water year 2018. Graphics generated by climateanalyzer.org (Walking Shadow Ecology 2019a).

Amistad Dam - Water Year Ending 2018

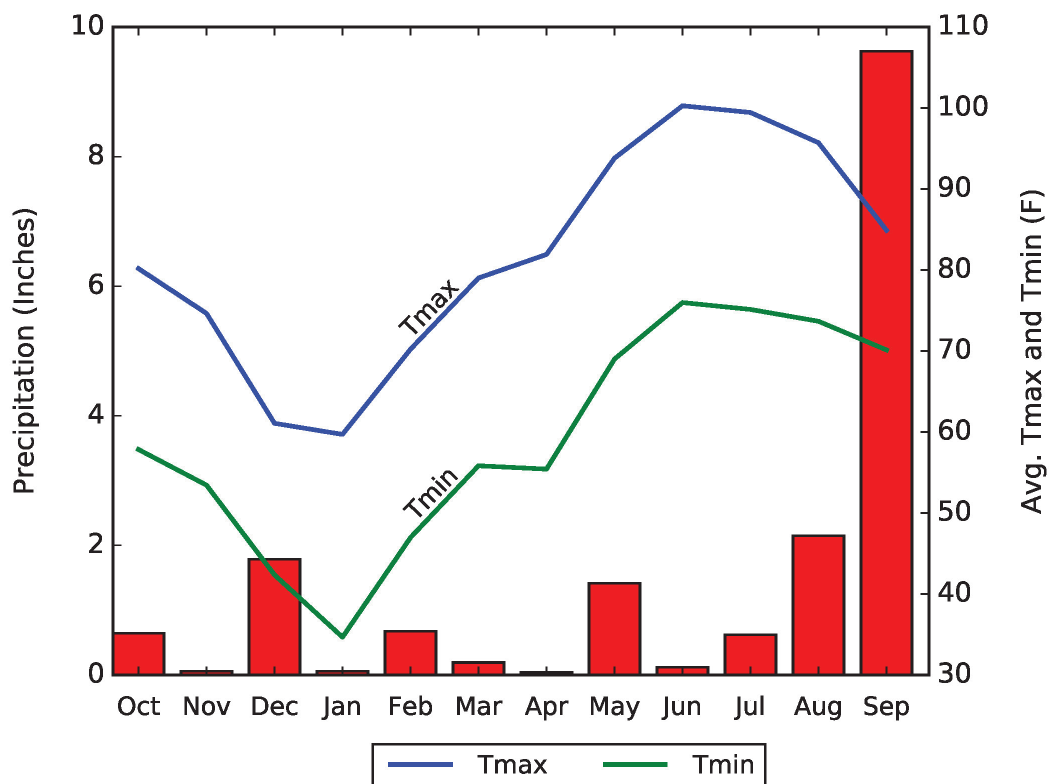


Figure 2-2. Climogram for Amistad NRA, water year 2018. Graphic generated by climateanalyzer.org (Walking Shadow Ecology 2019a).

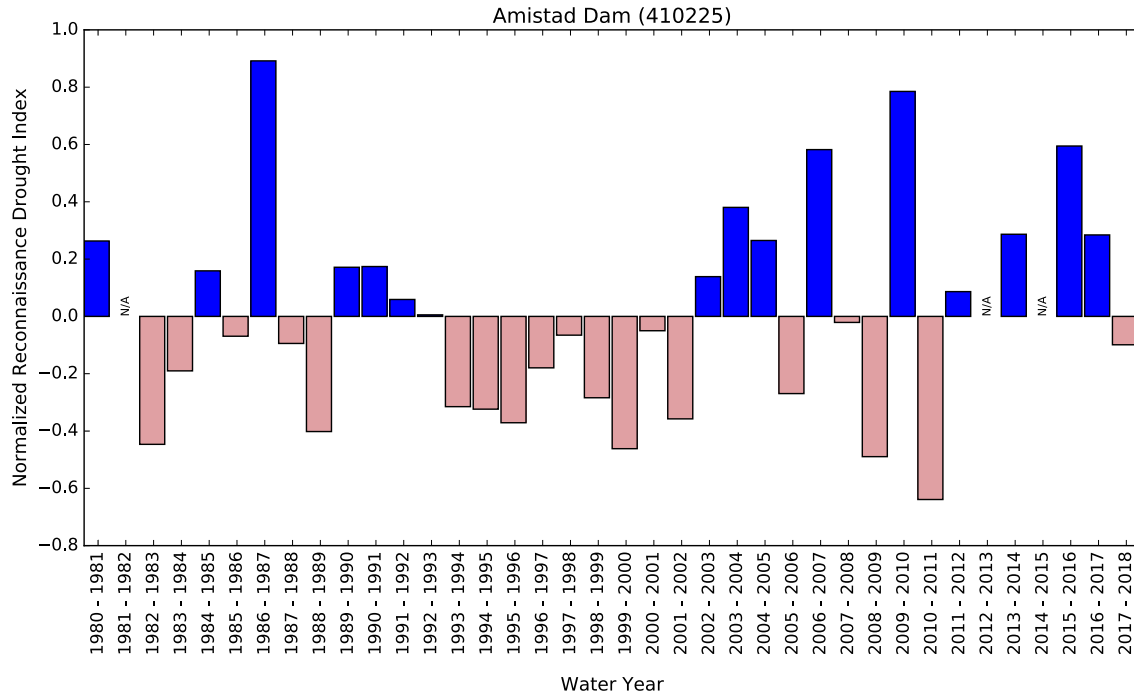


Figure 2-3. Reconnaissance drought index (RDI), Amistad NRA, water years 1981–2018. “n/a” = insufficient data to generate reliable RDI estimates. Values above zero (in blue) indicate wetter than average conditions whereas values below zero (in red) indicated dryer than average conditions. The calculations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

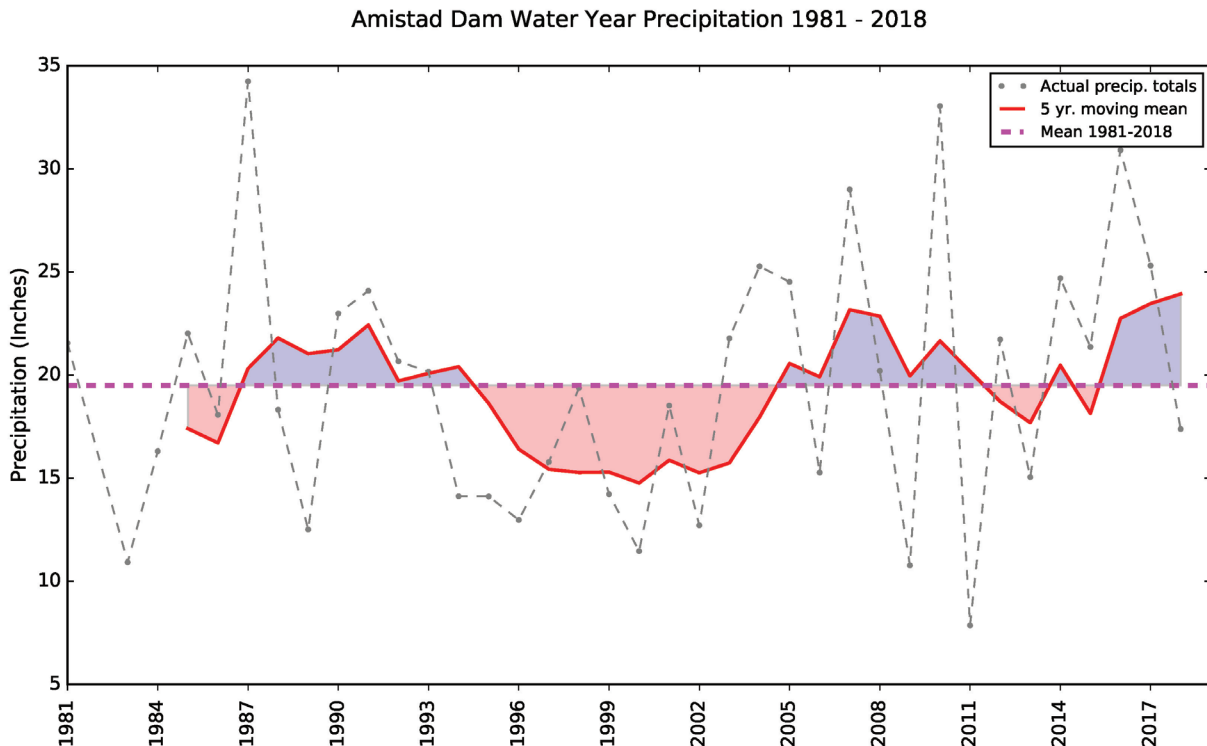


Figure 2-4. Five-year moving mean of annual precipitation, Amistad NRA, 1981–2018. The moving mean (solid red line) is based on a time series with 2.6% (1 of 38) missing values, and includes the current year and previous four years. Blue (above the mean) and red fields (below the mean) represent water surplus and deficit. Missing years are linearly interpolated (dashed grey lines). Graphic generated by climateanalyzer.org (Walking Shadow Ecology 2019a).

example, sustained warm temperatures increase evapotranspiration rates and can result in lower water levels in the reservoir, impacting nearby groundwater and surface waters. Extreme precipitation events can also cause localized flooding and erosion events, spur or inhibit plant productivity and reproduction, and modify animal behavior (Sumner 1988).

The frequency of extremely warm days ($>102^{\circ}\text{F}$, 95th percentile of 1981–2010 data) was slightly

less than normal (17 vs. 19.4 ± 2.5 days). Extremely cold days ($<35^{\circ}\text{F}$, 5th percentile of 1981–2010 data) occurred 35% more often than normal in WY2018 (24 vs. 17.8 ± 1.5 days), and were of a similar duration (2.4 consecutive days vs. 2.7 ± 0.2 days). Four days with extreme precipitation events (>1 inch) occurred in WY2018 compared to the mean of 4.9 days for 1981–2010. Large events occurred on December 7 (1.19 inches), August 13 (1.43 inches), September 6 (1.62 inches), and September 17 (2.62 inches).

3 Reservoir Level

3.1 Background

The Amistad International Reservoir was formed by the construction of Amistad Dam between 1964 and 1969. The primary functions of the dam are to control flooding and provide conservation storage for domestic and irrigation uses in the United States and Mexico. Secondary purposes include providing a recreational area and producing electrical power. The Amistad Dam is owned and operated by the International Boundary and Water Commission (IBWC), as authorized by the 1944 Treaty between the United States and Mexico: Utilization of Waters of the Colorado and Tijuana Rivers and of the Rio Grande (59 Stat 1219; TS 994).

The reservoir level constantly fluctuates in response to upstream inflows, evaporation, transpiration, infiltration, and downstream releases from Amistad Dam. The lake receives drainage from basins within the United States and Mexico, including the Rio Grande, Pecos River and Devil's River, with a total watershed size of approximately 126,423 square miles (327,434 square km) (TWDB 2008). The large surface area of the reservoir, between 32 and 81 square miles (83 to 210 square km) depending on lake levels (TWDB 2019a), results in a large loss due to evaporation (Porter et al. 2009). The inundation zone of the reservoir has become habitat for invasive non-native species, including *Tamarix* sp. (salt cedar), which has a high rate of transpiration (Porter et al. 2009). The reservoir was designed to minimize seepage by excavating the dam foundation, filling sinkholes, and constructing a grout curtain along the dam centerline. However, since construction, several new sinkholes have formed in the karstic carbonate rocks characteristic of the near-surface geology (Stanton et al. 2007). Seepage and infiltration into sinkholes and along fractures likely represents a substantial source of loss at the reservoir. The IBWC controls releases from the Amistad Dam to the Rio Grande, and calculates the ownership of the conservation storage and releases on a weekly basis.

The fluctuating water level has important impacts on the park's infrastructure and resources. In drought years, water level drops, exposing boat docks to dry land, impacting visitor access to the lake. The invasive

non-native clam *Corbicula* spp. utilizes the shoreline zone, and expands into new areas as lake level changes. Burrowing by these clams has the potential to disturb archeological sites (Shaffer et al. 1997). The adjacent aquifer is also hydraulically connected to the Amistad Reservoir, demonstrated by increased groundwater levels that followed the initial filling of the reservoir. Infiltration from the reservoir has stabilized groundwater levels and likely caused a substantial increase in baseflow from streams and springs from the same aquifer compared to the pre-reservoir period (Boghici 2004). Due to hydraulic connectivity of groundwater to the reservoir, increased groundwater pumping may potentially result in a decrease in the reservoir water level (TWDB 2018).

Reservoir level is not a Chihuahuan Desert Network vital sign; however, it is addressed in this report because the reservoir level has implications for natural resources throughout Amistad NRA, including groundwater and springs.

3.2 Methods

The IBWC has operated a water level gage at Amistad Reservoir (International Amistad Reservoir Storage Station Number 08-4508.00) since 1968 when filling began. The gage is located at the downstream end of the reservoir at the outlet to the Rio Grande. Water level data is collected every 15 minutes. Amistad Reservoir water level data is available from the [IBWC \(https://www.ibwc.gov/Water_Data/rtdata.htm\)](https://www.ibwc.gov/Water_Data/rtdata.htm) and the [Texas Water Development Board \(TWDB\) \(https://waterdatafortexas.org/reservoirs/individual/amistad\)](https://waterdatafortexas.org/reservoirs/individual/amistad), which we utilized for this report (TWDB 2019a).

3.3 Results

Mean reservoir level in WY2018 was 1089.37 feet above mean sea level (amsl), 3.14 feet lower than the mean for WY2017, and 4.29 feet lower than the mean of 1990–2017. The daily water level in WY2018 remained below the daily mean for water years 1990–2017 (0.73–12.66 feet below) (Figure 3-1). The WY2018 mean water level was 27.63 feet below the conservation pool elevation. The reservoir ranged from being 55.7–75.8% full (TWDB 2019a).

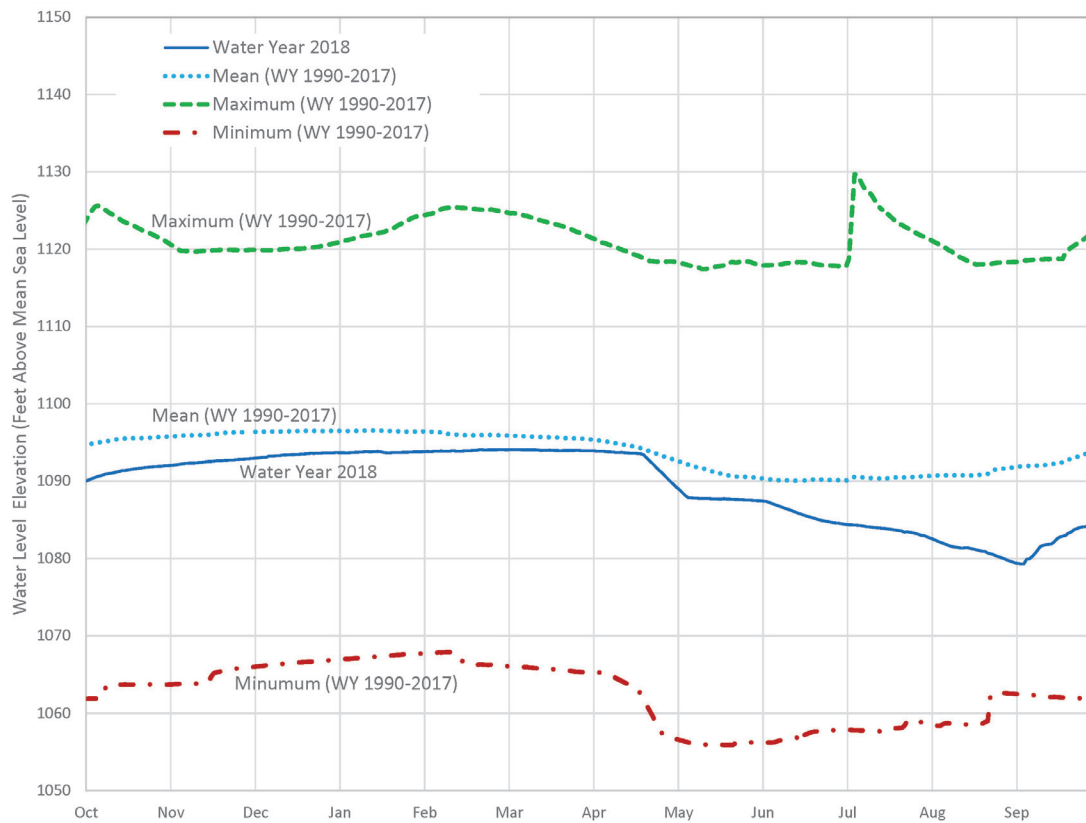


Figure 3-1. Daily Amistad Reservoir water level elevation in water year 2018, with daily mean, maximum and minimum for water years 1990–2017 (TWDB 2019a).

4 Groundwater

4.1 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 almost all people in the southwestern United States. Groundwater, therefore, interacts either directly or indirectly with all key ecosystem features of the arid Chihuahuan Desert ecoregion (Filippone et al. 2014).

Since the reservoir was completed and filled, the reservoir level has been the main driver of groundwater levels at Amistad NRA. In comparison, direct infiltration of precipitation and streamflow play a minor role in groundwater recharge. While groundwater measurements in Val Verde Country generally do not show an increasing or decreasing trend, the wells in the vicinity of Amistad reservoir increased as much as 100 feet after Amistad Reservoir was filled, due to the increased hydraulic pressure (TWDB 2018). Groundwater up to 20 miles (32 km) away may have been affected by the increased pressure head in the reservoir. Overall, the hydraulic gradient near the reservoir is relatively flat (Boghici 2004), and wells near Amistad Reservoir track closely to the water level in the reservoir (TWDB 2018). Water chemistry data also indicates that water from Amistad Reservoir, which is a mixture of surface water and groundwater, has displaced groundwater down gradient from the reservoir (TWDB 2018).

Although Amistad NRA was not included in the initial Chihuahuan Desert Network groundwater monitoring protocol (Filippone et al. 2014), it is addressed in this report because of its interaction with lake level and springs.

4.1.1 Methods and monitoring wells

Six wells in or near Amistad NRA (Figure 4-1 and Table 4-1) are monitored annually by the TWDB and data were downloaded from their [website \(http://www.twdb.texas.gov/groundwater/data/gwdbbrpt.asp\)](http://www.twdb.texas.gov/groundwater/data/gwdbbrpt.asp) (TWDB 2019b). All monitoring wells are completed within the Edwards Limestone Aquifer (TWPD 2019), the upper part of the Edwards-Trinity (Plateau) Aquifer (TWPD 2018). There are several additional wells in Amistad NRA, and many have historic data.

4.2 Results

All six wells were monitored on February 14 or 15, 2018. Results for WY2018 are provided in Table 4-2. Figures 4-2 and 4-3 display the depth to water and elevation of the wells for the entire period of record. Groundwater levels in wells 7033302, 714021, 7140307 were within 11.03 feet of the reservoir levels. The groundwater level in well 7033508 was more than 43 feet below the reservoir level; however, the historic record indicates that water levels at this well has fluctuated with the lake level, similar to wells 7033302 and 7140201. Water levels in wells 7017403 and 7140307 are both substantially above the reservoir level because they are up gradient of the reservoir, adjacent to the Devils River and the Pecos River, respectively. Additional data at these two wells and 7140307 are required to determine the influence of the reservoir on the groundwater levels.



Figure 4-1. Location of monitoring wells at Amistad NRA.

Table 4-1. Wells in and near Amistad NRA currently monitored by Texas Water Development Board (TWDB 2019b)

State Well Number	Owner	Water Use	Inside or Outside Park (miles from boundary)	Elevation (feet)	Depth of Well (feet)
7017403	Devil's River SNA Lodge	Public Supply	Outside – 0.04 miles	1180	625
7033302	Private	Stock	Outside – 0.32 miles	1215	Unknown
7033508	Private	Domestic	Outside – 0.20 miles	1175	437
7122403	National Park Service	Public Supply	Inside	1312	Unknown
7140201	National Park Service	Unused	Inside	1167	405
7140307	Laughlin Air Force Base	Public Supply	Inside	1162	400

Table 4-2. Groundwater monitoring results in water year 2018, Amistad NRA (TWDB 2019a; 2019b).

State Well Number	Depth to Water (feet bgs)	Elevation (feet amsl)	Change in elevation from water year 2017 ($\pm$ feet)	Elevation difference from Amistad Reservoir Level ($\pm$ feet)
7017403	61.92	1118.08	+0.22	+24.20
7033302	129.93	1085.07	-4.83	-8.80
7033508	124.34	1050.66	-5.34	-43.21
7122403	160.31	1151.69	+2.69	+57.82
7140201	80.11	1086.89	+9.29	-6.98
7140307	79.16	1082.84	+8.62	-11.03

bgs = below ground surface. amsl = above mean sea level.

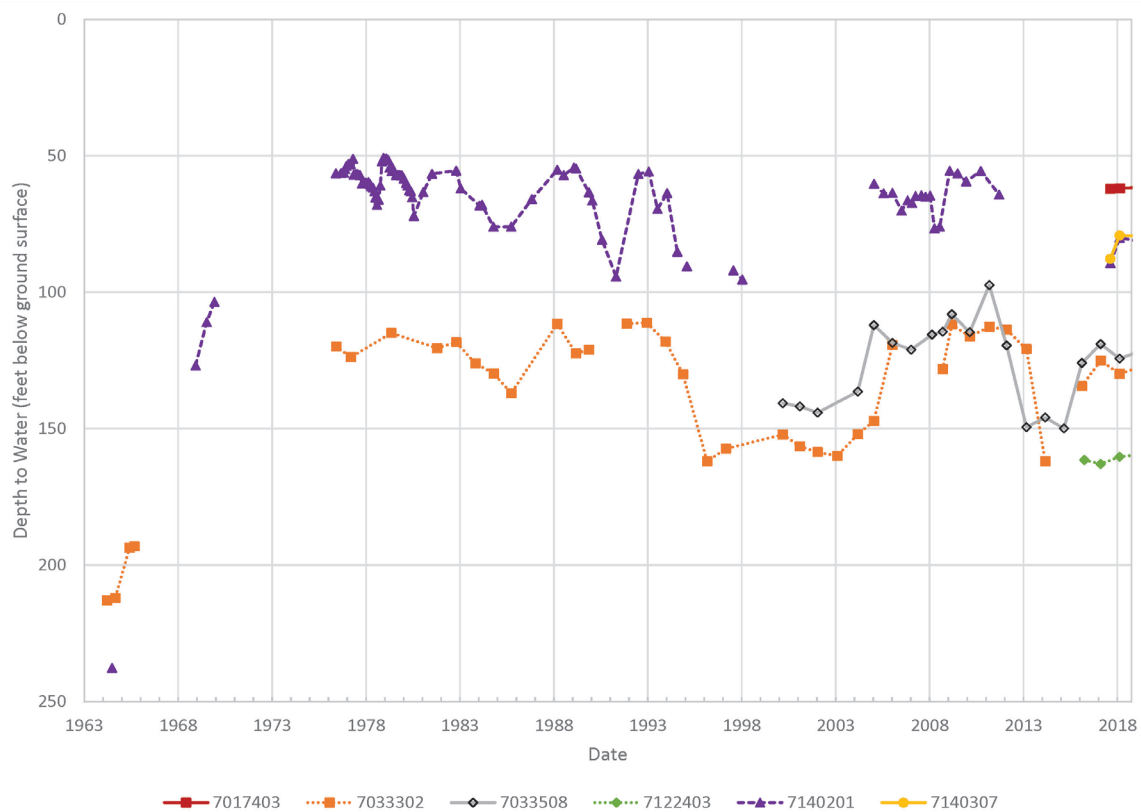


Figure 4-2. Depth to water below ground surface at six groundwater monitoring wells, 1964–2018, Amistad NRA. Data from TWBD (2019b).

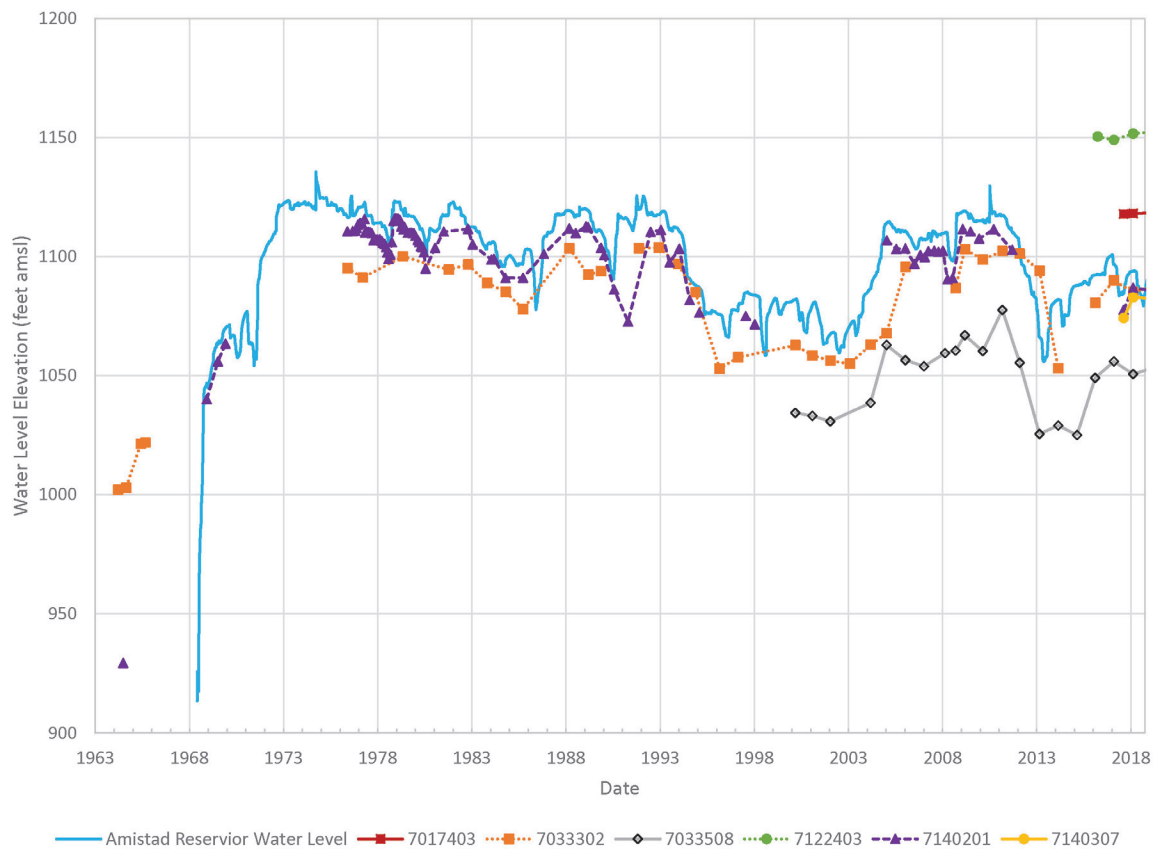


Figure 4-3. Water level elevation at six groundwater monitoring wells and Amistad Reservoir, 1964–2018, Amistad NRA. TWBD (2019b).

5 Springs

5.1 Background

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

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

5.2 Methods

The Chihuahuan Desert Network monitoring focuses on four “sentinel sites” (McIntyre et al. 2018): Big Satan Canyon Spring, Dead Mans Canyon Spring, Indian Springs Canyon Spring, and Mouth of the Pecos. Note that the statistical inference provided by this design is limited to each individual spring monitored over time.

The Chihuahuan Desert Network monitors a suite of vital signs and parameters organized into four modules: site characterization, site condition, water quantity, and water quality (McIntyre et al. 2018). A brief description of the data collection methodologies followed at Amistad NRA during WY2018 is extracted from the protocol (McIntyre et al. 2018) and presented below. See McIntyre et al. (2018) for additional details.

5.2.1 Site characterization

The site characterization module is a modification of the inventory methods developed for the Mojave Desert Network (Sada and Pohlmann 2006). The site characterization module is completed once every five years, or after significant events, and provides context for interpreting change in the other modules. The

module includes spring type and characterization, GPS locations, site diagram and site description, and vegetation community description. See the springs monitoring protocol for details (McIntyre et al. 2018). This module was completed at Amistad NRA in 2018 and will be recollected in 2023. This report presents a highly condensed and edited version of the information collected in the site characterization module.

5.2.2 Site condition

The site condition module is based on inventory methods developed for the Mojave Desert Network (Sada and Pohlmann 2006) and contains four subsections: disturbance, photo points, obligate/facultative wetland plants, and invasive non-native plants and wildlife (McIntyre et al. 2018). The disturbance assessment is a categorical measure of natural and anthropogenic disturbance and the level of stress on vegetation and soils in spring ecosystems (Sada and Pohlmann 2006). Types of natural disturbance evaluated include flooding, drying, fire, wildlife, windthrow of trees and shrubs, beaver activity, and insect infestations. Types of anthropogenic disturbance include roads and off-highway vehicle trails, hiking trails, livestock, feral animals, removal of invasive non-native plants, flow modification, and contemporary human use as evidenced by presence of campsites, fire rings, trash, etc. An “other” category is also included for both natural and anthropogenic disturbances. Magnitude of each disturbance on the spring is classified on a scale of 1–4, where 1 = undisturbed, 2 = slightly disturbed, 3 = moderately disturbed, and 4 = highly disturbed (Sada and Pohlmann 2006).

5.2.3 Water quantity

The water quantity module provides information on the persistence of springs, spring discharge, and wetted extent (McIntyre et al. 2018). The persistence of surface water at springs is estimated by analyzing the variance of temperature measurements taken every hour by electronic data recorders (Anderson et al. 2015). A sensor placed at the orifice is utilized to estimate presence of water as submersion of the sensor mediates diurnal temperatures (Anderson et al. 2015). The method can yield both false wet and false dry estimates, and quality control/quality assurance procedures are yet to be developed. Volumetric discharge calculates the system’s surface

outflow through a timed sample of water volume. Wetted extent measures the length (up to 100m; 328ft), width, and depth of surface water.

5.2.4 Water quality

Water quality monitoring includes core water quality parameters and water chemistry. Core parameters sampled by the Chihuahuan Desert Network include water temperature, pH, specific conductivity, dissolved oxygen, and total dissolved solids. Discrete samples of these parameters are collected with a multiparameter meter (YSI Professional Plus) and an optical dissolved oxygen meter (YSI ProODO) deployed on-site (McIntyre et al. 2018). Water chemistry is assessed by collecting a surface water sample(s) and estimating the concentration of major ions with a photometer (YSI 9500) (McIntyre et al. 2018).

5.3 Results and discussion

5.3.1 Big Satan Canyon Spring

5.3.1.1 Site characterization and visit information

Big Satan Canyon Spring (Figure 5-1) was classified as a rheocrene spring because the water trickles into the highest extent of the lake. The monitoring crew estimated that the water present on April 5, 2018 was dominated by spring discharge. The reservoir level was 333.4m (1093.8ft) amsl on the day of the survey (TWDB 2019a). Big Satan Canyon Spring emerges from a series of six orifices. Orifices A–F gently flow into the lake in a circular pattern. Orifice A is the farthest east and trickles from a 10–20cm (0.3–0.7ft) deep crack. Orifice B is 10–15m (32.8–49.2ft) to the southwest and emerges as a 2–3m (6.6–9.8ft) trickle over bedrock with vegetation. Orifice C is 10m (32.8ft) farther southwest and is within a 30cm



Figure 5-1. Big Satan Canyon Spring landscape, Amistad NRA, April 2018.

(1.0ft) deep crack, and almost immediately pours into the lake. Orifice D is at the west edge of the pool and emerges from within 2 cracks within a meter. Orifice E and F are on the north-northwest edge of the canyon. Orifice E is in a deep crack and orifice F emerges from a 1m (3.3ft) square cave-like hole. Water from all orifices is cool and clear and almost immediately flows into the lake. Substrate is bedrock with many fractures, some filled with vegetation.

5.3.1.2 Site condition

Disturbance surveys resulted in a median value of 1 = undisturbed for both anthropogenic and natural disturbance. There was minimal evidence of contemporary human use based on trash along the hike to the site. Park staff indicated that this site is known to be a destination for park visitors. Mouflon sheep were also observed on the hike in, with slight indications of browsing and scat at the spring site.

The crew observed two obligate/facultative wetland plant genera and one family: spikerush (*Eleocharis* sp.), fogfruit (*Phyla* sp.), and rush (Juncaceae family). Three invasive plants were noted at Big Satan Canyon

Spring: tree tobacco (*Nicotiana glauca*) and King Ranch /yellow bluestem (*Bothriochloa ischaemum*), both in scattered patches, and a few individual prickly lettuce (*Lactuca serriola*). Crayfish were observed in the lake near orifice C.

5.3.1.3 Water quantity

Temperature sensors were not deployed due to concern about sensor loss so there is no data on wet/dry periods. Discharge from orifice F was estimated at 71.7 ± 1.9 L/minute (19.0 ± 0.5 gal/minute). Although classified as a rheocrene spring, Big Satan Canyon Spring was surveyed as having standing water with an average length of 32.5m (106.6ft) and width of 11.4m (37.4ft). Depth was unmeasurable. Due to its proximity to the lake, these measurements may be more indicative of the lake level.

5.3.1.4 Water quality

In 2018, core water quality (Table 5-1) and water chemistry (Table 5-2) were measured at each orifice, totaling six samples.

Table 5-1. Water Quality data for Big Satan Canyon Spring at Amistad NRA, WY2018.

Sampling Location	Orifice(s)	Sample time (24 hr)	Temperature (°C)	Dissolved Oxygen (mg/L)	pH	Specific Conductivity (µS/cm)	Total Dissolved Solids (mg/L)	Exposure
1	A	12:04	22.4	4.82	7.39	422.2	274.3	Shade
2	B	11:50	22.8	4.39	7.29	434.0	282.1	Shade
3	C	11:46	23.1	4.77	7.33	431.2	280.2	Shade
4	D	11:39	23.9	5.14	7.36	434.2	282.1	Shade
5	E	11:29	22.7	4.49	7.34	431.0	280.2	Shade
6	F	11:25	22.7	4.60	7.32	431.8	280.8	Sun

Table 5-2. Water Chemistry data for Big Satan Canyon Spring at Amistad NRA, WY2018. All results in mg/L.

Sampling Location	Orifice(s)	Alkalinity	Calcium	Chloride	Magnesium	Potassium	Sulfate
1	A	245	62	11	15	1.6	2
2	B	205	58	10	16	1.4	1
3	C	240	64	15	15	1.6	2
4	D	320	54	11	14	1.5	4
5	E	320	52	8	15	0.6	0
6	F	310	64	9	16	1.6	1

5.3.2 Dead Mans Canyon Spring

5.3.2.1 Site characterization and visit information

Dead Mans Canyon Spring (Figure 5-2) is a hanging garden and the crew estimated that the water present on April 4, 2018 was dominated by spring discharge. The reservoir level was 333.4m (1093.86ft) amsl on the day of the survey (TWDB 2019a). Dead Mans Canyon Spring emerges several meters above the lake and is about 25m (82.0ft) wide with six orifices. Three orifices with consolidated flow occur along the face that is rich in vegetation. The flow from orifice A at the northeast end combines into a channel with a pool. Orifice B and C flow directly into the lake. Orifice D from preliminary 2017 sampling was dry. Orifice E and orifice F emerge to the north side of the drainage. All water from all orifices is cool and clear with algae in pools.

5.3.2.2 Site condition

Disturbance surveys resulted in a median value of 1 = undisturbed for both natural and anthropogenic

sources. The only disturbance in 2018 noted by staff was a broken beer bottle. Other possible disturbances were difficult to determine due to the bedrock substrate.

The crew observed several obligate/facultative wetland plants: mule-fat (*Baccharis salicifolia*), sneezeweed (*Helenium* sp.), maidenhair fern (*Adiantum* sp.), giant reed (*Arundo* sp.), and spikerush (*Eleocharis* sp.). Four invasive non-native species were noted at Dead Mans Canyon Spring. A few tree tobacco (*Nicotiana glauca*) plants were found and removed by the crew at orifice B. King Ranch/yellow bluestem (*Bothriochloa ischaemum*), Bermudagrass (*Cynodon dactylon*) and potentially dallisgrass (*Paspalum dilatatum*) occurred in scattered patches. Presumably the giant reed is non-native invasive but the crew did not record density information for it. No invasive non-native wildlife (crayfish or bullfrogs) was observed.



Figure 5-2. Dead Mans Canyon Spring landscape, Amistad NRA, April 2018

5.3.2.3 Water quantity

Temperature sensors installed at orifice A during the visit indicated that the spring was wetted from April 2018–October 2018 (Figure 5-3). Discharge from orifice A was estimated at 6.7 ± 0.1 L/minute (1.8 ± 0.03 gallons/minute), orifice E was estimated at 10.4 ± 0.2 L/minute (2.8 ± 0.1 gallons/minute), and orifice F was estimated at 9.5 ± 0.5 L/minute (2.5 ± 0.1 gal/minute). Dead Mans Canyon Spring was assessed as a rheocrene system with a channel length of 6.7m (22.0ft). Width and depth averaged 92.9cm (3.0ft) and 5.8cm (0.2ft) respectively.

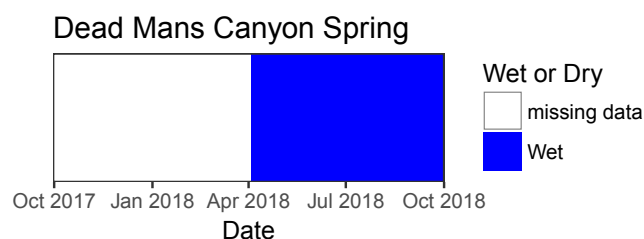


Figure 5-3. Estimated wet/dry days at Dead Mans Canyon Spring.

5.3.2.4 Water quality

Core water quality (Table 5-3) and water chemistry (Table 5-4) were sampled at five locations at Dead Mans Canyon Spring.

5.3.3 Indian Springs Canyon Spring

5.3.3.1 Site characterization and visit information

Indian Springs Canyon Spring (Figure 5-4) is a rheocrene spring with a single orifice and the crew estimated that the water present on April 3, 2018 was dominated by spring discharge. The reservoir level was 333.4m (1093.8ft) amsl on the day of the survey (TWDB 2019a). Orifice A emerges from a long bedrock seam with most flow from the northeast corner of the first pool. This flow is cool and clear. The substrate is mainly bedrock with the sides and downstream portion changing to gravel on bedrock. A thick algae mat is present on the surface of much of the pool and submerged algae is found throughout.

5.3.3.2 Site condition

Disturbance surveys resulted in a median value of 1 = undisturbed. The site is likely used contemporarily by campers at the campsite downstream, but there was no evidence of human use during this sample period. Barbary sheep were noted to have caused moderate disturbance to the site.

No obligate/facultative wetland plants were observed. There were four invasive non-native species noted by the crew. King Ranch/yellow bluestem (*Bothriochloa ischaemum*) was the most prominent, occurring in

Table 5-3. Water Quality data for Dead Mans Canyon Spring at Amistad NRA, WY2018.

Sampling Location	Orifice(s)	Sample time (24 hr)	Temperature (°C)	Dissolved Oxygen (mg/L)	pH	Specific Conductivity (µS/cm)	Total Dissolved Solids (mg/L)	Exposure
1	A	14:37	21.4	12.02	8.18	424.6	275.6	Shade
2	B	14:40	22.7	8.28	7.93	463.3	301.0	Shade
3	C	14:46	23.3	7.07	7.59	463.3	301.0	Shade
5	E	14:53	24.2	6.01	7.35	463.2	301.0	Sun
6	F	14:56	24.5	15.42	7.49	439.7	286.0	Sun

Table 5-4. Water Chemistry data for Dead Mans Canyon Spring at Amistad NRA, WY2018. All results in mg/L.

Sampling Location	Orifice(s)	Alkalinity	Calcium	Chloride	Magnesium	Potassium	Sulfate
1	A	180	58	14	96	1.7	3
2	B	195	70	14	17	2.1	5
3	C	175	66	14	17	2.0	2
5	E	220	68	14	12	2.0	4
6	F	175	60	14	15	1.2	8



Figure 5-4. Indian Springs Canyon Spring orifice A, Amistad NRA, April 2018

scattered patches. One to five individual plants were noted for the other three species: common mullein (*Verbascum thapsus*), Bermudagrass (*Cynodon dactylon*), and lilac chastetree (*Vitex agnus-castus*). No invasive non-native wildlife (crayfish or bullfrogs) was observed.

5.3.3.3 Water quantity

Temperature sensors indicated that the spring was dry for the majority of the sampled period (April 2018–October 2018; Figure 5-5). The sensor stopped recording on September 14, 2018 and it is unclear if it was dislodged prior to that date. Discharge from orifice A was estimated at 86.5 ± 2.8 L/minute (22.8 ± 0.7 gal/minute). Indian Springs Canyon Spring was assessed as a rheocrene system. The channel length was 29.1m (95.6ft), with a mean wetted width of 293.1cm (9.6ft) and mean depth of 13.7cm (0.4ft).

5.3.3.4 Water quality

The crew measured core water quality (Table 5-5) and water chemistry (Table 5-6) at orifice A.

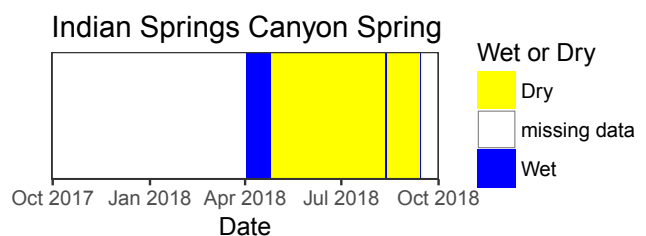


Figure 5-5. Estimated wet/dry days at Indian Springs Canyon Spring.

5.3.4 Mouth of the Pecos

5.3.4.1 Site characterization and visit information

The Mouth of the Pecos Spring (Figure 5-6) is a limnocrene spring with four potential orifices and the crew estimated that the water present on April 4, 2018 was dominated by spring discharge. The reservoir level was 333.4m (1093.8ft) amsl on the day of the survey (TWDB 2019a). The spring emerges as a series of pools and a long heleocrene the last $\frac{2}{3}$ of the system. Orifice A flows into the first pool. No flow was noted at orifice B, C, or D. Several large boulders separate this pool from the second and

Table 5-5. Water Quality data for Indian Springs Canyon Spring at Amistad NRA, WY2018.

Sampling Location	Orifice(s)	Sample time (24 hr)	Temperature (°C)	Dissolved Oxygen (mg/L)	pH	Specific Conductivity (µS/cm)	Total Dissolved Solids (mg/L)	Exposure
1	A	9:27	23.5	6.97	7.40	397.4	258.1	Sun

Table 5-6. Water Chemistry data for Indian Springs Canyon Spring at Amistad NRA, WY2018. All results in mg/L.

Sampling Location	Orifice(s)	Alkalinity	Calcium	Chloride	Magnesium	Potassium	Sulfate
1	A	180	52	8	13	0.9	4



Figure 5-6. Mouth of the Pecos orifice A, Amistad NRA, April 2018

largest/deepest pool. All flow is cool and clear with some algae on the gravel deposits. Boulders impound the spring with gravel and cobbles in the channel. Vegetation makes it difficult to see most of the system.

5.3.4.2 Site condition

Disturbance surveys resulted in a median value of 1 = undisturbed for both natural and anthropogenic disturbance. Contemporary graffiti was noted at the spring site. There was evidence of flooding (moved rocks, twisted sensor cord) but this appeared to have minimal effect on the spring system.

Six obligate/facultative wetland plants were observed: mule-fat (*Baccharis salicifolia*), giant reed (*Arundo* sp.), fogfruit (*Phyla* sp.), rabbitsfoot grass (*Polypogon* sp.), cattail (Typhaceae family), and saltcedar (*Tamarix* sp.). The crew found eight invasive non-native species at the spring site. There was a matrix of giant reed (*Arundo donax*), an even distribution of Bermudagrass (*Cynodon dactylon*) and scattered patches of prickly lettuce (*Lactuca serriola*). One to five individuals of saltcedar (*Tamarix ramosissima*), tree tobacco (*Nicotiana glauca*), annual rabbitsfoot grass (*Polypogon monspeliensis*), common sowthistle (*Sonchus oleraceus*), and castorbean (*Ricinus communis*) were also observed. Crayfish were observed.

Mouth of the Pecos



Figure 5-7. Estimated wet/dry days at Mouth of the Pecos.

5.3.4.3 Water quantity

Temperature sensors in the second (deepest) pool indicated that the spring was wetted throughout WY2018 (Figure 5-7). Discharge was not assessed due to high flow and lack of reliable sampling location. The pool at orifice A was assessed as a limnocrone system with an average length of 329.0cm (10.8ft), width of 245.3cm (8.0ft), and depth of 18.2cm (0.6ft). A second pool ~5m (~16.4ft) downstream had an average length of 529.7cm (17.4ft), width of 417.3cm (13.7ft), and depth of 45cm (1.5ft).

5.3.4.4 Water quality

The crew measured core water quality (Table 5-7) and water chemistry (Table 5-8) at two sampling locations associated with orifice A. Sampling location 1 is in the first, upstream pool and sampling location 5 is in the second, downstream pool.

Table 5-7. Water Quality data for Mouth of the Pecos at Amistad NRA, WY2018.

Sampling Location	Orifice(s)	Sample time (24 hr)	Temperature (°C)	Dissolved Oxygen (mg/L)	pH	Specific Conductivity (µS/cm)	Total Dissolved Solids (mg/L)	Exposure
1	A	10:53	24.0	5.26	7.39	552.0	357.5	Sun
5	A	11:07	22.8	3.77	7.40	553.0	357.5	Sun

Table 5-8. Water Chemistry data for Mouth of the Pecos at Amistad NRA, WY2018. All results in mg/L.

Sampling Location	Orifice(s)	Alkalinity	Calcium	Chloride	Magnesium	Potassium	Sulfate
1	A	205	60	35	19	2.0	29
5	A	215	60	21	20	2.9	34

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