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Natural Resource Stewardship and Science

Status of Climate and Water Resources at Saguaro National Park

Water Year 2019

Natural Resource Report NPS/SODN/NRR—2021/2336



ON THE COVER

Springs monitoring at Saguaro National Park. NPS photo.

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Water Year 2019

Natural Resource Report NPS/SODN/NRR—2021/2336

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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 water quality and quantity is central to assessing the condition of park biota and key cultural resources. The Sonoran Desert Network collects data on climate, groundwater, and surface water at 11 National Park Service units in southern Arizona and New Mexico. This report provides an integrated look at climate, groundwater, and springs conditions at Saguaro National Park (NP) during water year 2019 (October 2018–September 2019).

Annual rainfall in the Rincon Mountain District was 27.36" (69.49 cm) at the Mica Mountain RAWS station and 12.89" (32.74 cm) at the Desert Research Learning Center Davis station. February was the wettest month, accounting for nearly one-quarter of the annual rainfall at both stations. Each station recorded extreme precipitation events (>1") on three days. Mean monthly maximum and minimum air temperatures were 25.6°F (-3.6°C) and 78.1°F (25.6°C), respectively, at the Mica Mountain station, and 37.7°F (3.2°C) and 102.3°F (39.1°C), respectively, at the Desert Research Learning Center station. Overall temperatures in WY2019 were cooler than the mean for the entire record. The reconnaissance drought index for the Mica Mountain station indicated wetter conditions than average in WY2019. Both of the park's NOAA COOP stations (one in each district) had large data gaps, partially due to the 35-day federal government shutdown in December and January. For this reason, climate conditions for the Tucson Mountain District are not reported.

The mean groundwater level at well WSW-1 in WY2019 was higher than the mean for WY2018. The water level has generally been increasing since 2005, reflecting the continued aquifer recovery since the Central Avra Valley Storage and Recovery Project came online, recharging Central Arizona Project water. Water levels at the Red Hills well generally declined starting in fall WY2019, continuing through spring. Monsoon storms led to rapid water level increases. Peak water level occurred on September 18. The Madrona Pack Base well water level in WY2019 remained above 10 feet (3.05 m) below measuring point (bmp) in the fall and winter, followed by a steep decline starting in May and continuing until the end of September, when the water level rebounded following a three-day rain event. The highest water level was recorded on February 15. Median water levels in the wells in the middle reach of Rincon Creek in WY2019 were higher than the medians for WY2018 (+0.18–0.68 ft/0.05–0.21 m), but still generally lower than 6.6 feet (2 m) bgs, the mean depth-to-water required to sustain juvenile cottonwood and willow trees. RC-7 was dry in June–September, and RC-4 was dry in only September. RC-5, RC-6 and Well 633106 did not go dry, and varied approximately 3–4 feet (1 m).

Eleven springs were monitored in the Rincon Mountain District in WY2019. Most springs had relatively few indications of anthropogenic or natural disturbance. Anthropogenic disturbance included spring boxes or other modifications to flow. Examples of natural disturbance included game trails and scat. In addition, several sites exhibited slight disturbance from fires (e.g., burned woody debris and adjacent fire-scarred trees) and evidence of high-flow events. Crews observed 1–7 taxa of facultative/obligate wetland plants and 0–3 invasive non-native species at each spring. Across the springs, crews observed four non-native plant species: rose natal grass (*Melinis repens*), Kentucky bluegrass (*Poa pratensis*), crimson fountaingrass (*Cenchrus setaceus*), and red brome (*Bromus rubens*). Baseline data on water quality and chemistry were collected at all springs. It is likely that that all springs had surface water for at least some part of WY2019. However, temperature sensors to estimate surface water persistence failed at one site and were not deployed at two others for all or part of the water year. Water was present for most of the year at the other eight sites. For the four sites with measurable discharge during the WY2019 visit, two sites had flow rates below 1 L/minute, one site had flow ~5 L/minute; and one site had flow ~14 L/minute.

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1 Introduction

Climate and hydrology are major drivers of ecosystems. They dramatically shape ecosystem structure and function, particularly in arid and semi-arid ecosystems. Understanding changes in climate, groundwater, and springs is central to assessing the condition of park biota.

This document summarizes climate, groundwater, and springs conditions for water year (WY) 2019 (October 2018–September 2019) at Saguaro National Park (NP). Detailed analyses of trends will follow in subsequent reports as the period of record warrants such assessments. For details on the monitoring protocols, park setting and resources, and information on other resources of management focus, please see http://www.nps.gov/im/sodn/.

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). It is the primary driver of ecological processes on Earth.

Climate mediates the fundamental properties of ecological systems, such as soil–water relationships, plant–soil interactions, net primary productivity, the cycling of nutrients and water, and the occurrence, extent, and intensity of disturbances—in short, the underpinnings of the natural resources the National Park Service manages and protects.

A broader temporal scale (seasons to years) is what distinguishes climate from the instantaneous conditions reflected by the term "weather." Saguaro NP has five weather stations: one in the Tucson Mountain District (TMD) and four in the Rincon Mountain District (RMD) (Table 2-1, Figures 2-1 and 2-2). The park has two National Oceanic and Atmospheric Administration (NOAA) Cooperative Observer Program (COOP) weather stations (one in each district). The record from the TMD station (#28795) provides a reliable long-term climate dataset. The RMD also contains a Remote Automated Weather Station (RAWS) and two Davis weather stations installed by the Sonoran Desert Network (SODN) to provide real-time weather conditions and cover the topographic variability of the park.

Data from the RMD COOP station were obtained from the Applied Climate Information System (2021) maintained by the NOAA regional climate centers. Data from the other four stations were obtained from the Climate Analyzer (Walking Shadow Ecology 2021a, 2021b, 2021c, 2021d), a website that allows users to make on-demand tables and graphs with data from weather stations updated daily (Walking Shadow Ecology 2021e). See the SODN climate monitoring protocol (Hubbard et al. in prep) for details on methods and data handling.

An Aridity Index (UNEP 1992), based on the long-term average annual precipitation relative to the average annual potential evapotranspiration, can be a useful tool for contrasting the local climate of national parks (Figure 2-3). Used globally to classify climate zones, aridity index seeks to answer the question "How dry is dry?" (Tsakiris and Vangelis 2005). Using the period of record (1960–present), the climate of Saguaro NP's lower elevations is classified as arid.[1]

2.2 Results and discussion

2.2.1 Data quality

Data quality during WY2019 was variable. Both COOP stations had large data gaps, partially due to the 35-day federal government shutdown in December and January. The TMD COOP station had missing values on 89 days and the RMD station had missing values on 55 days. In the RMD, the RAWS station had missing values on four days

[1] The park's sky islands are not classified as arid, because they are substantially cooler and receive more rain than the valley bottoms.

Table 2-1. Weather stations at Saguaro National Park.

Type/ID	District	Location	Elevation	Start of service
NOAA COOP/Tucson 17 NW #28795	TMD	near Red Hills Visitor Center	2,562 feet (781 m)	1982
NOAA COOP/Saguaro National Park #27398	RMD	near Rincon Mountain Visitor Center	3,080 feet (939 m)	2008
RAWS/Rincon Arizona #21207	RMD	near Mica Mountain	8,210 feet (2,502 m)	1994
Davis	RMD	Desert Research Learning Center	2,750 feet (838 m)	2014
Davis	RMD	Madrona Ranger Station	3,424 feet (1,044 m)	2014

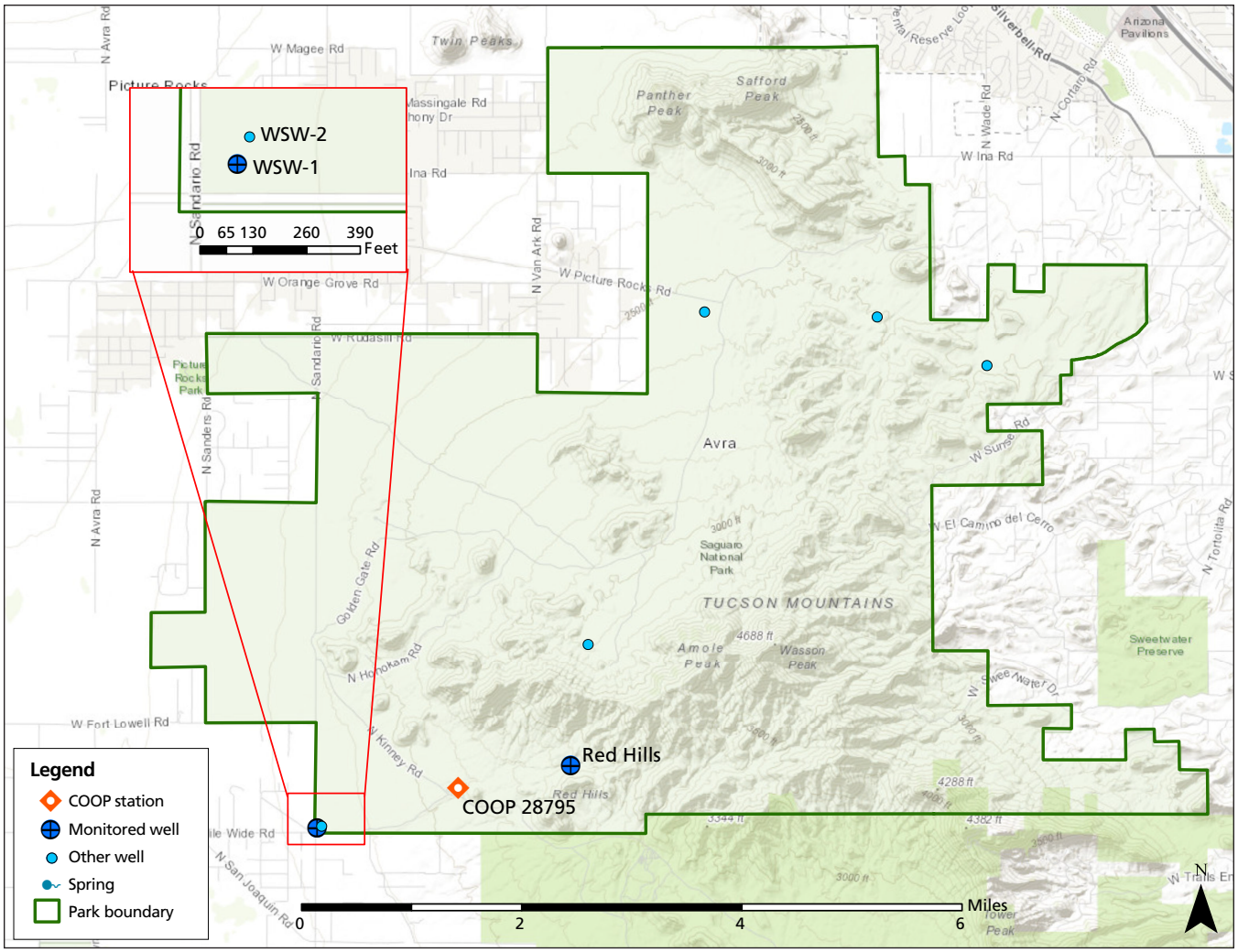


Figure 2-1. Climate stations and groundwater wells in the Tucson Mountain District, Saguaro National Park.

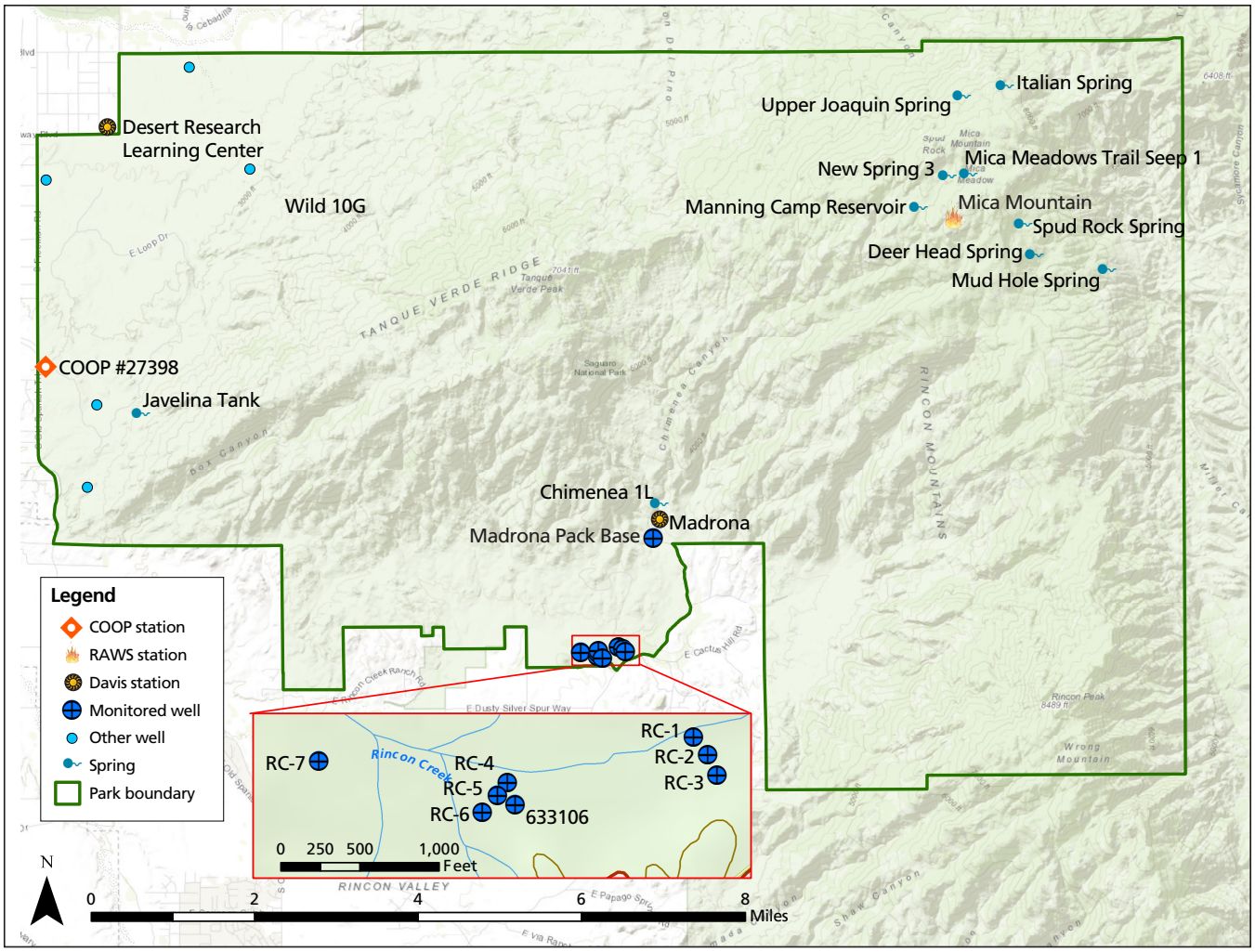


Figure 2-2. Climate stations, groundwater wells, and monitored springs in the Rincon Mountain District, Saguaro National Park.

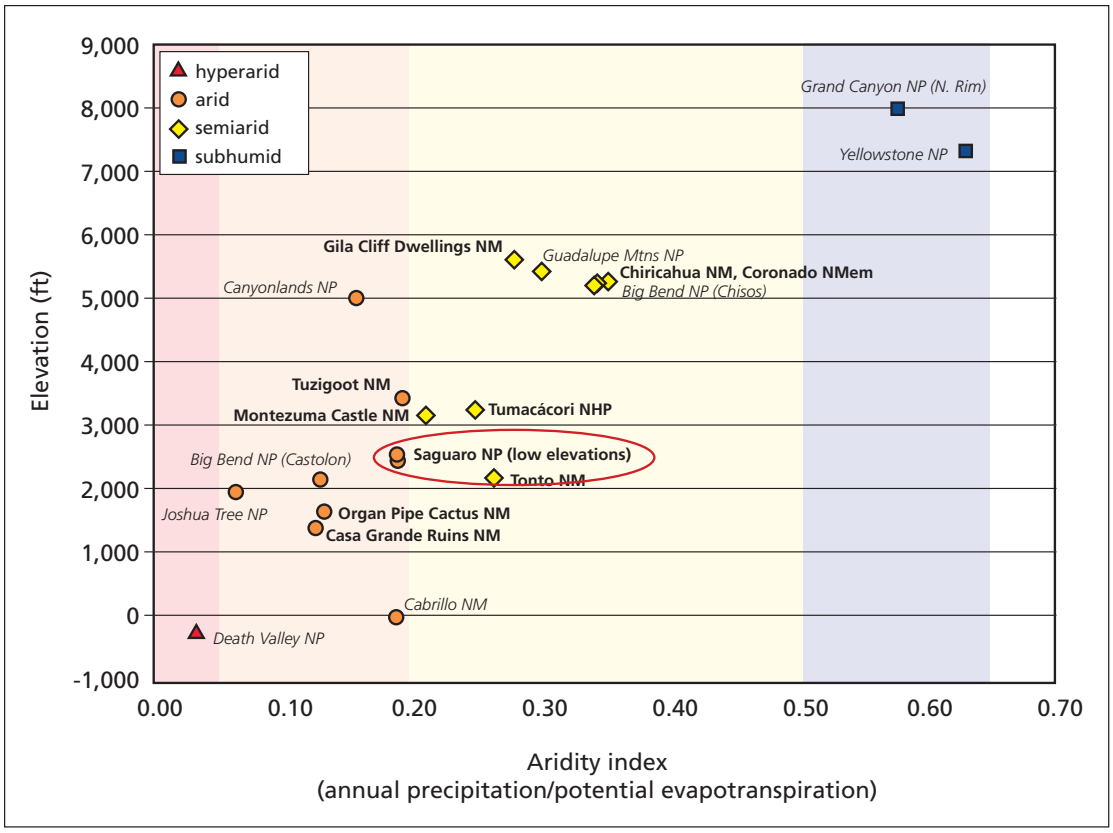


Figure 2-3. Aridity index and elevation of selected western national parks, including Saguaro National Park. Figure from Hubbard and others (in prep).

in March. The Desert Research Learning Center (DRLC) Davis station had missing temperature values on 10 days, primarily in April, and the Madrona Davis station stopped working in March. Due to the data-quality issues with the COOP stations, WY2019 climate data are only reported for the RAWS and DRLC stations (see Figure 2-2).

2.2.2 Annual and monthly temperature and precipitation

Overall annual precipitation at the Mica Mountain RAWS station in WY2019 was 27.36" (69.49 cm), 23% higher than the mean annual precipitation (22.33"/56.72 cm) for the data record (WY1995–2018). Total precipitation at the DRLC Davis station was 12.89" (32.74 cm). February was the wettest month, accounting for nearly a quarter of the annual rainfall at both stations (Figure 2-4).

The mean annual maximum and minimum air temperatures at the RAWS station were 60.5°F (15.8°C) and 41.4°F (5.2°C), respectively. These mean maximum and minimum temperatures were 2.8°F (1.6°C) and 1.2°F (0.7°C) cooler, respectively, than the means for the station record (WY1995–2018). Mean annual maximum and minimum temperatures at the DRLC Davis station were 82.1°F (27.8°C) and 53.0°F (11.7°C), respectively. These represented the coolest mean maximum and minimum temperatures in the five-year station record.

2.2.3 Reconnaissance Drought Index

Reconnaissance drought index (Tsakiris and Vangelis 2005) provides a measure of drought severity and extent relative to the long-term climate based on the ratio of average precipitation to average potential evapotranspiration over shorter periods of time (seasons to years). The reconnaissance drought index for the RMD RAWS station indicated wetter conditions in WY2019 than the average for WY1995–2019, from the perspective of both precipitation and evaporative demand (Figure 2-5).

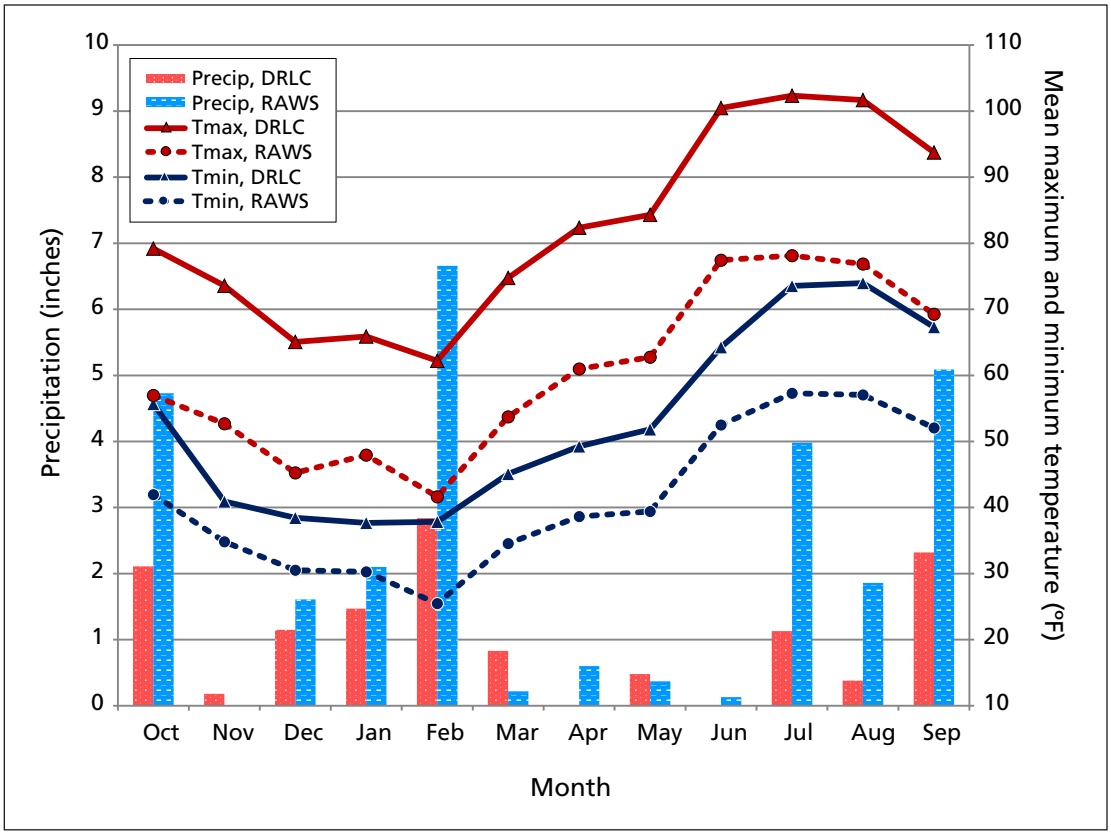


Figure 2-4. Climogram for Saguaro National Park, WY2019. The Mica Mountain RAWS station was missing >10% of daily data in March. The DRLC Davis station was missing >10% of daily temperature data in April. Care should be taken when interpreting values during those months. Graphic generated by climateanalyzer.org.

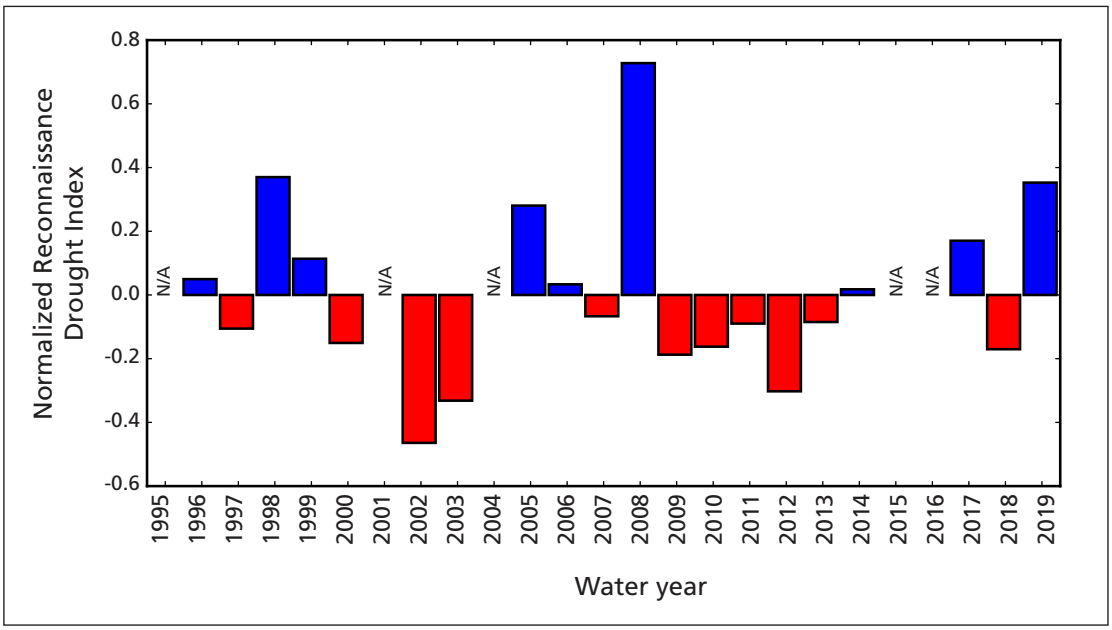


Figure 2-5. Reconnaissance drought index from the Mica Mountain RAWS station, Rincon Mountain District, Saguaro National Park, WY1995–2019. "N/A" = insufficient data to generate reliable RDI estimates. Graphic generated by climateanalyzer.org.

2.2.4 Extreme weather events

Stochastic events, such as air-temperature extremes and unusually intense precipitation events, may be as important to understanding ecological patterns as long-term climate averages are. Although high air temperatures are a defining feature of warm deserts, extreme frost events also have important consequences for Sonoran Desert ecosystems. In particular, sustained low air temperatures can damage or even kill long-lived keystone plants, including saguaro cactus (*Carnegiea gigantea*), the park's namesake and most iconic plant of the Sonoran Desert (Turner et al. 2003), and the aquatic organisms that live in spring pools and Rincon Creek. Extreme precipitation events can also cause localized flooding and erosion events, spur or inhibit plant productivity and reproduction, and modify animal behavior.

The Mica Mountain RAWS station recorded freezing temperatures on 84 days in WY2019. This was slightly more than the annual mean for 1995–2018 (81.2 days). Eleven days remained below freezing all day. The DRLC Davis station recorded freezing temperatures on 22 days, but none remained below 32°F (0°C) all day. The RAWS station recorded eight extreme precipitation events (days with >1"/2.54 cm precipitation) in WY2019, compared to a mean of 7.2 days for the period of record (WY1995–2018). These events ranged from 1.02" to 2.32" (2.59–5.89 cm) of precipitation. The DRLC Davis station recorded one extreme precipitation event on February 22, 2019 (1.13"/2.87 cm).

3 Groundwater

3.1 Background and methods

Groundwater is one of the most critical natural resources of the American Southwest. It provides drinking water, irrigates crops, and sustains 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, or even centuries later as perennial and intermittent streams and springs. Groundwater also sustains vegetation and is the primary source of water for most humans in the southwestern U.S. Groundwater therefore interacts either directly or indirectly with all key ecosystem features of the Sonoran Desert ecoregion.

SODN groundwater monitoring has both short- and long-term goals. Knowledge of groundwater status informs resource managers about ongoing, impending, or potential impacts to ecosystems and cultural resources that can occur when there is too much or too little water stored below the ground surface. This is especially important for the protection of high-value riparian habitats in the Sonoran Desert. Over the long term, groundwater data help us to recognize trends that are not part of normal variability, and to understand the linked above- and below-ground hydrologic processes that comprise the water balance. This understanding is essential for anticipating ecosystem response to climate change or other externally driven pressures affecting water resources. At Saguaro NP, groundwater monitoring is conducted via a combination of automated and manual sampling of water levels in wells.

Groundwater measurements are generally expressed in terms of depth-to-water (feet below ground surface) or water-level elevation (feet above mean sea level). Water-level elevation, which is equal to the land-surface elevation minus depth-to-water, allows direct comparison across multiple wells. More detailed information on monitoring methods may be found in the SODN groundwater monitoring protocol (Filippone et al. 2014).

3.1.1 Tucson Mountain District

Of the seven groundwater wells in the Tucson Mountain District (TMD), NPS staff and volunteers routinely monitor one deep and one shallow well: WSW-1 and Red Hills (see Figure 2-1 and Table 3-1). Other wells have been occasionally measured. WSW-1, the former water-supply well, has been manually measured quarterly since WY2009. The shallow Red Hills well has been monitored using an automated sensor since WY2015.

WSW-1 was the sole water supply for the TMD between 1964 and 2009. When a new, 660-foot-deep well, WSW-2 (ADWR 910129), came online in 2009, WSW-1 was converted to a monitoring well. The old and new wells are approximately 50 feet (15 m)

Table 3-1. Groundwater wells monitored at Saguaro National Park.

Name	State Registration Number/ GWSI Number	District	Year completed	Total depth (ft)	Wellhead elevation (est. ft)	Monitoring frequency (type)
WSW-1	629094/321453111130001	TMD	1964	560.0	2,336.00	4× per year (manual)
Red Hills	629095/not applicable	TMD	1937	32.4	2,795.00	1× per year (manual) 4× per day (automated)
Madrona Pack Base	629099/320902110363201	RMD	1964	117.0	3,350.00	1× per year (manual) 4× per day (automated)
RC-4	206880/320741110371301	RMD	2005	9.0	3,150.42	12× per year (manual)
RC-5	206879/320740110371401	RMD	2005	11.5	3,153.19	12× per year (manual)
RC-6	206878/320739110371501	RMD	2005	13.0	3,153.75	12× per year (manual)
RC-7	206877/320743110372701	RMD	2005	10.0	3,144.93	12× per year (manual)
633106	633106/320737110371001	RMD	1964	455.0	3,155.17	12× per year (manual)

apart. They are completed in the same water source, a permeable zone about 540–560 feet (165–171) below ground surface (bgs). This permeable zone is believed to be connected to the main Avra Valley aquifer, because water levels at monitoring wells in that aquifer track closely with those at the park (Valentine-Darby et al. 2017).

The Red Hills well is in the pediment zone, where a shallow alluvial fan, as well as terrace and colluvium sediments, cover near-surface bedrock. In the 1930s, the Civilian Conservation Corps developed the Red Hills well as a wildlife watering facility. It was upgraded in 1990 as part of wildlife mitigation for the Central Arizona Project (Saguaro National Park 2020). However, the well is not functional today. Monitoring at this well is focused on its potential to once again supply perennial water to wildlife.

3.1.2 Rincon Mountain District

Groundwater monitoring in the Rincon Mountain District (RMD) is focused on the middle reach of Rincon Creek, which supports an extensive riparian ecosystem and has both deep and shallow groundwater resources. The shallow aquifer occupies the highly permeable basin-fill alluvium. It is recharged primarily by mountain-front recharge originating as winter precipitation (Eastoe et al. 2012). Outflow from the alluvial aquifer occurs through seepage to Rincon Creek and its pools, evapotranspiration, subflow, and leakage to the deep bedrock aquifer (NPS 2008). The deep aquifer occupies rock fractures and is likely confined beneath an aquiclude. Groundwater in the deep aquifer is thousands of years old and likely originates as surface water (Eastoe et al. 2012). Discharge of groundwater from the deep aquifer occurs through pumping and at a few springs outside the park where there are breaches in the aquiclude. The park only has access to wells in the shallow alluvial aquifer.

NPS staff and volunteers monitor six wells along Rincon Creek (see Figure 2-2 and Table 3-1). RC-4, RC-5, RC-6, RC-7, and Well 633106 have been monitored monthly since WY2005 using manual and automated methods. The Madrona Pack Base well has been monitored with a pressure transducer since WY2011. Three more wells, RC-1, RC-2, and RC-3, located on inholdings within the legislated park boundary, were monitored until WY2015, when the park lost access to them. The other RMD groundwater wells are not routinely monitored because groundwater in those areas is not used by visitors, riparian vegetation, or wildlife (Valentine-Darby et al. 2017).

The Madrona Pack Base well is 117 feet (37 m) deep. It is located in the Upper Rincon Creek watershed, in Chimenea Creek (see Figure 2-2). Because the creek bottom frequently fluctuates, depth-to-water is is calculated as below measuring point (bmp), which is the top of the well casing, rather than bgs. The remaining five wells are located approximately two miles (3.2 km) downstream from the Madrona Pack Base well, along the middle reach of Rincon Creek.

The watershed of Middle Rincon Creek includes three major tributaries: Chimenea Creek, Madrona Creek, and the main stem of Rincon Creek. Monitoring wells RC-1, RC-2, and RC-3 are located perpendicular to Rincon Creek, with RC-1 closest to the channel and RC-3 furthest away. These shallow wells are 7.84–15.08 feet (2.39–4.60 m) deep, constructed to bedrock. RC-4, RC-5, and RC-6 are located 0.2 miles (0.32 km) further downstream. They are similarly positioned perpendicular to Rincon Creek, with RC-4 closest to the channel. These wells are 8.83–12.89 feet (2.69–3.93 m) deep, constructed to bedrock. RC-7 is an 8.98-foot (2.73-m) deep well located 0.25 miles (0.40 km) further downstream. Well 633106 is located immediately upstream from RC-5. At 455 feet, this well is substantially deeper than the other monitored wells in Rincon Mountain District, but it does not penetrate the deep aquifer (Manera Inc. 1982, as cited by Valentine-Darby et al. 2017).

3.2 Results and discussion

Data used for this section are considered preliminary. Caution should be exercised when interpreting the results.

3.2.1 Tucson Mountain District

In the TMD, mean groundwater levels in WY2019 were higher than in WY2018 (Table 3-2). Mean water level for WSW-1 was 319.81 feet (97.47 m) below ground surface (bgs) in WY2019. This was 5.69 feet (1.73 m) higher than the measurement in WY2018, and 167.05 feet (50.92 m) higher than the lowest water level observed in 2005 (Figures 3-1 and 3-2). The data reflect the

Table 3-2. Groundwater monitoring results, Saguaro National Park, WY2019.

Well	District	Measurement expression	Depth-to-water (feet bgs)	Water-level elevation (feet amsl)[A]	Highest water level (feet bgs)	Lowest water level (feet bgs)	Elevation difference from water year 2018 (+/- feet)
WSW-1	TMD	Mean	319.81	2,016.19	316.57	327.16	+5.69
Red Hills	TMD	Mean	8.51	2,786.49	3.43	12.09	+5.75
Madrona Pack Base	RMD	Mean	9.48[B]	3,357.72	1.86[B]	26.55[B]	n/a[C]
RC-4	RMD	Median	6.56	3,144.45	5.20	>8.83[D]	+0.18
RC-5	RMD	Median	8.77	3,144.37	7.28	11.04	+0.65
RC-6	RMD	Median	9.87	3,143.90	8.23	12.14	+0.68
RC-7	RMD	Median	8.42	3,136.48	6.87	>8.98[D]	+0.32
633106	RMD	Median	8.24	3,145.36	6.86	9.82	+0.59

[A] amsl = above mean sea level.
[B] Depth-to-water in feet below measuring point. Data presented for a subset available (10/1/2018–7/31/2019).
[C] Incalculable due to missing data in WY2018.
[D] Water level below the bottom of shallow well.

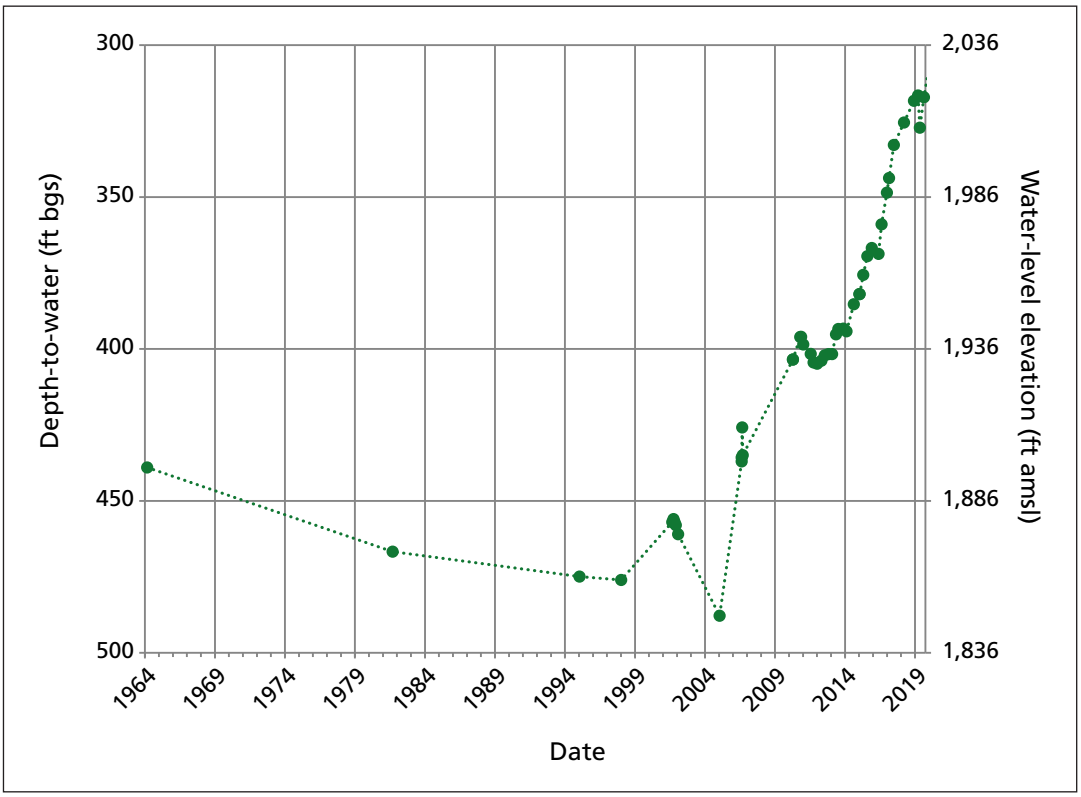


Figure 3-1. Depth-to-water and water-level elevation at well WSW-1 (ADWR 629094), 1964–2019, Saguaro National Park, Tucson Mountain District.

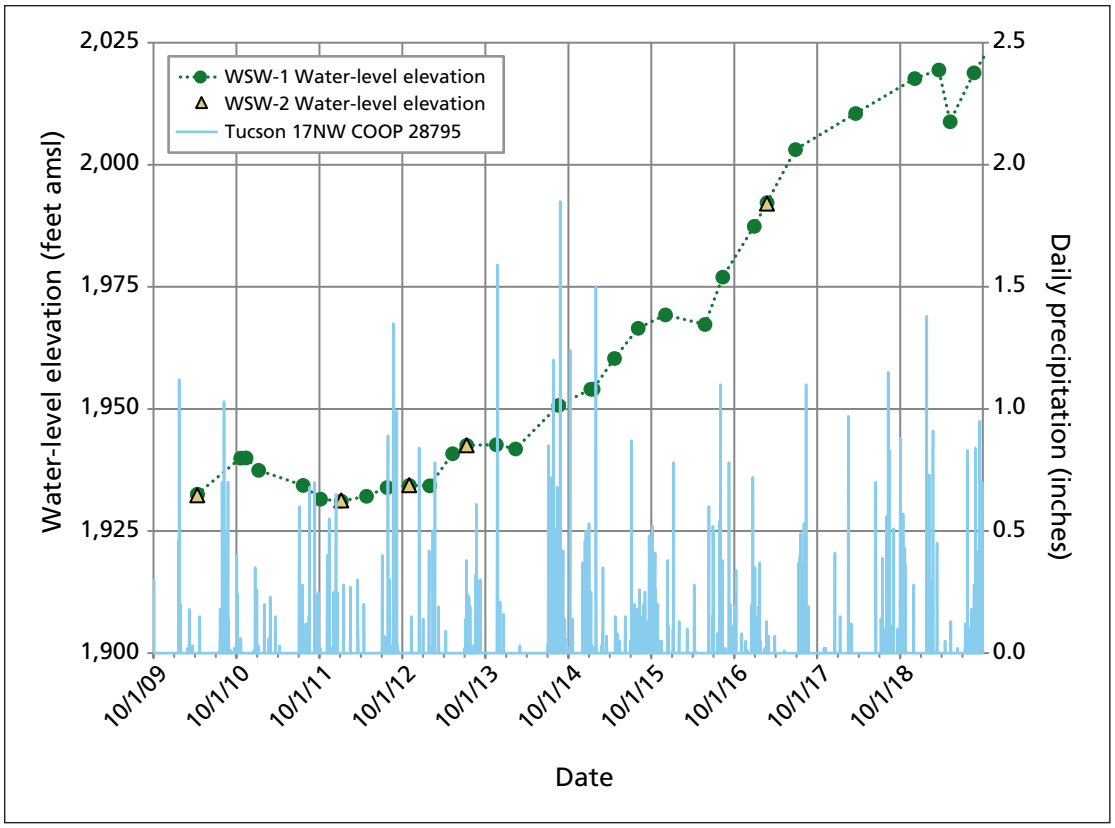


Figure 3-2. Water-level elevations at WSW-1 (ADWR 629094) and WSW-2 (ADWR 910129), with daily precipitation from COOP station 28795, WY2010–2019, Tucson Mountain District, Saguaro National Park. These data indicate that water-level elevation in WSW-1 is representative of the TMD's current water-supply well, WSW-2.

historical groundwater depletion of the Avra Valley aquifer, with water levels declining until WY2005, when the lowest water level on record was observed (486.86 ft/148.39 m bgs). Groundwater levels began to recover as the Central Avra Valley Storage and Recovery Project (CAVSARP), recharging Central Arizona Project water, came online. This recovery continues today.

Daily precipitation at the TMD COOP station (Tucson 17 NW #28795) is shown with water-level elevation in Figure 3-2. No obvious relationship between aquifer water level and precipitation is apparent. This is attributed to the depth of the water table below land surface, evapotranspiration, and the dominant signal of artificial recharge via CAVSARP over any natural-recharge signal. Studies have suggested that recharge to the Avra Valley aquifer from the Tucson Mountains varies from negligible to around 9,000 acre-feet per year (Dody et al. 2001, Mason and Bota 2006).

Mean water level at the Red Hills well was 8.51 feet (2.59 m) bgs in WY2019. This was 5.75 feet (1.75 m) higher than the WY2018 mean. Water levels generally declined starting in fall WY2019 and continuing through spring, followed by rapid increases during the monsoon season (Figure 3-3). The lowest water level recorded in WY2019 was 12.09 feet (3.69 m) bgs on July 23, one day prior to the first monsoon storm of the year. Peak water level was 3.43 feet (1.05 m) bgs on September 18, 2019, following a monsoon rain event. Similar seasonal fluctuations in water level also occurred in water years 2015, 2016, and 2018. However, water levels declined throughout WY2017, even during the monsoon season. This may indicate that the contributing watershed to this shallow aquifer is small, and subject to infiltration of precipitation from highly localized storm events.

3.2.2 Rincon Mountain District

Water levels at the Madrona Pack Base well remained above 10 feet (3 m) below measuring point (bmp) in the fall and winter of

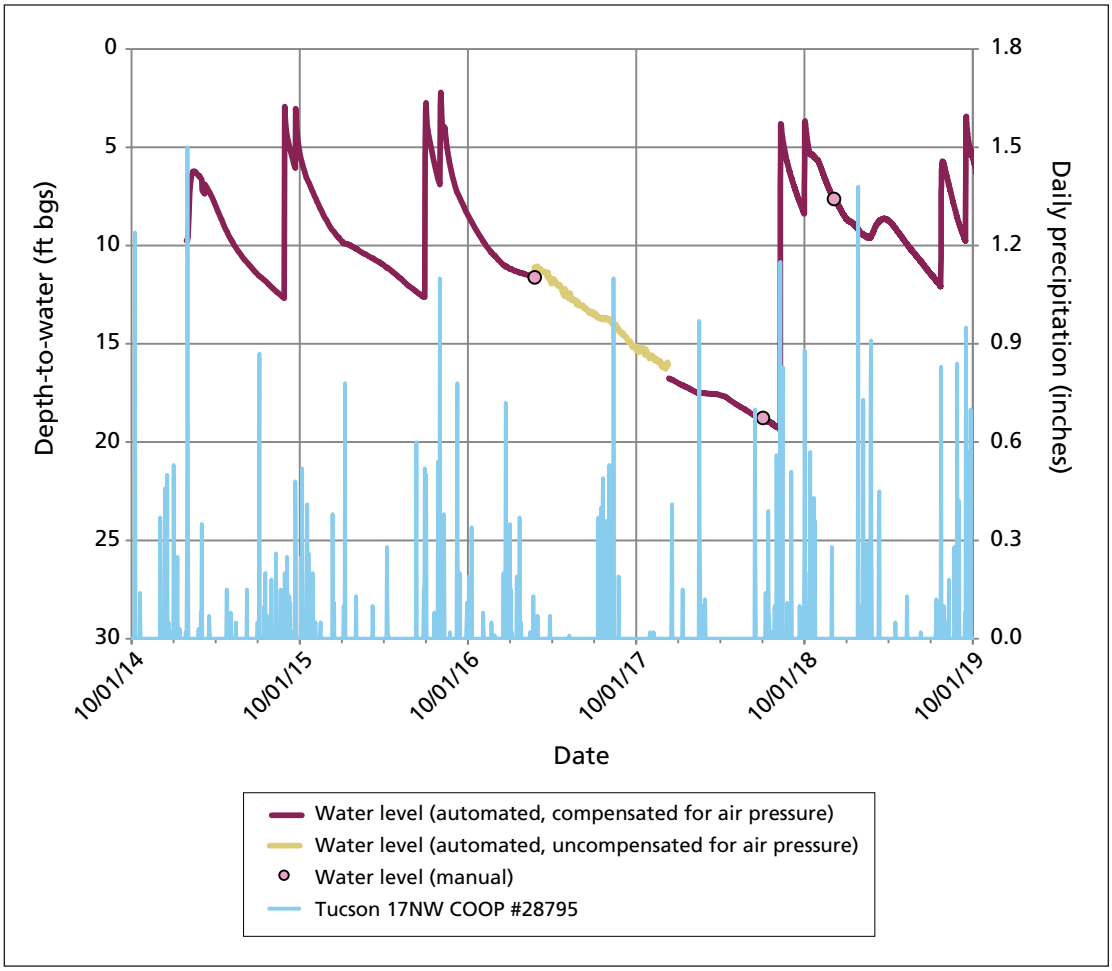


Figure 3-3. Depth-to-water at the Red Hills well (ADWR-629095), with daily precipitation from COOP Station Tucson 17NW #28795, WY2015–2019, Saguaro National Park, Tucson Mountain District. Automatic water levels were not corrected with barometric pressure from 02/22/17 to 09/30/17 due to equipment failure.

WY2019, fluctuating with precipitation (Figure 3-4). The highest water level, 1.86 feet (0.57 m) bmp, was recorded on February 15, following a two-day 3.34" (8.48 cm) rain event, as observed at the Mica Mountain RAWS station. Water levels began to steeply decline in May, and continued through September 24, to 26.55 feet (8.09 m) bmp. But they quickly rebounded to approximately 9 feet (2.7 m) bmp following a 2.67" (6.78-cm), three-day rain event. Water-level data for WY2019 were within the observed range of the monitoring record (starting in WY2011), indicating that subsurface flow in Chimenea Creek has varied from a peak of 0.45 feet (0.13 m) bmp in August 2015 to a minimum water level (unpumped) of 41.32 feet (12.59 m) bmp in July 2011 (Figure 3-4). Water levels in the well decline during periods without substantial precipitation, with annual minimum levels typically occurring during the months of June–August, following the normally dry spring months. To a lesser extent, water levels also often decline in fall. Following the onset of monsoon season, water-level rise in the Madrona Pack Base well may occur instantaneously or lag a few months (Valentine-Darby et al. 2017).

Water level in the wells in the middle reach of Rincon Creek (RC-4, RC-5, RC-6, RC-7, and 633106) were manually measured 12 times. Because water level frequently drops below the bottom of the wells, a mean cannot be calculated. For these wells, measurements are expressed in median rather than mean (see Table 3-2). Median water levels in WY2019 were higher than the medians for WY2018 (+0.18–0.68 ft/0.05–0.21 m). RC-7 was dry June through September. RC-4 was dry in only September. RC-5, RC-6 and Well 633106 did not go dry, but their levels (3.76

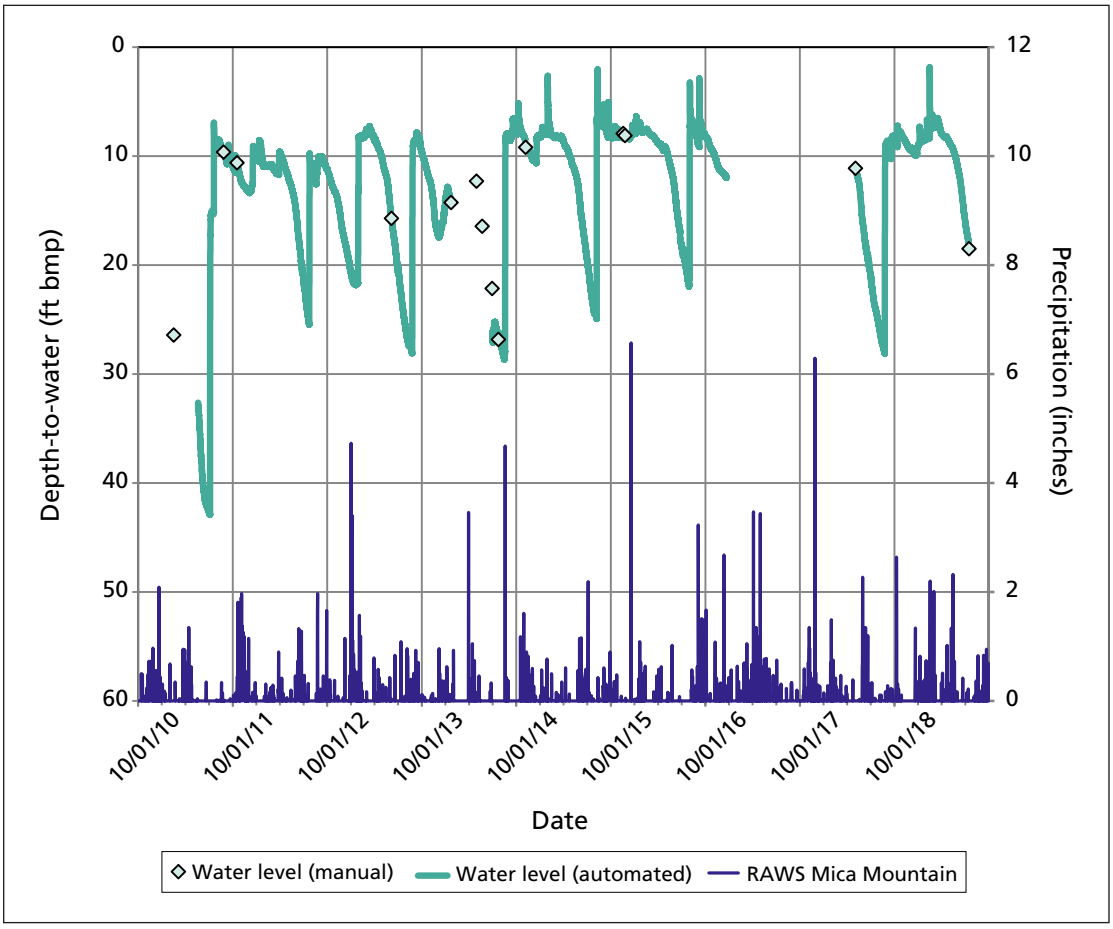


Figure 3-4. Depth-to-water below the measuring point at the Madrona Pack Base well (ADWR 629099), with daily precipitation from the Mica Mountain RAWS station, WY2011–2019, Rincon Mountain District, Saguaro National Park.

ft/1.15 m, 3.91 ft/1.19 m, and 2.96 ft/0.90 m bgs, respectively) varied. Median water level in each well in WY2019 was higher than the mean of the annual median for WY2006–2018 (+0.34–1.53 ft/0.10–0.47 m), except at RC-7, where water levels were 0.2 feet (0.06 m) lower. Total precipitation for WY2019, recorded at the Mica Mountain RAWS station, was 5.04" (12.8 cm) more than the mean annual precipitation for the period of record, WY2006–2018 (27.36" vs. 22.32"/69.49 vs. 56.69 cm; see Section 2.2.1). Higher-than-average rainfall in the mountains likely contributed to increased subsurface flow in the alluvium.

In WY2019, groundwater levels in Middle Rincon Creek were generally lower than 6.6 feet (2 m) bgs, the mean depth-to-water required for juvenile cottonwood and willow trees (Stromberg et al. 1996) (Figure 3-5). The bottoms of all the wells except 633106 are relatively shallow, precluding direct interpretation of the area's ability to sustain mature willow trees with water levels more than 10.5 feet (3.2 m) bgs. Based on the water levels at well 633106, and its correlation to the other Rincon Creek wells, it is likely that water levels were sufficient (higher than 16.7 feet/5.1 m bgs) to support mature cottonwood trees at all wells during the entire water year.

The monitoring record since 2005 for the eight wells in Middle Rincon Creek shows the down-gradient movement of ephemeral flows (Figure 3-6). The lateral spreading of subsurface water from the channel outward (RC-1 to RC-3 and RC-4 to RC-6) generally results in a dampening of peaks further from the active channel. Annual minimum water levels generally occur in June–August or early winter, and coincide with sustained dry conditions in Rincon Creek.

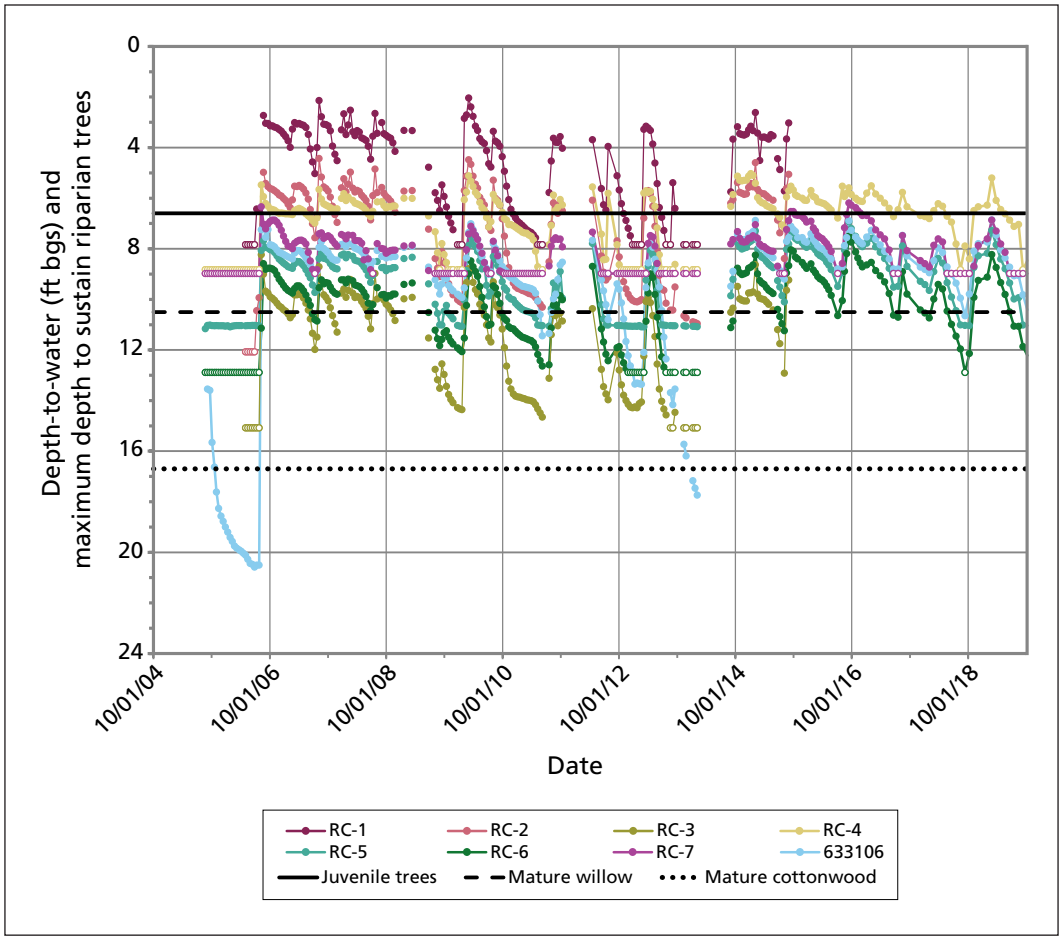


Figure 3-5. Depth-to-water at the eight wells in the middle reach of Rincon Creek, with the maximum depth of water to sustain juvenile and mature cottonwood and mature willow trees (Stromberg et al. 1996), WY2005–2019, Rincon Mountain District, Saguaro National Park. Open circles indicate dry conditions. Data for wells RC-1/2/3 not available after 2015.

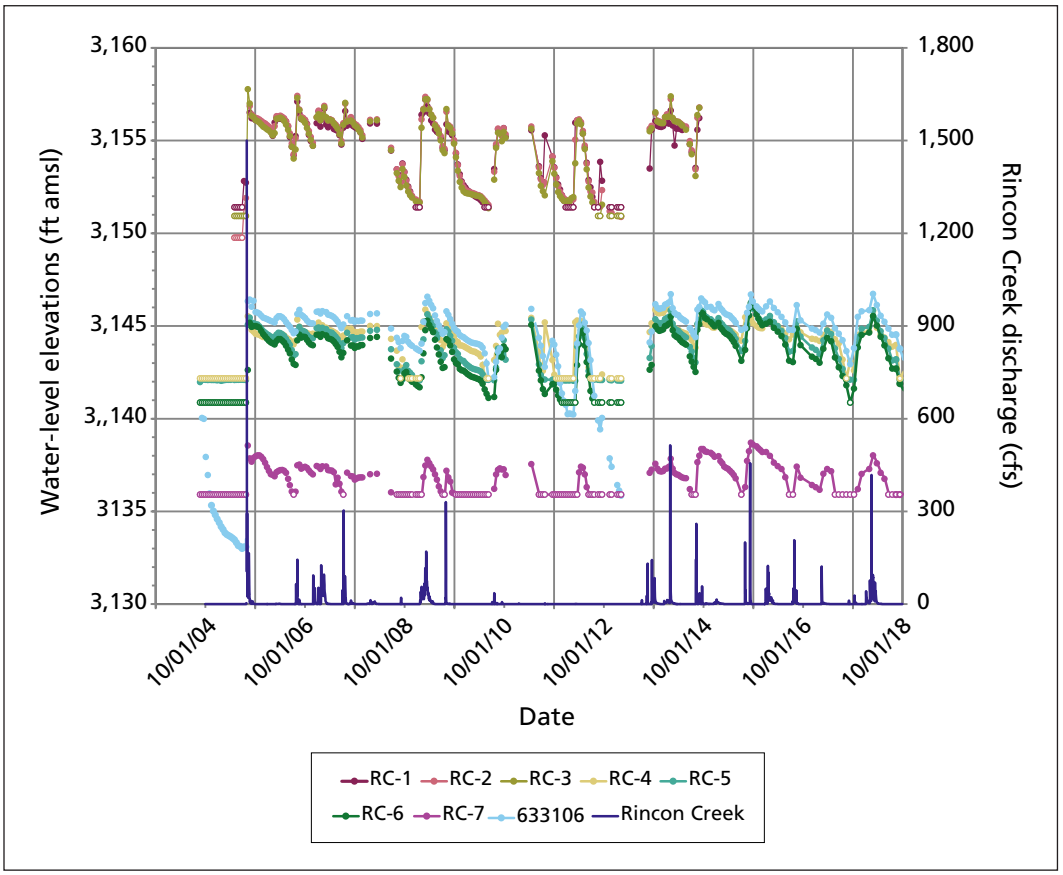


Figure 3-6. Water-level elevation in the eight wells in the middle reach of Rincon Creek, with Rincon Creek discharge, WY2005–2019, Rincon Mountain District, Saguaro National Park. Open circles indicate dry conditions. Discharge measurements (cubic feet/second) from Alert Station 4110-Rincon Creek at X-9 Ranch. Data for wells RC-1/2/3 not available after 2015.

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 (e.g., freezing, high temperatures), reduced light penetration (due to turbidity), and biochemical conditions outside the usual "environmental envelope" for a given site (Sada 2013a, 2013b).

Climate change is an emerging impact on springs in the American Southwest. Anticipated changes include increased air temperatures, evaporation rates, and drought intensity; more frequent 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

Sonoran Desert Network springs monitoring at Saguaro NP included 11 "sentinel sites" (sites chosen based on representativeness or other criteria) in WY2019: Chimenea 1L (a tinaja in the complex of tinajas and seeps in the lower Chimenea Canyon drainage), Deer Head Spring, Italian Spring, Javelina Tank, Manning Camp Reservoir, Mica Meadows Trail Seep 1, Mud Hole Spring, New Spring 3, Spud Rock Spring, Upper Joaquin Spring, and Wild 10G (a tinaja in a complex of tinajas and seeps in Wildhorse Canyon) (Table 4-1). Each sentinel site is located in the Rincon Mountain District (RMD). This sampling 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 Sonoran Desert Network monitors a suite of springs vital signs and parameters organized into four modules: site characterization, site condition, water quantity, and water quality. A brief description of data-collection methods 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 (see 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. Springs-monitoring dates, by module, for the most recent sampling period, Saguaro National Park.

Spring	Site condition, water quantity, and water quality	Site characterization
Chimenea 1L	April 9, 2019	WY2017
Deer Head Spring	June 8, 2019	WY2019
Italian Spring	June 6, 2019	WY2018
Javelina Tank	April 5, 2019	WY2017
Manning Camp Reservoir	June 7, 2019	WY2018
Mica Meadows Trail Seep 1	June 7, 2019	WY2019
Mud Hole Spring	June 9, 2019	WY2018
New Spring 3	June 10, 2019	WY2019
Spud Rock Spring	June 8, 2019	WY2018
Upper Joaquin Spring	June 10, 2019	WY2018
Wild 10G	April 8, 2019	WY2017

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. It 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 site description, and a vegetation-community description. See McIntyre and others (2018) for additional details. This module was completed for springs at Saguaro NP from WY2017 to WY2019 (see Table 4-1). Data for this module will be reassessed in WY2022. 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 anthropogenic and natural disturbance and the level of stress on vegetation and soils in spring ecosystems (Sada and Pohlmann 2006). 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). Types of natural disturbance evaluated include flooding, drying, fire, wildlife, windthrow of trees and shrubs, beaver activity, and insect infestations. 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 of >1 described in the text.

Photographs are taken from designated photopoints to show the spring and its landscape context. The presence of a suite of obligate or facultative wetland plants is noted during each visit using a picklist that identifies plants to the family, genus, or species level. The presence and density of invasive non-native plants is also recorded, with a goal of identifying them to the species level. The presence of invasive bullfrogs and crayfish (potentially non-native invasive wildlife) is also recorded.

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 or two hours (Anderson et al. 2015). A sensor placed at or near the orifice (or in the deepest-possible part of a pool) is used 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 so <68°F? on consecutive days. This 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

Baseline 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 sample(s) and estimating the concentration of major ions with a photometer (YSI 9500) in the field.

4.3 Results

4.3.1 Chimenea 1L

4.3.1.1 Site characterization

Chimenea 1L is part of a multi-pool tinaja complex (Figure 4-1). There is no discrete, known orifice location but instead a talus-filled area of the drainage that leads into a canyon with more than 15 flowing pools. The tinaja chosen for sampling, designated orifice A, is historically known to be persistently wetted, but ephemerally connected by flow to other pools. The tinaja is approximately 9.8 × 13.1 feet (3 × 4 m). It begins and ends in a small plunge pool. Chimenea 1L is dominated by bedrock, with approximately 25% gravel and 10% large boulder in the center. When characterized in WY2017, about 15% of the pool was filled with filamentous algae. A small backwater corner provided macroinvertebrate and amphibian habitat.



Figure 4-1. Chimenea 1L, sampling location 1, Saguaro National Park, April 2019.

4.3.1.2 Site condition

Disturbance surveys estimated a mean of 1.1 (undisturbed) for anthropogenic and 1.13 (undisturbed) for natural disturbance. Median values for both disturbance categories were 1 (undisturbed). Contemporary bolts were attached to a boulder for water-level monitoring. Recent flooding was obvious; the water-temperature logger was found outside the tinaja and sediment had been redistributed from previous years.

We observed two obligate/facultative wetland plant families and three genera: rush family (Juncaceae), cattail family (Typhaceae), cottonwood (*Populus* sp.), monkeyflower (*Mimulus* sp.), and sycamore (*Platanus* sp.). Invasive rose natal grass (*Melinis repens*) was noted in scattered patches. No bullfrogs or crayfish were observed.

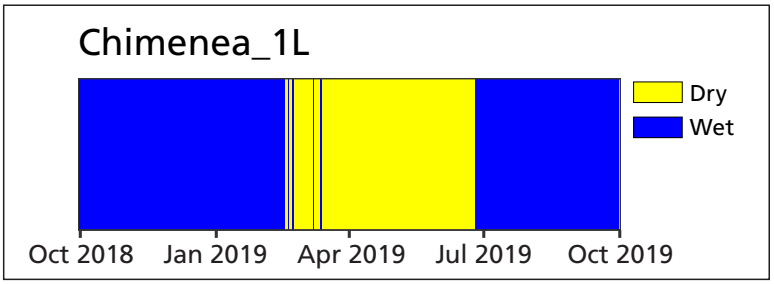


Figure 4-2. Estimated wet/dry days at Chimenea 1L, Saguaro National Park, WY2019.

4.3.1.3 Water quantity

Temperature sensors indicated the spring was wetted for most of the sampled period, until flooding events washed the logger out of the pool (Figure 4-2). The volume of water flowing out of Chimenea 1L was greater than what sampling equipment could safely and effectively measure. Chimenea 1L was assessed as a flowing spring with an average length, width, and depth of 95.4" (242.3 cm) × 79.4" (201.7 cm) × 17.9" (45.5 cm).

4.3.1.4 Water quality

In WY2019, core water quality (Table 4-2) and water chemistry (Table 4-3) were measured inside the pool (sampling location 1 in orifice A).

Table 4-2. Water-quality data for Chimenea 1L, Saguaro NP, WY2019.

Sampling location	Orifice	Sample time	Temperature (°C)	Dissolved oxygen (mg/L)	pH	Specific conductivity (µS/cm)	Total dissolved solids (mg/L)	Exposure
1	A	09:51	16.2	9.04	7.77	49.2	31.2	Sun

Table 4-3. Water-chemistry data for Chimenea 1L, Saguaro 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	35	4	3	Not detected	0.4	1

4.3.2 Deer Head Spring

4.3.2.1 Site characterization

Deer Head Spring is a rheocrene spring. When characterized in WY2019, it emerged across the bottom of a gently sloping drainage, saturating the soil and eventually collecting and flowing through small, shallow pools and diverse channels into a flowing springbrook. While the site had a distinct channel downstream, there was no clear orifice or origin point (Figure 4-3). However, there was a small pool near the adjacent hiking trail. Park staff have speculated that the channel was cleared and maintained to provide water for people and packstock until 1976, when the Saguaro Wilderness was established (Wilderness Act of 1964) and maintenance ceased. Sediment subsequently filled the springbrook, although we observed evidence of animals or hikers digging a small area for water to collect near the trail.



Figure 4-3. Deer Head Spring, sampling location 1, Saguaro National Park, May 2019.

4.3.2.2 Site condition

Disturbance surveys estimated a mean of 1.2 (undisturbed) for anthropogenic and 1.38 (undisturbed) for natural disturbance. Median values for both disturbance categories were 1 (undisturbed). Hiking trails led to a dug-out orifice, evidence of recent (though slight) human disturbance. There was minimal evidence of fire, wildlife use, and windthrow.

The crew observed two obligate/facultative wetland plant families, two genera, and one species: sedge family (Cyperaceae), rush family (Juncaceae), bulrush (*Scirpus* sp.), sedge (*Carex* sp.), and water speedwell (*Veronica anagallis*). Invasive Kentucky bluegrass (*Poa pratensis*) was observed in evenly distributed patches. No bullfrogs or crayfish were observed.

4.3.2.3 Water quantity

Sensors were not deployed at this spring, at the discretion of the former protocol lead. Discharge from orifice A, located at the upstream end of the springbrook, was not measurable. Deer Head Spring was measured as a flowing spring with a channel length of 42.65 feet (13.00 m). Width and depth averaged 10.83" (27.50 cm) × 0.4" (1.01 cm).

4.3.2.4 Water quality

In WY2019, core water quality (Table 4-4) and water chemistry (Table 4-5) were measured at orifice A.

Table 4-4. Water-quality data for Deer Head Spring, Saguaro NP, WY2019.

Sampling location	Orifice	Sample time	Temperature (°C)	Dissolved oxygen (mg/L)	pH	Specific conductivity (µS/cm)	Total dissolved solids (mg/L)	Exposure
1	A	11:40	15.4	3.30	6.50	109.0	Not collected	Partial

Table 4-5. Water-chemistry data for Deer Head Spring, Saguaro NP, WY2019.

Sampling location	Orifice	Alkalinity (mg/L)	Calcium (mg/L)	Chloride (mg/L)	Magnesium (mg/L)	Potassium (mg/L)	Sulfate (mg/L)
1	A	35	4	0	3	0.4	4

4.3.3 Italian Spring

4.3.3.1 Site characterization

Italian Spring (Figure 4-4) was characterized in WY2018 as a rheocrene spring that emerged as a cool, clear pool on a non-channelized backslope. It formed a shallow channel of moist soil rather than a flowing springbrook. The substrate of the orifice pool was primarily fine gravel, transitioning to silt and soil downstream. The channel and apparent soil moisture continued downstream for at least 328 ft (100 m), but no measurable surface water occurred beyond 32.8 ft (10 m) of the orifice pool.



Figure 4-4. Italian Spring, sampling location 1, Saguaro National Park, May 2019.

4.3.3.2 Site condition

Disturbance surveys estimated a mean of 1.3 (undisturbed) for anthropogenic and 1.25 (undisturbed) for natural disturbance. Median values for both disturbance categories were 1 (undisturbed). Hiking trails led to a dug-out orifice, representing slight-to-moderate contemporary human disturbance. Evidence of slight disturbance from wildlife and windthrow was observed.

The crew observed two obligate/facultative wetland plant families and three genera: sedge family (Cyperaceae), rush family (Juncaceae), fowl mannagrass (*Glyceria striata*), sedge (*Carex* sp.), and water speedwell (*Veronica anagallis*). No invasive plants, bullfrogs, or crayfish were observed.

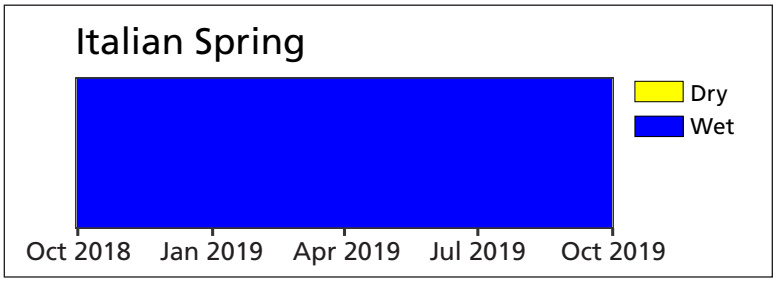


Figure 4-5. Estimated wet/dry days at Italian Spring, Saguaro National Park, WY2019.

4.3.3.3 Water quantity

Temperature sensors indicated the spring was wetted for the majority of the sampled period (Figure 4-5). Discharge was too low to measure. Italian Spring was surveyed

as a flowing spring with a channel length of 57.41 feet (7.50 m). Width and depth averaged 27.2" (69.01 cm) × 0.4" (0.9 cm). The orifice pool of Italian Spring was also surveyed. The pool had an average length, width, and depth of 72.8" (185.0 cm) × 47.9" (121.7 cm) × 6.0" (15.3 cm).

4.3.3.4 Water quality

In WY2019, core water quality (Table 4-6) and water chemistry (Table 4-7) were measured at the first pool downstream of the orifice.

Table 4-6. Water-quality data for Italian Spring, Saguaro NP, WY2019.

Sampling location	Orifice	Sample time	Temperature (°C)	Dissolved oxygen (mg/L)	pH	Specific conductivity (µS/cm)	Total dissolved solids (mg/L)	Exposure
1	A	09:28	10.2	6.04	6.60	86.0	not collected	Shade

Table 4-7. Water-chemistry data for Italian Spring, Saguaro NP, WY2019.

Sampling location	Orifice	Alkalinity (mg/L)	Calcium (mg/L)	Chloride (mg/L)	Magnesium (mg/L)	Potassium (mg/L)	Sulfate (mg/L)
1	A	20	2	5	5	0.4	3

4.3.4 Javelina Tank

4.3.4.1 Site characterization

Javelina Tank (Figure 4-6) is a tinaja complex. When the site was characterized in WY2017, orifice A was the largest pool in a series of small plunge pools along a 33-foot (10 m) bedrock cliff. At the base of the cliff, water slowly seeped into a series of shallow, ephemerally flowing pools within a bedrock channel. Subsurface flow reemerged downstream as a larger, sedimented pool (orifice B) with a Typha (*Typha dominigensis*) stand. Below orifice B, a steep pour-off led to another large, sandy pool (orifice C).



Figure 4-6. Javelina Tank, sampling location 1, Saguaro National Park, April 2019.

4.3.4.2 Site condition

Disturbance surveys estimated a mean value of 1.1 (undisturbed) for anthropogenic and 1.13 (undisturbed) for natural disturbance. Median values for both disturbance categories were 1 (undisturbed). Scouring was obvious in the last pool containing sediment and exposed bedrock was observed in the channel floor.

We observed one obligate wetland plant family and one wetland genera: cattail family (Typhaceae) and monkeyflower (*Mimulus* sp.). Three invasive non-native plants were also detected: crimson fountaingrass (*Cenchrus setaceus*) and red brome (*Bromus rubens*), with 1–5 individuals/each, with scattered patches of rose natal grass (*Melinis repens*). No bullfrogs or crayfish were observed.

4.3.4.3 Water quantity

Temperature sensors indicated the spring was wetted for most of the sampled period (Figure 4-7). Discharge was too low to measure. The wetted extent of Javelina Tank was surveyed as a flowing spring with a channel length of 179.5 feet (54.7 m). Width and depth averaged 46.2" (117.4 cm) × 3.4" (8.6 cm).

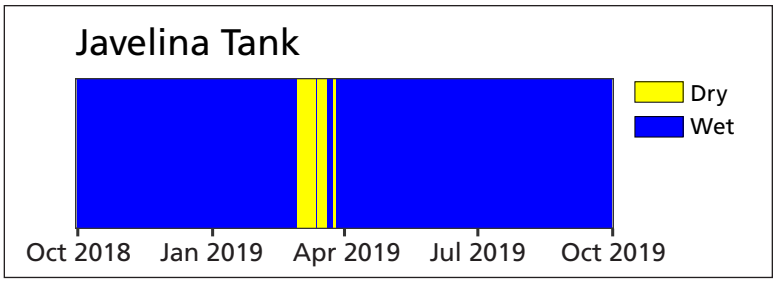


Figure 4-7. Estimated wet/dry days at Javelina Tank, Saguaro National Park, WY2019.

4.3.4.4 Water quality

In WY2019, core water quality (Table 4-8) and water chemistry (Table 4-9) were measured at three locations: the largest plunge pool tank (sampling location 1, orifice A), the downstream pool with a dense Typha (*Typha dominigensis*) stand (sampling location 2, orifice B), and a sandy pool downstream of a large pour-off from sampling location 2 (sampling location 3, orifice C).

Table 4-8. Water-quality data for Javelina Tank, Saguaro NP, WY2019.

Sampling location	Orifices	Sample time	Temperature (°C)	Dissolved oxygen (mg/L)	pH	Specific conductivity (µS/cm)	Total dissolved solids (mg/L)	Exposure
1	A	09:17	14.2	9.12	7.77	192.2	124.8	Partial
2	B	09:21	15.0	9.27	7.77	195.0	126.8	Sun
3	C	09:24	15.0	7.94	7.56	188.5	122.9	Sun

Table 4-9. Water-chemistry data for Javelina Tank, Saguaro 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	12	9	8	1.1	24
2	B	40	12	4	4	0.5	24
3	C	70	14	4	8	0.9	25



Figure 4-8. Manning Camp Reservoir, sampling location 2, Saguaro National Park, May 2019.

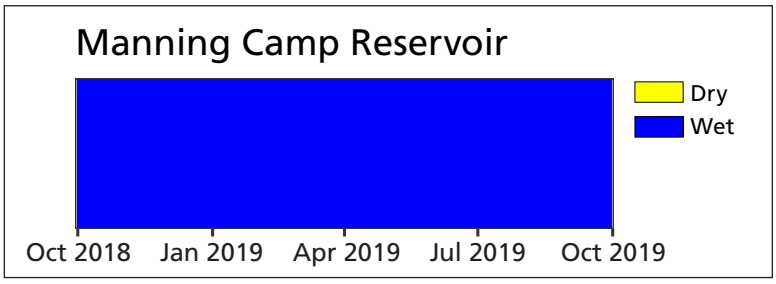


Figure 4-9. Estimated wet/dry days at Manning Camp Reservoir, Saguaro National Park, WY2019.

4.3.5 Manning Camp Reservoir

4.3.5.1 Site characterization

Manning Camp Reservoir (Figure 4-8) was classified in WY2018 as a limnocrene spring. It is a large-pool tinaja modified with a small dam at Manning Camp. The site was monitored as a non-flowing spring. The water was warm and clear, with a film on the surface. There was no inflow, and one observable outflow was too small to measure. The substrate was small gravel, occasionally covered by dense patches of organic material. According to park managers, the substrate is periodically dredged to ensure adequate water capacity for supplying domestic water to Manning Camp.

4.3.5.2 Site condition

Disturbance surveys estimated a mean value of 1.8 (slightly disturbed) for anthropogenic and 1.13 (undisturbed) for natural disturbance. Median values for both disturbance categories were 1 (undisturbed). Contemporary human disturbance was high due to the dredged pool, dam, and springbox, which also modified flow. We observed slight disturbance from wildlife use.

We observed two obligate/facultative wetland plant families and five genera: sedge family (Cyperaceae), rush family (Juncaceae), bulrush (*Scirpus* sp.), fowl mannagrass (*Glyceria striata*), sedge (*Carex* sp.), water speedwell (*Veronica anagallis*), and willow (*Salix* sp.). No invasive plants, bullfrogs, or crayfish were observed.

4.3.5.3 Water quantity

Temperature sensors indicated the spring/reservoir was wetted for the entirety of the sampled period (Figure 4-9). Discharge was not measurable. The wetted extent of Manning Camp Reservoir was surveyed as a non-flowing spring with an average length, width, and depth of 630.6" (1,601.7 cm) × 349.4" (887.5 cm) × 12.7" (32.3 cm).

4.3.5.4 Water quality

In WY2019, core water quality (Table 4-10) and water chemistry (Table 4-11) were measured at the pool near the midpoint of the dam (sampling location 1, orifice A).

Table 4-10. Water-quality data for Manning Camp Reservoir, Saguaro NP, WY2019.

Sampling location	Orifice	Sample time	Temperature (°C)	Dissolved oxygen (mg/L)	pH	Specific conductivity (µS/cm)	Total dissolved solids (mg/L)	Exposure
1	A	12:23	17.3	4.98	5.60	46.0	not collected	Sun

Table 4-11. Water-chemistry data for Manning Camp Reservoir, Saguaro NP, WY2019.

Sampling location	Orifice	Alkalinity (mg/L)	Calcium (mg/L)	Chloride (mg/L)	Magnesium (mg/L)	Potassium (mg/L)	Sulfate (mg/L)
1	A	25	2	4	4	0.0	0

4.3.6 Mica Meadows Trail Seep 1

4.3.6.1 Site characterization

Mica Meadows Trail Seep 1 (Figure 4-10) was characterized in WY2019 as a rheocrene spring that emerged as a non-flowing pool along the bank of a drainage. The water was warm. It contained substantial suspended organic matter, making the pool largely opaque. The orifice emerged at a large bedrock slab beneath a hillslope, while the surrounding drainage was a narrow, dry, cobble-substrate streambed.

4.3.6.2 Site condition

Disturbance surveys estimated a mean value of 1.0 (undisturbed) for anthropogenic and 1.13 (undisturbed) for natural disturbance. Median values for both disturbance categories were 1 (undisturbed). Burned and charred trees near the orifice evidenced fire in the area.

We observed two obligate/facultative wetland plant families and one genus: sedge family (Cyperaceae), rush family (Juncaceae) and sedge (*Carex* sp.). No invasive plants, bullfrogs, or crayfish were observed.

4.3.6.3 Water quantity

Temperature sensors indicated the spring was wetted for the entirety of the sampled period (Figure 4-11). Discharge from orifice A was estimated at 5.3 ± 0.3 L/minute. Mica Meadows Trail Seep 1 was surveyed as a flowing spring with a channel length of 42.7 feet (13.0 m). Width and depth averaged 68.8" (174.8 cm) × 2.4" (6.0 cm). The orifice pool was also surveyed. The pool had an average length, width, and depth of 71.8"



Figure 4-10. Mica Meadows Trail Seep 1, sampling location 1, Saguaro National Park, May 2019.

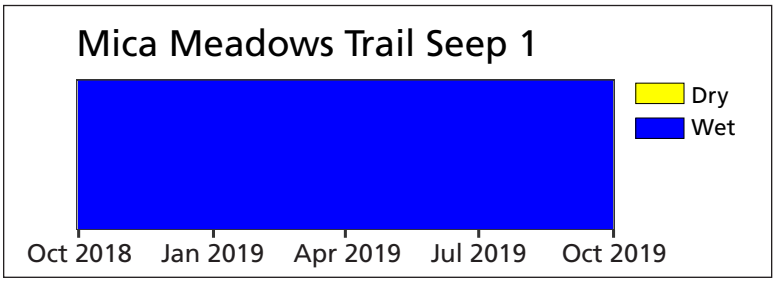


Figure 4-11. Estimated wet/dry days at Mica Meadows Trail Seep 1, Saguaro National Park, water year 2019.

(182.3 cm) × 45.9" (116.5 cm) × 3.4" (8.5 cm).

4.3.6.4 Water quality

In WY2019, core water quality (Table 4-12) and water chemistry (Table 4-13) were measured at the first pool downstream of the orifice.

Table 4-12. Water-quality data for Mica Meadows Trail Seep 1, Saguaro NP, WY2019.

Sampling location	Orifice	Sample time	Temperature (°C)	Dissolved oxygen (mg/L)	pH	Specific conductivity (µS/cm)	Total dissolved solids (mg/L)	Exposure
1	A	08:18	9.4	4.27	5.90	54.0	Not collected	Shade

Table 4-13. Water-chemistry data for Mica Meadows Trail Seep 1, Saguaro NP, WY2019.

Sampling location	Orifice	Alkalinity (mg/L)	Calcium (mg/L)	Chloride (mg/L)	Magnesium (mg/L)	Potassium (mg/L)	Sulfate (mg/L)
1	A	20	11	2	11	0.3	0

4.3.7 Mud Hole Spring

4.3.7.1 Site characterization

Mud Hole Spring (Figure 4-12) was characterized in WY2018 as a rheocrene spring occurring on an upland backslope rather than within a drainage. The cool, clear discharge emerged into a small, human-developed, rock-lined pool. Immediately below the pool, the springbrook formed a shallow, narrow channel with low velocity before subsiding into channel sediment. Both the pool and springbrook were characterized by a consistent substrate of small gravel. This site had been historically developed, as evidenced by the obvious lining of the orifice pool with rocks. However, it is difficult to assess this development's impact to the natural system without an historical record.



Figure 4-12. Mud Hole Spring, sampling location 1, Saguaro National Park, May 2019.

4.3.7.2 Site condition

Disturbance surveys estimated a mean of 1.6 (slightly disturbed) for anthropogenic and 1.13 (undisturbed) for natural disturbance. Median values for both disturbance categories were 1 (undisturbed). There was evidence the spring had been dug out and rocked in by humans. An obvious hiking trail runs along Turkey Creek, which resulted in slight and moderate disturbance in the hiking-trail and contemporary human-use disturbance categories, respectively. Wildlife use was also noted.

We observed two obligate/facultative wetland plant families and three wetland genera: sedge family (Cyperaceae), rush family (Juncaceae), monkeyflower (*Mimulus* sp.), sedge (*Carex* sp.), spikerush (*Eleocharis* sp.). Invasive Kentucky bluegrass (*Poa pratensis*) was detected, with 1–5 individuals. No bullfrogs or crayfish was observed.

4.3.7.3 Water quantity

Temperature sensors indicated the spring was wetted for the first part of the year, the entire period for which we have data (Figure 4-13). The sensor deployed in WY2019 was not found during the WY2020 visit; therefore, data are missing for the second part of WY2019. Discharge from orifice A was estimated at 0.3 ± 0.02 L/min. Mud Hole Spring was surveyed as a flowing spring with a channel length of 29.5 feet (9.00 m). Width and depth averaged 14.7" (37.4 cm) × 0.2" (0.6 cm).

4.3.7.4 Water quality

In WY2019, core water quality (Table 4-14) and water chemistry (Table 4-15) were measured at the orifice pool.

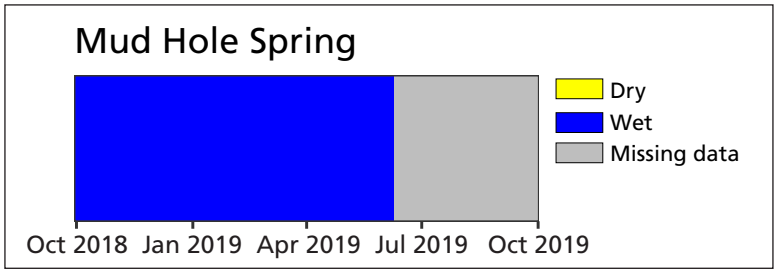


Figure 4-13. Estimated wet/dry days at Mud Hole Spring, Saguaro NP, WY2019.

Table 4-14. Water-quality data for Mud Hole Spring, Saguaro NP, WY2019.

Sampling location	Orifice	Sample time	Temperature (°C)	Dissolved oxygen (mg/L)	pH	Specific conductivity (µS/cm)	Total dissolved solids (mg/L)	Exposure
1	A	10:30	16.6	3.49	6.20	191.0	Not collected	Partial

Table 4-15. Water-chemistry data for Mud Hole Spring, Saguaro NP, WY2019.

Sampling location	Orifice	Alkalinity (mg/L)	Calcium (mg/L)	Chloride (mg/L)	Magnesium (mg/L)	Potassium (mg/L)	Sulfate (mg/L)
1	A	65	12	2	6	0.5	0



Figure 4-14. New Spring 3, sampling location 1, Saguaro National Park, May 2019.

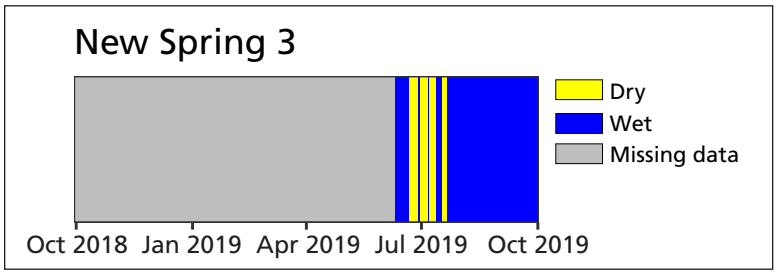


Figure 4-15. Estimated wet/dry days at New Spring 3, Saguaro National Park, WY2019.

4.3.8 New Spring 3

4.3.8.1 Site characterization

This rheocrene spring was characterized in WY2019 as emerging from a low-angle drainage at an area of exposed bedrock (Figure 4-14). Orifice A was a small, shallow pool that flowed down a bedrock pouroff. The orifice was sheltered by soil, rock, and woody debris on three sides. The water within the pool was clear, with a fine gravel substrate. There were numerous aquatic insects in the pool. Upslope of orifice was a meadow of riparian obligates, including fowl mannagrass (*Glyceria striata*), monkeyflower (*Mimulus* sp.) and sedge (*Carex* sp.). There were a few damp patches of soil within the meadow, but no surface water.

4.3.8.2 Site condition

Disturbance surveys estimated a mean of 1.3 (undisturbed) for anthropogenic and 1.38 (undisturbed) for natural disturbance. Median values for both disturbance categories were 1 (undisturbed). Slight-to-moderate disturbance was observed in the hiking-trail and contemporary human-use categories. Slight natural disturbance in the flooding, wildlife, and windthrow categories were noted.

We observed one obligate/facultative wetland plant family and three wetland genera: sedge family (Cyperaceae), fowl mannagrass (*Glyceria striata*), monkeyflower (*Mimulus* sp.) and sedge (*Carex* sp.). Invasive Kentucky bluegrass (*Poa pratensis*) was noted in scattered patches. No bullfrogs or crayfish were observed.

4.3.8.3 Water quantity

No sensors were deployed in WY2018, so wet/dry days were not estimated for most of WY2019 (Figure 4-15). Discharge from orifice A was estimated at 0.2 ± 0.01 L/min. New Spring 3 was surveyed as a flowing spring with a channel length of 55.1 feet (16.8 m). Width and depth averaged 18.4" (46.7 cm) × 0.1" (0.2 cm).

4.3.8.4 Water quality

In WY2019, core water quality (Table 4-16) and water chemistry (Table 4-17) were measured at the orifice pool.

Table 4-16. Water-quality data for New Spring 3, Saguaro NP, WY2019.

Sampling location	Orifice	Sample time	Temperature (°C)	Dissolved oxygen (mg/L)	pH	Specific conductivity (µS/cm)	Total dissolved solids (mg/L)	Exposure
1	A	13:11	17.8	5.50	5.60	53.0	Not collected	Sun

Table 4-17. Water-chemistry data for New Spring 3, Saguaro NP, WY2019.

Sampling location	Orifice	Alkalinity (mg/L)	Calcium (mg/L)	Chloride (mg/L)	Magnesium (mg/L)	Potassium (mg/L)	Sulfate (mg/L)
1	A	25	2	0	5	0.1	0

4.3.9 Spud Rock Spring

4.3.9.1 Site characterization

Spud Rock Spring (Figure 4-16) was characterized in WY2018 as a rheocrene spring that emerged midslope below an aspen grove. The springbrook began as a small earthen pool that fed a shallow but distinct channel. Spud Rock Spring is part of the historic—and largely unstudied—Spud Rock Cabin/Farm (now dismantled). During the cabin's period of occupation, a springbox piped water to a developed second pool to the north, where a concrete pad supporting an aboveground cistern is still visible.



Figure 4-16. Spud Rock Spring, sampling location 1, Saguaro National Park, May 2019.

4.3.9.2 Site condition

Disturbance surveys estimated a mean of 1.4 (undisturbed) for anthropogenic and 1.25 (undisturbed) for natural disturbance. Median values for both disturbance categories were 1 (undisturbed). The spring lies next to the Spud Rock Campground trail, which receives contemporary use. An old springbox lies upslope of the monitoring pool, and a cistern foundation and human-made pool are below, indicating historic use and development of the spring. We observed wildlife and windthrow disturbance.

We observed two obligate/facultative wetland plant families and one genera: sedge family (Cyperaceae), rush family (Juncaceae), and sedge (*Carex* sp.). Invasive Kentucky bluegrass (*Poa pratensis*) was detected in evenly distributed patches. No bullfrogs or crayfish were observed.

4.3.9.3 Water quantity

Temperature sensors indicated the spring was wetted for the majority of the sampled period (Figure 4-17). Discharge was too low to be measured. The wetted extent of Spud Rock Spring was surveyed as a flowing spring with a channel length of 29.5 feet (9.00 m). Width and depth averaged 40.8" (103.5 cm) × 0.3" (0.8 cm).

4.3.9.4 Water quality

In WY2019, core water quality (Table 4-18) and water chemistry (Table 4-19) were measured at the first orifice pool.

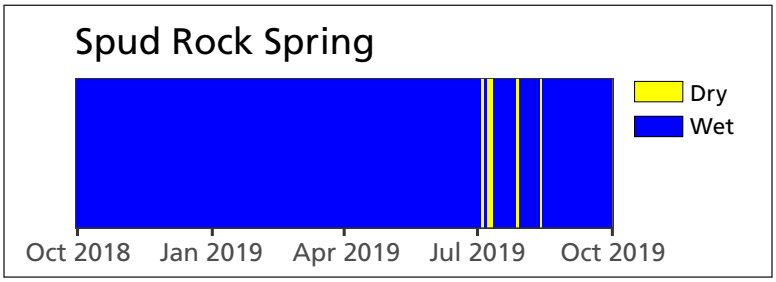


Figure 4-17. Estimated wet/dry days at Spud Rock Spring, Saguaro National Park, WY2019.

Table 4-18. Water-quality data for Spud Rock Spring, Saguaro NP, WY2019.

Sampling location	Orifice	Sample time	Temperature (°C)	Dissolved oxygen (mg/L)	pH	Specific conductivity (µS/cm)	Total dissolved solids (mg/L)	Exposure
1	A	08:29	13.9	5.30	6.40	115.0	Not collected	Partial

Table 4-19. Water-chemistry data for Spud Rock Spring, Saguaro NP, WY2019.

Sampling location	Orifice	Alkalinity (mg/L)	Calcium (mg/L)	Chloride (mg/L)	Magnesium (mg/L)	Potassium (mg/L)	Sulfate (mg/L)
1	A	50	8	0	6	0.8	3

4.3.10 Upper Joaquin Spring

4.3.10.1 Site characterization

Upper Joaquin Spring (Figure 4-18) was characterized in WY2018 as a rheocrene spring at the confluence of two orifices located approximately 328 feet (100 m) upstream. The system's upper reaches were fed by orifices emerging from the banks of the channel that flowed intermittently to the confluence where sampling occurred. The water in the orifice pool emerged cold and clear into a springbrook that continued downstream for more than 1,640.4 feet (500 m) as a series of narrow, gravel-bedded channels interspaced between variably sized pools and occasional bedrock-slab pour-overs.



Figure 4-18. Upper Joaquin Spring, sampling location 1, Saguaro NP, May 2019.

4.3.10.2 Site condition

Disturbance surveys estimated a mean of 1.0 (undisturbed) for anthropogenic and 1.75 (slightly disturbed) for natural disturbance. Median values for both disturbance categories were 1 (undisturbed). Organic debris along the channel indicated recent flooding. Evidence of the adjacent Helens 2 Fire (2009) included burned snags and downed trees. Wildlife use and windthrow were also observed.

We observed two obligate/facultative wetland plant families and two wetland genera: sedge family (Cyperaceae), rush family (Juncaceae), monkeyflower (*Mimulus* sp.), and sedge (*Carex* sp.). No invasive plants, crayfish, or bullfrogs were observed.

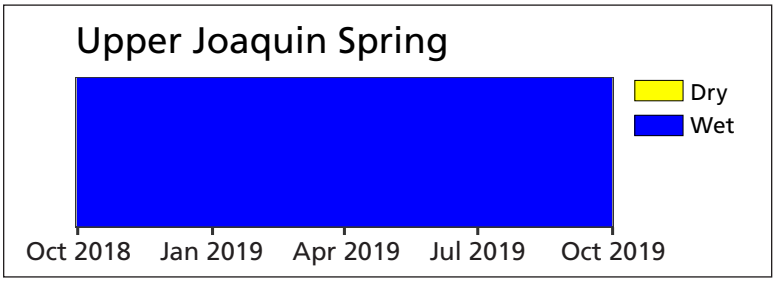


Figure 4-19. Estimated wet/dry days at Upper Joaquin, Saguaro National Park, WY2019.

4.3.10.3 Water quantity

Temperature sensors indicated the spring was wetted for the entirety of WY2019 (Figure 4-19). Discharge from orifice A was estimated at 13.8 ± 0.3 L/min. The wetted extent of Upper Joaquin Spring was surveyed as a flowing spring with a channel length of 1,640.4 feet (>500 m). Width and depth averaged 47.0" (119.4 cm) × 1.4" (3.6 cm).

4.3.10.4 Water quality

In WY2019, core water quality (Table 4-20) and water chemistry (Table 4-21) were measured at the first pool downstream of the orifice confluence.

Table 4-20. Water-quality data for Upper Joaquin Spring, Saguaro NP, WY2019.

Sampling location	Orifice	Sample time	Temperature (°C)	Dissolved oxygen (mg/L)	pH	Specific conductivity (µS/cm)	Total dissolved solids (mg/L)	Exposure
1	A	08:30	10.6	8.40	7.30	50.0	Not collected	Shade

Table 4-21. Water-chemistry data for Upper Joaquin Spring, Saguaro NP, WY2019.

Sampling location	Orifice	Alkalinity (mg/L)	Calcium (mg/L)	Chloride (mg/L)	Magnesium (mg/L)	Potassium (mg/L)	Sulfate (mg/L)
1	A	15	2	1	11	0.6	3

4.3.11 Wild 10G

4.3.11.1 Site characterization

Wild 10G (Figure 4-20) is a tinaja. When characterized in WY2017, about 50% of the tank bottom was covered in a mix of sand and gravel. The channel was a bedrock-dominated system with no surface flow between the many water-exuding locations. This small pool had a slightly red-brown tinge, though the water was opaque. There were four wetted locations within 164 feet (50 m) of the tinaja.



Figure 4-20. Wild 10G, sampling location 1, Saguaro National Park, April 2019.

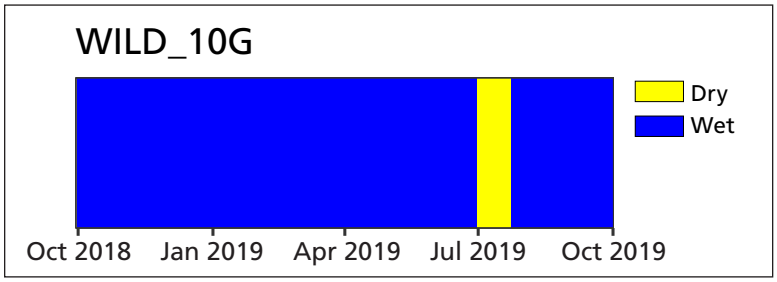


Figure 4-21. Estimated wet/dry days at Wild 10G, Saguaro National Park, WY2019.

4.3.11.2 Site condition

Disturbance surveys estimated a mean of 1.0 (undisturbed) for anthropogenic and 1.0 (undisturbed) for natural disturbance. Median values for both disturbance categories were 1 (undisturbed). Although there is a trail only 656 feet (200 m) upstream, there was no evidence of disturbance at the site.

We observed one obligate/facultative wetland genus: monkeyflower (*Mimulus* sp.). Invasive rose natal grass (*Melinis repens*) was observed in scattered patches. No bullfrogs or crayfish were observed.

4.3.11.3 Water quantity

Temperature sensors were retrieved and deployed during this survey. Sensors indicated the spring was wetted for the majority of the sampled period, with a dry period in summer (Figure 4-21). Discharge was not measurable. The wetted extent of Wild 10G was surveyed as a non-flowing spring with an average length, width, and depth of 67.0" (170.12 cm) × 190.8" (484.7 cm) × 17.8" (45.2 cm).

4.3.11.4 Water quality

In WY2019, core water quality (Table 4-22) and water chemistry (Table 4-23) were measured in the tinaja.

Table 4-22. Water-quality data for Wild 10G, Saguaro NP, WY2019.

Sampling location	Orifice	Sample time	Temperature (°C)	Dissolved oxygen (mg/L)	pH	Specific conductivity (µS/cm)	Total dissolved solids (mg/L)	Exposure
1	A	09:12	18.3	Not collected	8.06	191.4	124.2	Partial

Table 4-23. Water-chemistry data for Wild 10G, Saguaro NP, WY2019.

Sampling location	Orifice	Alkalinity (mg/L)	Calcium (mg/L)	Chloride (mg/L)	Magnesium (mg/L)	Potassium (mg/L)	Sulfate (mg/L)
1	A	60	14	2	3	0.3	0

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