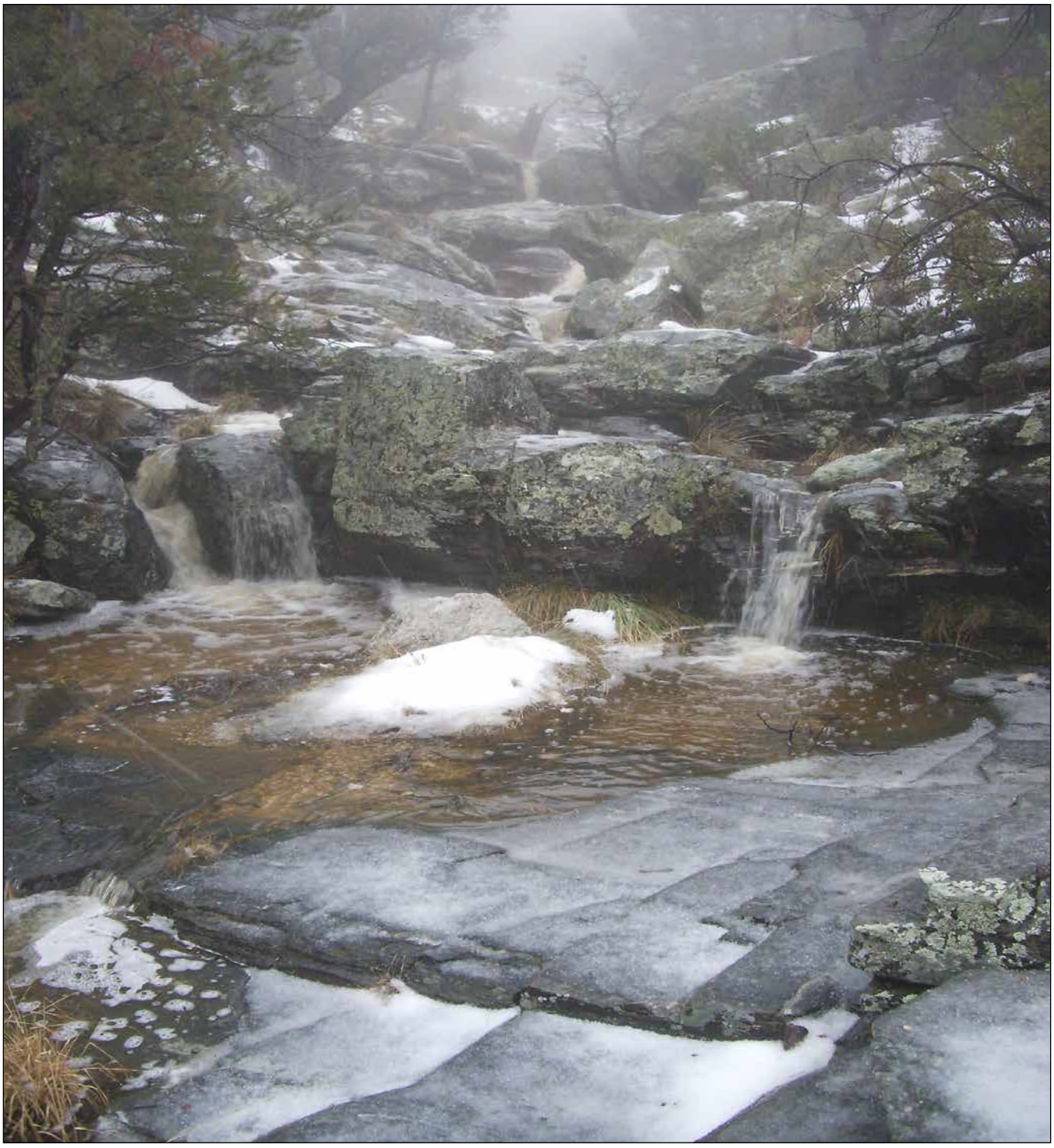
National Park Service
U.S. Department of the Interior

Natural Resource Stewardship and Science

Saguaro National Park

Natural Resource Condition Assessment

Natural Resource Report NPS/SODN/NRR—2017/1364



ON THIS PAGE
Snow in Rincon Mountain District, Credit: NPS

ON THE COVER
Top: Panoramic View from Tucson Mountain District's Visitor Center, Credit: Don Swann / NPS; Bottom Left: Snow in Rincon Mountain District, Credit: Bob Love / NPS; Bottom Right: Summer in Rincon Mountain District, Credit: Don Swann / NPS.

Saguaro National Park

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Natural Resource Report NPS/SODN/NRR—2017/1364

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January 2017

U.S. Department of the Interior
National Park Service
Natural Resource Stewardship and Science
Fort Collins, Colorado

The National Park Service, Natural Resource Stewardship and Science office in Fort Collins, Colorado, publishes a range of reports that address natural resource topics. These reports are of interest and applicability to a broad audience in the National Park Service and others in natural resource management, including scientists, conservation and environmental constituencies, and the public.

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Please cite this publication as:

Valentine-Darby, P., L. Baril, K. Struthers, C. Filippone, D. Swann, A. Mathis, and N. Chambers. 2017. Saguaro National Park: Natural resource condition assessment. Natural Resource Report NPS/SODN/NRR—2017/1364. National Park Service, Fort Collins, Colorado.

NPS 151/135629, January 2017

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Executive Summary

The Natural Resource Condition Assessment (NRCA) Program, administered by the National Park Service's (NPS) Water Resources Division, aims to provide documentation about current conditions of important park natural resources through a spatially explicit, multidisciplinary synthesis of existing scientific data and knowledge. The workshop for Saguaro National Park's (NP) NRCA was held in conjunction with their State of the Park report planning effort on October 28 - 29, 2014.

Saguaro NP was originally established as a national monument in 1933, and its rich scientific legacy predates its inception. This body of literature and research was used to report on current conditions for the 15 natural resource topics park staff selected for its NRCA. Some of the assessments included combined resources, such as grassland, woodland, and forest vegetation and soils, whereas other assessments included resource topics as indicators and measures (e.g., non-native invasive plants detected or water quality conditions).

The 15 natural resources were grouped into three broad categories: landscape-scale, supporting environment (i.e., physical resources), and biological integrity, which included wildlife and vegetation topics. Most of the assessments resulted in a moderate concern condition rating. The most significantly impacted resources included night sky, soundscape, air quality, and the middle reach of Rincon Creek -one of the park's most biologically rich areas. The only natural resources considered to be in good condition were biodiversity, although its trend is deteriorating due to the many threats negatively impacting park resources and birds. Saguaro cactus was assessed as good to moderate condition.

Saguaro NP faces many threats due to an ever-increasing human population within and surrounding Tucson, Arizona and was identified as one of the most threatened national parks because of the surrounding land use change. Couple that with its ranking as one of 25 national parks most at risk due to climate change, and the park's scientific legacy will become even more important in informing resources conditions and identifying necessary adaptations in a rapidly changing environment.

Acknowledgements

All natural resource staff in the Saguaro National Park Division of Science and Resource Management, Scott Stonum, Division Chief; Don Swann, Biologist; Dana Backer, Ecologist; Perry Grissom, Fire Ecologist; and Natasha Kline, former Biologist, provided their expertise as chapter and assessment reviewers and as information facilitators assisting with the development of indicators and measures as needed. Don Swann also wrote the science legacy section of the report, providing an overview of the significance of the park's long-term research.

National Park Service's Sonoran Desert Inventory and Monitoring Program's annual monitoring data for Saguaro National Park formed the basis for the biological soil crusts and desert, grassland, woodland, and forest vegetation assessments in Chapter 4. Colleen Filippone, National Park Service Intermountain Region hydrologist and groundwater protocol lead for the Sonoran Desert Inventory and Monitoring Network wrote the groundwater assessments for the Tucson and Rincon Mountain Districts and was involved in all phases of the NRCA's planning and review.

Donna Shorrock, former National Park Service Intermountain Region Natural Resource Condition Assessment Coordinator, assisted with overall project facilitation and provided viewshed equipment training at the park for staff. To all of the additional reviewers listed in Appendix A and contributors who are listed within each Chapter 4 assessment, we thank you. Your contributions have increased the value of Saguaro NP's NRCA report.

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An NRCA reports the current condition for a subset of a park's natural resources.

Chapter 1: NRCA Background Information

Natural Resource Condition Assessments (NRCAs) evaluate current conditions for a subset of natural resources and resource indicators in national park units, hereafter "parks." NRCAs also report on trends in resource condition (when possible), identify critical data gaps, and characterize a general level of confidence for study findings. The resources and indicators emphasized in a given project depend on the park's resource setting, status of resource stewardship planning and science in identifying high-priority indicators, and availability of data and expertise to assess current conditions for a variety of potential study resources and indicators.

NRCAs represent a relatively new approach to assessing and reporting on park resource conditions. They are meant to complement — not replace — traditional issue- and threat-based resource assessments. As distinguishing characteristics, all NRCAs:

- are multi-disciplinary in scope;[1]
- employ hierarchical indicator frameworks;[2]
- identify or develop reference conditions/values for comparison against current conditions;[3]
- emphasize spatial evaluation of conditions and GIS (map) products;[4]
- summarize key findings by park areas; and[5]
- follow national NRCA guidelines and standards for study design and reporting products.

NRCAs Strive to Provide…

- Credible condition reporting for a subset of important park natural resources and indicators
- Useful condition summaries by broader resource categories or topics, and by park areas

1. The breadth of natural resources and number/type of indicators evaluated will vary by park.
2. Frameworks help guide a multi-disciplinary selection of indicators and subsequent "roll up" and reporting of data for measures [conditions for indicators] condition summaries by broader topics and park areas
3. NRCAs must consider ecologically-based reference conditions, must also consider applicable legal and regulatory standards, and can consider other management-specified condition objectives or targets; each study indicator can be evaluated against one or more types of logical reference conditions. Reference values can be expressed in qualitative to quantitative terms, as a single value or range of values; they represent desirable resource conditions or, alternatively, condition states that we wish to avoid or that require a follow-on response (e.g., ecological thresholds or management "triggers").
4. As possible and appropriate, NRCAs describe condition gradients or differences across a park for important natural resources and study indicators through a set of GIS coverages and map products.
5. In addition to reporting on indicator-level conditions, investigators are asked to take a bigger picture (more holistic) view and summarize overall findings and provide suggestions to managers on an area-by-area basis: 1) by park ecosystem/habitat types or watersheds, and 2) for other park areas as requested.

Important NRCA Success Factors

- Obtaining good input from park staff and other NPS subject-matter experts at critical points in the project timeline
- Using study frameworks that accommodate meaningful condition reporting at multiple levels (measures / indicators) broader resource topics, and park areas
- Building credibility by clearly documenting the data and methods used, critical data gaps, and level of confidence for indicator-level condition findings

Although the primary objective of NRCAs is to report on current conditions relative to logical forms of reference conditions and values, NRCAs also report on trends, when appropriate (i.e., when the underlying data and methods support such reporting), as well as influences on resource conditions. These influences may include past activities or conditions that provide a helpful context for understanding current conditions, and/or present-day threats and stressors that are best interpreted at park, watershed, or landscape scales (though NRCAs do not report on condition status for land areas and natural resources beyond park boundaries). Intensive cause-and-effect analyses of threats and stressors, and development of detailed treatment options, are outside the scope of NRCAs.

Due to their modest funding, relatively quick timeframe for completion, and reliance on existing data and information, NRCAs are not intended to be exhaustive. Their methodology typically involves an informal synthesis of scientific data and information from multiple and diverse sources. Level of rigor and statistical repeatability will vary by resource or indicator, reflecting differences in existing data and knowledge bases across the varied study components.

The credibility of NRCA results is derived from the data, methods, and reference values used in the project work, which are designed to be appropriate for the stated purpose of the project, as well as adequately documented. For each study indicator for which current condition or trend is reported, we will identify critical data gaps and describe the level of confidence in at least qualitative terms. Involvement of park staff and National Park Service (NPS) subject-matter experts at critical points during the project timeline is also important. These staff will be asked to assist with the selection of study indicators;

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An NRCA is intended to provide useful science-based information products in support of all levels of park planning.

recommend data sets, methods, and reference conditions and values; and help provide a multi-disciplinary review of draft study findings and products.

NRCAs can yield new insights about current park resource conditions, but in many cases, their greatest value may be the development of useful documentation regarding known or suspected resource conditions within parks. Reporting products can help park managers as they think about near-term workload priorities, frame data and study needs for important park resources, and communicate messages about current park resource conditions to various audiences. A successful NRCA delivers science-based information that is both credible and has practical uses for a variety of park decision making, planning, and partnership activities.

However, it is important to note that NRCAs do not establish management targets for study indicators. That process must occur through park planning and management activities. What a NRCA can do is deliver science-based information that will assist park managers in their ongoing, long-term efforts to describe and quantify a park's desired resource conditions and management targets. In the near term, NRCA findings assist strategic park resource planning[6] and help parks to report on government accountability measures.[7] In addition, although in-depth analysis of the effects of climate change on park natural resources is outside the scope of NRCAs, the condition analyses and data sets developed for NRCAs will be useful for park-level climate-change studies and planning efforts.

NRCA Reporting Products…

- Provide a credible, snapshot-in-time evaluation for a subset of important park natural resources and indicators, to help park managers:
- Direct limited staff and funding resources to park areas and natural resources that represent high need and/or high opportunity situations (near-term operational planning and management)
- Improve understanding and quantification for desired conditions for the park's "fundamental" and "other important" natural resources and values (longer-term strategic planning)
- Communicate succinct messages regarding current resource conditions to government program managers, to Congress, and to the general public ("resource condition status" reporting)

NRCAs also provide a useful complement to rigorous NPS science support programs, such as the NPS Natural Resources Inventory & Monitoring (I&M) Program.[8] For example, NRCAs can provide current condition estimates and help establish reference

6. An NRCA can be useful during the development of a park's Resource Stewardship Strategy (RSS) and can also be tailored to act as a post-RSS project.

7. While accountability reporting measures are subject to change, the spatial and reference-based condition data provided by NRCAs will be useful for most forms of "resource condition status" reporting as may be required by the NPS, the Department of the Interior, or the Office of Management and Budget.

8. The I&M program consists of 32 networks nationwide that are implementing "vital signs" monitoring in order to assess the condition of park ecosystems and develop a stronger scientific basis for stewardship and management of natural resources across the National Park System. "Vital signs" are a subset of physical, chemical, and biological elements and processes of park ecosystems that are selected to represent the overall health or condition of park resources, known or hypothesized effects of stressors, or elements that have important human values.

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An NRCA uses a variety of data to assess the condition of a park's natural resources.

conditions, or baseline values, for some of a park's vital signs monitoring indicators. They can also draw upon non-NPS data to help evaluate current conditions for those same vital signs. In some cases, I&M data sets are incorporated into NRCA analyses and reporting products.

Over the next several years, the NPS plans to fund a NRCA project for each of the approximately 270 parks served by the NPS I&M Program. For more information on the NRCA program, visit http://www.nature.nps.gov/water/nrca/.

DON SWANN / NPS

Mica Mountain in Saguaro National Park's Rincon Mountain District.

Chapter 2: Introduction and Resource Setting

2.1. Introduction

2.1.1. Enabling Legislation/Executive Orders

Saguaro National Park (NP) was initially established as a national monument on March 1, 1933. The monument was created to preserve the saguaro cactus (*Carnegiea gigantea*) forest at the base of the Rincon Mountains, within the Rincon Mountain District (RMD). The Tucson Mountain District (TMD) was added to the park in 1961, also to protect the saguaro and associated vegetation in the area. Several boundary changes have occurred throughout the park's history increasing the acreage to what is currently 37,005.43 hectares (91,442.42 ac), some of which is under non-federal ownership.

The park's unique resources and values are identified in its purpose statement,

> "..... to preserve and protect saguaro cacti; diverse biotic communities (including the Sonoran Desert, associated mountain ecosystems, and Rincon Creek); cultural and archeological features; and scientific, scenic, and wilderness values. The park provides opportunities for research, education, and public enjoyment, and strives to protect its resources from the effects of the encroachment from urbanization and development" (NPS 2014a),

and further described in its six significance statements as follows (text excerpted from NPS (2014a)):

> The saguaro is the tallest cactus in the United States and is the namesake of Saguaro National Park. Its distinctive form is recognized worldwide as an iconic symbol of the American Southwest. The Sonoran Desert ecosystem, represented within the park, contains superb saguaro stands that are easily accessed by visitors.
>
> Saguaro National Park contains the largest roadless sky island in the American Southwest. Encompassing a wide range of elevations, the Rincon Mountains support extraordinary

biodiversity within a small geographic area. Within a few miles, the species within the park range from desert dwellers such as Gila monsters, desert tortoise, and saguaro cacti to montane residents such as American black bear, spotted owl, and Douglas fir.

Saguaro National Park preserves one of the largest concentrations of rare and distinct aquatic micro- habitats such as tinajas, seeps, and springs, in the desert Southwest. These habitats, along with the riparian corridor of Rincon Creek, support rare and special status species such as lowland leopard frog, yellow- billed cuckoo, gray hawk, and southwestern willow flycatcher, as well as plant species uncommon to the desert, including sycamore and ash.

Saguaro National Park has a long human history and legacy of scientific interest and research and serves as an exceptional living laboratory for studying ecological and geological processes as well as the environmental consequences of climate change.

Saguaro National Park's close proximity to a large urban community provides exceptional access to wild places in which visitors can experience wilderness and scenic views.

Saguaro National Park contains a rich concentration of cultural resources that tell the history of continuous and diverse human occupation in the Southwest from prehistoric to modern times. The landscape contains evidence of how people adapt, modify, and thrive in an arid environment, and is an important part of the cultural heritage of associated American Indian tribes, Hispanic populations, and other groups.

Additional fundamental and other important resources and values are identified for the park, which further expand on themes related to its purpose and significance statements. These resources and values are listed in Chapter 3, providing a summary of how the natural resources selected for the park's Natural Resource Condition Assessment (NRCA) report connect to its most important resources identified in its recently completed foundation document (NPS 2014a).

Saguaro NP Wilderness

Wilderness comprises 78% (28,895 ha/ 71,400 acres) of the park, which was designated by an act of Congress in 1976 (P.L. 94- 567) (Figure 2.1.1-1; Saguaro NP's wilderness areas are shown in the darker shade of green). Since then the park has acquired additional land, which may or may not be eligible for wilderness designation. Additional wilderness land (15,617 ha / 38,590 acres) surrounds RMD on three sides and is managed by the United States Forest Service (USFS) within the Coronado National Forest's Rincon Mountain Wilderness Area. This additional protection beneficially affects the overall management of wilderness lands and associated resources within and surrounding the park (NPS 2014a).

Wilderness is defined as "an area of undeveloped federal land retaining its primeval character and influence without permanent improvements or human habitation…" (The Wilderness Act of 1964; Public Law 88- 577 [16 U.S.C. 1131- 1136]). While few developments exist within Saguaro NP's wilderness boundary, rapid urban development originating from and surrounding the city of Tucson, Arizona, threaten the survival of wildlife species and their associated habitats within wilderness. It is also this juxtaposition of a protected area within a sea of development that makes the Saguaro NP wilderness area a very important and unique resource.

From a biological perspective, the species diversity found within the park's wilderness is globally rare (Conservation International 2014) and supports a total of six biotic communities, ranging from the lowest elevation of 664 m (2,180 ft) in TMD to the highest elevation of 2,641 m (8,666 ft) in RMD.

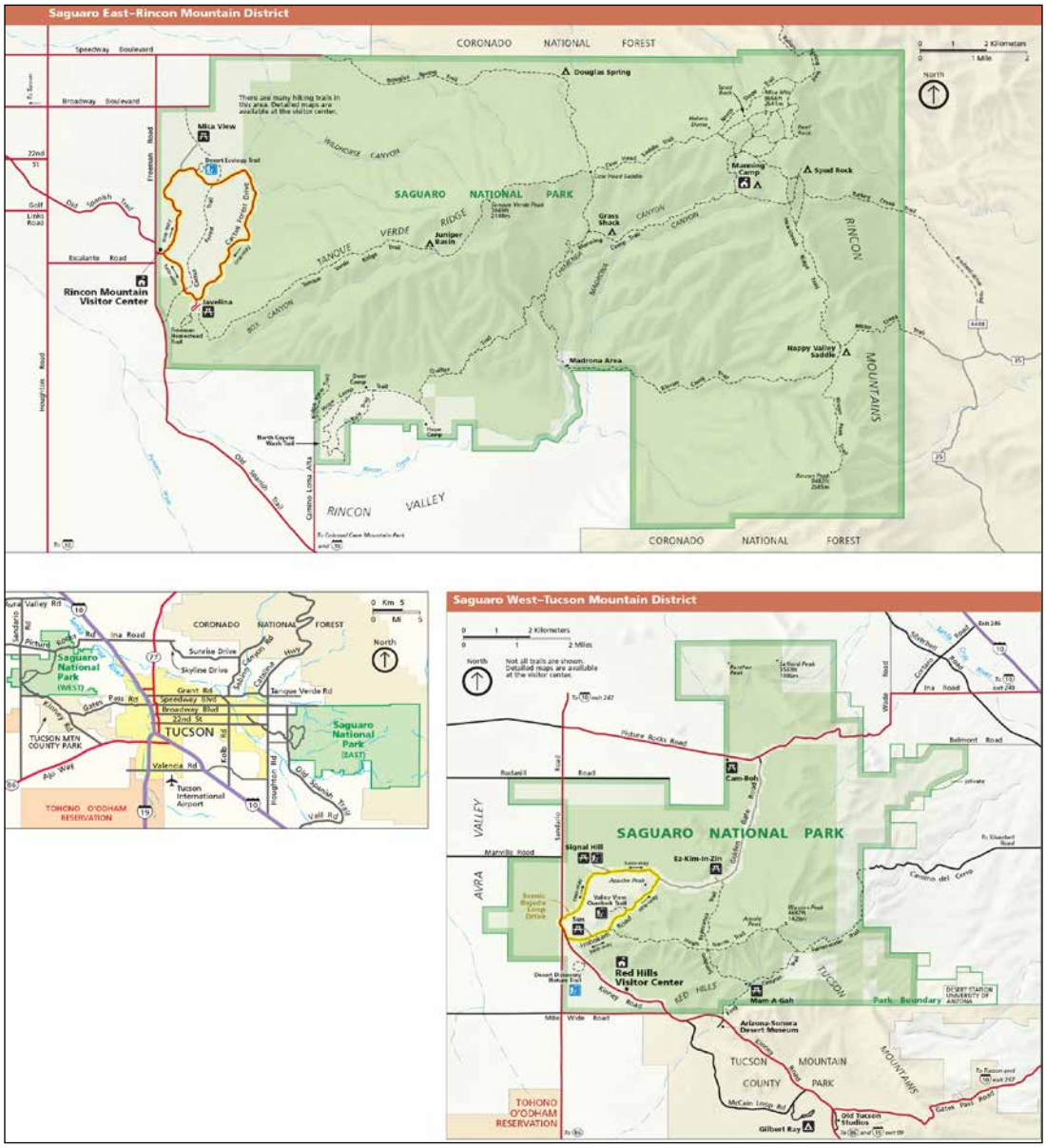

Figure 2.1.1- 1. Saguaro NP is comprised of the Rincon Mountain District (top) and of the Tucson Mountain District (bottom right), separated by the city of Tucson, Arizona (bottom left). Figure Credit: NPS (2014a)

Saguaro's wilderness also protects culturally significant sites such as Civilian Conservation Corps structures and resources important to the Tohono O'odham people (NPS 2014a).

From a recreational/visitor use perspective, the park's wilderness offers outstanding opportunities for unconfined recreation by protecting and managing a landscape where visitors can experience solitude and self-reliant activities. Saguaro NP attracts more than a half million visitors each year (NPS Public Use Statistics Office 2016) and provides easy access to its globally rare environment to visitors and Tucson's 500,000+ residents.

Public surveys of Tucson residents conducted by Yeasmin (2011), Harris and Shaw (1997) and Casey et al. (2005) found that while locals placed a high value on living adjacent to protected areas and on wildlife conservation, there was a lack of accurate knowledge and understanding of wildlife biology and associated human- caused impacts. This lack of knowledge may inadvertently threaten the resources that make the Tucson area so unique, but also offers tremendous opportunities to engage the local and surrounding communities in meaningful ways to help preserve the wilderness values well into the future.

2.1.2. Geographic Setting

Saguaro NP is located in southeastern Arizona's Pima County just outside the city limits of Tucson, Arizona. The park's two districts are separated by approximately 48.3 km (30 mi), with RMD situated to the east of Tucson (top map in Figure 2.1.1-1) and TMD located west of the city (bottom left map in Figure 2.1.1-1). In TMD, the elevation ranges from 664–804 m (2,180–4,687 ft), with Wasson Peak representing the highest point in the district. The RMD has much higher elevations, ranging from 814–2,641 m (2,670–8,665 ft), including Mica Mountain, Saguaro NP's tallest peak.

Population

The population has been increasing rapidly throughout Arizona, and the greater Tucson metropolitan area is one of the fastest growing population centers in the United States. Between 1950 and 2000 there was a 584% increase in population (Pima County Association of Governments n.d.), and the U.S. Census Bureau's (2005) interim state population projections predict Arizona to be the second highest state for population growth between 2000- 2030, increasing by 109% (U.S. Census Bureau 2012).

According to the 2010 census, Pima County's population was 980,263 and is projected to reach 1.45 million by 2041 (Pima County Association of Governments 2016). In 2000, 55% of the private land surrounding Saguaro NP was undeveloped, but exurban development is expected to increase 38% by 2030 and 105% by 2060 (Hansen et al. 2014). Housing densities are greater around TMD than they are around RMD (Monahan et al. 2013), but developments are increasing adjacent to both districts' boundaries. If developments continue to increase under existing zoning, by 2040, Saguaro NP will be considered a suburban park (Monahan et al. 2013).

Climate

The climate of the U.S. Southwest is most influenced by its location between the mid- latitude and subtropical atmospheric circulation regimes. This creates the typical southwestern climate of dry, sunny days (low annual precipitation) and warm temperatures year round. Rain comes in July/August from monsoon storms that originate in the Pacific Ocean and the Gulf of Mexico, and in December/January from winter storms that originate in the Pacific Ocean (Sheppard et al. 2002). This bimodal precipitation regime is a prominent feature of the Sonoran Desert in particular (Davey et al. 2007).

The Sonoran Desert region's high level of biological diversity is due, in part, to the influence of precipitation patterns (both warm- season and cool- season rains) and geographic diversity (Davey et al. 2007). Due to the large geographic area and the variation in topography with the Sonoran Desert and Madrean Sky Islands (refer to the ecological units discussion in section 2.2.1), there is wide variation in climate. The isolated mountain regions of the Sky Islands, which includes the Rincon Mountains in RMD provide a high diversity of habitat types over a relatively small geographic region. Temperatures decrease and precipitation increases with elevation, which has led to the establishment and persistence of plant communities that are adapted to the conditions and fluctuations in temperature and precipitation (Davey et al. 2007). Ecosystem condition is dependent on weather patterns and long- term climate. The iconic columnar cactus for which the park is named, is a very long- lived species and is adapted to wet and dry cycles. Saguaro cacti are impacted, however, by extreme temperatures (especially cold) and the nurse plants upon which they depend are more sensitive to prolonged periods of drought.

Temperature

Temperatures in the Sonoran Desert are variable ranging from a mean annual temperature of 10°C in the northern highlands to 20°C in the western lowlands. The average temperature for the period 2010- 2015 was 70.6°F, with a maximum temperature of 113°F and a minimum of 16°F (Figure 2.1.2- 1; WRCC 2015). Long- term data show an increase in the mean annual temperature between 1901- 2002 (Figure 2.1.2- 2; Gonzalez 2013).

Precipitation

Annual precipitation in the Sonoran Desert varies between 76- 500 mm based on elevation and latitude (Davey et al. 2007). Saguaro NP is in the eastern region of the Sonoran Desert and has an average annual precipitation of 11.23 inches in the TMD and 9.93 inches in the RMD (Figure 2.1.2- 3; measured from 2000- 2010; Rojas et al. 2011). [Notice the "Manning" (Manning Camp) location has consistently higher amounts of rainfall due to its higher elevation of 8,000 feet.] Longer-term trend data (1901- 2002) show high inter-annual variation in precipitation, but a general flat line trend (Figure 2.1.2- 4; Gonzalez 2013). The summer monsoons are usually the most productive rain events for Saguaro NP (Figure 2.1.2- 5), though there is high variability between wet years and drier years (Figure 2.1.2- 6) and between winter (Figure 2.1.2- 7) and summer rains. Also note the difference in precipitation between the high elevation (Manning Camp) and the lower- elevation gauges (Rojas et al. 2011).

2.1.3. Visitation Statistics

Monthly recreation visitor data for Saguaro NP are available from 1979- 2015 (NPS Public Use Statistics Office 2016). Visitation data are collected via traffic and horse counters,

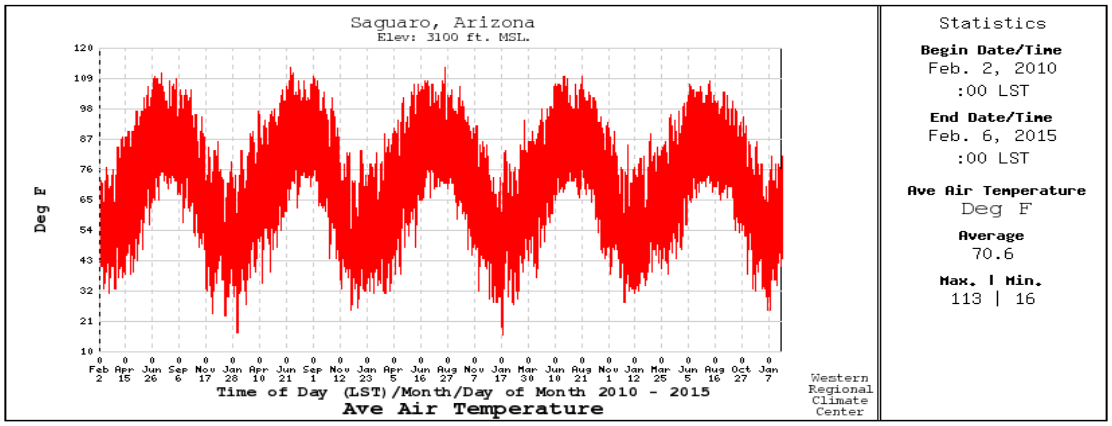

Figure 2.1.2-1. Average air temperature (2010-2015) from the Saguaro weather station (WRCC 2015).

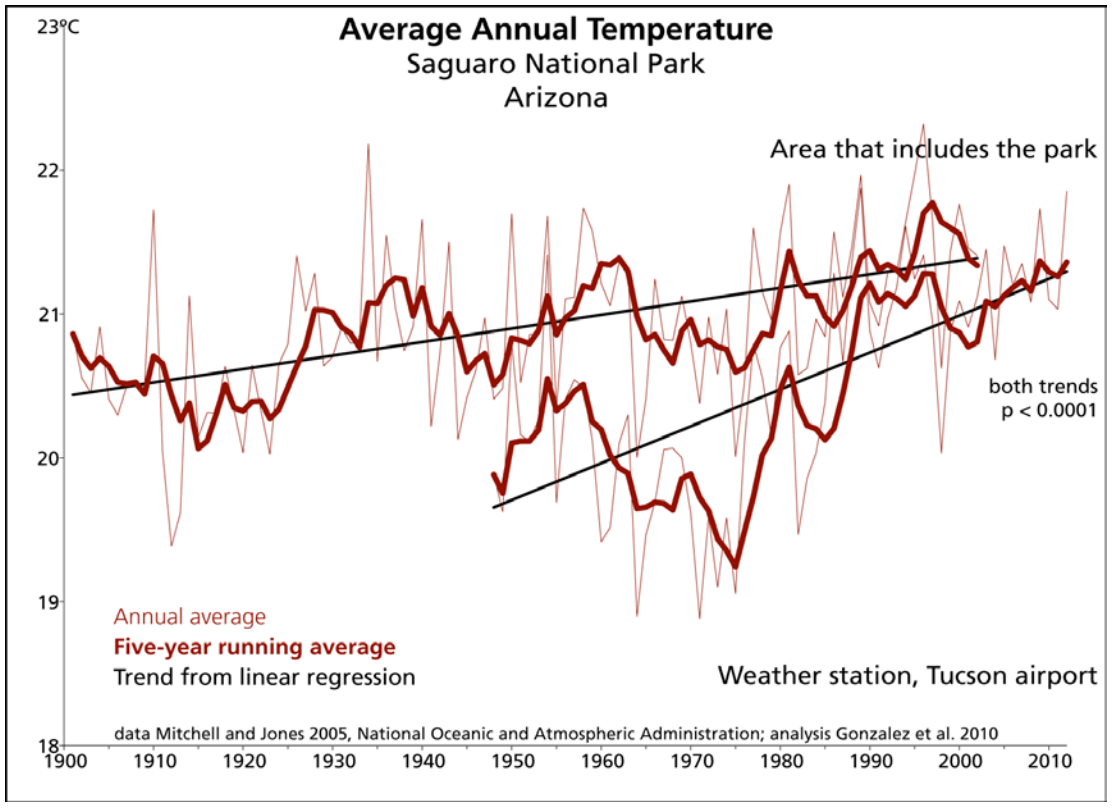

Figure 2.1.2-2. Average annual temperature in the Tucson area, 1901-2002 (Gonzalez 2013).

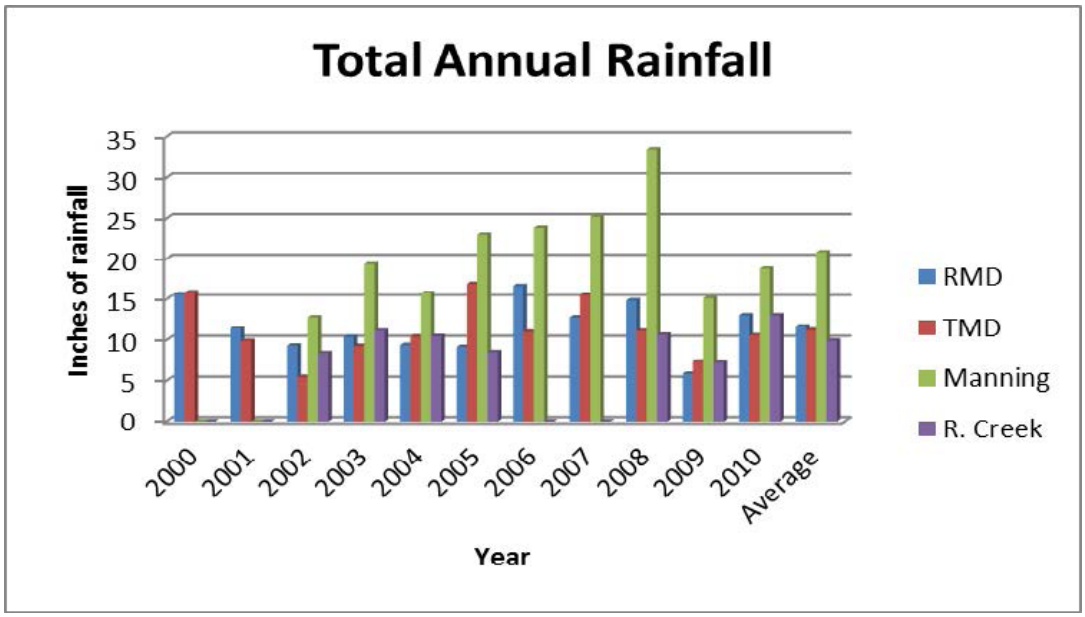

Figure 2.1.2-3. Total annual precipitation at four locations in Saguaro National Park, with RMD representing the Visitor Center (Rojas et al. 2011). Note: Data were not collected at Manning Camp for 2000-2001, or at Rincon Creek 2000- 2002, and most of 2006-2007.

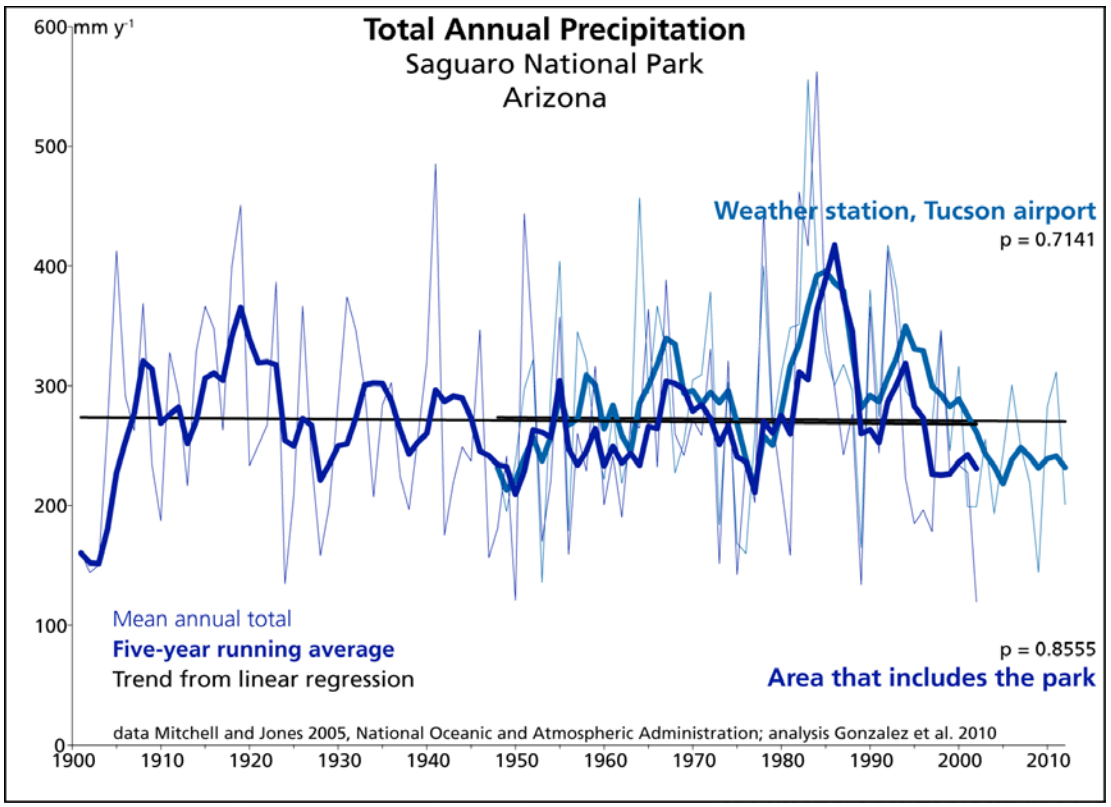

Figure 2.1.2-4. Total annual precipitation in the Tucson area, 1901-2002 (Gonzalez 2013).

trail registers, and commercial use licensee reporting at the park (NPS Public Use Statistics Office 2006). In some instances, counts are summed and multiplied by a designated factor to reduce duplicate reporting of total recreation visits (NPS Public Use Statistics Office 2001).

The total number of visitors each year to Saguaro NP ranged from a low of 470,598 (in 1981) to a high of 828,267 (in 1993). The months with the highest average number of visitors over the recording period were February - April (Figure 2.1.3- 1).

2.2. Natural Resources

A brief summary of the key natural resources at Saguaro NP is presented in this section to provide an introduction to the study area and park resources. Further details for most

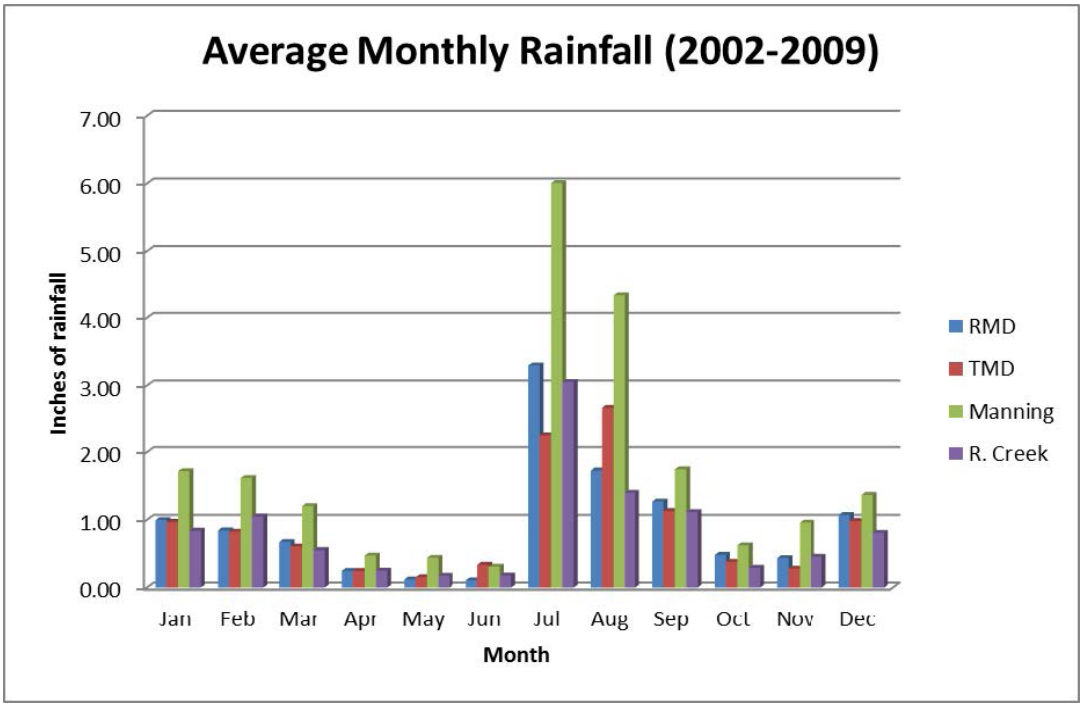

Figure 2.1.2- 5. Average monthly precipitation at four locations in Saguaro National Park, with RMD representing the Visitor Center (Rojas et al. 2011). Note: Data were not collected at Rincon Creek 2000- 2002, and most of 2006- 2007.

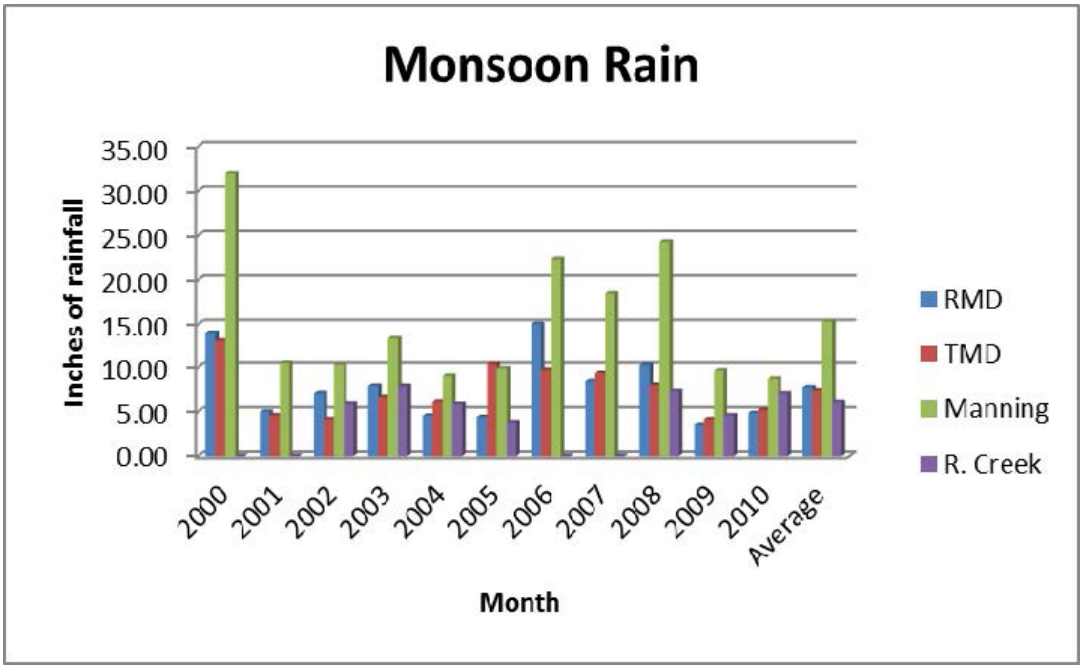

Figure 2.1.2- 6. Total summer precipitation at four locations in Saguaro National Park, 2000- 2010, with RMD representing the Visitor Center (Rojas et al. 2011). Note: Some data were not collected at Manning Camp in 2000- 2001, or at Rincon Creek 2000- 2002, and 2006- 2007; summer is defined as June- November.

of the resource topics presented in this section can be found in the report's Chapter 4 assessments.

2.2.1. Ecological Units, Watersheds, and NPScape Landscape- scale

Ecological Units

Saguaro NP lies at the boundary of two distinct and diverse ecoregions: the Sonoran Desert and the Madrean Sky Islands (also known as the Madrean Archipelago). The boundary between these two areas has given rise to ecosystems that occur nowhere else in America and as a result, Saguaro NP ranks as one of the most biologically diverse parks in the U.S. (NPS 2014a).

The Madrean Archipelago consists of about 40 mountain ranges stretching from the Sierra Madre Occidental in Sonora, Mexico to the Mogollon Rim in Central Arizona, with vast areas of desert and grasslands between the

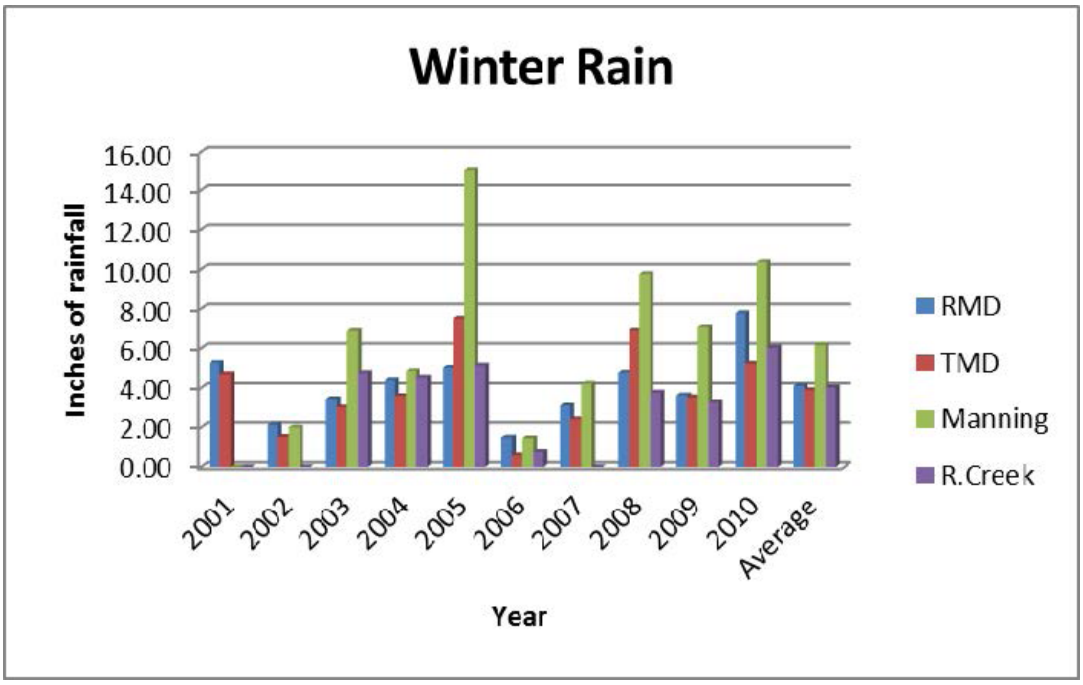

Figure 2.1.2-7. Total winter precipitation at four locations in Saguaro National Park, 2000- 2010, with RMD representing the Visitor Center (Rojas et al. 2011). Note: Data were not collected at Manning Camp for 2000- 2001, or at Rincon Creek 2000- 2002, and 2006- 2007; summer is defined as June- November.

ranges. The RMD lies within the Madrean Sky Islands region at the northern end of a biodiversity hotspot known as the Madrean Pine- Oak Woodlands (Critical Ecosystem Partnership Fund 2016) and TMD is located completely within the Sonoran Desert ecoregion. The biodiversity assessment in this report describes the species richness of these two ecological units within the park and the important role the park has in preserving them.

Watershed Units

There are five watersheds in TMD (Figure 2.2.1- 1) and nine watersheds in RMD (Figure 2.2.1- 2) (USGS 2014). Most of the watersheds are small containing first, second, and third order perennial interrupted, intermittent or ephemeral streams (Mott 1997). The areas of these 14 watersheds and percent area of park within each watershed are listed in Table 2.2.1- 1.

Most of the precipitation that both districts receive flows into the Santa Cruz River onto adjacent lands surrounding the park's boundary; however, there are a few exceptions. These exceptions include the west side of TMD, which drains into White Tank - Brawley Wash and Avra Valley, and

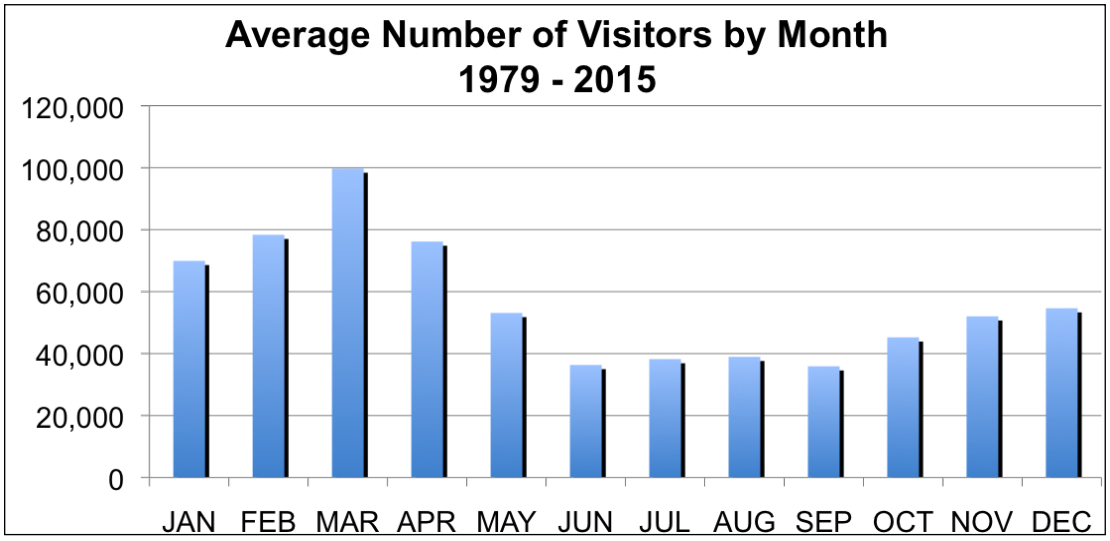

Figure 2.1.3- 1. Average number of visitors by month from 1979 - 2015 to Saguaro NP.

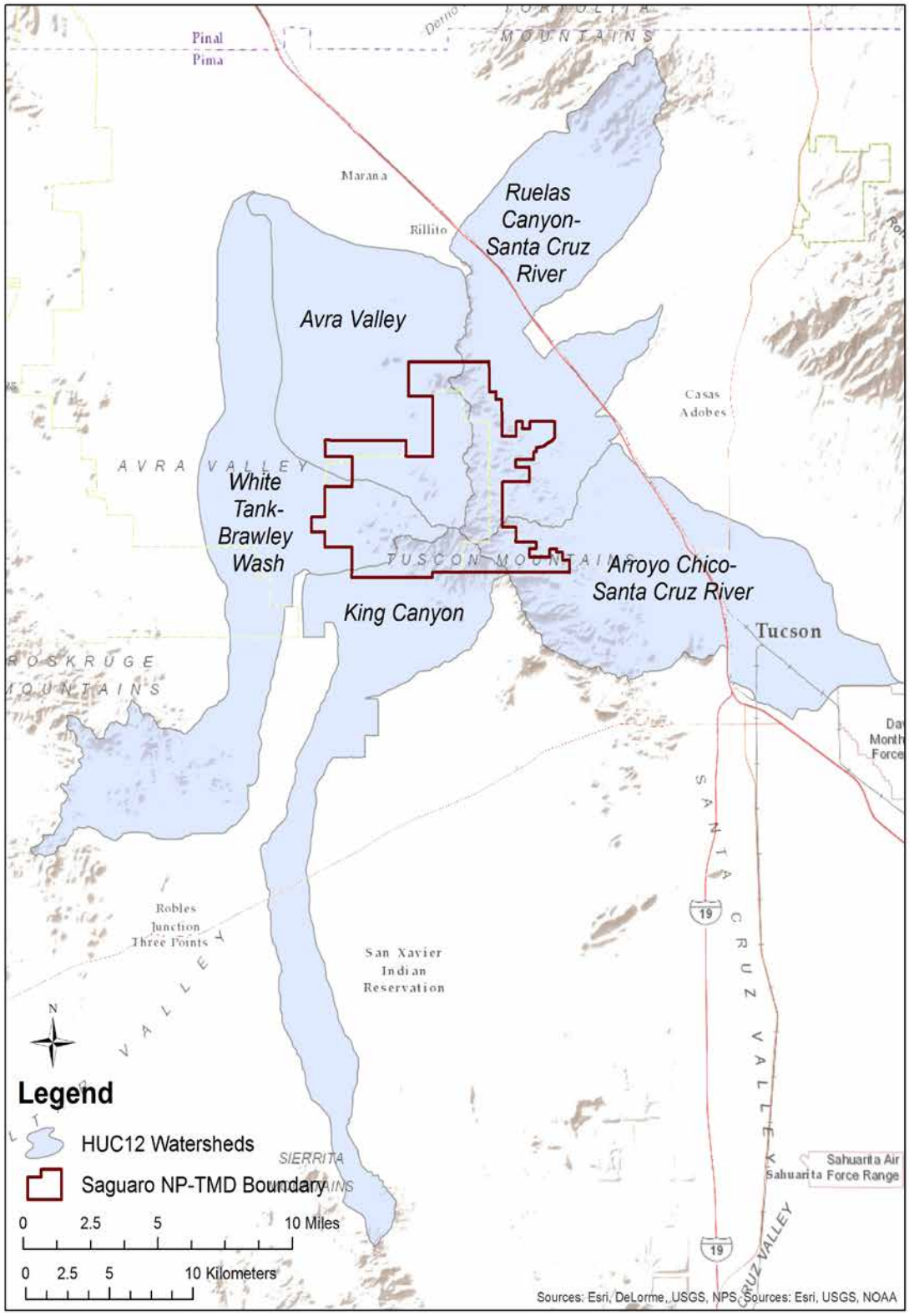

Figure 2.2.1-1. Saguaro NP's TMD is located within five watersheds (USGS 2014).

the east side of RMD, which primarily drains through Paige Creek into the San Pedro River.

Within TMD, the Avra Valley watershed drains the largest surface area within the district, although only 34.1% of the district occupies the watershed. RMD encompasses almost the entire Upper Rincon Creek watershed (91.3%), which includes the district's highest mountain peak, Mica Mountain. RMD also occupies 52.1% of the Middle Tanque Verde Creek watershed. Eighty percent of RMD's

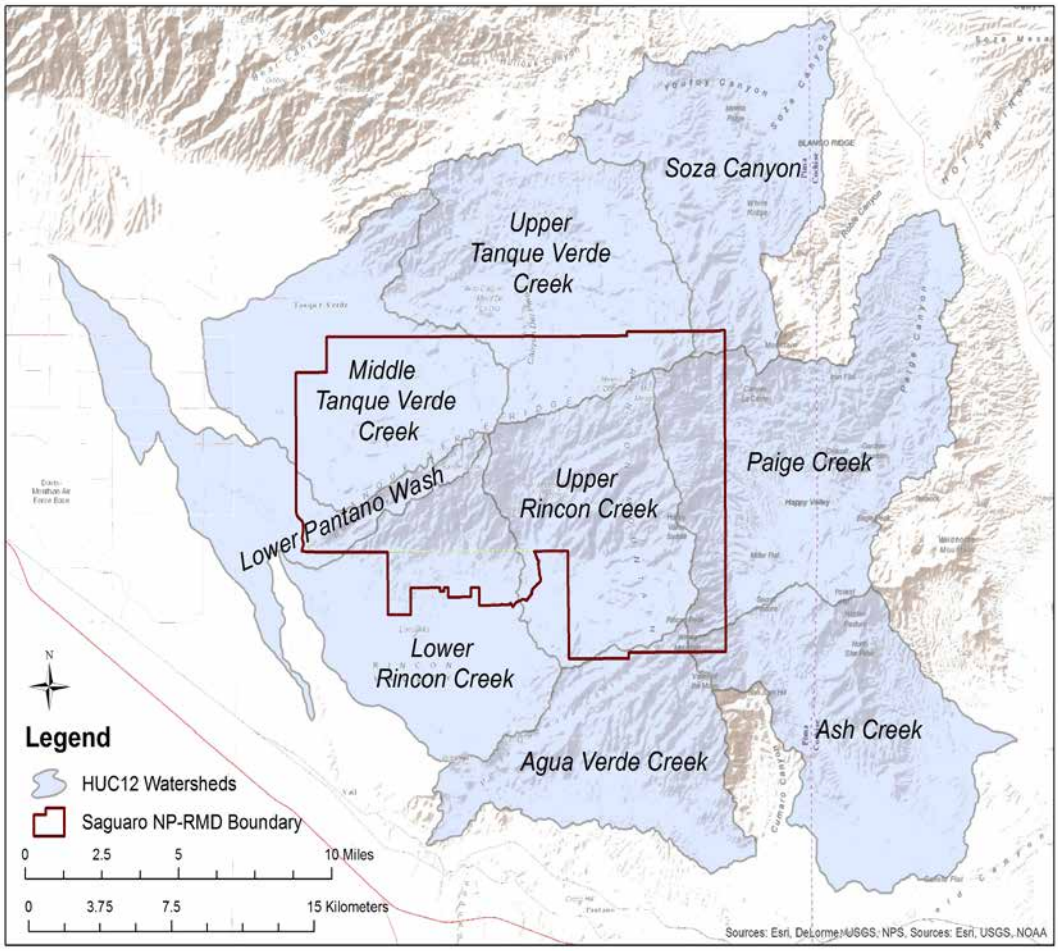

Figure 2.2.1-2. Saguaro NP's RMD is located within nine watersheds (USGS 2014).

Table 2.2.1- 1. Watersheds within Saguaro National Park.

Watershed Name	Total Watershed Area (km^2)	Total Area of Park in Watershed (km^2)	Total % Watershed Area in Park
Tucson Mountain District			
Avra Valley	151.02	34.11	22.6
Ruelas Canyon- Santa Cruz River	187.14	25.13	13.4
White Tank- Brawley Wash	207.24	21.66	10.5
King Canyon	141.11	12.65	9.0
Arroyo Chico- Santa Cruz River	178.16	7.24	4.1
Rincon Mountain District			
Upper Rincon Creek	100.92	91.26	90.4
Middle Tanque Verde Creek	122.26	63.7	52.1
Lower Rincon Creek	112.16	35.01	31.2
Lower Pantano Wash	76.97	15.97	20.7
Upper Tanque Verde Creek	133.41	27.22	20.4
Paige Creek	168.72	32.74	19.4
Agua Verde Creek	98	2.73	2.8
Soza Canyon	117.37	1.72	1.5
Ash Creek	123.42	1.69	1.4

surface area is drained by the two Tanque Verde Creek watersheds and the two Rincon Creek watersheds, flowing toward the Santa Cruz (USGS 2014 HUC12 data).

NPScape Landscape- scale
Most of the Saguaro NP's resources (e.g., viewshed, night sky, vegetation, wildlife, etc.) are affected by landscape- scale processes, and this broader perspective can provide more comprehensive information to better understand resource conditions throughout the park.

Studies have shown that natural resources rely upon the larger, surrounding area to support their life cycles (Coggins 1987 as cited in Monahan et al. 2012), and most parks are not large enough to encompass self- contained ecosystems for the resources found within park boundaries. This is especially important to Saguaro's natural resources due to the increasing developments that surround its districts and fragment what is currently intact natural areas.

When feasible, landscape- scale indicators and measures were included in the condition assessments to provide an ecological, landscape- scale context for reporting resource conditions. NPS' NPScape metrics were used to report on these resource conditions, providing a framework for conceptualizing human effects (e.g., housing densities, road densities, etc.) on landscapes (NPS 2014b).

2.2.2. Resource Descriptions

Supporting Environment

Saguaro NP lies within the southern portion of the Basin- and- Range Physiographic Province, with TMD occupying the Sonoran Desert section and RMD primarily occupying the Mexican Highland section (Figure 2.2.2-1).

The two districts contain very different geology, with the Rincon Mountains serving as the type locality for metamorphic core complexes and detachment faults (Davis 2013). The Rincons provide the basis for distinguishing and classifying the fundamental structural characteristics of metamorphic core complexes (Figure 2.2.2-2; Davis 1987). This core complex consists of metamorphosed basement rocks overlain by unmetamorphosed rock units, separated by a detachment fault. Diagnostic features of the

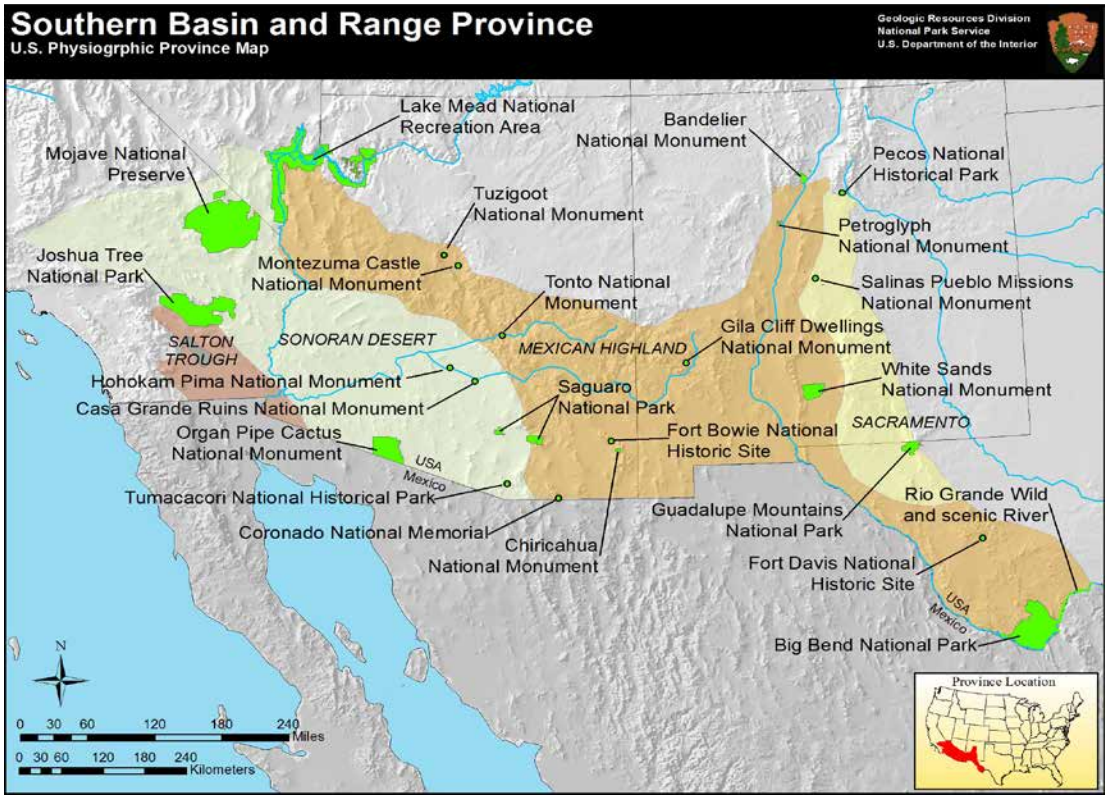

Figure 2.2.2-1. A map showing the southern portion of the Basin and Range Geographic Province (NPS GRD 2014).

metamorphic core complex can easily be seen in the outcrops along RMD's Cactus Forest Drive.

TMD's geology offers an opportunity to study events associated with the formation of the Tucson Mountains Caldera, created by an extremely large volcanic eruption that occurred approximately 70 to 75 million years ago (Bezy 2005). The park's caldera is a depression that is approximately 20 to 25 km (12 to 15 mi) wide (note that Crater Lake National Park's caldera is only 10 km (6 mi) in diameter in comparison; Graham 2010). This eruption caused the existing rocks to collapse creating a disordered mass of limestone, sedimentary, metamorphic, and volcanic rocks, which were later covered by additional volcanic rocks (Graham 2010).

Between TMD's Tucson Mountains to the west and the Rincon and Santa Catalina Mountains to the east lies the Tucson Basin, with Tucson, Arizona located at its center. The Tucson Basin is part of the larger Santa Cruz Basin, which is divided into upper and lower basins. The basin is filled with fluvial, lacustrine, and debris flows along with alluvial fan deposits along the basin's perimeter. The sediment characteristics including porosity, permeability, and lithology control the occurrence and movement of groundwater throughout the basin (Graham 2010) (refer to the Chapter 4 groundwater assessments for very detailed information about groundwater movement within the Tucson Basin and others).

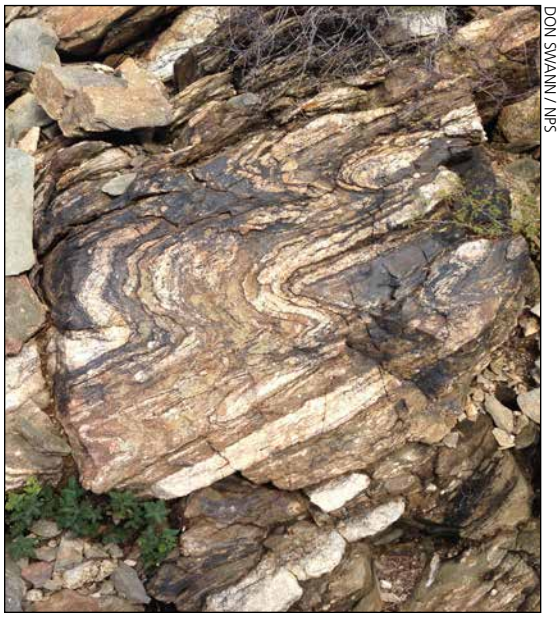

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Figure 2.2.2-2. Thrust in ultramylonite on Tanque Verde Mountain.

Groundwater

At Saguaro NP groundwater availability to ecosystems is dependent on climatic variables, including the quantity and timing of precipitation as well as whether the precipitation falls as rain or as snow. Atmospheric factors that influence snow melt and the rate of evaporation, including temperature, wind speed and direction, and relative humidity, play a significant role. Potable groundwater availability to park operations at both districts is affected by the factors listed above but is strongly moderated by the importation of Colorado River water via the Central Arizona Project aqueduct and the ability to pump and transport stored groundwater from hundreds of feet below the surface in the central groundwater basins to points of use throughout the area. With the exception of the eastern slopes of the RMD, both districts are located within the Tucson Active Management Area (AMA), (which includes the Avra Valley and the Upper Santa Cruz Sub- basins) and as such, the potable water supply future for the park is linked to overall groundwater status within the Tucson AMA. The eastern flanks of the Rincons include drainages in the Mammoth subbasin to the east- northeast and the Sierra Vista subbasin to the southeast, which are not included in the Tucson AMA.

In the TMD, perennial natural surface water is unknown (Mott 1997), and a small number of wildlife watering facilities supplied by groundwater has been developed. In RMD, the few perennial pools and bedrock pools (tinajas) upon which wildlife and aquatic plants and animals depend for survival through the hottest and driest times of year are sustained by groundwater (Figure 2.2.2-3).

Tinajas, Springs, and Seeps

Tinajas ("earthen jar" in Spanish) and springs are perennial or intermittent pools of water on which aquatic and riparian wildlife and plants depend. Seeps are small seasonally wet areas with minimal pooled water that

support plants and animals adapted to drier conditions (Gaun et al. 2016).

Saguaro NP's tinajas and springs serve as breeding pools and refugia for reptiles and amphibians including the lowland leopard frog (*Rana* [or *Lithobates*] *yavapaiensis*), canyon treefrog (*Hyla arenicolor*), and Sonoran mud turtle (*Kinosternon sonoriense*) (Swann et al. 2008). Other animals are also attracted to tinajas because they provide reliable sources of drinking water, foraging opportunities, and refuge for species including mountain lion (*Puma concolor*), black bear, (*Ursus americanus*) Yellow-billed Cuckoo (*Coccyzus americanus*), and Gray Hawk (*Buteo plagiatus*) among dozens of other species (Boyle and Conway 2003, Sidner 2003, Swann et al. 2008). In addition to the benefits these surface waters provide to wildlife and plants, tinajas, springs and seeps serve as recreational areas and sources of drinking water for many of Saguaro NP's visitors and backcountry users (NPS 2014a).

Surface Water Quantity and Riparian Habitat in the Middle Reach of Rincon Creek

Rincon Creek is an intermittent stream located in Saguaro NP's RMD, the U.S. Forest Service's Coronado National Forest, and on private lands. The creek originates in the Coronado National Forest and in the Rincon Mountains in the park above 2,621 m (8,600 ft) then leaves the park where it flows through private land before re- entering the park (NPS 2008a).

Rincon Creek is the largest and most well developed riparian woodland in Saguaro NP with Freemont cottonwood (*Populus fremonti*), Arizona sycamore (*Platanus wrightii*), velvet ash (*Fraxinus velutina*), willow (*Sailix spp.*), and netleaf hackberry (*Celtis reticulata*) growing along its banks (Baird et al. 2001). While not perennial, Rincon Creek is the most reliable water resource in the park, flowing in some years throughout the entire year. The riparian woodland in the creek contains the greatest diversity of birds in the park, including breeding populations of species such as Yellow- billed Cuckoo and Gray Hawk and is considered one of the most significant areas for birds in the Tucson area (Powell 2004, Conway et al. 2012). The creek and its tributaries contain some of the region's most stable populations of the lowland leopard frog, as well as other aquatic species such as Sonoran mud turtles, and supports an important mammal community that includes coati (*Nasua narica*), black bear, and mountain lions (Stitt et al. 2008).

Air Quality

Different categories of air quality areas (Class I and II) have been established through the authority of the Clean Air Act of 1970 (42 U.S.C. §7401 et seq. (1970)). Saguaro NP is designated as a Class I airshed and several air quality monitoring stations are located within the required distances to provide long- term air quality trends for ozone levels and visibility within the park's airshed. No monitors are within the requisite distances to determine long- term trends for wet deposition, including nitrogen, sulfur, and mercury; however, beginning in 2014, up to 50 national parks, including Saguaro NP, participated in an on- going citizen science study, Dragonfly Mercury Project (DMP). Students and volunteers collected dragonfly larvae from sampling sites to "provide baseline data to better understand the spatial distribution of mercury contamination in national parks" (NPS- Air Resources Division 2016). Sampling continued in 2016 and the DMP is expected to continue well into the future (NPS- Air Resources Division 2016).

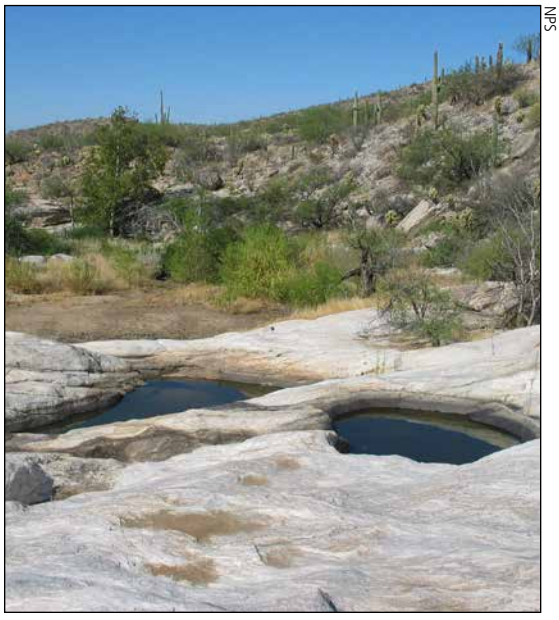

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Figure 2.2.2-3. Tinajas in Madrona Creek in the Rincon Mountains.

Landscape- scale Resources

Viewshed,

Viewsheds are considered an important part of the visitor experience at Saguaro NP and features on the visible landscape influence a visitor's enjoyment, appreciation, and understanding of the park (Figure 2.2.2- 4). The park's wilderness and proximity to a large urban community provides "exceptional access to wild places in which visitors can experience wilderness, and in some areas, undeveloped scenic views" (NPS 2014a). These views represent much more than just scenery; they represent a way to better understand the connection between self and nature. The panoramas taken and analyses performed for the viewshed condition assessment represent baseline data and are a way to measure the integrity and intactness of the scenic landscape within and surrounding Saguaro NP.

Night Sky

Dark night skies are considered an aesthetic in national parks and offer an experiential quality that is also integral to natural and cultural resources (Moore et al. 2013). Historically, American Indian's observation of the sun, moon and stars was essential for planning festivals and activities such as when to start planting and when to harvest (Aveni 2003). In an estimated 20 national parks, stargazing events are the most popular ranger- led program (NPS 2010). But the values of night skies go far beyond visitor experience and scenery. The photic environment affects a broad range of species, is integral to ecosystems, and is a natural physical process (Moore et al. 2013). The NPS Natural Sounds and Night Skies Division (NSNSD) conducted an assessment of the night sky condition in Saguaro NP at multiple locations in March 2007, April 2008, and October 2011. The results of those surveys are discussed in the night sky condition assessment.

Soundscape

According to a majority of members of the American public surveyed, opportunities to experience natural quiet and the sounds of nature is an important reason for having national parks (Haas and Wakefield 1998). To evaluate the soundscape at Saguaro NP, baseline acoustical data were collected by Saguaro NP personnel, in conjunction with scientists from NPS' NSNSD, at the park in February and April of 2016. A "snapshot report" was written by NSNSD, with a full report expected after data analysis is completed (NPS NSNSD 2016). As a result of the brief report, distinctions between intrinsic versus extrinsic sounds were not differentiated for the 2016 sites. Additional acoustical monitoring has occurred previously at the park, and the data were used in the soundscape condition assessment even

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Figure 2.2.2-4. A sweeping view from Reef Rock, located in RMD's wilderness.

though no monitoring effort occurred at the same location more than once.

Biological Resources

Biodiversity

Saguaro NP lies at the boundary of two distinct and diverse ecoregions: the Sonoran Desert ecoregion and the Madrean Sky Islands ecoregion (also known as the Madrean Archipelago). The boundary between these two areas has given rise to ecosystems that occur nowhere else in America and as a result, Saguaro NP ranks as one of the most biologically diverse parks in the U.S. (NPS 2014a). The biodiversity that Saguaro NP preserves through its legislated wilderness and management actions benefits humans with ecosystem services, such as clean water and air, in addition to its intrinsic worth, which serves as an essential part of humanity's natural and spiritual surroundings. This biodiversity is reflected in the number and breadth of resource topics selected for the park's NRCA.

Saguaro Cactus

Among the many notable resources at Saguaro NP is the saguaro cactus, the signature species of the national park and one signature species of the Sonoran Desert. Reaching a height of 12 m (39.4 ft) or more (Turner et al. 1995), the saguaro cactus is the largest cactus in the United States. It occurs in southern Arizona and extreme southeastern California, as well as in Mexico and is slow- growing and may live an average of 100- 175 years (Pierson et al. 2013). This cactus is an ecologically important member of the Sonoran Desert community, providing nesting or resting habitat (Figure 2.2.2- 5) or food for a diversity of animals, such as large and small species of birds, bats and other mammals, reptiles, and insects. Native people also use the saguaro cactus as a building material, for food, and in other ways (Turner et al. 1995, Toupal et al. 2006).

The saguaro cactus has been the subject of research and monitoring at the park for more than 70 years. Ahnmark and Swann (2009) summarized much of the work that has been done and separated it into three general and interwoven phases: 1) the initial findings, that is, the "state of saguaros," 1910–1939; 2) identifying the agent of decline of the saguaro (and gaining a better understanding of the cactus itself) and implementing a cure, 1940–1960; and 3) ecological studies, a second set of census results, and the population surge, 1961–present. During these phases of saguaro cactus research and monitoring, information was collected on saguaro establishment, growth rates, and recruitment; effects of freezing temperatures and frost; population density; disease; effects of grazing, deforestation, and air quality; and saguaro respiratory and circulatory systems (Ahnmark and Swann 2009). Some of the results of long- term monitoring, particularly those related to recruitment and population/ density, are used in the condition assessment and are further described in Chapter 4.

Sonoran Desert Vegetation

Saguaro NP is best known for its desert environment, which occurs from the park's lowest elevation up to 1,370 m (4,500 ft) (NPS SODN 2016). The Sonoran Desert is the only place in the world where the saguaro cactus grows in the wild (NPS SODN 2016). Along with the famous cactus, the valley bottom desert community is characterized by several species including velvet mesquite (*Prosopis velutina*), acacias (*Acacia spp.*), paloverdes (*Cercidium spp.*), and creosotebush (*Larrea tridentata*), among others. Succulents, including agave (*Agave spp.*), yucca (*Yucca spp.*), barrel cactus (*Ferocactus* and *Echinocactus spp.*), hedgehog

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Figure 2.2.2-5. Saguaro cactus (*Carnegiea gigantea*), with cavity serving as potential nesting or resting habitat.

cactus (*Mammillaria spp.*), and pricklypear and cholla (*Opuntia spp.*) are common in the park (NPS SODN 2016). Desert plants thrive in the region's arid climate with special adaptations that make them uniquely suited to the desert environment. Ascending from the valley bottom to the bajada, the vegetation gives way to thornscrub desert vegetation. Thornscrub is composed primarily of small trees (e.g., velvet mesquite) and shrubs (e.g., *catclaw acacia*, *Acacia greggii*), with cacti (particularly *Opuntia spp.*) (NPS SODN 2016). Farther upslope, the plant community transitions into semi- desert grasslands. Semi-desert grasslands are composed of perennial short- and mid- grass species. Annuals and geophytes are also common, with occasional shrubs or trees. The desert environment in Saguaro NP is found throughout the TMD and at lower elevation areas in the RMD.

Grasslands, Woodlands, and Forests in the RMD

Saguaro NP's RMD consists of a much more diverse assemblage of habitat types than found in TMD as a result of a wide topographical gradient, ranging from 814 m to 2,641 m (2,670–8,665 ft) at Mica Mountain (NPS SODN 2016). These types include thornscrub, (common species listed in the previous paragraph), which is found at RMD's lowest elevation to temperate coniferous forests, which occurs at the highest elevation. Semi-desert grasslands occur above thornscrub and are composed of perennial short- and mid- grass species. Annuals and geophytes are also common, with occasional shrubs or trees.

At middle elevations (1,372- 1,828 m (4,501-6,000 ft) the Madrean evergreen woodland is the dominant vegetation type. Madrean evergreen woodlands are characterized by evergreen oaks such as emory oak (*Quercus emoryi*), Arizona white oak (*Quercus arizonica*), and Mexican blue oak (*Quercus oblongifolia*) (NPS SODN 2016). Mexican pinyon pine (*Pinus cembroides*) and alligator juniper (*Juniperus deppeana*) are also common often occurring with an understory of perennial grasses. Interior chaparral is found interspersed with Madrean evergreen woodlands. The natural fire regime for chaparral includes intense, fast- moving fires that are often stand- replacing (NPS SODN 2016).

High mountain areas are dominated by temperate forests consisting of pines (*Pinus spp.*), with north slopes covered with pines, Douglas fir (*Pseudotsuga menzieseii*), and white fir (*Abies concolor*). The park has five areas with aspen (*Populus tremuloides*), and Gambel oak (*Quercus gambelii*) is scattered at the higher elevations and on north slopes (Powell et al. 2006, NPS SODN 2016). The most common pines at upper elevations are Arizona pine (*Pinus arizonica*), ponderosa pine (*P. ponderosa*), and southwestern white pine (*P. strobiformis*), and pine stands often have a grassy understory. On the north-facing slopes at upper elevations, Douglas fir, ponderosa pine, southwestern white pine, and white fir dominate. Conifer forests are fire- adapted, with natural, low- intensity fires occurring every 9–15 years (NPS SODN 2016). Elevation, aspect and local geomorphological characteristics determine which tree species occur (NPS SODN 2016).

Wildlife

Birds

A variety of habitats is available to birds in the two districts of Saguaro NP, and this variety has led to a diversity of birds. The most recent efforts to inventory and/or monitor birds in the park were an inventory of each park district in 2001- 2003 (by the University of Arizona; Powell [2006] and Powell [2007]) and annual bird monitoring (2007- present) conducted by the Sonoran Desert Inventory and Monitoring Network (SODN). Within the park, SODN monitors birds in upland habitats (desert scrub, forest, and woodland) and riparian habitat. Although research on birds in both districts had been conducted prior to the 2001- 2003 inventories, the Powell (2006, 2007) work was the most comprehensive and well- documented up to that time. Using four different survey methods, they recorded 173 species in the RMD and 73 species in the TMD. The Powell (2006 and 2007) reports also provided a summary of research and other work on birds in the RMD and TMD dating back to 1956; some of this summary

information is included in the Chapter 4 assessment.

There are now eight years of data on birds in the park from the SODN annual surveys. Preliminary analyses of these data have been conducted, and some information on 1) occupancy of some species common in the SODN and 2) species richness in the areas sampled is presented in Chapter 4. A comprehensive list of species in the park was reviewed and updated in 2016 by avian experts (including a Saguaro NP biologist). This comprehensive list contains a total of 222 species. There are three species (or subspecies) that are known to occur in Saguaro NP that are listed under the Endangered Species Act. These are the Southwestern Willow Flycatcher (*Empidonax traillii extimus*; endangered), the Mexican Spotted Owl (*Strix occidentalis lucida*; threatened), and the Yellow- billed Cuckoo; threatened) (NPS 2014a; USFWS 2014). Designated critical habitat for the Mexican Spotted Owl also occurs within the park.

Mammals

A diversity of habitats exist for mammals in Saguaro NP's districts. The park's location in southeastern Arizona places it within an area characterized as having the greatest mammalian diversity in North America north of Mexico (Figure 2.2.2- 6) (Turner et al. 1995). Both tropical mammal species and more northern species inhabit the area. Due to the districts' differences in habitat and elevation, some differences exist in mammal species occurrence.

Although mammals in the park had been studied prior to the 2000s, especially in the RMD (see Swann and Powell 2006, 2007 for review), the first comprehensive surveys of mammals in both park districts were conducted in 2001- 2005 (Swann and Powell [2006] for the RMD, and Swann and Powell [2007] for TMD). This work was conducted as part of a larger vascular plant and vertebrate inventory of the park by SODN. This work was later supplemented by two technical reports, one for each district, which summarized known current and historic information on all mammal species in the districts (Swann 2011, Swann 2012). The most recent survey (2011- 2012) of mammals (as a group) in both districts of the park focused on medium and large mammals using the relatively new technology of infrared- triggered cameras (Swann and Perkins 2013). From all of these efforts, more than 70 mammal species have been documented in Saguaro NP. Four of the species are considered non- native or domestic. Approximately 16 of the species are considered Species of Greatest Conservation Need with the State of Arizona (Arizona Game and Fish Department 2012). This includes one species, the lesser long- nosed bat (*Leptonycteris yerbabuenae*), which is listed as endangered by the U.S. Fish and Wildlife Service. This species, and some others, have

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Figure 2.2.2-6. Striped skunk (*Mephitis mephitis*; left) and American black bear (*Ursus americanus*; right), two mammal species that occur in Saguaro NP.

been monitored at the park regularly in recent years.

Herpetofauna

Amphibians and reptiles in Saguaro NP have been relatively well- studied (Flesch et al. 2006) and several species lists have been compiled for each district (e.g., Lowe and Holm 1991; Flesch et al. 2006, 2007). However, surveys conducted by Flesch et al. (2006 and 2007) were the first efforts to assemble well- documented species lists and to quantify relative abundance and species richness of herpetofauna in each district (Flesch et al. 2006, 2007). Approximately 61 species in total have been recorded during the 2001- 2002 surveys by Flesch et al. (2006, 2007) or during past studies or more recently by park personnel. The vast majority, 52, of these species are reptiles (e.g., Figure 2.2.2- 7), and nine of the species are amphibians. Three of the 61 species are non- native. Almost one-fourth of the species are considered Species of Greatest Conservation Need with the State of Arizona (Arizona Game and Fish Department 2012). This includes one species, the Sonoran desert tortoise (*Gopherus morafkai*), which was considered a federal candidate species until recently. The populations of two of the species, the Sonoran desert tortoise and the lowland leopard frog, have been or are being monitored within portions of the park. The Sonoran desert tortoise is found in both districts, while the lowland leopard frog is found only within RMD. There are other differences in species occurrence between the two districts, probably due to differences in species' ranges, differences in location and elevation, and the absence of aquatic habitat in TMD (Flesch et al. 2007).

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Figure 2.2.2-7. Greater short-horned lizard (*Phrynosoma hernandesi*), which has been documented in the Rincon Mountain District.

2.2.3. Resource Issues Overview

Climate Change

Like many places, the desert southwest is already experiencing the impacts of climate change. The predictions are that the Sonoran Desert will likely continue to become warmer and drier with climate change (Garfin et al. 2014, Monahan and Fisichelli 2014). According to Kunkel and others (2013), the historical climate trends (1895- 2011) for the southwest (including the states of Arizona, California, Colorado, Nevada, New Mexico, and Utah) have seen an average annual temperature increase of 0.9ºC (greatest in winter months) and more than double the number of four- day periods of extreme heat. Future climate predictions (Kunkel et al. 2013) for 2070- 2099 (based on climate patterns from 1971- 1999) estimate temperatures could rise between 2.5ºC and 4.7ºC. Monahan and Fisichelli (2014) report that Saguaro NP is already experiencing extreme warming (Figure 2.2.3- 1; also see Figure 2.1.2- 2 above), and Saunders et al. (2009) identified Saguaro NP as one of 25 parks most at risk due to climate change.

Monahan and Fisichelli (2014) assessed the magnitude and direction of changes in climate variables for Saguaro NP, including temperature and precipitation between 1901-2012 (historical range of variability (HRV)). Results for extreme climate were defined as experiencing either <5th percentile or >95th percentile climates relative to the HRV. The results for the extreme climate variables at Saguaro NP were as follows:

- Four temperature variables were "extreme warm" (annual mean temperature, mean temperature of the driest quarter, mean temperature of the warmest quarter, and mean temperature of the coldest quarter);
- No temperature variables were "extreme cold;"

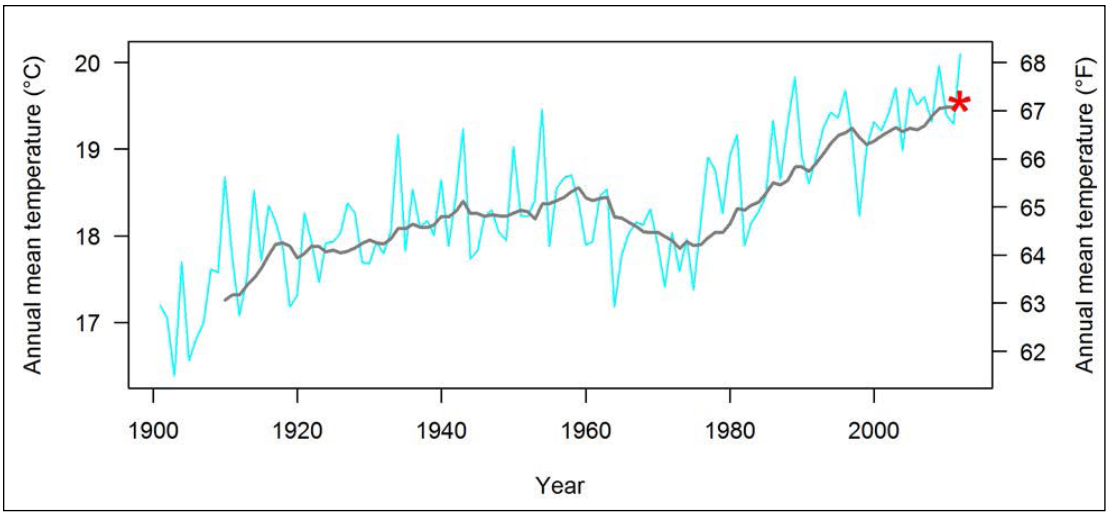

Figure 2.2.3-1. Time series used to characterize the historical range of variability and most recent percentile for annual mean temperature at Saguaro National Park (including areas within 30- km [18.6- mi] of the park's boundary). The blue line shows temperature for each year, the gray line shows temperature averaged over progressive 10- year intervals (10- year moving windows), and the red asterisk shows the average temperature of the most recent 10- year moving window (2003–2012). The most recent percentile is calculated as the percentage of values on the gray line that fall below the red asterisk (Monahan and Fisichelli 2014).

- No precipitation variables were "extreme dry;"
- No precipitation variables were "extreme wet" (brief can be accessed at (http://science.nature.nps.gov/climatechange/?tab=0&CEtab=3&PanelBrief3=open#PanelBrief).

The graph of the temperature for each year between 1901- 2012, the averaged temperatures over progressive 10- year intervals, and the average temperature of 2003- 2012 (the most recent interval) is shown in Figure 2.2.3- 1. The results indicate that recent climate conditions have already begun shifting beyond the HRV, with the 2003- 2012 decade representing the warmest decade on record. It's likely that future climate change will increasingly affect all aspects of park resources and operations (Monahan and Fisichelli 2014).

Groundwater

Key uncertainties in groundwater condition arise from unquantified changes in water balances in response to future climatic conditions and to concomitant changes in ecosystem and human consumption. Projected increases in temperature and decreases in precipitation, as well as projected increases in extreme winter precipitation events (Garfin et al. 2013) have the potential to result in added stress to shallow groundwater reserves when infiltration is reduced and plant transpiration demands are increased. Soil losses that occur during extreme events reduce the ability of watersheds to retain water and deteriorate groundwater conditions. Within the Avra Valley groundwater subbasin, sustainability depends upon continued inflows from the Colorado River, a source that depends on many factors outside of the control of the end user (Bureau of Reclamation 2012). Three primary threats to groundwater resources at Saguaro NP's RMD include climate change, groundwater pumping, and landscape- scale surface modification, especially by wildfire. Key uncertainties exist associated with lack of data about some of RMD's groundwater systems and how changes in one will propagate through the other systems (refer to the RMD groundwater assessment for details).

Surface Waters

On July 13, 2001, The Arizona Department of Water Resources issued a Certificate of Assured Water Supply No. 27- 400201 to Mountain Creek Ranch (a subdivision) near Rincon Creek (NPS 2008a). The Certificate was for a three- fold increase in water withdrawal from the Rincon Creek watershed (NPS 2008a). The park became concerned

about the effects this increase would have on wildlife, plants, and the recreational value of the creek. To determine the amount of water needed to support the riparian and aquatic ecosystems within the middle reach, the NPS conducted hydrologic studies beginning in 2003 (NPS 2008a). Data collected during these studies were used to complete a water right application (No. 33- 96733), requesting instream- flow maintenance from the Arizona Department of Water Resources (NPS 2008a, b). The status of the water right application has not been resolved; however, the NPS has continued hydrologic studies in the middle reach to monitor long- term changes in water resources and their effects on wildlife and plants. Recent drought, climate change, and high water demands due to the expanding urban population will increasingly affect water resources in Rincon Creek. The occurrence of wildlife and plants along and in the middle reach of Rincon Creek depend on streamflow and pools located within the creek. The wetland plant community is dependent on near- surface soil saturation; however, mature trees and other vegetation in Rincon Creek already show signs of water stress, and there is a general lack of seedling recruitment (Baird et al. 2001).

Tinajas, springs and seeps are additional water-based natural resources that are important to Saguaro NP. Despite their importance, there is relatively little information partly due to their remote location. The few data that exist on springs indicate that in both high elevation and low elevation areas in the park, springs have experienced reduced flows, or in some cases, complete loss of flowing water (Gaun et al. 2016). Because of their reliance on the amount of water in bedrock aquifers, which is related to precipitation quantity and intensity, tinajas are considered highly vulnerable to climate change. A recent study shows that the desert southwest, which is already a dry region, has become drier and warmer over the last several decades (Prein et al. 2016).

Furthermore, human disturbance of tinajas may alter animal behavior, trample plants and introduce bacteria such as *Escherichia coli*, which may have unwanted effects on water quality (NPS 2014a). Other impacts to water resources include urbanization and development surrounding the park, groundwater pumping, livestock trespass, and introduction of non- native plants (NPS 2014a).

Geology

Fires affecting tinajas due to debris flows is both a water- resources and geologic threat. The Box Canyon Fire in 1999 led to the filling of nearly all tinajas with sediment in Loma Verde Canyon and to the extirpation of the lowland leopard frog in that drainage (Parker 2006). Increased sedimentation following the 2003 Helen's II Fire led to declines in leopard frogs in Joaquin Canyon and other tributaries of Tanque Verde Creek (O'Brien et al. 2015). Pools that filled with sediment following fires may take decades to recover (Parker 2006). Headcut migration is also a geologic- related concern and has occurred along constructed roads, creating additional erosion issues. In addition, there are over 146 abandoned mine shafts and adits in TMD. One potential threat from the previous mining operations is the migration of contaminants in surface water runoff and airborne dust.

Air Quality

Saguaro NP is considered to be one of the most polluted national parks due to degraded visibility conditions (NPCA 2015). As a result, vistas at the park are at times obscured by pollution- caused haze (Figure 2.2.3- 2), which can occur episodically during fires or more regularly due to local and regional industry emissions. Ozone sometimes reaches levels that can make breathing difficult for sensitive groups of people and/or cause injury to ozone- sensitive plants. Grasslands and shrublands are particularly vulnerable to changes caused by nitrogen deposition. Interactions between nitrogen, non- native invasive grasses, and fire have implications for changes to biodiversity in non- fire adapted ecosystems like the Sonoran Desert. Airborne toxics, including mercury, can deposit with rain and snow and accumulate in organisms, such as bats and frogs. The predicted concentrations of methylmercury in surface waters at the park are very high compared to other NPS units, which is why Saguaro NP is part of the NPS Air Resources Division

NPS

Figure 2.2.3-2. A hazy view from Rincon Peak looking toward Rincon Creek and the city of Tucson, AZ in the far distance.

(ARD) mercury program where dragonflies are sampled as bioaccumulators.

Viewshed, Soundscape, and Night Sky

Although Saguaro NP is considered a non-urban park (Turina et al. 2013), the 48.3 km (30 mi) separating the two park districts are now mostly filled in with urban and suburban developments that abut the park's boundaries in some locations (NPS 2014a). The landscape- scale resources, including viewshed, night sky, and soundscape, are especially threatened in these areas of the park due to the visual, sound, and lighting intrusions. Busy roads, including ones that pass through the park (e.g., Picture Rocks Road in the TMD), contribute to degraded sound and scenic conditions. Dark night skies in the park are threatened by the large and expanding urbanization and development surrounding the park. A planned construction project to widen Houghton Road approximately 3.2 km (2 mi) outside of the entrance to RMD could further degrade landscape- scale resource conditions in Saguaro NP. The City of Tucson Department of Transportation has been working to refine street lighting specifications along Houghton Road to minimize the impacts to night skies while maintaining safe roadways (M.J. Dillard, Houghton Road Corridor Project Manager, pers. comm., November 2015). Several additional proposed developments and expansions adjacent or near park boundaries have the potential to further degrade the park's resources. These threats are described in detail in the viewshed, night sky and soundscape Chapter 4 assessments.

Wildlife

In Saguaro NP and its vicinity, threats to birds include habitat loss, development and changes in surrounding land uses, groundwater depletion and decreased surface water availability, effects of climate change, wildfire, and impacts from fire management. Additional threats may exist from non- native species, such as feral cats. Migratory bird species face additional threats throughout their range, including impacts from agriculture and forestry activities, collisions with man- made structures (e.g., buildings, wind turbines, communication towers, and electrical lines), poisoning, and landscape changes due to climate change (USFWS 2016). Some of these issues are addressed in more detail in Chapter 4.

As with other types of wildlife, mammal species that reside in or pass through Saguaro NP face threats. One of the largest threats for mammals is habitat loss and fragmentation, including a loss of connectivity between habitats within the park and the surrounding landscape. This is becoming more of an issue, especially for TMD, as habitat within the

region is developed and barriers to movement (e.g., roadways) are created. This issue is of concern to personnel at the park, and may result in the continued extirpation of species.

Amphibians and reptiles in the park and surrounding environment also face threats, some minor, some more substantial, from a variety of sources. Some of these threats are due to habitat loss and fragmentation (including a loss of connectivity between habitat within the park and the surrounding landscape), disease, the invasion of non-native animals and plants, and alteration of habitat due to sedimentation after fire (in the case of amphibians and tinajas in RMD; Parker 2006).

Extirpated Wildlife Species

There are six mammal species considered extirpated in Saguaro NP (Swann and Perkins 2013). All of them are discussed in the biodiversity and mammal assessments of the NRCA. Extirpated mammals include the Mexican gray wolf (*Canis lupus baileyi*), grizzly bear (*Ursus arctos*), bighorn sheep (*Ovis canadensis*), jaguar (*Panthera onca*), North American porcupine (*Erethizon dorsatum*), and banner- tailed kangaroo rat (*Dipodomys spectabilis*). All six were once documented in the RMD, and three were documented in the TMD (Swann and Perkins 2013). In RMD: grizzly bears were last recorded in the early 1920s; Mexican gray wolves in 1948; bighorn sheep in the 1950s; jaguars in the 1930s; and porcupines in the early 1990s (Swann and Perkins 2013). In TMD, the bighorn sheep was last recorded in the 1950s; the Mexican gray wolf in the 1930s or 1940s; and the porcupine in the 1960s.

Non- native Wildlife Species

Twelve non- native species of bird, mammal, reptile and amphibian occur in Saguaro NP (Powell et al. 2006, Powell et al. 2007). Many are human adapted species including the House Sparrow (*Passer domesticus*), Rock Pigeon (*Columba livia*), European Starling (*Sturnus vulgaris*), Eurasian Collared- dove (*Streptopelia decaocto*), feral cat (*Felis catus*), domestic dog (*Canis lupus familiaris*), and domestic cow (*Bos taurus*). Although the three non- native mammals have not established populations within the park, their presence may influence local biodiversity through overgrazing native vegetation and erosion of riparian areas, spreading invasive species such as buffelgrass and through direct mortality of native species (e.g., feral cats killing native birds).

Vegetation

Of particular concern are the 125 non-native plant species found in the park, 87 of which are considered invasive (NPS 2014c). In addition, a number of plants have been extirpated from the park; however, the list has not been finalized.

One of the main reasons for the initial research and monitoring of the saguaro cactus in the park was a decline in the large, mature cacti in the Cactus Forest. Eventually, it was believed that the decrease was due to wood- cutting and cattle grazing, along with cold temperatures and drought in the mid-1900s (McAuliffe 1993 as cited by Swann et al. 2011; O'Brien et al. 2011). The later surge in recruitment of young saguaros may be related to an end of wood- cutting and cattle grazing, along with warmer winter temperatures and generally wetter conditions since the 1970s (Swann et al. 2011, O'Brien et al. 2011). Although the Cactus Forest still does not appear as it did in the early days of the park, the area has experienced some level of recovery because of the high recruitment starting in the 1970s. A more recent threat to saguaro cacti at the park is the non- native invasive plant buffelgrass.

Invasive species (e.g., buffelgrass) are those which cause considerable harm to native plants through displacement of native species and changes in ecosystem structure and function (e.g., altered fire regimes). Some invasive species may cause irreversible changes to the ecosystem in which they invade. The spread of invasive species in difficult to reach wilderness areas of the park is particularly alarming. The NPS has established a management plan to control and limit the spread of invasive plant species into wilderness areas through ground- based and aerial application of herbicides as well as physical removal of individual plants.

The invasion of buffelgrass, fountain grass (*P. setaceum*), red brome (*Bromus rubens*) and other invasive plant species in Saguaro's desert environment has increased fire in an ecosystem that is not fire- adapted. These non- native species crowd native plants and compete with them for limited resources including water and nutrients vital to their growth and survival. Climate change has already altered patterns of precipitation and temperature in the Sonoran Desert, which often promotes invasion by non- native species and further stresses native plants (Prein et al. 2016). In fact, Saguaro NP was identified as one of 25 national parks in peril due to predicted climate change because the warmer, drier conditions will favor the expansion of buffelgrass and negatively impact the saguaro cactus (Saunders et al. 2009)

Suppression of fires by humans has disrupted the natural fire regime in the park (NPS 2007). Although fire is no longer suppressed where possible, restoring forest stand structure to its natural state will likely require several burn cycles (NPS 2007). However, tree mortality has increased from a combination of causes, including warmer temperatures, less precipitation, forests pests (e.g., bark beetles), and pathogens, which may alter the natural fire regime (USDA 2015).

2.3. Resource Stewardship

2.3.1. Management Directives and Planning Guidance

In addition to NPS staff input based on the park's purpose, significance, and fundamental resources and values, and other potential resources/ecological drivers of interest, the NPS Washington (WASO) level programs guided the selection of key indicators and/ or measures for the selected condition assessments. These included Sonoran Desert Inventory and Monitoring (I&M) Network (SODN) Program, I&M NPScape Program for landscape dynamics, Air Resources Division for air quality, and the Natural Sounds and Night Skies Program for the soundscape and night sky sections.

SODN I&M Program

In an effort to improve overall national park management through expanded use of scientific knowledge, the I&M Program was established to collect, organize, and provide natural resource data as well as information derived from data through analysis, synthesis, and modeling (NPS 2011). The primary goals of the I&M Program are to:

- inventory the natural resources under NPS stewardship to determine their nature and status;
- monitor park ecosystems to better understand their dynamic nature and condition and to provide reference points for comparisons with other altered environments;
- establish natural resource inventory and monitoring as a standard practice throughout the National Park System that transcends traditional program, activity, and funding boundaries;
- integrate natural resource inventory and monitoring information into NPS planning, management, and decision making; and
- share NPS accomplishments and information with other natural resource organizations and form partnerships for attaining common goals and objectives (NPS 2011).

To facilitate this effort, 270 parks with significant natural resources were organized into 32 regional networks. Saguaro NP is part of the SODN, which includes 10 additional parks. Through a rigorous multi- year, interdisciplinary scoping process, SODN and parks selected a number of important physical, chemical, and/or biological elements and processes for long- term monitoring. These ecosystem elements and processes are referred to as 'vital signs', and their respective monitoring programs are intended to provide high- quality, long- term information on the status and trends of those resources. Saguaro NP's air quality, climate, groundwater, tinajas/ seeps/springs, landbirds, and vegetation/soils were selected for monitoring (NPS SODN 2016).

Park Planning Reports

Natural Resource Condition Assessments

The structural framework for NRCAs is based upon, but not restricted to, the fundamental and other important values identified in a park's foundation document or General Management Plan. NRCAs are designed to deliver current science- based information translated into resource condition findings for a subset of a park's natural resources. The NPS State of the Park (SotP) and Resource Stewardship Strategy (RSS) reports rely on credible information found in NRCAs as well as a variety of other sources (Figure 2.3.1- 1).

Foundation Document

Foundation documents describe a park's purpose and significance and identifies fundamental and other important park resources and values. A foundation document was completed for Saguaro NP in 2014 (NPS 2014a) and was initially used to identify some of the primary natural features throughout the park for the development of the NRCA report.

State of the Park

A State of the Park (SotP) report is intended for non- technical audiences and summarizes key findings of park conditions and management issues, highlighting recent park accomplishments and activities. NRCA condition findings were used to complete Saguaro NP's natural resources section of their SotP report and summary tables are presented in Chapter 5 of this report.

Resource Stewardship Strategy

A Resource Stewardship Strategy (RSS) uses past and current resource conditions to identify potential management targets or objectives by developing comprehensive strategies using all available reports and data sources, including NRCAs. National Parks are encouraged to develop an RSS as part of the park management planning process. Indicators of resource condition, both natural and cultural, are selected by park staff. After each indicator is chosen, a target value is determined and the current condition is compared to the desired condition. An RSS has not yet been started for Saguaro NP.

2.3.2. Status of Supporting Science

Saguaro NP has a rich scientific legacy dating back to the early years of the 20th century and research has played an important role throughout nearly the entire history of the

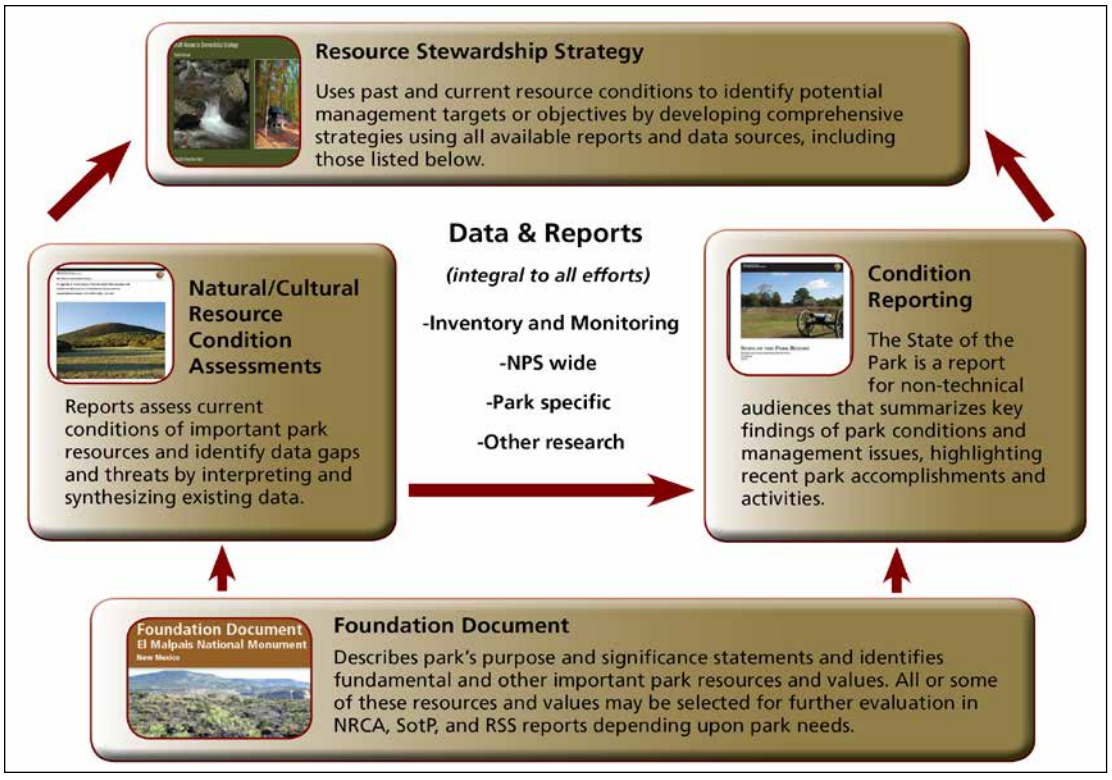

Figure 2.3.1- 1. The diagram shows the relationship of NRCAs to other park planning reports.

park (refer to Chapter 4, science legacy). Hundreds of scientific papers have been published, including many seminal papers on saguaros and fire ecology with a long- term cooperative relationship between the park and the University of Arizona that began in the 1930s and continues to this day. This large body of scholarship was used to inform resource conditions of selected topics.

Additional information supporting condition reporting for this effort was provided by Washington level programs, including SODN, I&M NPScape, Climate Change Response Program, Natural Sounds and Night Skies, and Air Resources Divisions.

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Saguaro National Park actively engages citizen science.

Chapter 3: Study Scoping and Design

This Natural Resource Condition Assessment (NRCA) is a collaborative project between the staff at Saguaro National Park (NP), Sonoran Desert Inventory and Monitoring Network (SODN), National Park Service's (NPS) Intermountain Region Office, and cooperators from Utah State University, University of West Florida, and Northern Rockies Conservation Cooperative.

The purpose of the NRCA is to provide a "snapshot-in-time" evaluation of the condition of a select set of Saguaro NP's natural resources that were chosen by the project team (NRCA team members are listed in Appendix A) during the October 28-29, 2014 scoping meeting. Condition findings will aid national park staff in the following objectives:

- Develop near-term management priorities
- Engage in watershed or landscape-scale partnership and education efforts
- Conduct park planning (e.g., compliance, Resource Stewardship Strategy, and resource management plans).

3.4. Preliminary Scoping

The approach we used to select natural resources was to assess the fundamental and important values of the national park by creating an initial list of natural resources identified in the park's Foundation document (NPS 2014). We then refined this list of resources during the on-site scoping meeting and during the initial review of resource indicators, measures, and reference condition NRCA Phase I table reviews. The resources assessed were limited to natural-based topics, and the discussions that followed focused on identifying important features, available reports and data, issues of concern, and data gaps for each topic. The resources selected for the NRCA and their connection to Saguaro NP's purpose, significance and fundamental resources and value statements are presented in Table (Table 3.1-1). This provides an overview of how each natural resource topic assessed for condition tied into the park's primary reasons for establishment.

Specific project expectations and outcomes included the following for the selected assessments:

Table 3.1-1. Summary of natural resource topic connection to Saguaro National Park's purpose and significance, fundamental and other important resources and values statements included in the park's Foundation Document (NPS 2014).

Natural Resource Condition Assessment Topics	Scientific Legacy	Viewshed	Night Sky	Soundscape	Air Quality	Surface Water	Tinajas, Seeps, and Springs	Groundwater	Biodiversity	Saguaro Cactus	Desert and Riparian	Grasslands, Woodlands, and Forests	Biological Soil Crusts	Mammals	Birds	Herpetofauna
I. Park Purpose																
Preserve and protect saguaro cacti; diverse biotic communities (including the Sonoran Desert, associated mountain ecosystems, and Rincon Creek); cultural and archeological features; and scientific, scenic, and wilderness values.	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•
Provides opportunities for research, education, and public enjoyment.	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•
Strives to protect its resources from the effects of the encroachment from urbanization and development.	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•
II. Park Significance																
Saguaro cactus and Sonoran Desert ecosystem	•	•							•	•	•		•	•	•	•
Largest roadless sky island in the American SW supporting extraordinary biodiversity along elevational gradient.	•			•		•	•	•	•		•	•	•	•	•	•
Aquatic micro-habitats such as tinajas, seeps, and springs and riparian corridor of Rincon Creek along with associated species.	•					•	•	•	•		•			•	•	•
Living laboratory for ecological, geological, and climate change processes research.	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•
Urban community access to wilderness and scenic views.	•	•	•	•												
Rich concentration of cultural resources that tell the history of continuous and diverse human occupation in the Southwest.	•		•			•	•			•		•				
III. Fundamental Resources and Values																
Saguaro Cacti	•	•							•	•	•				•	
Sonoran Desert and Sky Island Ecosystems Integrity (rich biotic assemblages)	•					•	•	•	•		•	•	•	•	•	•
Rincon Creek and Aquatic Habitats (includes tinajas and associated species)	•					•	•	•	•		•			•	•	•
Cultural Resources	•		•			•	•			•		•				

Table 3.1.1. Summary of natural resource topic connection to Saguaro National Park's purpose and significance, fundamental and other important resources and values statements included in the park's Foundation Document (NPS 2014) continued.

Natural Resource Condition Assessment Topics	Scientific Legacy	Viewshed	Night Sky	Soundscape	Air Quality	Surface Water	Tinajas, Seeps, and Springs	Groundwater	Biodiversity	Saguaro Cactus	Desert and Riparian	Grasslands, Woodlands, and Forests	Biological Soil Crusts	Mammals	Birds	Herpetofauna
Wilderness Stewardship in an Urban Area	•	•	•	•	•	•	•	•	•		•	•				
Clean Air, Class I Park	•	•	•		•											
IV. Other Important Resources and Values																
Geologic Resources: metamorphic core complex	•						•	•								

- consolidate the most relevant park data, reports, and geospatial information from appropriate sources;
- enlist the help of subject matter experts for each resource topic where appropriate and feasible;
- define an appropriate description of reference conditions
- develop graphic illustrations and spatial representation of data, ecological processes, resource stressors, or other valuable information to aid in reporting;
- perform analysis of specific existing datasets about key natural resource indicators.

3.5. Study Design

3.5.1. Indicator Framework, Focal Study Resources and Indicators

This NRCA utilized an assessment framework adapted from "The State of the Nation's Ecosystems 2008: Measuring the Lands, Waters, and Living Resources of the United States", by the H. John Heinz III Center for Science, Economics and the Environment. This framework was endorsed by the national NRCA program as an appropriate framework for listing resource components, indicators/measures, and resource conditions.

Each NRCA project represents a unique assessment of key natural resource topics that are important to the specific park that is being assessed. For the purposes of Saguaro NP's NRCA, 16 resources were chosen for assessment and are listed in Table 3.2.1-1 along with a summary of indicators and number of measures for each topic. This list of focal study resources is not all inclusive of every natural resource at the national park, but includes natural resources and processes that were of greatest significance for park staff at the time of this assessment.

Reference conditions were identified with the intent of providing a benchmark to which the current condition of each indicator/measure could be compared. Attempts were made to utilize existing research and documentation to identify reference conditions; however, some of the indicators lack a quantifiable reference condition. When a quantifiable reference condition for a given resource was not feasible, an attempt was made to include a qualitative reference to provide some context for interpreting current condition relative to the indicators and measures chosen.

3.5.2. Reporting Areas

National Park

The primary focus of the reporting areas for the NRCA was within the national park's authorized boundary, which includes the Tucson and Rincon Mountain Districts; however, some of the analyses and data encompassed areas beyond the park's boundary such as viewshed or air quality. In addition, some of the resource topics were assessed by either one or both park districts, depending upon the natural resource topic and available information.

Table 3.2.1-1. Saguaro National Park Natural Resource Condition Assessment framework.

Natural Resource	Indicators (number of measures)
Scientific Legacy	• Provides an overview of the scientific legacy at Saguaro NP. No indicators or measures were developed.
I. Landscape Condition Context	
Viewshed	• Scenic Integrity (3 measures)
Night Sky	• Sky Brightness (4 measures) • Sky Quality (1 measures)
Soundscape	• Sound Level (2 measures) • Geospatial Model (1 measure)
II. Supporting Environment	
Air Quality	• Visibility (1 measure) • Level of Ozone (2 measures) • Wet Deposition (4 measures)
Surface Water Quantity in the Middle Reach of Rincon Creek	• Water Quantity (4 measures)
Tinajas, Springs and Seeps - Rincon Mountain District	• Water Availability (4 measures) • Water Quality (6 measures)
Groundwater - Tucson Mountain District	• Groundwater Level in Avra Valley Aquifer (1 measure) • Groundwater Flow Direction in Avra Valley Aquifer (1 measure) • Groundwater Level in Shallow Alluvial Wells (1 measure)
Groundwater - Rincon Mountain District	• Groundwater Supplying Perennial High Elevation Springs (1 measure) • Groundwater Occurring in Mountain Block Regional-scale Fractures (1 measure) • Groundwater Supplying Low Elevation Springs, Pools, and Tinajas (1 measure) • Shallow Alluvial Aquifer In Rincon Valley And Upper Pantano Formation (1 measure) • Detachment-Fault Related Groundwater (1 measure) • Upper-plate Groundwater (1 measure)
III. Biological Integrity	
Biodiversity	• Species Richness (3 measures) • Non-native Species (4 measures) • Extirpated Species (4 measures) • Threatened and Endangered Species (3 measures)
Vegetation	
Saguaro Cactus	• Population Status / Health (2 measures) • Historic Integrity & Appearance on Landscape (1 measure) • Habitat Availability & Quality (2 measures)
Desert and Riparian Vegetation and Soils	• Plant Community Resilience (2 measures) • Erosion Hazard (2 measures) • Fire Hazard (3 measures) • Non-native and Invasive Plants (10 measures) • Threatened, Endangered, or Rare Plants (1 measure) • Conservation Potential of Rincon Creek (1 measure) • Prevalence of Native Vegetation Along Rincon Creek (4 measures) • Prevalence of Non-native Plants Along Rincon Creek (1 measure)
Grasslands, Woodlands, and Forest Vegetation and Soils	• Plant Community Resilience (4 measures) • Erosion Hazard (2 measures) • Departure from Fire Return Interval (1 measure) • Forest Health (2 measures) • Non-native and Invasive Plants (9 measures) • Threatened, Endangered, or Rare Plants (1 measure)
Biological Soil Crusts	• Biological Soil Crust (1 measure)

Table 3.2.1. Saguaro National Park Natural Resource Condition Assessment framework continued.

Natural Resource	Indicators (number of measures)
Wildlife	
Mammals	• Species Occurrence (2 measure) • Population Status / Abundance for Selected Species (2 measures) • Habitat Corridors and Connectivity (1 measure)
Birds	• Occupancy of Species Common in SODN (1 measure) • Species Richness in SODN Survey Area (1 measure) • Species Richness & Abundance (2 measures) • Status of Threatened & Endangered Species (3 measures) • Extirpated Species (1 measure) • Non-native Species (1 measure)
Herpetofauna	• Species Occurrence (1 measure) • Population Status/Abundance of Selected Species (2 measures) • Occurrence of Herpetofauna Diseases (2 measures) • Presence of Non-native Species (1 measure) • Habitat Corridors & Connectivity (1 measure)

Landscape-scale

For some of the natural resource condition assessments, such as viewshed, landscape-level analysis was conducted or highlighted based on other research (i.e., mammals and herpetofauna) to provide an ecological, landscape-scale context. NPScape data were used for the viewshed analyses, which characterize landscape-scale factors relevant to park resources (Monahan et al. 2012).

3.5.3. General Approach and Methods

The general approach to developing the condition assessments included reviewing literature and data and/or speaking to subject matter expert(s) for each of the focal resource topics, and when applicable, analyzing existing data to provide new interpretations for condition reporting. Following the NPS NRCA guidelines (NPS 2010), each assessment included the following six sections:

Background and Importance

This section of the NRCA report provided information regarding the relevance of the resource to the national monument using existing project proposals or descriptions previously developed by park staff for various planning documents.

Data and Methods

This section of the assessment described the existing data sets and methodologies used for evaluating the indicators/measures for current condition.

Reference Conditions

This section described the reference conditions used to evaluate the condition of each measure.

Condition and Trend

This section provided a discussion of the condition and trend, if available, for each indicator/measure based on the reference condition(s). Condition icons were presented in a standard format consistent with *State of the Park* reporting (NPS 2012) and serve as visual representations of condition/trend/level of confidence for each measure that was evaluated. Figure 3.2.3-1 shows the condition/trend/confidence level scorecard used to describe the condition for each assessment.

Circle colors convey condition. Red circles signify that a resource is of significant concern; yellow circles signify that a resource is in moderate condition; and green circles denote that a measure is in good condition. A circle without any color, which is often associated with the low confidence symbol-dashed line, signifies that there is insufficient information to make a statement about condition; therefore, condition is unknown.

Arrows inside the circles signify the trend of the indicator/measure. An upward pointing arrow signifies that the measure is improving;

Condition Status		Trend in Condition		Confidence in Assessment	
	Warrants Significant Concern		Condition is Improving		High
	Warrants Moderate Concern		Condition is Unchanging		Medium
	Resource is in Good Condition		Condition is Deteriorating		Low
	An open (uncolored) circle indicates that current condition is unknown or indeterminate; this condition status is typically associated with unknown trend and low confidence.				

Figure 3.2.3-1. Condition, trend, and level of confidence key used in the NRCA.

double pointing arrows signify that the measure's condition is currently unchanging; a downward pointing arrow indicates that the measure's condition is deteriorating. No arrow denotes an unknown trend.

The level of confidence in the assessment ranges from high-low and is symbolized by the border around the condition circle. Figure 3.2.3-2 is an example of a final condition graphic used in the resource assessments.

Key uncertainties and resource threats are also discussed in the condition and trend section for each resource topic.

Sources of Expertise

Individuals who were consulted and/or provided a review are listed in this section, along with the writer(s) who drafted the assessment.

Literature Cited

This section lists all of the referenced sources for the assessment. A DVD is included in the final report with copies of all literature cited unless the citation was from a book.

Figure 3.2.3-2. An example of a good condition, unchanging trend, and high confidence level in the assessment graphic used in NRCAs.

3.6. Literature Cited

H. John Heinz III Center for Science, Economics and the Environment. 2008. The state of the nation's ecosystems 2008: measuring the lands, waters, and living resources of the United States. Washington, D.C.

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4.1. Scientific Legacy at Saguaro National Park

4.1.1. Background and Importance

> "Whereas a certain area within the Catalina Division of the Coronado National Forest in the State of Arizona and certain adjacent lands are of outstanding scientific interest because of the exceptional growth thereon of various species of cacti, including the so-called giant cactus, it appears that the public interest will be promoted by reserving as much land as may be necessary for the proper protection thereof as a national monument."
>
> --Proclamation to create Saguaro National Monument, March 1, 1933

This first sentence from this proclamation in 1933 reminds us that Saguaro National Monument was set aside for its scientific value. Indeed, Saguaro was the first national monument created to preserve a specific plant. The person most responsible for the Monument was a biologist: Homer Shantz, president of the University of Arizona (UA) and botanist who pioneered the use of photography in documenting ecological change. In the 1920s and early 1930s Shantz often visited what he called the "Cactus Forest" in the foothills of the Rincon Mountains east of Tucson, to study and photograph desert plants, particularly the saguaro (*Carnegiea gigantea*) (Figure 4.1.1-1; Clemenson 1987). He and other scientists came to appreciate the area's stunning scenery and variety of cacti, as well as its vulnerability to wood-cutting, cattle grazing, and development. Shantz advocated for a monument that would be "…a vast outdoor laboratory, ranging from the cactus-studded desert to the pine-wreathed mountains, free from human disturbance and studied by generations of student scientists" (NPS 2015).

Saguaro's science legacy is both unique and related to changing views of science within the National Park Service (NPS) over time. As Richard West Sellars illustrates in his landmark book on NPS natural resource management (Sellars 1997), science and park management have long had a complicated relationship; science research has occasionally been discouraged and decision-making was not always scientifically informed. As a result, some park superintendents and rangers at Saguaro have sometimes restricted scientific studies, and support of research has waxed and waned over the years.

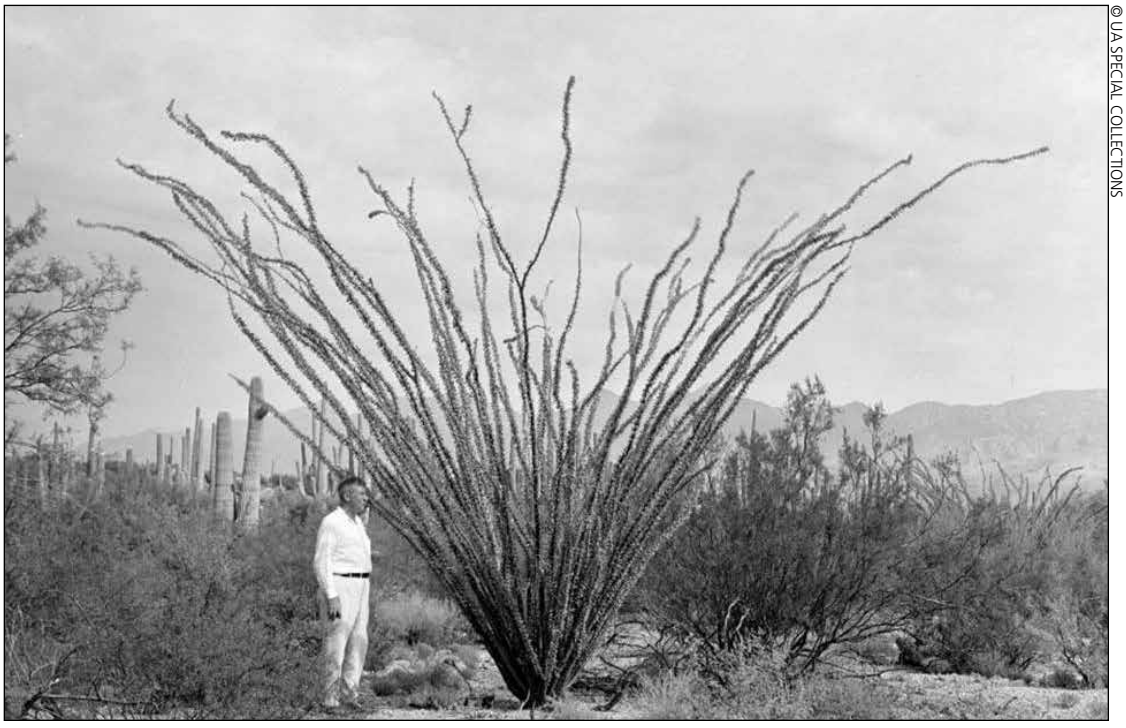

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Figure 4.1.1-1. Homer Shantz in the Cactus Forest, now part of the Saguaro National Park's Rincon Mountain District, in the 1920s.

Nevertheless, scientific research has played an important role throughout nearly the entire history of the monument and park. Literally hundreds of scientific papers have been published based on research at the park, including many seminal papers on saguaros and fire ecology. More importantly, at several key points in the park's history, scientists and their research results have been the drivers of major management decisions. As a result of the directive in Saguaro's proclamation mentioned above, science has always played an important role in the park's interpretive themes and the steady interchange of students and employees between the park and the UA that began in the 1930s and continues to this day has had a large impact on the park's natural resource knowledge base.

This chapter briefly summarizes the history of research at the park and draws from both primary and secondary sources (particularly Clemenson 1987, McAuliffe 1996, Burtner 2011, and Pinto 2014) to address how science has influenced management and interpretation, while at the same time being influenced by them.

4.1.2. Science and the Saguaro

The major scientific theme – and in some ways, the major theme – running through the history of Saguaro National Park (NP) has been concerns about the health of the saguaro population. Indeed, the complicated relationship between scientists and NPS officials as they struggled to understand the causes of the apparent decline of saguaros in the Cactus Forest is the subject of a paper by McAuliffe (1996). He makes a compelling case that poor communication of scientific studies and results (and sometimes poor science and management) led to no end of visitor confusion about the status of this iconic plant.

However, much of what we know about saguaros – and much of how we interpret saguaros to visitors – is based on research at Saguaro NP. As befits a plant that lives longer than humans do, many of these studies are multi-generational, with modern scientists continuing to study individual plants that were first surveyed more than 70 years ago (Ahnmark and Swann 2009).

The "Saguaro Problem" and Disease Investigations

In May 1940 park custodian Don Egermayer observed a large number of saguaros in the Cactus Forest with black spots and reported that many had died. Some scientists, including UA plant pathologist James G. Brown, believed that the saguaros had developed a contagious disease (McAuliffe 1996). Although other UA professors did not agree with that assessment, park staff and visitors feared that soon all saguaros would become infected and die (Clemenson 1987). In 1941 NPS officials met at the University with Brown, his graduate student Paul Lightle, and others to determine the cause of the problem and design a treatment. Lightle and Lance Gill, a plant pathologist with the U.S. Department of Agriculture's Bureau of Plant Industry who had studied the contagious chestnut blight in the eastern United States, took the lead on studies at the park.

In 1941 an entire one-square-mile section of the Cactus Forest (Section 17) was chosen for a large-scale experiment to determine if removal of infected plants could check the spread of the disease to healthy saguaros (McAuliffe 1996, Gill 1942, Gill and Lightle 1942). Saguaros in the southern half of Section 17 were removed by heavy equipment, bucked up, and buried after being doused with kerosene and pesticides (Figure 4.1.2-1) while those in the northern half were left untreated as a control. Although the treatment essentially halted with the outbreak of World War II, Gill continued to follow up, eventually publishing a report that documented no differences between treatment and control areas (Gill 1951) and averring that contagious disease was not the cause of the die-off.

Natural History and Ecology

As the saguaro population continued to decline in the Cactus Forest during the 1950s and 1960s, research on saguaro diseases continued (Figure 4.1.2-2) and expanded into other fields. UA plant pathologist Stan Alcorn (Figure 4.1.2-3) continued annual monitoring on selected plots established by Gill and Lightle. He also collaborated with Ray Turner, ecologist with the U.S. Geological Survey and Rod Hastings, meteorologist in Atmospheric

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Figure 4.1.2-1. Saguaros being buried in Section 17 in Saguaro National Park, Rincon Mountain, as part of a large experiment related to saguaro disease in 1941.

Sciences at UA, on studies of seedling survival (Turner and Alcorn 1966), pollination (McGregor et al. 1962), the critical role of nurse trees in saguaro establishment (Turner et al. 1966) and other aspects of saguaro natural history (Alcorn and Kurtz 1959, Alcorn et al. 1961, Hastings and Alcorn 1961). In 1965, Hastings and Turner published The Changing Mile; they used repeat photography to evaluate long-term vegetative change in the Sonoran Desert (Hastings and Turner 1965). Their stunning photographs of Saguaro NP documented the extent of the loss of large saguaros from the Cactus Forest over time. They suggested that climate, in combination with cultural factors such as the destruction of nurse trees and cattle overgrazing and trampling, may have affected establishment of saguaros at the park. Most importantly, Hastings and Turner recognized the value of understanding the long-lived saguaro in its larger temporal and spatial context, and establishing long-term monitoring plots throughout southern Arizona and northern Sonora, Mexico, including in both the Rincon Mountain District (RMD) and the Tucson Mountain District (TMD) of the park (Pierson et al. 2013).

In the mid-1960s, Warren Steenbergh, an NPS biologist, began intensive studies on aspects of saguaro life history with Charles Lowe, a UA ecologist. Their focus was on how climate, particularly intense freeze events, affected

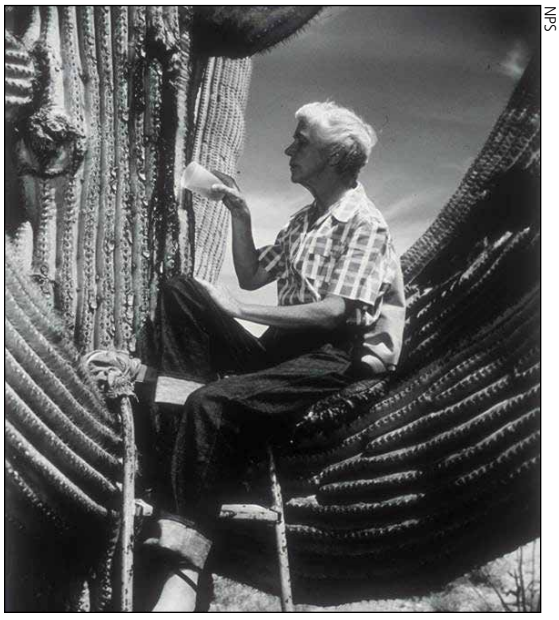
NPS

Figure 4.1.2-2. Alice Boyle, UA plant pathologist, testing application of antibiotic to potentially heal a saguaro with cortical rots in the RMD Cactus Forest area, circa 1950.

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Figure 4.1.2-3. UA plant pathologist measuring saguaro in Cactus Forest in 1950s.

reproduction and growth. Steenbergh and Lowe specifically discounted disease and attributed the die-offs of the late 1930s to freeze events in 1937 and 1939, as well as the long-term effects of cattle grazing (described in the next section). Their work culminated in a 3-part series published as The Ecology of the Saguaro (Steenbergh and Lowe 1976, 1977, 1983) that continues to serve as the definitive work on the plant.

The Return of the Cactus Forest

In 1962, two scientists predicted that saguaros in the Cactus Forest would be extinct by the turn of the century (Alcorn and May 1962). In the late 1980s continued low establishment of saguaros in the Cactus Forest led the NPS to fund an expensive research program to investigate the impacts of air pollution on the plant. While the saguaro decline and air pollution were determined to be unrelated, an important outcome of that research was the creation, in 1990, of the first long-term monitoring program based on a randomized study design in both park districts (Duriscoe and Graben 1991). This study now known as the "Saguaro Census", is a large citizen-science project that has been repeated in 1990, 2000, 2010, and is next planned for 2020.

By the 1990s, however, it was clear that changes were taking place in the Cactus Forest. Young saguaros began to appear in the long-term monitoring plots surveyed by Ray Turner (Turner 1992). Continued monitoring for more than 25 years by UA researchers (Pierson et al. 2013, Orum et al. 2016) and the Saguaro Census (Turner and Funicelli 2004, O'Brien et al. 2011, Conver et al. 2013) confirm that the saguaro population in the park has increased dramatically in the past few decades. Today the population throughout the park, but especially in the Cactus Forest, is relatively young and rapidly growing.

Most scientists now agree that the long period of saguaro decline in saguaro reproduction was due to intensive wood-cutting in the late 1800s and early 1900s that removed nurse trees critical to the protection of young saguaros, as well as heavy cattle grazing (Pierson et al. 2013). The surge of establishment that began in the 1960s followed the cessation of both wood-cutting (which had diminished since the 1920s) and cattle grazing (terminated in 1957 in the Cactus Forest). Interestingly, that surge has now ended, and far fewer young saguaros have established since the early 1990s. Recent papers (Pierson et al. 2013, Springer et al. 2015, Orum et al. 2016) have explored the link between saguaro and climate change. The evidence suggests that recent declines are driven by drought and increasing summer temperatures. Nevertheless, one lesson learned from the long history of monitoring is that the saguaro is a resilient plant that responds very slowly to both natural and human-caused environmental changes.

Saguaros and the End of Cattle Grazing

One significant result of saguaro science in the park was its role in eliminating cattle grazing in the 1970s. Grazing management in national parks has been and continues to be politically complicated: on the one hand, NPS management policies discourage livestock grazing; on the other hand, many parks still permit grazing where enabling acts guarantee its continuance. In addition, the NPS has

often ceded grazing management to other land agencies (Pinto 2014).

Robin Pinto's dissertation on the history of cattle grazing provides a richly detailed view of the critical role science played in the decades-long process to remove cattle from the park (Pinto 2014). Cattle had long been present in the Rincon Mountains (Figure 4.1.2-4) when Saguaro National Monument was first established under the administration of the US Forest Service in March 1933. Local ranchers were assured grazing would continue. Three months later, however, Saguaro and all other USFS monuments were transferred to the NPS. Initially the NPS agreed to retain the Forest Service as grazing manager and continue its well-established grazing policies. With little involvement by the NPS, cattle grazing continued on Saguaro lands for four more decades.

Nevertheless, park staff and visitors often expressed their dissatisfaction with the noticeable destruction of vegetation, including saguaros, by cattle. Park management, however, felt that they were powerless to effect any change, especially after 1950 when Assistant NPS Director Arthur Demaray promised four ranchers who held grazing leases in the park that they would be allowed to continue to run their cattle in perpetuity (Clemensen 1987, Pinto 2014). Pinto notes that even though grazing and disease had been implicated as a factor in saguaro declines, the park chose to investigate only disease as the primary agent and made no attempt to initiate research or monitoring on grazing.

Three significant events occurred in the early 1960s that were instrumental in shifting attention – and research – toward the issue of cattle grazing. First was the national significance of the 1963 Robbins report (National Academy of Sciences 1963), which criticized the lack of research in parks; the second was the 1964 hiring of Warren Steenbergh at Saguaro NP. (Steenbergh was one of about 10 scientists brought into NPS as a direct result of the Robbins report.) Steenbergh immediately began the saguaro ecological studies mentioned in the previous section with Charles Lowe, as well as other studies (Pinto 2014).

The third event was the initiation, in 1961, of a research project by Lowe, William Niering and Richard Whittaker to examine the factors affecting the survival of saguaros in the park. Niering and Whittaker were perhaps the most highly regarded ecologists in the United States. Their resulting paper (Niering et al. 1963), published in prestigious journal Science, highlighted the effects of cattle grazing on saguaro establishment. In their discussion the authors did not mince words, stating the Rincon Mountain portion of Saguaro NP "may now be of value principally as a demonstration of the ruinous effects of long-continued grazing on a once-splendid saguaro forest of the upper bajada

NPS

Figure 4.1.2-4. Cattle grazing in Saguaro National Park, circa 1970.

forest, which the monument was created to preserve."

Soon after the article appeared, NPS officials were deluged with letters demanding to know why they continued to permit cattle grazing in a national park (Pinto 2014). Secretary of the Interior, Stewart Udall, asked for a reconsideration of the legal status of the Demaray promise and was advised that the promise was not legally binding. Along with Steenbergh and Lowe's continuing research, and aided by an extended drought that reduced the incentive for ranchers, Saguaro began the slow process of terminating the four grazing permits and eliminating cattle from the park. In 1978, the last rancher finally removed his cows (Pinto 2014, Burtner 2011).

Warren Steenbergh in an unpublished report (Steenbergh 1967) warned park managers of the ongoing effects of cattle grazing at Saguaro NP:

> "The Monument contains the last remaining example in the southwestern United States of natural continuum of warm-desert to mountain-forest plant and animal associations essentially unaltered by the intrusion of public roads, associated developments, and related uses. The singular rarity of that resource clearly indicates the importance of maintaining the integrity of natural associations and ecological relationships within Saguaro National Monument. That integrity has not been maintained – and cannot be maintained – in the presence of grazing livestock. Livestock grazing precludes full effectiveness of management programs required to restore and maintain the basic natural ecological processes responsible for the evolution and maintenance of representative biotic communities within the Monument."

The elimination of grazing in Saguaro NP resulted from a confluence of factors, including public pressure for better resource management. But the role of both scientific investigations and "activist" scientists like Steenbergh, Lowe, Niering, and Whittaker were crucial to initiating management change.

4.1.3. Fire Ecology and Invasive Plants

Tree Ring Research and Fire Management in the Rincon Mountains

The RMD, as a Sky Island with desert, grassland, woodland, and forest, has a complex fire regime and history. Park managers have often turned to scientists to help effectively manage fire. Since 1937, the park has recorded and preserved records of all wildfires, including date, size, location, fuel type, and narrative descriptions (Swetnam and Baisan 1996, Swantek et al. 1999). Consistent with fire management throughout public lands in the United States, suppression was the major fire management activity in Saguaro NP beginning with the US Forest Service in the early 1900s. This pattern of suppression continued during the first few decades of NPS management as well.

However, by the late 1960s, fire management in the NPS began to slowly shift away from suppression. Two major reports on NPS science policy released in 1963 (Leopold et al. 1963 and National Academy of Sciences 1963) suggested that the NPS should consider fire as an important ecological factor. In the late 1960s younger scientists who had studied fire ecology in graduate school entered the NPS and began to advocate for policies of letting natural fires burn, as well as the use of prescribed fire. Even though the first efforts to implement these policies were at Yosemite, Saguaro was among the first parks to embrace these changes in the early 1970s (Rothman 2007, Pyne 2015, Chapter 2).

Research by the Tree Ring Laboratory (TRL) at the University of Arizona was an important factor in understanding past fire histories of western forests and in providing insight into how fire suppression has changed forest structure. In the late 1980s, TRL scientists Thomas Swetnam and Chris Baisan used tree ring data from Rincon Mountain to determine that historically the high elevation forests burned on average every 6.1 years until the

late 1800s. Subsequently fires nearly ceased altogether due to a number of changing use patterns including suppression (Baisan 1990, Swetnam and Baisan 1996). Most fires burned in the late spring and early summer near the onset of the summer monsoon rains. A more comprehensive study by Farris (2010) indicates that these results were reliable and representative of the mountain as a whole, although Rincon Peak has a more complex fire history (Iniquez 2009, Hunter et al. 2014).

The work by the TRL has had an important and lasting effect on how park managers have thought about and planned for fires in the park. Fire management plans (Saguaro National Park 2007) now fully acknowledge and embrace the concept that fire at high elevations is natural and frequent, and should be suppressed only when necessary. These plans also encourage prescribed fire (Figure 4.1.3-1) to bring forests back to a more natural condition. Implementing these changes on the ground has been difficult for many reasons, but the park has had some successes, particularly in the 1980s and 1990s when more resources were available for prescribed fire. In his essay, "The View from Tanque Verde Ridge," fire historian Stephen J. Pyne summarizes the history of fire management in the park and discusses the many challenges of managing fires for ecological benefit in a rapidly changing human landscape (Pyne 2015).

Invasive Plants

Compounding the challenges of managing for natural fires in Saguaro NP's woodlands and forests has been the decidedly unnatural increase in desert fires in recent decades. Major fires, notably the 1994 Mother's Day Fire and the 1999 Box Canyon Fire, burned in desert areas where fire has not historically been a major ecological factor. Saguaros and many other desert plants did not evolve with fire and are killed by it. After the Mother's Day Fire, Esque et al. (2004) found that approximately 25% of all saguaros on their plots in the burned area had been killed as a result of the fire. Both of these desert fires were fueled in part by non-native grasses such as red brome (*Bromus rubens*) and buffelgrass (*Pennisetum ciliare*) that are invading the northern Sonoran Desert.

Esque's fire study focused the park's attention on buffelgrass for the first time. Subsequent research on this plant both inside the park, and outside the park with NPS support, has evaluated the ecological impacts of this invasive African grass. McDonald and McPherson (2011) found that buffelgrass generates more intense fires than those in surrounding ecosystems (Figure 4.1.3-2), even in communities with comparable fuels. However, because of its competitive abilities, including the ability to double its patch size every 2 to 7 years, the plant can transform desert ecosystems even without

NPS

Figure 4.1.3-1. Prescribed fire in the Rincon Mountains, 2000s.

fire (Olsson et al. 2011), reduce survival of native seedlings (Sommers 2015), and reduce the body condition of Sonoran desert tortoise (*Gopherus morafkai)*, which may decrease their health (Gray and Steidl 2015). Collectively these studies have provided further incentive for the park to make buffelgrass management a major priority. For the past decade the park has removed the plant manually and with herbicides, while working in a wide science partnership to monitor the effectiveness and potential impacts of these treatment strategies. Research by Scott Abella (Abella et al. 2012, 2013) indicates that areas with heavy buffelgrass infestations can be restored to native plant communities because their seeds remain in the seed-bank and soil nutrients are sufficient.

4.1.4. Sky Islands, Wildlife, and Ecological Research

Saving the Mountain in the Late 1930s

Although the health of saguaros in the Cactus Forest has always been a predominant research focus, Saguaro NP also has a long history of research on other topics, especially geology and wildlife. The Rincon Mountains are the type locality for metamorphic core complexes and detachment faults (Davis 2013) and has been studied extensively by UA Geosciences professor George Davis and his students (Figure 4.1.4-1). Ecological studies in the Rincon Mountains go back to the early years of the 20th century. Burtner (2011) outlines the key role that scientists played in one of the most important controversies in the early years of the park, the well-organized effort to remove the higher portions of the Rincon Mountains from Saguaro National Monument in the 1930s and 1940s.

This controversy began within a few months of the establishment of the monument in March 1933. Although saguaros only occurred in lower elevations of the Rincons, local ranchers and the US Forest Service had supported inclusion of higher elevation grasslands, woodlands, and forests because the area would be managed by the Forest Service. When President Franklin Roosevelt transferred all existing monuments managed by the Forest Service to the NPS in June, 1933, the concerned ranchers appealed to their political representatives, even though the NPS did not have immediate plans to eliminate grazing. The primary complication for the NPS lay in fact that all of the Cactus Forest lands -- those with the greatest number of saguaros -- were held by private owners, the State of Arizona, or the University of Arizona.

Between 1937 and 1945 Arizona Senator Carl Hayden introduced five bills that would return the mountainous section of the Monument to the Forest Service and buy out state and private lands in the Cactus Forest (Clemenson 1987, Burtner 2011). Each of these bills failed. NPS Regional Director Minor Tillotson and Southwestern National Monument Superintendent Frank Pinkley believed that removing the mountain portions of the monument might provide

PERRY GRISSOM / NPS

Figure 4.1.3-2. Prescribed buffelgrass fire in Avra Valley, circa 2008, part of the McDonald and McPherson (2011) study of buffelgrass fire effects.

an acceptable compromise that would help retain and preserve the all-important Cactus Forest

DON SWANN / NPS

Figure 4.1.4-1. UA Geosciences professor George Davis leading a field trip of interns and graduate students in the park, 2014.

In 1937, NPS Director Arno Cammerer sent a survey team to Saguaro to determine whether the monument was worth keeping and if the upper elevation portions were of "National Park Service quality" (Burtner 2011). Consisting of NPS wildlife biologist W.B. McDougall, two foresters, a geologist, and three landscape architects, the team embarked on a field trip to Manning Camp (Figure 4.1.4-2). They also interviewed prominent local biologists including UA zoologist Charles Vorhies and the well-known desert ecologist Forrest Shreve.

Both the trip and the interviews convinced the team that not only was the Rincon Mountain complex worthy of national monument status, but essential to the ecology of the saguaro. Shreve told biologist McDougall that "the Rincon Mountain watershed is largely responsible for the very favorable moisture conditions in the Saguaro forest and that this watershed should, therefore, be protected" (Burtner 2011). Vorhies stated further that the "greatest scientific value of the monument lies in its value as a biotic community and not merely as a saguaro forest… the scientific value [of the monument] is, and will remain, much greater if we retain everything from the Saguaro desert up to the yellow pine forest than if we have the saguaro forest only" (Burtner 2011). In the end, the team recommended that the forest be retained, and Cammerer agreed.

Burtner notes that the Cammerer's decision represented an important example of the rise of ecological values in the NPS as traced by Sellers (1997). As part of the Wildlife Division led by George M. Wright, biologist McDougall was able to articulate the connections

NPS

Figure 4.1.4-2. The Madrona Pools in Chimenea Creek. Photo was taken during 1937 trip to evaluate whether the mountain portion of the monument should be retained.

between the bajada and the mountain that had been previously noted by Homer Shantz, noting that a reduction in the size of the monument would "detract from its value as a sanctuary for both plants and animals." Burtner notes that although the "Sky Island" vision of the Rincons and other surrounding mountains was still in development in the 1930s, "the use of life zones would become a foundational metaphor to narrate and justify the Monument."

Later work by scientists in the park affirmed the biological value of the park's higher elevations. Lowell Sumner, part of George Wright's NPS Biological Survey team in the 1930s, completed an elegant summary of the status of mammals (Sumner 1951; Figure 4.1.4-3) that addressed the question of whether the park should allow predator management. Sumner argued forcefully that it should not. A few years later, Joe Marshall conducted his classic study of the birds of an Arizona sky island (Marshall 1956, 1957). Similar work was done by Charles Lowe and his graduate students for reptiles and amphibians, and Lowe's work on the biogeography of rattlesnakes (Lowe 1992) continues to be widely cited. In the 1980s, Russ Davis, Ronnie Sidner and their colleagues described a number of surprising mammal distributions in the high country (Davis and Dunford 1987, Davis and Brown 1989, Davis and Sidner 1992). Jan Bowers and Steve McLaughlin (1987) did the same for plants. Today the idea of the Sky Islands is celebrated by the presence of conservation groups such as the Sky Island Alliance as well as a wealth of books, articles, conservation initiatives and scientific meetings. At Saguaro NP, it remains a fundamental interpretive theme.

Wildlife and Urban Development

The most important years for wildlife research in Saguaro NP were in the 1980s and 1990s, when park managers became aware of the potential impacts of urban development on natural resources. Alarmed by the rapid growth of Tucson, Superintendent Bill Paleck worked with the UA Cooperative Park Studies Unit (CPSU), and wildlife ecologist William Shaw to develop a series of studies to Illuminate how different wildlife species were responding to humans and urbanization.

Some of the results of these studies were fascinating. Researchers found that mule deer (*Odocoileus hemionus*) and collared peccary (*Pecari tajacu*) regularly moved in and out of the park (Bellantoni and Krausman 1992), which allowed them to take advantage of human-created water sources, but made them more vulnerable to roadkill and other threats. Coyotes (*Canis latrans*) were also extremely abundant near the park boundary (McLure et al. 1996), possibly because they had the best of both natural and human worlds.

NPS

Figure 4.1.4-3. NPS wildlife biologist Lowell Sumner examining specimens at Madrona Ranger Station, 1951.

A series of studies by Cecil Schwalbe and his graduate students provided insights into herpetofauna. Indeed, much of what is known about the Sonoran desert tortoise is based on research in both districts of the park in the late 1990s and early 2000s (Schwalbe et al. 2002, Edwards et al. 2004, Zylstra and Swann 2009). Long-term studies of tree lizards (*Urosaurus ornatus*) by Robert M'Closkey (1990) and Don Miles (Miles 1994) and rodents at TMD by Robert Parmenter (SNP, unpublished data) provided insight into how wildlife may be affected by the same types of changes that influenced saguaros and Sonoran Desert vegetation. Finally, roadkill studies by park staff (Gerow et al. 2010) demonstrated the large number of animals that were being killed on roads in and near the park and has influenced similar studies and planning throughout the region.

Many of these wildlife studies were intended to provide evidence to support land use planning outside park boundaries. Although this period of park history has not been researched in detail, it is clear that the results of these studies clearly influenced subsequent conservation plans. The extent of the Pima County Buffer Overlay Zone created to protect Saguaro NP from urban encroachment was directly based on the documented movements of deer and collared peccary (W. Shaw, pers. comm.). In the late 1980s the proposed development of the large Rocking K Ranch next to the park led to large protests in Tucson. Planning efforts that included UA scientists and local developers were led by the newly-created Sonoran Institute that used science to blend ecological and economical values in development of lands adjacent to the park. The results included creation of wildlife corridors, restoration of riparian habitat in Rincon Creek, and the sale of some of the best wildlife habitat to the park (Propst et al. 1998).

Some of the outcomes of this work are still in progress more than 25 years later. The Rocking K Ranch has yet to be developed, and the park is still trying to protect large sections of the X9 Ranch that were sold subsequent to their inclusion within park boundaries. UA professor Bill Shaw, now retired, continues to be consulted on wildlife values along Rincon Creek as park officials attempt to prioritize parcels for potential future inclusion in the park.

Environmental Compliance

Finally, in addition to the changes occurring outside of the park's boundaries in the last few decades of the 20th century, changes that occurred politically in America had a strong influence on science in the park. The 1960s and 1970s saw the passage of environmental laws including the Wilderness Act (1964), National Environmental Policy Act (1969), Clean Air Act (1970), Endangered Species Act (1973), and others. The Endangered Species Act, in particular, has influenced research in many ways. For example, the listing of the Mexican spotted owl (*Strix occidentalis lucida*) as a threatened species in 1993 required that the park understand and take actions to protect the park's small population in the Rincon Mountains, especially in areas where fire management was occurring. Surveys and research by David Willey (Willey 2013) and others (Berner and Mannan 1992) allowed the park to better understand this species and create Protected Activity Centers to protect it. Decades of surveys by Ronnie Sidner and her UA colleagues (e.g., Davis and Sidner 1992) provided similar baseline data on the endangered lesser long-nosed bat (*Leptonycteris yerbabuenae*) and other sensitive bat species. More recent research by Sandy Wolf and Dave Dalton has not only helped the park scientifically manage roost sites but also created a deeper understanding of the local ecology of these species, including the use of hummingbird feeders in Tucson by lesser long-nosed bats.

4.1.5. Saguaro National Park in a Changing World

Today we are entering a new era of science in all national parks. Although some resistance to science still occurs in the parks, current NPS policies make clear that resource management decisions must be based on the best available science. The NPS now has a well-established inventory and monitoring program, a functioning Cooperative Ecosystems Study Unit (CESU), and both actual and virtual learning centers designed

to communicate science issues to visitors and the general public. "Citizen science" has become an important part of public science at the park as part of the 10-year saguaro census (Figure 4.1.5-1), a Gila monster (*Heloderma suspectum*) research partnership with UA biologist Kevin Bonine (Figure 4.1.5-2), the Tucson Bird Count (http://www.tucsonbirds.org) and other projects. In 2011, the park worked with the National Geographic Society and many other partners to produce a major bioblitz. The 2011 Bioblitz, the largest event in the history of the park, brought in approximately 200 scientists to work with literally thousands of students and adult volunteers to sample Saguaro's biodiversity (Figure 4.1.5-3).

Beyond this, there is growing recognition that science has value in parks for documenting the effects of global climate change and helping guide the impending and difficult management decisions as temperatures rise, weather patterns change, and ecosystems respond in ways difficult to predict. At Saguaro NP, this recognition has led to recent collaborative research projects with UA scientists on climate effects on saguaros (Springer et al. 2015), lowland leopard frogs (*Rana yavapaiensis*) (Zylstra et al. 2015) and other resources that appear vulnerable to climate change (e.g., Munson et al. 2012), and the repeating of studies that have occurred in the past. For example, a repeat survey of the entire Section 17 in 2011-2012 underscored the important changes in the Cactus Forest (Conver et al., in review), and a repeat of a collared peccary and deer study from the 1960s and 1970s (Day 1977) documented a dramatic decline in the park's mule deer population (Beaupre 2012, SNP unpublished data).

TOM UHLMAN / NPS

Figure 4.1.5-1. Students helping the park measure saguaros in a large Citizen Science project, 2011.

Although the number of research projects has declined at Saguaro NP during the past decade as funding for both NPS and government science has been reduced, the park has a energetic monitoring program with the NPS Sonoran Desert Inventory and Monitoring network focused on a wide range of biological and physiological "vital signs." Saguaro's resource managers seek project money and work with partners and volunteers to support continued long-term monitoring of saguaros, lowland leopard frogs, invasive plants, water and air resources, and wildlife. Concern about the potential loss of wildlife as the TMD becomes increasingly surrounded by urban development, has led park staff to work in partnership with Pima County, the Arizona Sonora Desert Museum, Bureau of Land Management, and others to use wildlife cameras to determine the changing status of mammals, particularly small carnivores (Perkins and Swann, in review). Similar concerns have led to the inter-disciplinary studies of water in the RMD described in the surface water quantity and the tinajas, seeps, and springs assessments.

Knowledge of Saguaro's scientific legacy is important for understanding the condition of natural resources in the park because -- as can be seen in the chapters that follow -- the data from past studies provide context for the significant ecological changes that have occurred since Saguaro National Monument's establishment in the 1930s. The fact that saguaros have been studied on the same plots for more than 75 years has provided a nearly unprecedented opportunity to understand environmental change at the park. They provide support for the idea that NPS policies such as ending grazing, preventing poaching, restoring a more natural fire regime, and

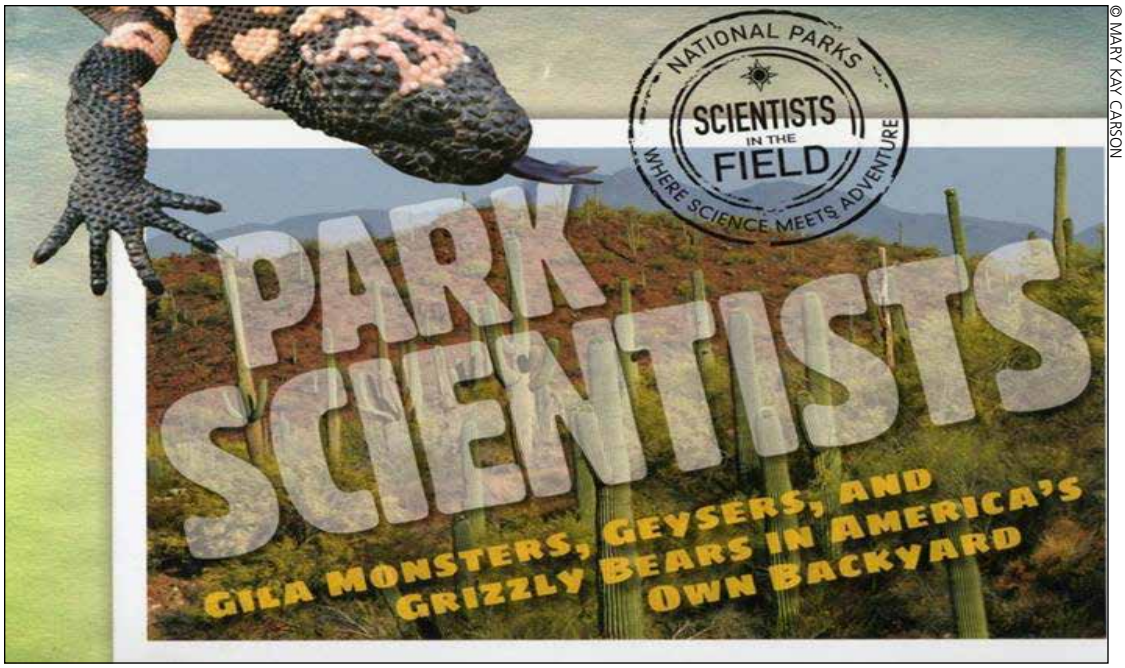

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Figure 4.1.5-2. Cover of a book about national park science by Mary Kay Carson that featured Saguaro's Gila monster research partnership with UA biologist Kevin Bonine.

removing invasive species have improved conditions for the saguaro and other native plants and wildlife. This legacy reminds us that national parks are complex places that cannot be separated from culture or the larger context in which they occur.

At the same time, studies at Saguaro NP have been essential for contributing important basic knowledge about saguaros, desert tortoises and other resources that are of significance far beyond the park's boundaries. As the park continues to be influenced by environmental changes occurring not only locally but globally, science will continue to play an important role - not only in helping park managers make important decisions for today and tomorrow, but as part of the "vast outdoor laboratory" envisioned by Homer Shantz that contributes knowledge to the world beyond.

4.1.6. Sources of Expertise

This section was authored by Don Swann, biologist at Saguaro National Park, with an early draft provided by intern Brian Cropper. Substantial reviews were provided by Robin Pinto (UA environmental historian), Perry Grissom (SNP fire ecologist), Dana Backer (SNP restoration ecologist), and Natasha Kline (former SNP biologist).

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Figure 4.1.5-3. UA graduate student Jason Schaller at the 2011 Bioblitz.

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4.2. Viewshed

Indicators/Measures

- Scenic Integrity (3 Measures)

Condition – Trend – Confidence

Moderate Concern – Varied - Medium

4.2.1. Background and Importance

The conservation of scenery is established in the National Park Service (NPS) Organic Act of 1916 ("… to conserve the scenery and the wildlife therein…"), reaffirmed by the General Authorities Act, as amended, and addressed generally in the NPS Management Policies 2006, sections 1.4.6 and 4.0 (Johnson et al. 2008). Although no management policy currently exists exclusively for scenic or viewshed management and preservation, parks are still required to protect scenic and viewshed quality as one of their most fundamental resources. According to Wondrak-Biel (2005), aesthetic conservation, interchangeably used with scenic preservation, has been practiced in the NPS since the early twentieth century. Aesthetic conservation strove to protect scenic beauty for park visitors to better experience the values of the park. The need for scenic preservation management is as relevant today as ever, particularly with the pervasive development pressures that challenge park stewards to conserve scenery today and for future generations.

Saguaro National Park (NP) was established in 1933 (originally as a national monument) to preserve the "Cactus Forest," the dense stand of large saguaros at the base of the Rincon Mountains east of Tucson (Figure 4.2.1-1). The Tucson Mountain District (TMD) was added to the park in 1961, also to protect the saguaro and associated vegetation in the area. Today, 78% of the park's districts (28,895 ha / 71,400 acres) is designated wilderness (P.L. 94-567). An additional 15,617 ha (38,590 acres) of designated wilderness within the Coronado National Forest's Rincon Mountain Wilderness Area is adjacent to three sides of Rincon Mountain District's (RMD) boundary, which beneficially affects the management of park land and associated resources (NPS 2014a), such as viewsheds.

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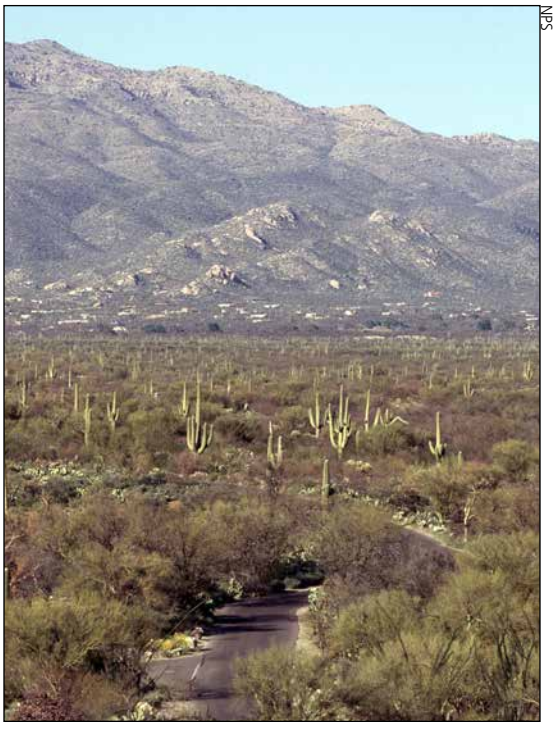

NPS

Figure 4.2.1-1. A view along the Cactus Forest Drive in Saguaro National Park's Rincon Mountain District in 1935 (left) and 75 years later in 2010 (right).

Rapid urban development originating from and surrounding the city of Tucson, Arizona, poses conversion risks for park species and their associated habitats, and for landscape-scale resources: night sky, soundscape, and viewsheds.

Visitor Experience

Viewsheds are considered an important part of the visitor experience at Saguaro NP and features on the visible landscape influence a visitor's enjoyment, appreciation, and understanding of the park. The park's wilderness and proximity to a large urban community provides "exceptional access to wild places in which visitors can experience wilderness, and in some areas, undeveloped scenic views (NPS 2014a). These views represent much more than just scenery; they represent a way to better understand the connection between self and nature.

Park visitors are provided opportunities to immerse themselves in the wilderness where experiences become more remote from anthropogenic sights and sounds, offering an opportunity to literally "visualize" their connection to nature. Unfortunately, undeveloped views and quiet environments are becoming increasingly rare at Saguaro NP as the city of Tucson and other surrounding areas continue to expand, encroaching upon the park and its natural environment.

When Saguaro NP was first established in 1933, access from Tucson was along 20 miles of poorly developed roads (Monahan et al. 2013). Today, Tucson is one of the fastest growing population centers in the United States, and according to the 2010 census, Pima County's population was 980,263 and is projected to reach 1.45 million by 2041 (Pima Association of Governments 2016a), making it increasingly difficult to manage for undeveloped views.

4.2.2. Data and Methods

The indicator and measures used for assessing the condition of Saguaro NP's viewsheds are based on studies related to perceptions people hold toward various features and attributes of scenic landscapes. In general, there is a wealth of research demonstrating that people tend to prefer natural over human-modified landscapes (Zube et al. 1982, Kaplan and Kaplan 1989, Sheppard 2001, Kearny et al. 2008, Han 2010). Human-altered components of the landscape (e.g., roads, buildings, powerlines, and other features) that do not contribute to the natural scene are often perceived as detracting from the scenic character of a viewshed. Despite this generalization for natural landscape preferences, studies have also shown that not all human-made structures or features have the same impact on visitor preferences. Visitor preferences can be influenced by a variety of factors including cultural background, familiarity with the landscape, and their environmental values (Kaplan and Kaplan 1989, Virden and Walker 1999, Kaltenborn and Bjerke 2002, Kearney et al. 2008).

While we recognize that visitor perceptions of an altered landscape are highly subjective, and that there is no completely objective way to measure these perceptions, research has shown that there are certain landscape types and characteristics that people tend to prefer over others. Substantial research has demonstrated that human-made features on a landscape are perceived more positively when they are considered in harmony with the landscape (e.g., Kaplan and Kaplan 1989, Gobster 1999, Kearney et al. 2008).

For example, Kearney et al. (2008) showed that survey respondents tended to prefer development that blended with the natural setting through use of colors, smaller scale, and vegetative screening. These characteristics, along with distance from non-contributing features and movement and noise associated with observable features on the landscape are discussed below.

Indicator/Measures

Scenic Integrity (Conspicuousness of Non-contributing Features, Extent of Development, and Extent of Scenic Conservation)

Scenic integrity is defined as the state of naturalness, or conversely, the state of disturbance created by human activities or alteration (U.S. Forest Service (USFS) 1995).

This aspect of the assessment focuses on the features of the landscape related to non-contributing human alteration/development and whether there is potential to preserve areas from further development, which would degrade the scenic quality as seen from the park.

Key Observation Points

Seven key observation points were selected by park staff (Table 4.2.2-1, Figure 4.2.2-1) and were used to qualitatively evaluate viewshed condition using panoramas and viewshed analysis overlaid with housing and road densities and conservation status datasets. These observation points were selected based on either a) where people most likely visit, b) areas of high potential for development (thus this analysis provides a baseline for future monitoring), or c) based on a prominent view due to high elevation (S. Stonum, Chief Science & Resource Management, pers. comm., 2016).

Two observation points were located in TMD: North Scenic Drive Trail along the northeastern boundary of the district; and a location just west of the Sus Picnic Area, along the southwestern boundary of the district. Both observation points were located outside of the park's designated wilderness.

Five observation points were selected in RMD, with only one located outside of the park's designated wilderness along the Cactus Forest Loop Drive at the overlook, which is highly visited and easy to access. The remaining four key observation points, Tanque Verde Ridge, Spud Rock, Reef Rock, and Rincon Peak were all located within the park's wilderness.

Measure

Conspicuousness of Non-contributing Features

GigaPan Images/Panoramas

We used a series of images stitched into panoramas to portray the viewshed from an "on the ground" observer's perspective. These images were taken from each key observation point using a Canon PowerShot digital camera and the GigaPan Epic 100 system, a robotic camera mount coupled with stitching software (Figure 4.2.2-2). A series of images were photographed and the individual photographs were then stitched into high-resolution panoramic images using GigaPan-Stitch software. For the purposes of this assessment, the photographer divided each photo session into four, 90 degree quadrants, resulting in four panoramas for each 360 degree view.

The GigaPan images provided a means of assessing the non-contributing features on the landscape and qualitatively evaluating the viewshed condition based on groups of man-made feature characteristics as follows: (1) distance from a given key observation point, (2) size, (3) color and shape, and (4) movement and noise. A general relationship between these characteristics and their influence on conspicuousness is presented in Table 4.2.2-2.

Table 4.2.2-1. Key observation points used to assess Saguaro NP's viewshed condition.

Location	District	In Wilderness?	Approximate Elevation of Observation Point (m/ft)	Panorama Date	Coordinates Easting, Northing (UTM NAD83 12N)
North Scenic Drive Trail	TMD	No	750 / 2,462	2/24/2016	0486984, 3579129
Peak W. of Sus Picnic Area	TMD	No	812 / 2,665	4/22/2015	0479899, 3570458
Cactus Forest Overlook	RMD	No	892 / 2,926	6/5/2015	0524966, 3562375
Tanque Verde Ridge	RMD	Yes	1,087 / 3,566	12/8/2015	0526466, 3557758
Rincon Peak	RMD	Yes	2,582 / 8,471	6/12/2015	0544985, 3553803
Reef Rock	RMD	Yes	2,306 / 7,566	9/28/2015	0543981, 3562720
Spud Rock	RMD	Yes	2,587 / 8,486	9/28/2015	0542404, 3564545

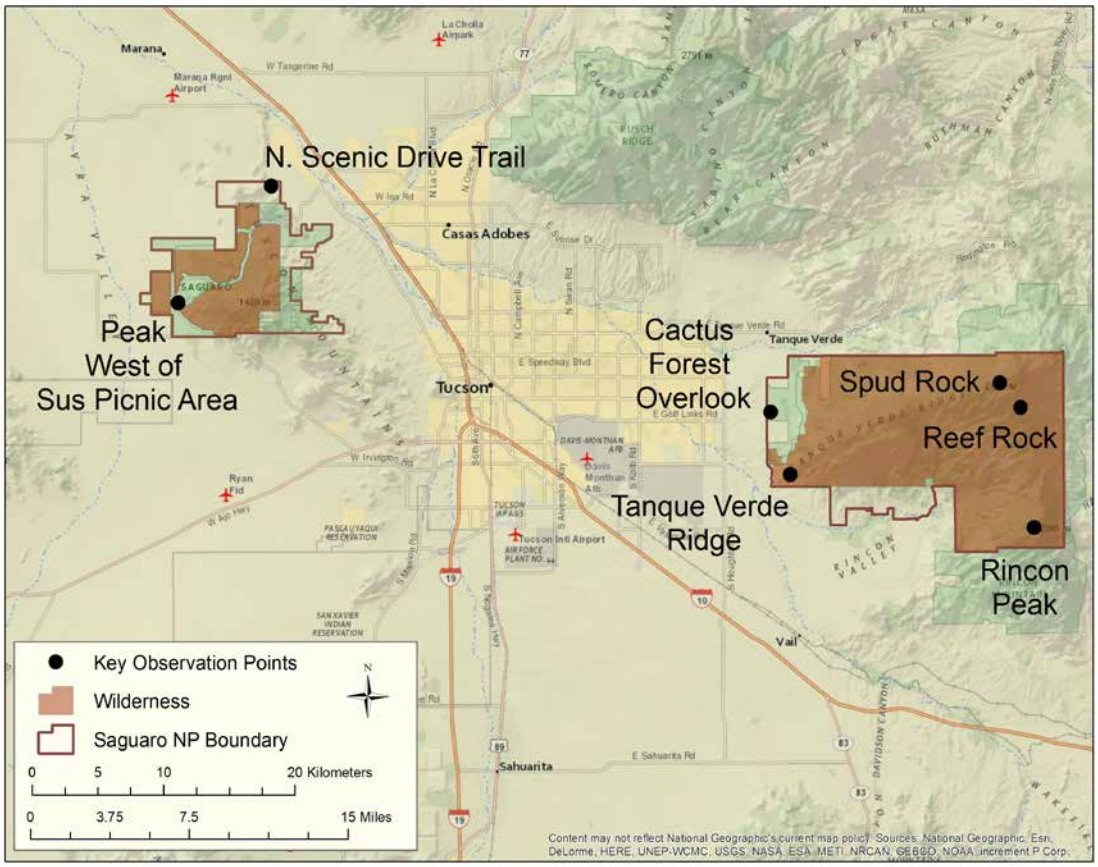

Figure 4.2.2-1. Locations of the seven key observation points selected for the viewshed condition assessment.

Distance. The impact that individual human-made features have on perception is substantially influenced by the distance from the observer to the feature(s). Viewshed assessments using distance zones or classes often define three classes: foreground, middle ground, and background (Figure 4.2.2-3). For this assessment, we have used the distance classes that have been recently used by the National Park Service:

- *Foreground* = 0 - 0.8 km (0-½ mi) from key observation point
- *Middle ground* = 0.8 - 4.8 km (½-3 mi) from key observation point
- *Background* = 4.8 - 96.6 km (3-60 mi) from key observation point.

Over time, different agencies have adopted minor variations in the different specific distances use to define these zones, but the overall logic and intent has been consistent.

The foreground is the zone where visitors should be able to distinguish variation in texture and color, such as the relatively subtle

Figure 4.2.2-2. The GigaPan system takes a series of images that are stitched together using software to create a single panoramic image.

Table 4.2.2-2. Characteristics that influence conspicuousness of human-made features.

Characteristic	Less Conspicuous	More Conspicuous
Distance	Distant from the observation point	Close to the observation point
Size	Small relative to the landscape	Large relative to the landscape
Color and Shape	Colors and shapes that blend into the landscape	Colors and shapes that contrast with the landscape
Movement and Noise	Lacking movement or noise	Exhibits obvious movement or noise

variation among vegetation patches, or some level of distinguishing clusters of tree boughs. Large birds and mammals would likely be visible throughout this distance class, as would small or medium-sized animals at the closer end of this distance class (USFS 1995). Within the middle ground there is often sufficient texture or color to distinguish individual trees or other large plants (USFS 1995). It is also possible to still distinguish larger patches within major plant community types (such as riparian areas), provided there is sufficient difference in color shades at the farther distance. Within the closer portion of this distance class, it still may be possible to see large birds when contrasted against the sky, but other wildlife would be difficult to see without the aid of binoculars or telescopes. The background distance class is where texture tends to disappear and colors flatten. Depending on the actual distance, it is sometimes possible to distinguish among major vegetation types with highly contrasting colors (for example, forest and grassland), but any subtle differences within these broad land cover classes would not be apparent without the use of binoculars or telescopes, and even then may be difficult.

Size

Size is another characteristic that may influence how conspicuous a given feature dominates the landscape, and how it is perceived. For example, Kearney et al. (2008) found human preferences were lower for human-made developments that tended to dominate the view, such as large, multi-storied buildings) and were more favorable toward smaller, single family dwellings. In another study, Brush and Palmer (1979) found that farms tended to be viewed more favorably than views of towns or industrial sites, which ranked very low on visual preference. This is consistent with other studies that have reported rural family dwellings, such as farms or ranches, as quaint and contributing to rural character (Schauman 1979, Sheppard 2001, Ryan 2006), or as symbolizing good stewardship (Sheppard 2001).

We considered the features on the landscape surrounding Saguaro NP as belonging to one of six size classes (Table 4.2.2-3), which reflect the preference groups reported by studies. Using some categories of perhaps mixed measures, we considered size classes within the context of height, volume, and length.

Color and Shape

Studies have shown that how people perceive a human-made feature in a rural scene depends greatly on how well it seems to fit or blend in with the environment (Kearney et al. 2008, Ryan 2006). For example, Kearney et al. (2008) found preferences for homes that exhibit lower contrast with their surroundings as a result of color, screening

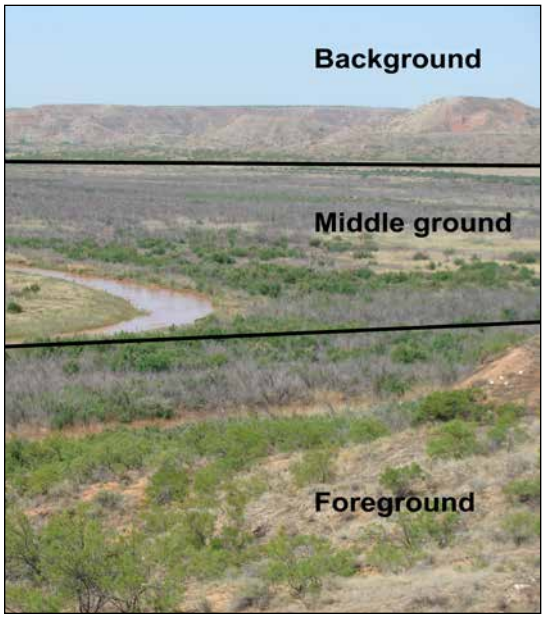

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Figure 4.2.2-3. An example of foreground, middle ground, and background distance classes.

Table 4.2.2-3. A matrix describing the six size classes used for conspicuousness of human-made features.

	Low Volume	Substantial Volume
Low Height	Single family dwelling (home, ranch house)	Small towns, complexes
Substantial Height	Radio and cell phone towers	Wind farms, oil derecks
Substantial Length	Small roads, wooden power lines, fence lines	Utility corridors, highways, railroads

vegetation, or other blending factors (see Figure 4.2.2-4). It has been shown that colors lighter in tone or higher in saturation relative to their surroundings have a tendency to attract attention (contrast with their surroundings), whereas darker colors (relative to their surroundings) tend to fade into the background (Ratcliff 1972), O'Connor 2008). This is consistent with the findings of Kearney et al. (2008) who found that darker color was one of the factors contributing to a feature blending in with its environment and therefore preferred. Some research has indicated that color can be used to offset other factors, such as size, that may evoke a more negative perception (O'Connor 2009). Similarly, shapes of features that contrast sharply with their surroundings may also have an influence on how they are perceived.

This has been a dominant focus within visual resource programs of land management agencies (Ribe 2005). The Visual Resource Management Program of the BLM (BLM 1980), for example, places considerable focus on design techniques that minimize visual conflicts with features such as roads and power lines by aligning them with the natural contours of the landscape. Based on these characteristics of contrast, we considered the color of a feature in relative harmony with the landscape if it closely matched the surrounding environment, or if the color tended to be darker relative to the environment. We considered the shape of a feature in relative harmony with the landscape if it was not in marked contrast to the environment.

Movement and Noise

Motion and sound can both have an influence on how a landscape is perceived (Hetherington et al. 1993), particularly by attracting attention to a particular area of a viewshed. Movement and noise parameters can be perceived either positively or negatively, depending on the source and context. For example, the motion of running water generally has a very positive influence on perception of the environment (Carles et al. 1999), whereas noise from vehicles on a highway may be perceived negatively. In Carles et al.'s 1999 study, sounds were perceived negatively when they clashed with aspirations for a given site, such as tranquility. We considered the conspicuousness of the impact of movement and noise to be consistent with the amount present (that is, little movement or noise was inconspicuous, obvious movement or noise was conspicuous).

Hierarchical Relationship among Conspicuousness Measures

The above-described characteristics do not act independently with respect to their influence on the conspicuousness of features; rather, they tend to have a hierarchical effect. For example, the color and shape of a house would not be important to the integrity of the park's viewshed if the house was located too far away from the key observation point. Thus, distance becomes the primary characteristic that affects the potential conspicuousness. Therefore, we considered potential influences on conspicuousness in the context of a hierarchy based on the distance characteristics having the most impact on the integrity of the viewshed, followed by the size characteristic, then both the color and shape, and movement and noise characteristic (Figure 4.2.2-5).

Measure
Extent of Development

The extent of development provides a measure of the degree to which the viewshed is altered from its natural (reference) state, particularly the extent to which intrusive or disruptive elements such as structures and roads may diminish the "naturalness" of the view (USFS

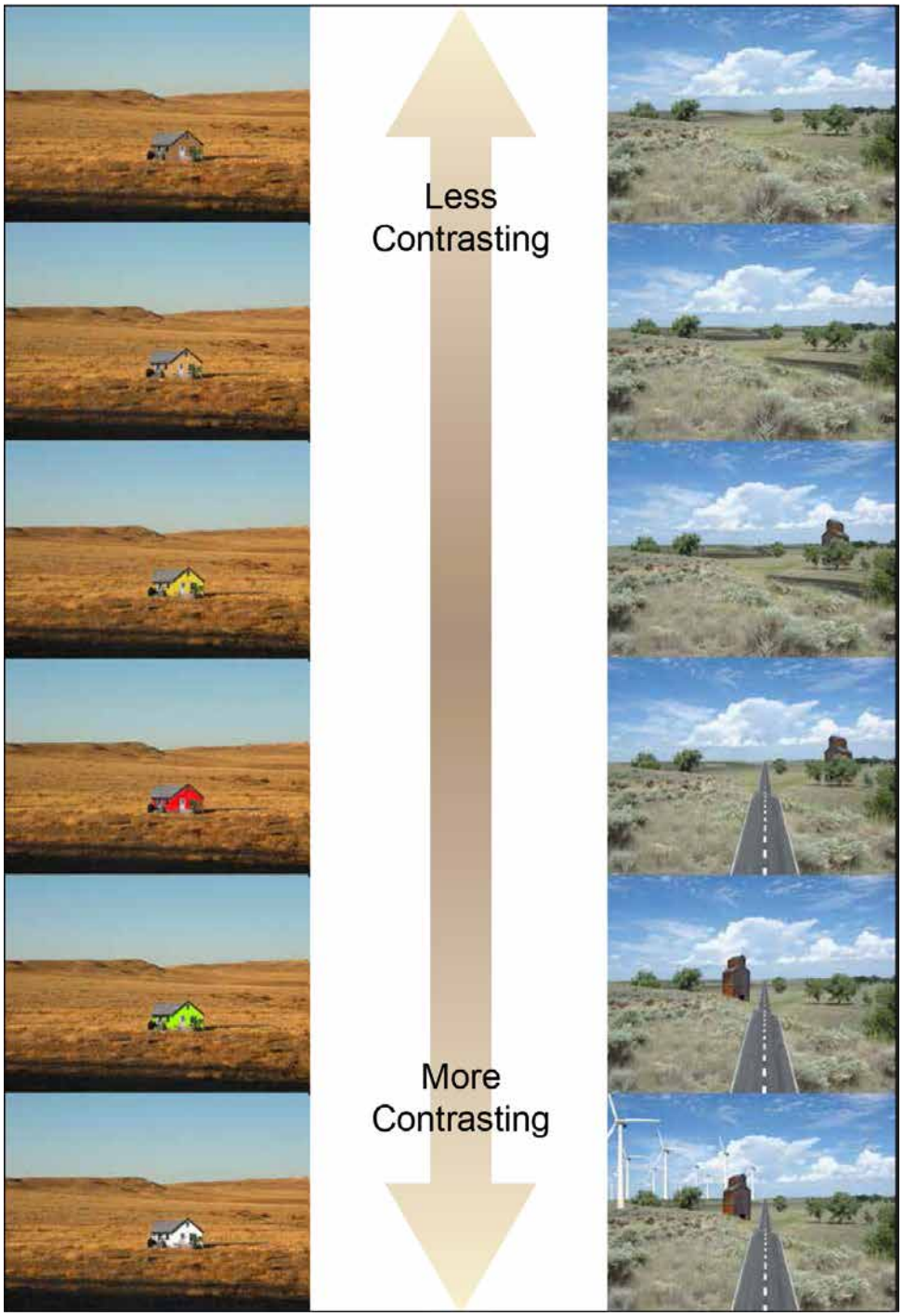

Figure 4.2.2-4. Graphic illustration of how color (left) and shape (right) can influence whether features are in harmony with the environment, or are in contrast.

1995, Johnson et al. 2008). We assess the extent of development using Geographic Information System (GIS) analysis to provide a spatial and quantitative assessment of the housing and road developments within the viewshed area of influence.

Viewshed Analysis

Viewshed analyses were conducted to evaluate areas that were visible and non-visible from a given observation point using ArcGIS Spatial Analyst Viewshed tool and a summary is included in Appendix B. A 10 meter (32.8 ft) National Elevation Dataset (NED) Digital Elevation Model (DEM), clipped to eastern Pima County was provided by Pima County's

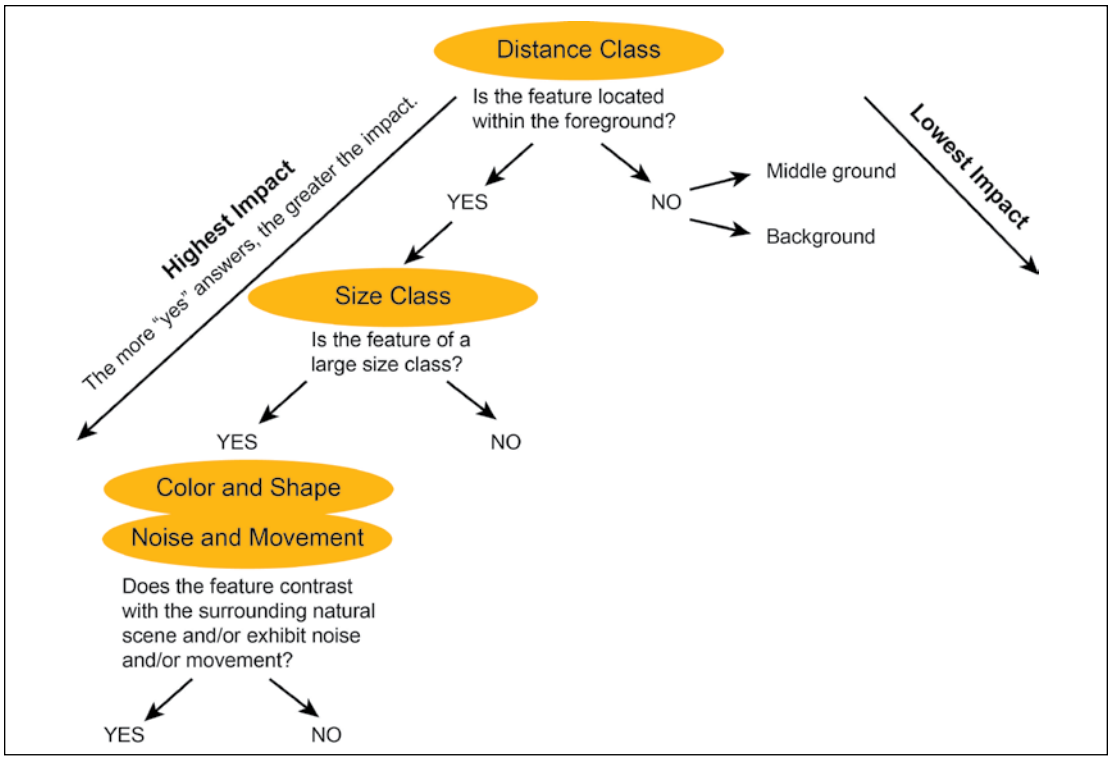

Figure 4.2.2-5. Conceptual framework for hierarchical relationship of characteristics that influence the conspicuousness of features within a viewshed.

GIS Department and used to create the viewshed Area of Analysis (AOA) as seen from each of the seven key observation points (Pima County 2016b). These seven AOAs were subsequently combined to create a park-wide composite viewshed. A composite viewshed shows multiple viewsheds as one, providing an overview of the visible/non-visible areas across all key observation points.

The viewshed analyses assumed that the viewsheds were not hindered by non-topographic features such as vegetation, visibility did not decay due to poor air quality, and that the observer was at ground level (1.68 m / 5.6 ft) in most instances, but refer to the key uncertainties discussion at the end of this assessment for more details.

NPScape Data

NPScape is a landscape dynamics monitoring program that produces and delivers GIS data, maps, and statistics that are integral to understanding natural resource conservation and conditions within a landscape context (NPS 2014b, Monahan et al. 2012). NPScape data include seven major categories (measures), three of which will be used in the viewshed condition assessment: housing, roads, and conservation status. These metrics will be used to evaluate resource conditions from a landscape-scale perspective and to provide information pertaining to threats and conservation opportunities related to scenic views surrounding Saguaro NP. NPScape data are consistent, standardized, and collected in a repeatable fashion over time, and yet are flexible enough to provide analyses at many spatial and temporal scales. The NPScape datasets used in this analysis are described in the sections that follow.

Housing Density

The NPScape 2010 housing density metrics are derived from Theobald's (2005) Spatially Explicit Regional Growth Model, SERGoM 100 m (328 ft) resolution housing density rasters. SERGoM forecasts changes on a decadal basis using county specific population estimates and variable growth rates that are location-specific. The SERGoM housing densities are grouped into six classes as shown in Table 4.2.2-4. NPScape's housing density standard operating procedure (NPS 2014c) and toolset were used to clip the raster to the background distance class of 96.5 km (60 mi) surrounding both districts, which is where textures and colors flatten and is the area most likely visible to the average observer (USFWS 1995).

Road Density

The NPScape road density metric is based ESRI's North America Detailed Streets road features (2010), which were used to calculate the road densities within the background distance class of 96.5 km (60 mi) surrounding both districts. The Feature Class Code values in the dataset are used to identify road types. According to NPScape's road density standard operating procedure (NPS 2014d), "highways are defined as interstates (FCC: A10-A19) or major roads (FCC: A20-A38, excluding ferry routes). All roads include all road features from the source data regardless of FCC value (excluding ferry routes). Weighted roads were produced by multiplying the lengths of interstate roads by a factor of 5 and remaining major roads by a factor of 3." A new road density raster, feature classes based on four density classes, and statistics were generated from these data.

Table 4.2.2-4. Housing density classes.

Housing Density Class (units / km²)	Grouped Housing Density Class
Urban-Regional Park	Urban-Regional Park
Commercial / Industrial	Commercial / Industrial
>2,470	Urban
1,235 - 2,470	
495 - 1,235	Suburban
146 - 495	
50 - 146	Exurban
25 - 49	
13 - 24	
7 - 12	
4 - 6	Rural
1.5 - 3	
<1.5	
Private undeveloped	

Measure

Degree of Scenic Conservation

Conservation Status

The U.S. Geological Survey (USGS) (2016) Gap Analysis Program (GAP) Protected Areas Database (PAD)-US version 1.4 conservation status metric was used to calculate the percent area protected and the percentage of area in broad ownership categories (e.g., federal, state, tribal, etc.), within the composite viewshed's visible area (NPS 2014e). According to Monahan et al. (2012), "the percentage of land area protected provides an indication of conservation status and offers insight into potential threats (e.g., how much land is available for conversion and where it is located in relation to the park boundary) as well as opportunities (e.g., connectivity and networking of protected areas)."

There are four GAP categories that vary based on degree of protection and management mandates. Saguaro NP is within the GAP Status 1 category, which is described as follows, along with the remaining three categories:

GAP Status 1: Lands that have permanent protection from conversion of natural land cover and are managed for biodiversity and disturbance events.

GAP Status 2: Lands that have permanent protection from conversion of natural land cover and are managed for biodiversity but disturbance events are suppressed.

GAP Status 3: Lands that have permanent protection from conversion of natural land cover and are managed for multiple uses, ranging from low intensity (e.g., logging) to high intensity (e.g., mining).

GAP Status 4: No known mandate for protection and include legally mandated easements (USGS 2011).

4.2.3. Reference Conditions

We used qualitative reference conditions to assess the scenic integrity of Saguaro NP's viewshed, which are as presented in Table 4.2.3-1.

4.2.4. Condition and Trend

Conspicuousness of Non-contributing Features

The GigaPan panoramas taken at the two TMD key observation points and their corresponding viewsheds are shown in Figures 4.2.4-1, -2, -3, and -4, and in Figures 4.2.4-5, -6, -7, -8, -9a,b, -10, -11, -12, -13a,b, and -14 for the five RMD key observation points. The panoramic images were evaluated to determine the conspicuousness of the

Table 4.2.3-1. Reference condition classes used to evaluate the scenic integrity of Saguaro NP's viewsheds.

Class	References
High Scenic Integrity *(Good Condition)*	Some noncontributing features or developments may be visible, but the vast majority of the landscape is dominated by natural features, especially in the foreground or middle ground distance classes. The integrity of the natural setting is well preserved such that an observer can easily visualize the natural aesthetic of the viewshed. As such, the features that contribute to the natural integrity are well preserved and the noncontributing features are generally absent or are sufficiently inconspicuous so as to not detract from the natural scenery.
Moderate Scenic Integrity *(Moderate Concern)*	Noncontributing features or developments occupy a moderate portion of the landscape and/or are moderately conspicuous, but sufficient intactness retains much of the scenic integrity. The integrity of the natural setting is also largely preserved such that an observer can experience an undeveloped viewshed.
Low Scenic Integrity *(Significant Concern)*	The vast majority of the landscape is dominated by noncontributing features or developments that are conspicuous enough (i.e., in the foreground or middle ground distance classes) that little scenic integrity remains. The integrity of the natural setting is essentially lost either from the contributing factors not being well preserved and/or the noncontributing features overwhelming the potential to experience a natural view.

non-contributing, man-made features as seen from each key observation point, and the viewshed anayses were referenced to discuss the visible areas from each observation point.

Tucson Mountain District's Key Observation Points

North Scenic Drive Trail

The conspicuousness of non-contributing features seen from the North Scenic Drive Trail (Figure 4.2.4-1), at an elevation of approximately 750 m (2,462 ft) and not located in wilderness, varies greatly depending upon whether the view is toward the city of Tucson, AZ or west— away from the city where there is currently far less development. The viewshed analysis (Figure 4.2.4-2) shows that the longer distance views are primarily seen from north - northwest to south - southeast, which is consistent with the panoramas.

The views from the northwest to southeast are largely comprised of housing developments located within the middle and background distance classes. While the conspicuous features are houses, relatively few, if any, are high profile structures and their color is uniform and of an earth tone, which lessens the impact of conspicuousness. A few roads are visible, but their low profiles are such that the housing developments dominate the view. As the image transitions from east to south, the view becomes increasingly natural, however, the view from south to west is dominated by a hill in the foreground, which blocks any view beyond. The last panorama shown from the west to north direction is initially comprised of natural features then becomes dominated by developments, which include houses and roads (looking toward Interstate 10 and the city of Tucson).

The viewshed condition from the North Scenic Drive Trail key observation point varies, ranging from good condition for the south to northwest views, although the south to west view is obscured by a hill in the immediate foreground, to significant concern from the northwest to southeast directions, which is toward Tucson and dominated by encroaching housing and road developments.

Peak West of Sus Picnic Area

The peak west of Sus Picnic Area key observation point was at an elevation of approximately 812 m (2,665 ft) (Figure 4.2.4-3) and not located in wilderness. The non-contributing features seen from this location is comprised of housing developments that are visible in the background distance class. A few roads, located in the middle ground distance class, bisect the scene.

Figure 4.2.4-1. Panoramic views in four, 90° directions from the North Scenic Drive Trail key observation point in Tucson Mountain District (from top: north to east, east to south, south to west, and west to north).

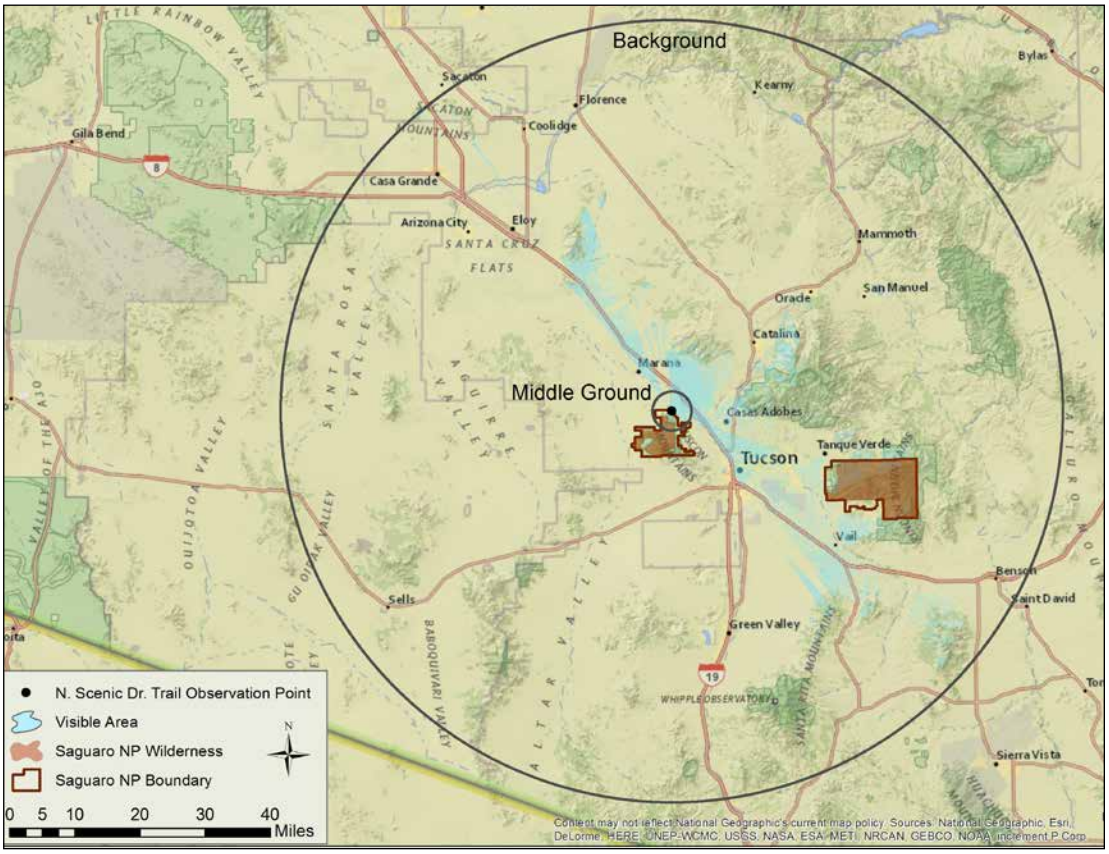

Figure 4.2.4-2. Visible area from North Scenic Drive Trail key observation point.

The viewshed analysis (Figure 4.2.4-4) shows that the primary distance views are generally from the south to the north, with some visible areas to the northeast and southeast. The viewshed analysis results for this key observation point isn't as consistent with the panoramas since a sweeping view is afforded from the east to south direction (refer to key uncertainties for a discussion about the inferences made when using a DEM).

The view from north to east is looking into the park across TMD and is dominated by natural features. The only non-contributing features seen from this 90-degree view are two roads located in the middle ground, and while visible, they do not significantly detract from the natural scenery. Panning from east to south then south to west, some housing developments and roads are conspicuous, although the houses are located in the background distance class, diminishing the degree of scenic impact. The few roads that are visible in the foreground and middle ground distance classes contribute to a somewhat dissected landscape pattern but sufficient intactness of the natural scene still remains. The last panorama, taken from west to north, transitions from fore- and middle grounds dominated by natural features and housing developments in the background to all natural.

Overall, the viewshed condition from the peak west of Sus West Picnic Area key observation point ranges from good condition in the north to east and west to north directions, which look across park land to good to moderate concern for the remaining two 90-degree directions, which are comprised of views with developments that are mostly located in the background and outside the park.

Rincon Mountain District's Key Observation Points

Cactus Forest Overlook

Only one key observation point was selected from within RMD's front country, which was the Cactus Forest Overlook along the Loop Drive, at an approximate elevation of 892 m (2,926 ft). This is a highly visited and easily accessible location, offering spectacular views of the cactus forest but is comprised of the

Figure 4.2.4-3. Panoramic views in four, 90° directions from the peak west of the Sus Picnic Area key observation point in Tucson Mountain District (from top: north to east, east to south, south to west, and west to north).

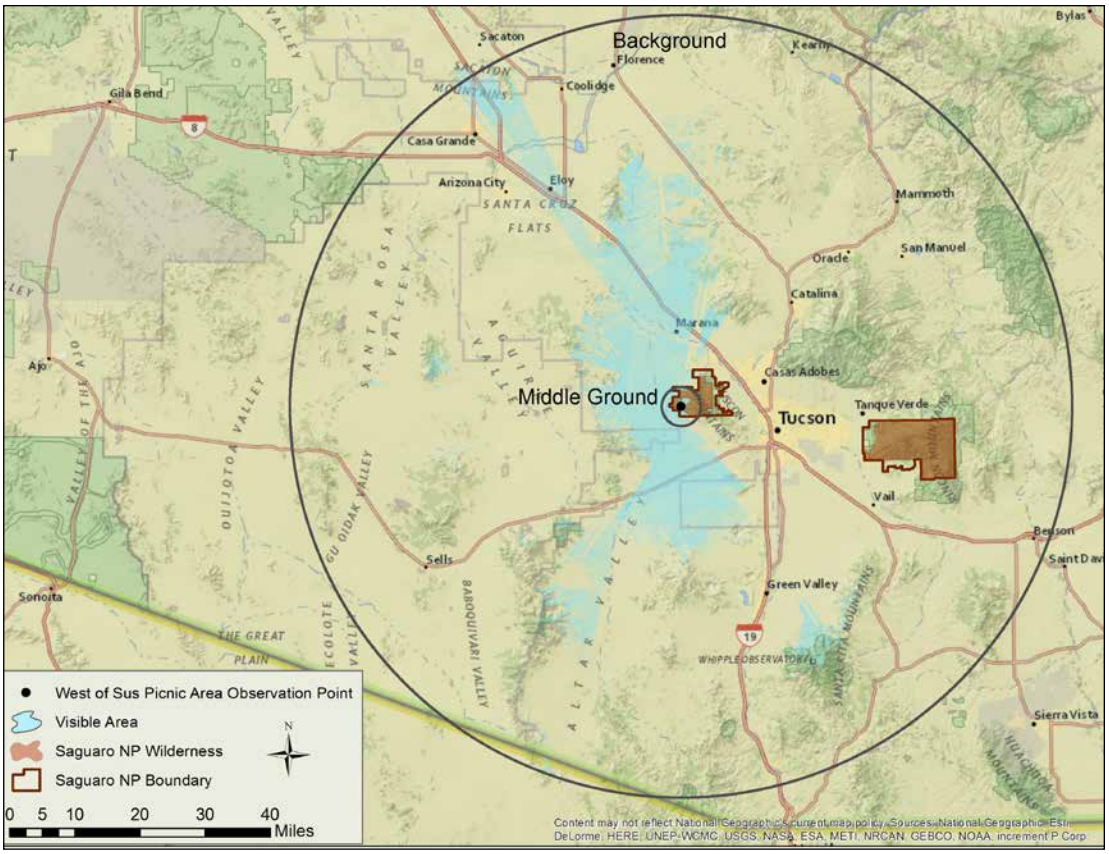

Figure 4.2.4-4. Visible area from west of Sus Picnic Area Trail key observation point.

smallest visible area as seen in the panoramas and viewshed analysis (Figure 4.2.4-6).

The view from the north to east is of Coronado National Forest's Catalina Mountains and RMD's cactus forest, offering an undeveloped viewscape except for the paved loop drive that is in the fore- and middle ground distance classes. Again, the view from the east to south offers a similar, natural view as seen in the north to east direction but looks into the RMD instead of onto USFS land. The views from the south to west and west to north show the housing developments that are encroaching along RMD's southern and eastern boundary, although the developments are located in the middle to background distance classes except for the paved loop drive, which is in the immediate foreground.

Previously presented in this assessment as Figure 4.2.1-1, is a view along the Cactus Forest Loop Drive, near the key observation point selected for this viewshed assessment, that was taken in 1935 and a photograph taken in 2010 from the same location. As one can see in the photo, housing developments have been built along the mountain's foothills and the road, which was a two-track, has since been paved, contributing to the non-natural features that are conspicuous from this location.

In general, the viewshed condition from the cactus forest overlook observation point directions is good, although the encroaching housing developments that are primarily located to the west detract from a purely natural "sense of place," warranting moderate concern when looking toward the city of Tucson.

Tanque Verde Ridge

The Tanque Verde Ridge key observation point is located in RMD's wilderness at an approximate elevation of 1,087 m (3,566 ft) and offers sweeping views from the southeast to the northwest, primarily of the city of Tucson, AZ (Figure 4.2.4-7). The viewshed analysis, showing the area visible from this key observation point is presented in Figure 4.2.4-8, and is primarily within the southwest to the northwest, which is consistent with what is seen in the panoramas.

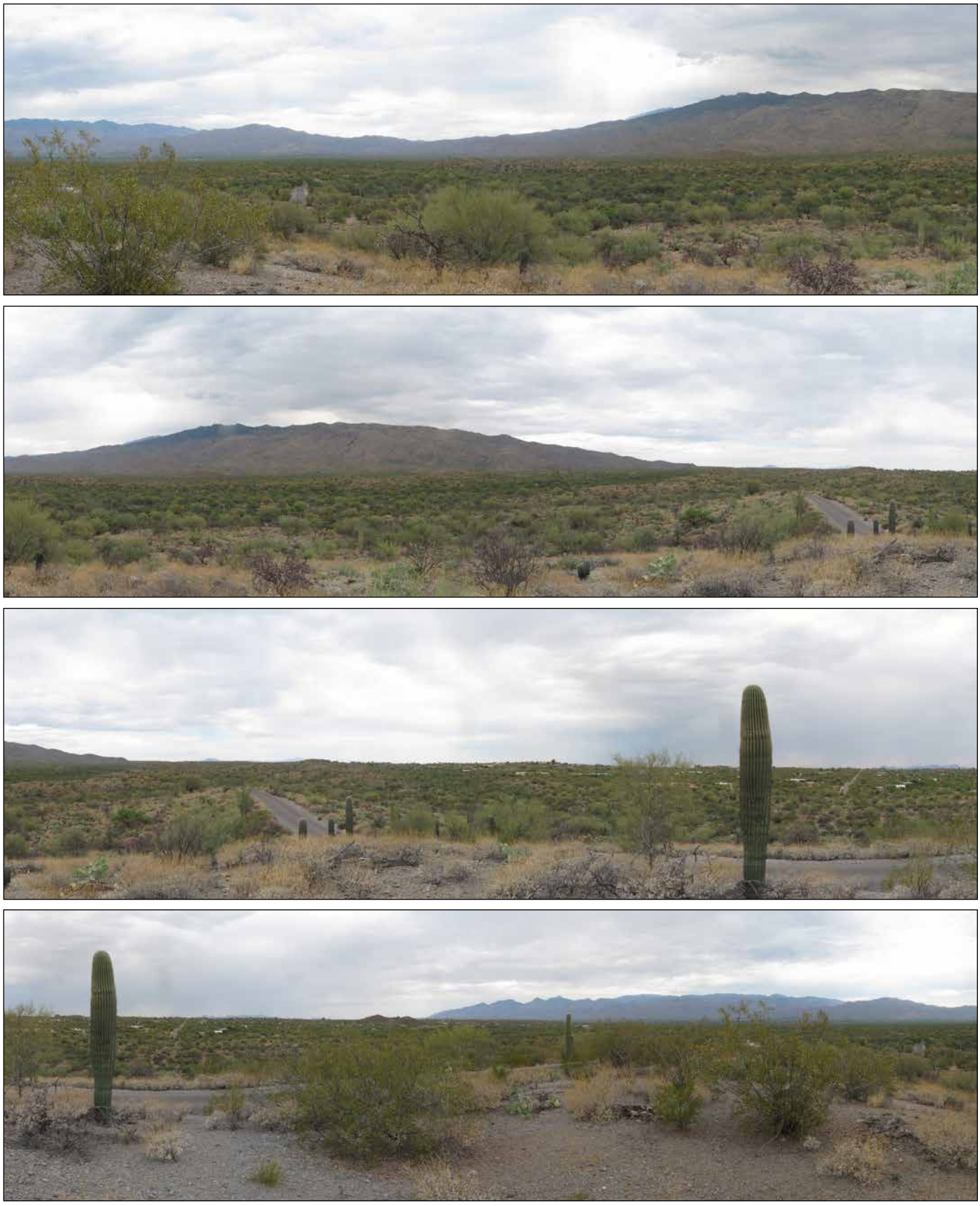

Figure 4.2.4-5. Panoramic views in four, 90° directions from the Cactus Forest Loop key observation point in Rincon Mountain District (from top: north to east, east to south, south to west, and west to north).

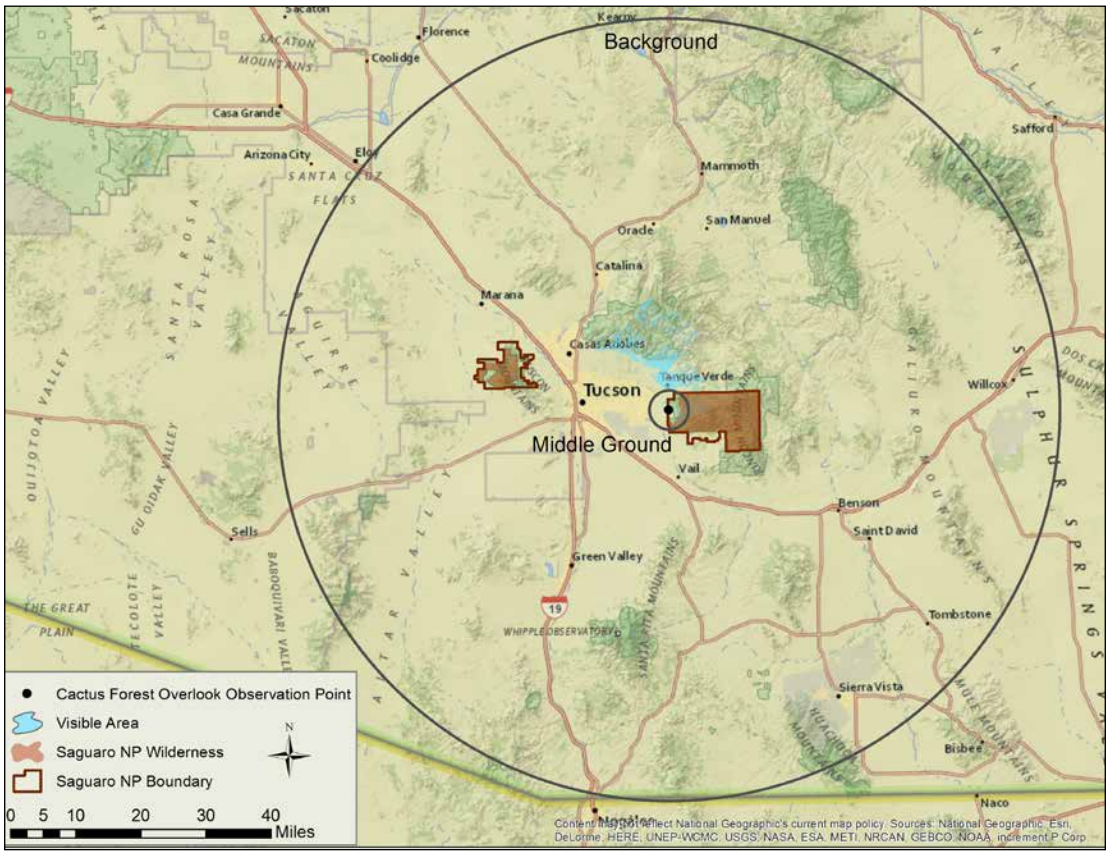

Figure 4.2.4-6. Visible area from the Cactus Forest Overlook key observation point.

The views from the north to southeast are located in the foreground distance class and include natural features such as vegetation, including saguaro cacti, boulders, and a hill within the north to east quadrant that largely blocks the view extending beyond the foreground distance class. While the developments seen from this key observation point are within the middle to background distance classes, they diminish the natural quality of the viewshed. This is also an area that has been approved for a large development, which is discussed in the Threats section of this assessment, but will likely be visually degraded in the future.

The viewshed condition from the Tanque Verde Ridge key observation point varies, ranging from good condition from north to east, to moderate / significant concern in the remaining directions, which is looking toward Tucson and dominated by encroaching housing and road developments.

Rincon Mountain District's Far Backcountry Key Observation Points:
Reef Rock, Spud Rock, and Rincon Peak

The Reef Rock, Spud Rock, and Rincon Peak key observation points, all located in wilderness, ranged from a lower elevation of 2,306 m to almost 2,591 m (7,566-8,500 ft), offering the largest viewsheds (presented in Figures 4.2.4-10, -12, and -14 due to the high elevations. Unfortunately, these three locations are also the least accessible of all observation points selected due to their remote locations that cannot be reached by vehicles; therefore, the least visited (and seen).

Of the three RMD backcountry key observation locations, the view from Reef Rock (Figure 4.2.4-9a,b) is more restricted compared to the views seen from Spud Rock (Figure 4.2.4-11) and Rincon Peak (Figure 4.2.4-13a,b). Regardless, the primary features observed in all directions from all three observation points are natural in both the foreground and middle ground distance classes.

Figure 4.2.4-7. Panoramic views in four, 90° directions from the Tanque Verde Ridge key observation point in Rincon Mountain District (from top: north to east, east to south, south to west, and west to north).

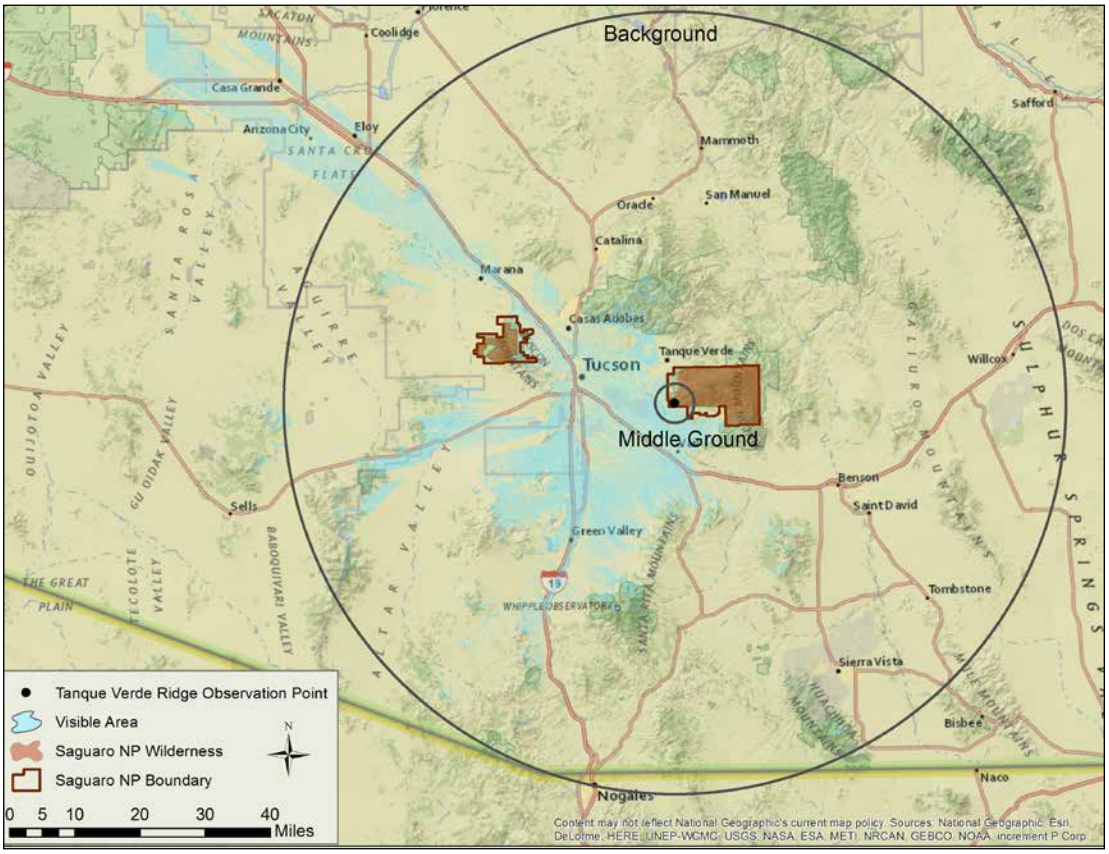

Figure 4.2.4-8. Visible area from the Tanque Verde Ridge key observation point.

Figure 4.2.4-9a. Panoramic views in two of the four, 90° directions from the Reef Rock key observation point in the Rincon Mountain District (top: north to east; bottom: east to south).

Figure 4.2.4-9b. Panoramic views in two of the four, 90° directions from the Reef Rock key observation point in the Rincon Mountain District (top: south to west; bottom: west to north) continued.

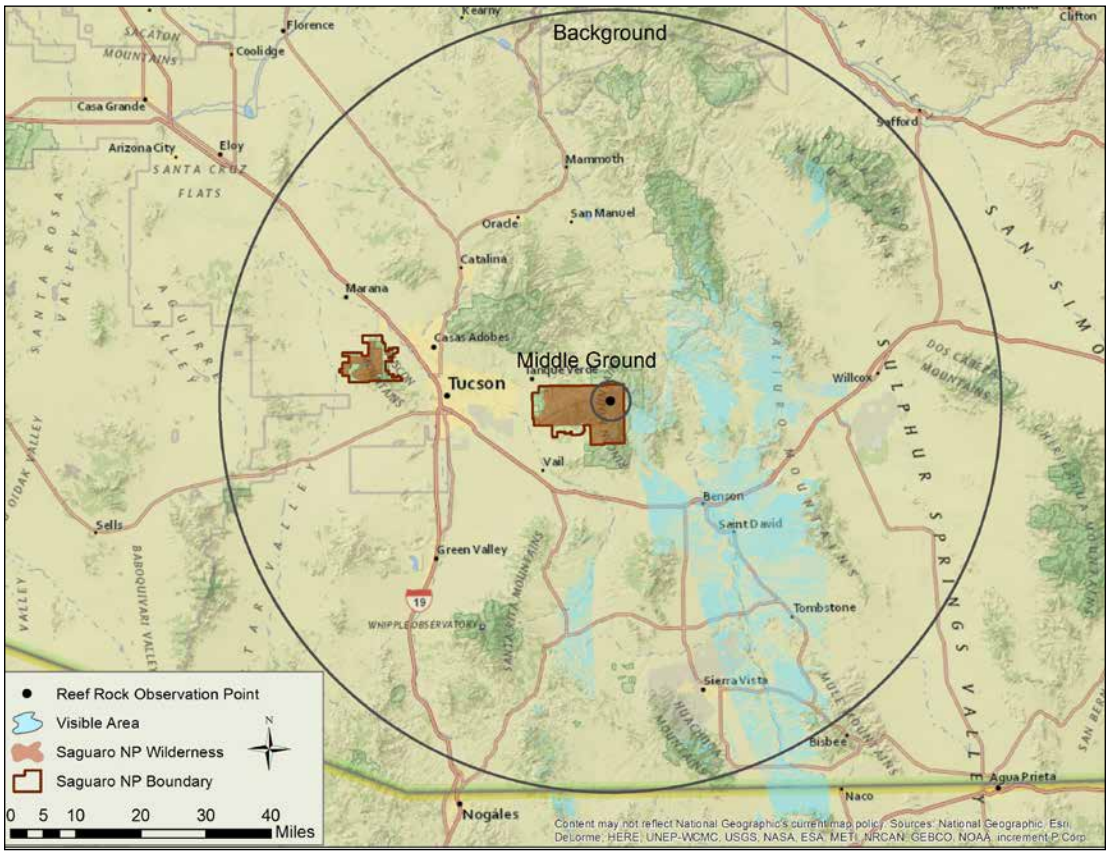

Figure 4.2.4-10. Visible area from the Reef Rock key observation point.

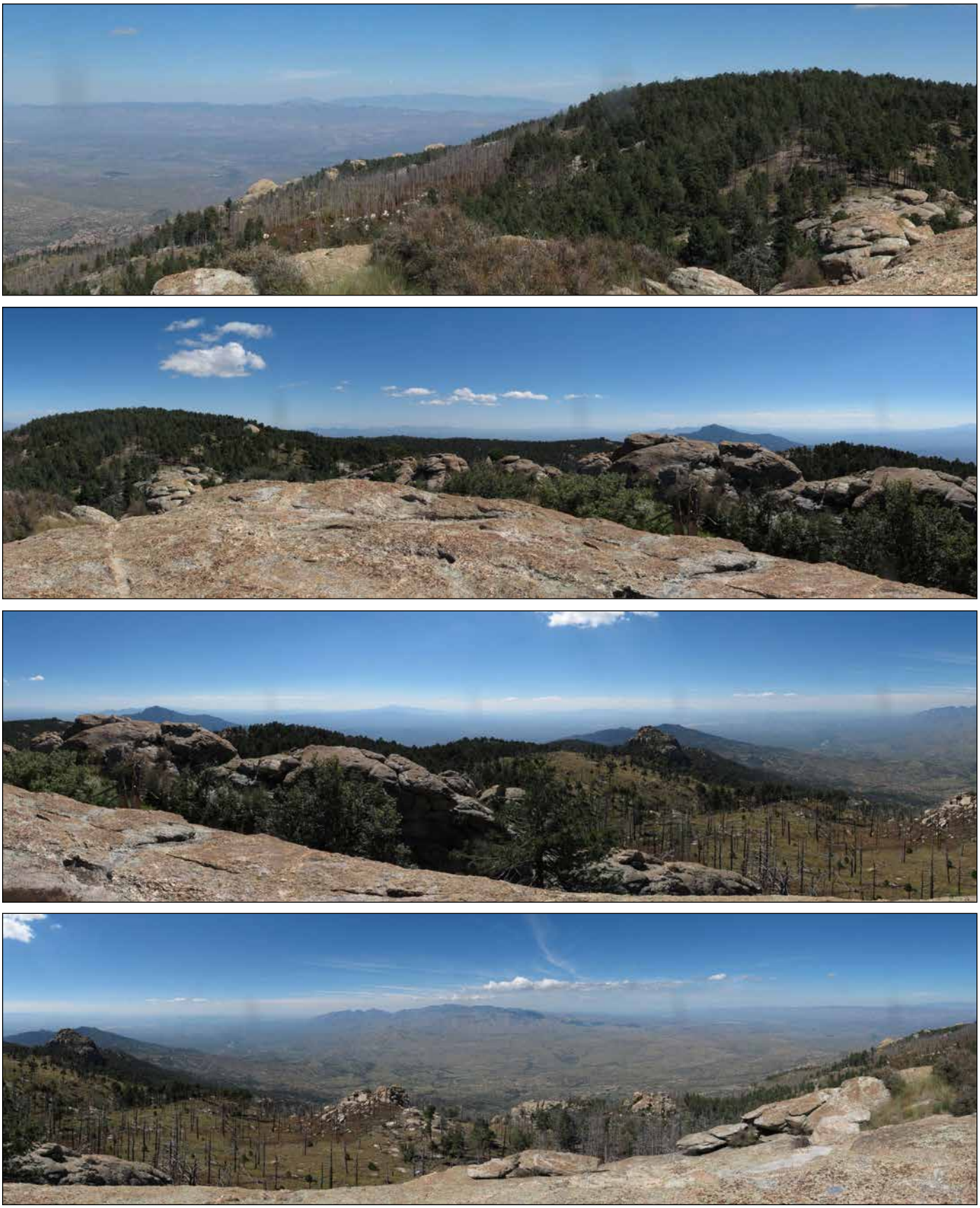

Figure 4.2.4-11. Panoramic views in four, 90° directions from the Spud Rock (USGS benchmark) key observation point in the Rincon Mountain District (from top: north to east, east to south, south to west, and west to north).

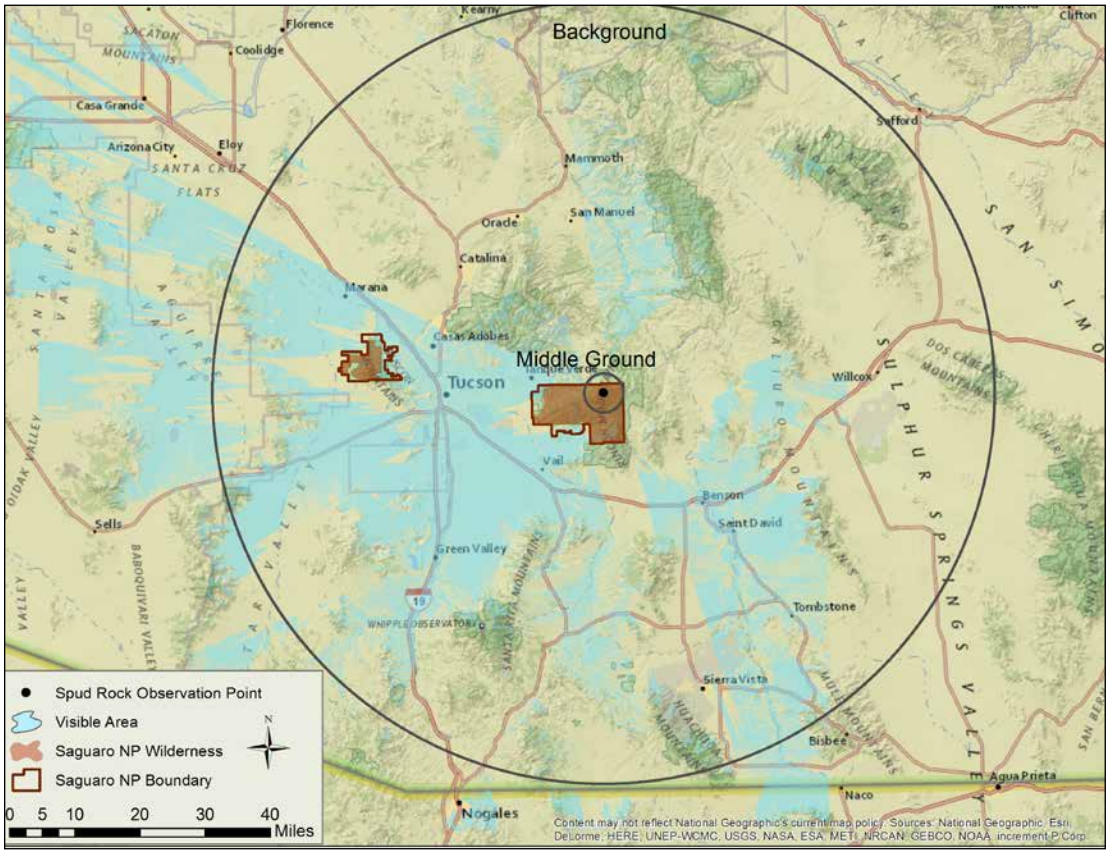

Figure 4.2.4-12. Visible area from the Spud Rock key observation point.

Figure 4.2.4-13a. Panoramic views in two of the four, 90° directions from the Rincon Mountain Peak key observation point in Rincon Mountain District (top: north to east; bottom: east to south).

Figure 4.2.4-13b. Panoramic views in two of the four, 90° directions from the Rincon Mountain Peak key observation point in Rincon Mountain District (top: south to west; bottom: west to north) continued.

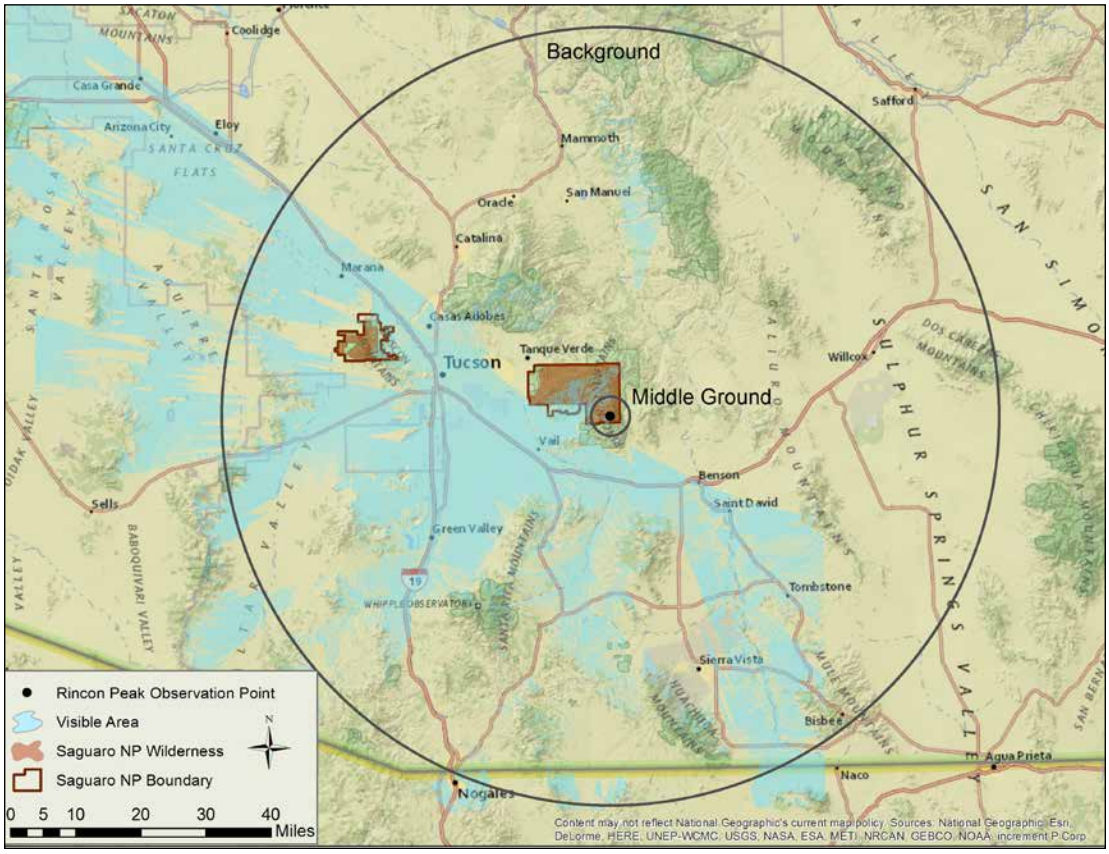

Figure 4.2.4-14. Visible area from the Rincon Peak key observation point.

From the Reef Rock location, all features in the background distance class are natural, although two directions - south to west and west to north- offer limited views due to the rocky outcrops located in the foreground. Of the three RMD backcountry key observation locations, Reef Rock provides the best view to the east, looking beyond the park's boundary. Overall, the condition of the viewshed from the Reef Rock key observation point is considered to be good.

The background view observed from the Spud Rock key observation point is comprised primarily of natural features, although developments are visible when looking west toward the city of Tucson. Within Spud Rock's foreground and middle ground distance classes, dead trees are visible, but are still natural features, although they may detract from an observer's enjoyment of the scenery. Even so, the viewshed condition from the Spud Rock key observation point is considered to be in good condition.

Similar to the background view as seen from Spud Rock, the view observed from Rincon Peak is also comprised primarily of natural features except when looking west where developments within and surrounding the city of Tucson are visible. However, the developments are located at far enough distances to render them small. This viewshed also offers an unobstructed view along Rincon Creek, which is considered a very important resource to the park for a number of reasons (refer to the water and vegetation assessments for Rincon Creek condition discussions). Overall, the viewshed condition from the Rincon Peak observation point is considered to be in good condition.

Composite Viewshed

The visible areas from each of the seven key observation points were combined into one composite viewshed (Figure 4.2.4-15). No area was visible from all seven viewsheds and very few areas included even five (purple) or six (red) of the combined viewsheds. Visible areas from a combination of three (tan) or four (brown) key observation points included the area north and south of TMD, the city of Tucson, the area near Rincon Creek along RMD's southwest boundary, and the area

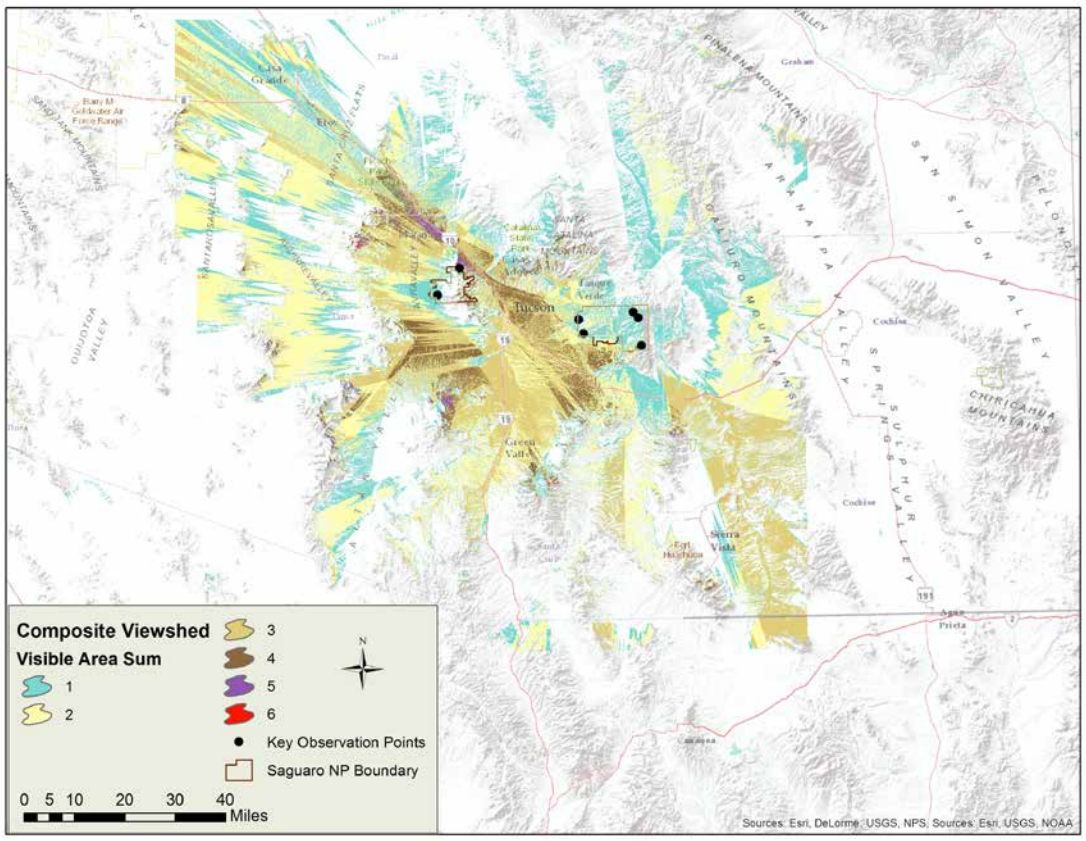

Figure 4.2.4-15. Composite viewshed showing the visible areas from the combined viewshed analyses.

southeast of RMD, although the latter area was only visible from RMD's three far backcountry key observation points: Reef Rock, Spud Rock, and Rincon Peak. The remaining combinations of one (teal) and two (yellow) viewsheds represent the largest area shown in Figure 4.2.4-15, especially in the far background areas surrounding the districts, along TMD's western boundary, along RMD's northern, eastern, and southern boundaries and within the majority of RMD. In summary, north and south of TMD, southwest of RMD, and the city of Tucson are the most visible areas from the combined seven key observation point viewsheds selected for analysis.

Extent of Development

Housing Density (2010)

While 84.4% of the housing densities within the 97 km (60 mi) surrounding the park, which represents the background distance class where texture tends to disappear and colors flatten, are classified as rural, the area that is observed from the highest number of combined key observation points combined is comprised of commercial, urban, and suburban developments (Figure 4.2.4-16, Table 4.2.4-1). Not surprisingly, this is especially true when looking toward the city of Tucson from within both districts. Perhaps, more of a visual intrusion are the areas that are classified as exurban, 10.4%, that are immediately adjacent to each district's boundaries. These areas are located along both districts' boundaries that are adjacent to Tucson, AZ.

In TMD, developments are beginning to flank its western boundary, and in RMD

Table 4.2.4-1. 2010 housing densities within 97 km (60 mi) of Saguaro NP districts.

Grouped Housing Density Class	Housing Density Class (units / km²)	% Area
Urban-Regional Park	290	1.4
Commercial / Industrial	289	1.4
Urban	29	0.14
Suburban	464	2.3
Exurban	2,138	10.4
Rural	17,400	84.4

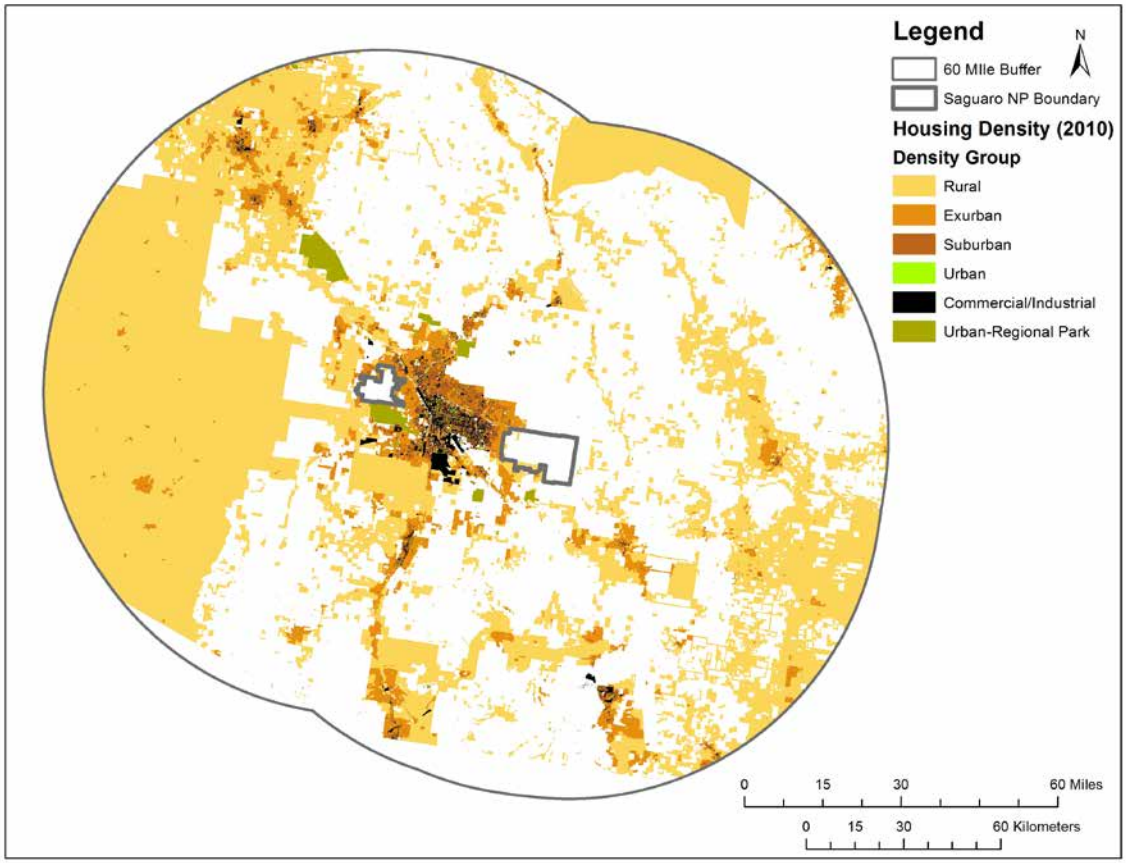

Figure 4.2.4-16. The 2010 grouped housing density classes that are within the 97 km (60 mi) background distance class.

developments are increasing along its southwestern boundary in the Rincon Creek area - an area of high biological value. The white space shown in Figure 4.2.4-16 indicates no census data; thus, housing densities could not be calculated for these areas. However, these data originate with the U.S. Census Bureau and units with unknown densities were probably not reported, which likely indicates undeveloped and/or protected areas like the USFS land surrounding RMD to the north, east, and south.

When considering the extent of housing/commercial densities that surround Saguaro NP as a stand-alone measure for viewshed condition (in other words, not considering the scenic context as observed from individual observation points), the exurban sprawl adjacent to each district's boundary and high housing densities warrant significant concern.

Road Density (2010)

The road transportation network within the 97 km (60 mi) area surrounding the park is extensive (Figure 4.2.4-17), especially within the city of Tucson and along the interstate highways, I-10 and I-19, leading toward Phoenix and Nogales, respectively. The I-10 corridor and associated surrounding developments was the most visually impacting from the North Scenic Drive Trail observation point (see Figure 4.2.4-1's north to east and west to north panoramas).

TMD has a higher road density surrounding its boundary compared to RMD, which is protected along its northern and eastern boundary by USFS land, but unfortunately much of these areas can only be seen from RMD's backcountry observation locations, which are difficult to access. We consider the extent of road developments to be of significant concern.

Degree of Scenic Conservation

The composite viewshed was used to clip the USGS GAP Protected Areas Database (2016) conservation status dataset. The results are shown in Figures 4.2.4-18 and 4.2.4-19 for the four GAP categories and for the land management agencies, respectively.

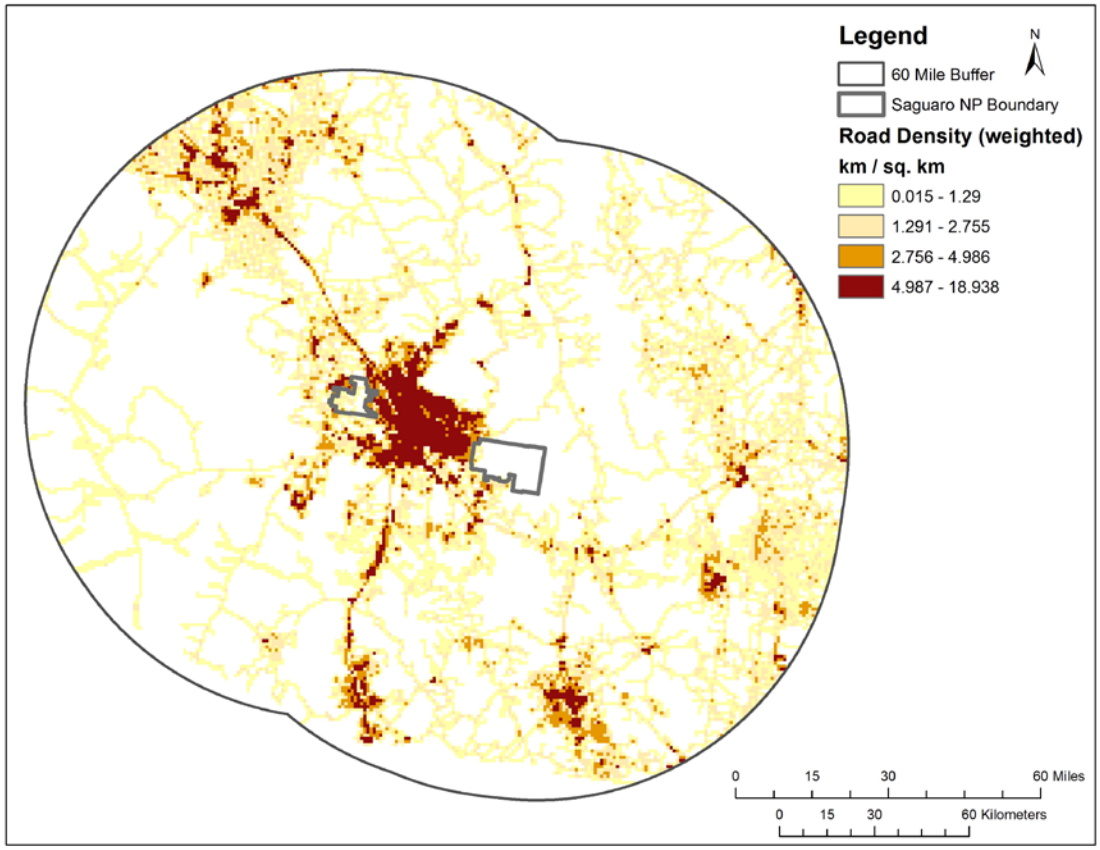

Figure 4.2.4-17. The road densities that are within the 97 km (60 mi) background distance class.

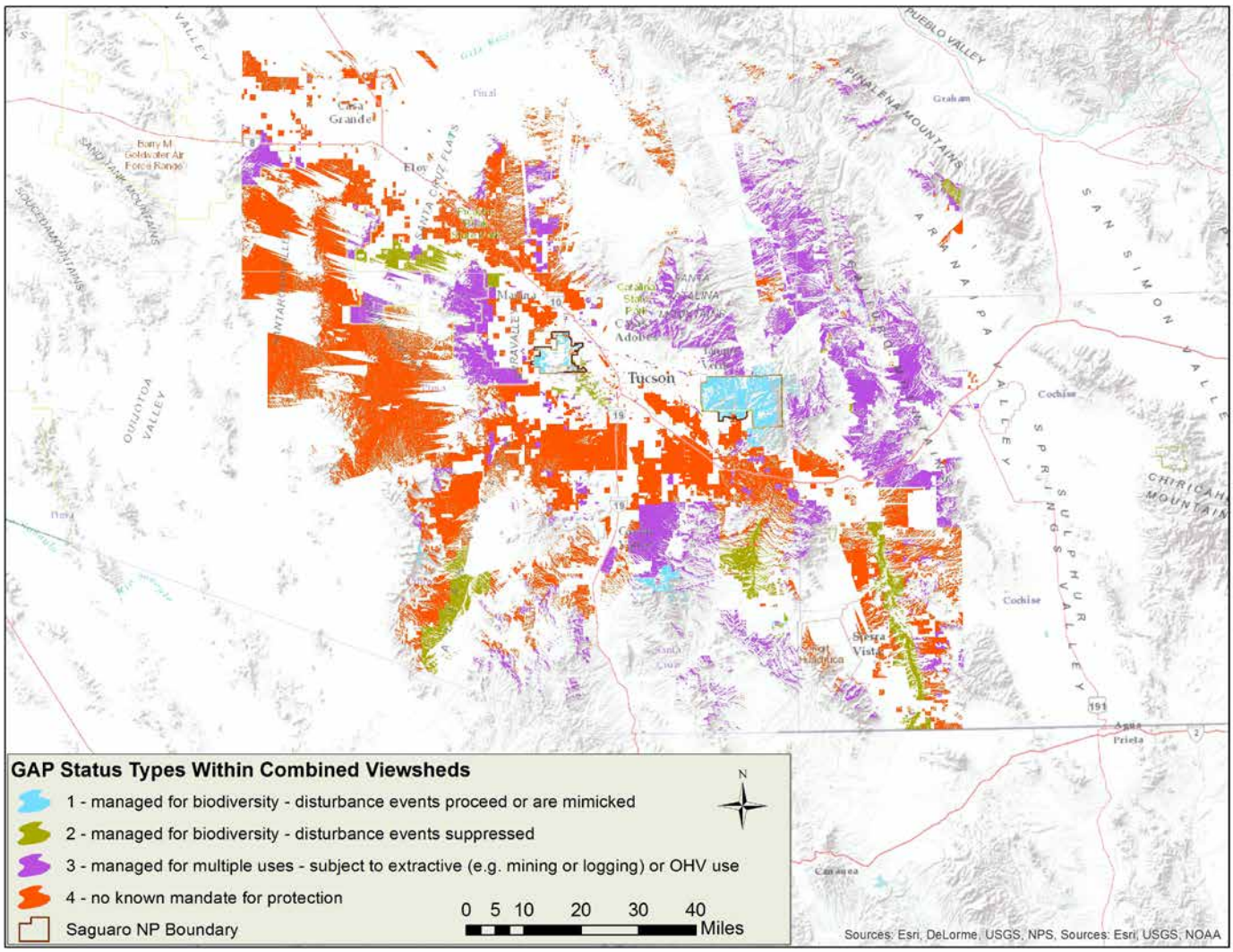

Figure 4.2.4-18. GAP status lands within the composite viewshed.

The GAP status 4 category, which are lands with no known mandate for protection, represents the largest amount of acreage (54%) that is located within Saguaro NP's combined visible area. This includes some of the lands managed by the Bureau of Indian Affairs, State Department of Land, Department of Defense, private, and city lands. GAP status 3 lands, which are managed for multiple uses, including mining, logging, or off-highway vehicle (OHV) use, account for 34.2% of the visible area within the composite viewshed. These include agencies such as the U.S. Forest Service, the Bureau of Land Management (BLM), the State Department of Land, and Agricultural Research Service. The remaining GAP categories 1 and 2, represent the least amount of land that is visible from Saguaro's seven key observation points. GAP 1 lands, which are managed for biodiversity by allowing or mimicking natural disturbance events, accounted for only 6% of the visible area and includes the NPS and a small area of U.S. Forest Service lands. GAP 2 lands accounted for 5.9% of the combined visible area and are also managed for biodiversity but disturbance events are suppressed. The GAP 2 lands include the U.S. Fish and Wildlife Service, BLM, and some State Department of Land management agencies.

The type of land management agencies (as shown in Figure 4.2.4-19) included 16 different ones throughout Saguaro NP's composite viewshed. Four agencies, State Department of Land (36.9%), BIA (22%), BLM (16.5%), and USFS (11.8%), accounted for 87.1% of the total land within the visible areas. According to Monahan et al. (2012), "the percentage of land area protected provides an

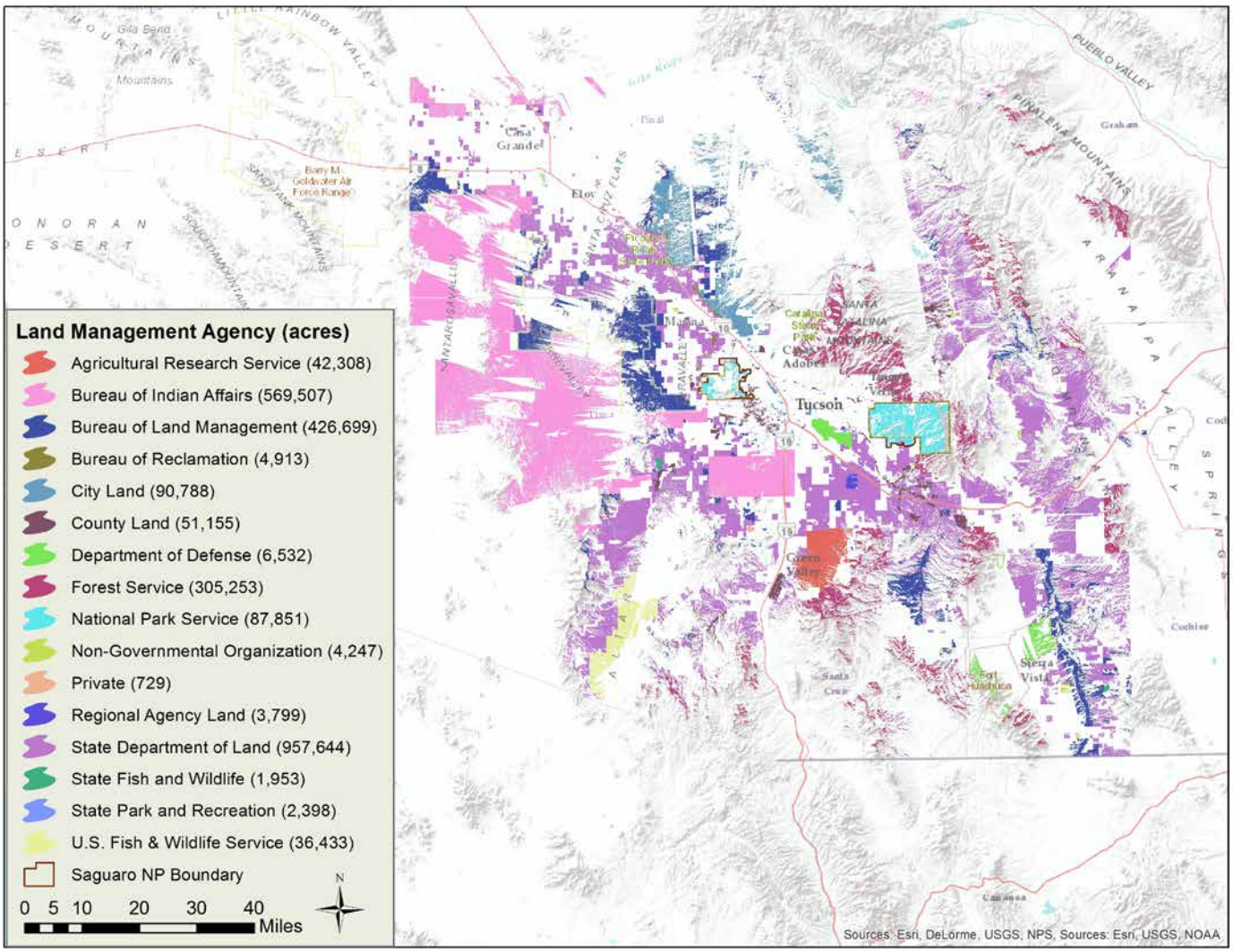

Figure 4.2.4-19. Types of and management agencies within the composite viewshed.

indication of conservation status and offers insight into potential threats (e.g., how much land is available for conversion and where it is located in relation to the park boundary) as well as opportunities (e.g., connectivity and networking of protected areas)."

A little less than half of the combined visible area (46%) as seen from Saguaro NP's seven key observation points has some sort of protection but not with the same management mandate as the NPS. Furthermore, one of the areas with the highest number of combined viewsheds (in other words the most common area seen from several key observation points) is the city of Tucson. Of the visible area within Tucson, the majority of land is managed and/or owned by agencies where there is no known protective mandate, making this area more susceptible to increasing development. While the least developed views were to the east of RMD's three backcountry key observation points on USFS land, their mandate is to manage for multiple use, which may include mining, logging, or other extractive activities that could possibly degrade the high quality viewshed in the future. Although, this same area does not have the housing and road developments that are conspicuous from TMD's key observation locations, which is due to the fact that the area is not privately owned.

While there are some areas where scenic conservation potential is high, many of the land management agencies responsible for the lands that are visible from Saguaro NP's observation points offer no additional protection and/or allow for extractive uses, therefore, we consider the extent of

scenic conservation for Saguaro NP to be of moderate to significant concern.

Overall Condition and Trend

The combination of the viewsheds seen from the seven key observation points offered a 360-degree view of the landscape surrounding Saguaro NP. From many of these observation locations, the visible areas were extensive and encompassed much of the greater Tucson area. A summary of the park's viewshed indicators and measures conditions is presented in Table 4.2.4-2.

The viewshed condition usually varied within a given location, ranging from good if looking into the park itself to moderate or significant concern if looking toward the city of Tucson and/or other developments extending beyond the park's boundary. While the views from the three highest points (i.e., Spud Rock, Reef Rock, and Rincon Peak) included the city of Tucson, Arizona, the developments were in the far background distance class rendering the non-contributing features small, which lessened the visual impact that were observed from these locations. Furthermore, the landscape to the east, extending beyond RMD's boundary across USFS land, offered the least developed, pristine views beyond the park's boundary.

Both of TMD's key observation points and RMD's Cactus Forest Loop and Tanque Verde Ridge key observation points were located closer to Tucson's sprawling and sometimes intensive development (i.e., North Scenic Drive Trail). Development has quickly encroached the park's boundary as observed from the peak west of Sus Picnic Area, Cactus Forest Loop, Tanque Verde Ridge, and North Scenic Drive Trail observation points. As a result, these panoramas were comprised of higher housing and road densities when viewing areas extending beyond the park's district boundaries, warranting moderate concern (sometimes significant concern if located closer to Tucson) to pristine views of natural features when viewing into and across the park warranting good condition.

Since the observation points were selected based upon different criteria, conditions were variable. The criteria included a

Table 4.2.4-2. Summary of the viewshed indicators, measures, and condition rationale.

Indicator of Condition	Measures	Condition	Rationale for Condition
Scenic Integrity	Conspicuousness of non-contributing features	Good to Moderate (overall)	From seven key observation points, two in TMD and five in RMD, the condition of the conspicuousness of non-contributing features ranged from good if looking into the park to moderate concern if looking outside of the park; two exceptions include the north to east view from TMD's North Scenic Drive Trail, and the southwest to northwest views from the Tanque Verde Ridge location, which are of significant concern. The viewsheds from RMD's backcountry sites were considered to be in the best scenic condition compared to the remaining four sites, which are located closer to the city of Tucson.
	Extent of Development	Significant Concern	The exurban sprawl adjacent to each district's boundary and high housing and road densities warrant significant concern.
	Degree of Scenic Conservation	Moderate to Significant Concern	While there are some areas where scenic conservation potential is high, many of the land management agencies responsible for the lands that are visible from Saguaro NP's observation points offer no additional protection and/or allow for extractive uses, therefore, we consider the extent of scenic conservation for Saguaro NP to be of moderate to significant concern.

frequently visited location (i.e., Cactus Forest Overlook), areas that had a high potential for development (i.e., Tanque Verde Ridge, peak west of Sus Picnic Area, and the North Scenic Drive Trail locations), or areas that offered prominent views due to high elevation (i.e., Reef and Spud Rocks and Rincon Peak). A summary of the varied conditions based on the location selection criteria just described is as follows:

- high elevation locations (RMD only) are in good condition;
- frequently visited locations are in good to moderate condition; and
- potential for development locations are currently in good to moderate condition, with the exception of the northwest to southeast direction for North Scenic Drive and the southwest to northwest views from the Tanque Verde Ridge, which are considered to be of significant concern.

While the housing and road densities are of significant concern and the degree of scenic conservation is of moderate to significant concern when reviewing the modeled data as stand-alone indicators and measures, when combined with what was actually observed from the seven key observation points, the overall viewshed condition is of moderate concern. Trend could not be determined since repeat photography has not been conducted at the park except for the one photo set taken at the Cactus Forest Overlook. The panoramas included in this assessment may serve as baseline data for future monitoring efforts.

Level of Confidence/Key Uncertainties/ Threats

The inferences made about the condition of Saguaro NP's viewsheds were made based on a 10 m (32.8 ft) digital elevation model resolution, with several assumptions about observer height, which for some locations had to be increased to more closely approximate what was observed in the panoramas (refer to Appendix B for more details), topography, input data, and air quality. A higher resolution model, which Pima County has, could be used to increase the accuracy of the results; however, the model only extends to the county's eastern boundary so it would not include much of the visible area that extends beyond RMD's eastern boundary. Regardless of the model that is used, the viewshed results should always be ground-truthed before being used for any specific planning purposes.

The viewshed analyses also assumed no degradation of visibility due to atmospheric conditions, but haze-producing particles can significantly diminish an observer's ability to see. In 2015, the National Parks Conservation Association (NPCA) released a new air quality analysis of 48 national parks, including Saguaro NP, which was ranked as the twelfth most harmed park for poor air quality related to the inability for "seeing clearly" (NPCA 2015). According to the NPCA (2015), on average, visitors miss out on 80.5 km (50 mi) of scenery due to haze pollution. An example demonstrating the impact of reduced visibility (in miles) at Saguaro NP is shown in Figure 4.2.4-20. It shows that under natural conditions, without haze, visibility does not degrade until at 259.9 km (161.5 mi), whereas under current, haze-induced conditions, visibility can significantly degrade at 143.4 km (89.1 mi). NPCA (2015) also stated that "90% of our national parks are currently

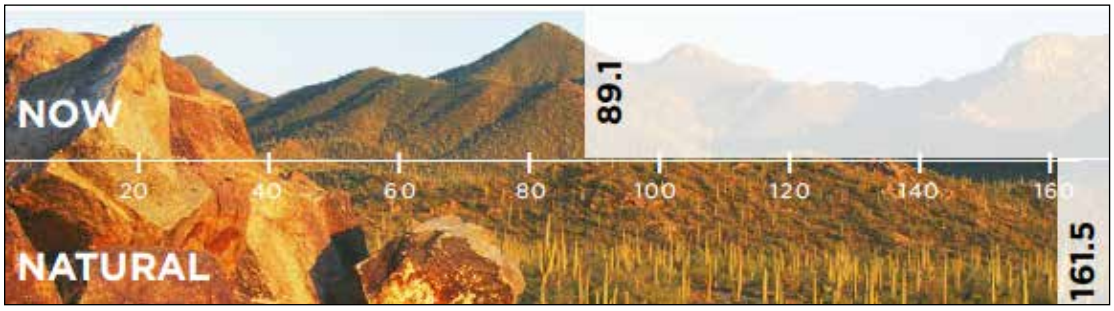

Figure 4.2.4-20. The visual impact (in miles) due to haze at Sagurao NP. The figure is from a 7/29/2015 online Mother Jones article summarizing the results of the NCPA (2015) air quality study.

experiencing extreme weather that scientists link to climate-changing air pollution: They are hotter, wetter, or drier than they were for most of the past century." This is true for Saguaro NP, although the visibility trend for the park is improving (refer to the air quality assessment).

In addition to climate change, increasing urbanization is a significant threat to Saguaro NP's viewshed condition. As stated in the park's foundation document (NPS 2014a), "denser populations and urban encroachment have increased noise pollution (vehicle, air traffic), decreased air quality, and increased light pollution, affecting dark skies, visibility, ecosystem health, and scenic viewsheds." According to the 2010 census, Pima County's population was 980,263 and is projected to reach 1.45 million by 2041 (Pima County Association of Governments 2016a). In 2000, 55% of the private land surrounding Saguaro NP was undeveloped, but exurban development is expected to increase 38% by 2030 and 105% by 2060 (Hansen et al. 2014). Housing densities are greater around TMD than they are around RMD (Monahan et al. 2013) but developments are increasing adjacent to both districts' boundaries. If developments continue to increase under existing zoning, by 2040, Saguaro NP will be considered a suburban park (Monahan et al. 2013).

Theobald's (2005) SERGoM projected housing densities for 2060 (Figure 4.2.4-21; Table 4.2.4-3) shows that the lands adjacent to both districts' boundaries are converted from

Table 4.2.4-3. 2060 housing densities within 97 km (60 mi) of Saguaro NP districts.

Grouped Housing Density Class	Housing Density Class (units / km^2)	% Area
Urban-Regional Park	290	1.4
Commercial / Industrial	289	1.4
Urban	34	0.16
Suburban	1105	5.4
Exurban	2508	12.2
Rural	16,385	79.5

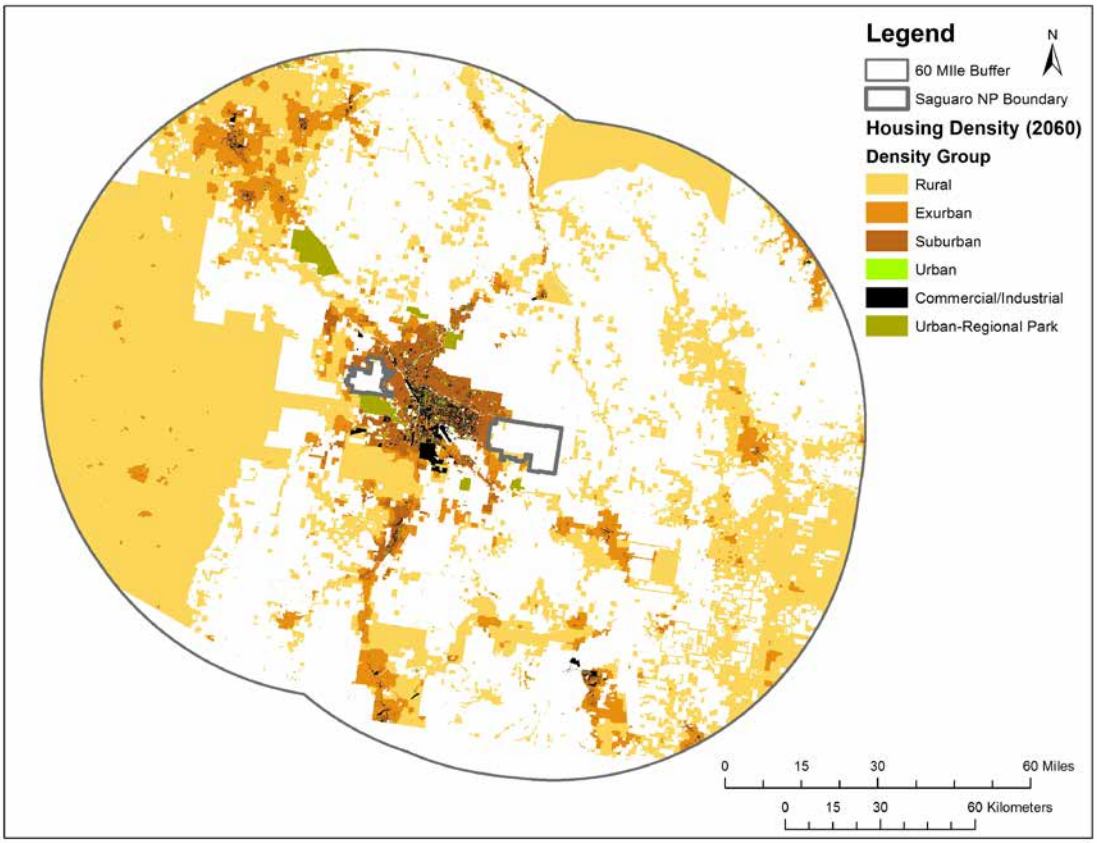

Figure 4.2.4-21. The 2060 grouped housing density classes that are within the 97 km (60 mi) background distance class.

rural and exurban to suburban. SERGoM forecasts changes on a decadal basis using county specific population estimates and variable growth rates that are location-specific. Distribution of projected growth was based on accessibility to the nearest urban core, defined as development >100 ha (>247 ac). The model assumed that housing density would not decline, which is consistent with population projections throughout Arizona. What the model isn't good at predicting is new developments, such as the proposed Interstate 11 corridor, which would be built almost immediately adjacent to TMD's western boundary (Figure 4.2.4-22). The corridor would extend from Nogales, AZ to Wiceknburg, AZ, which would undoubtedly negatively impact most, if not all of the park's resources, including its scenic vistas. The model is also not good at predicting development of state lands east of the Rincon Mountains along the San Pedro River corridor. A transmission line has been approved along the river, and this could lead to additional roadway and other linear developments. This area is currently rural, but is mostly state and private lands that have high future potential for residential development. State lands in Arizona are open lands whose sole purpose is to generate revenues, especially for education, and are sold for development as area housing values rise. Urbanization of the San Pedro River valley would have considerable impact on viewsheds to the east of the Rincons, in addition to impacts to air quality, night skies, wildlife corridors, and other wilderness values.

Another significant impact to the park's scenic resources that has yet to be fully realized began in the early 1990s. A planned resort and residential development south of RMD (where the Tanque Verde Ridge Trail key observation point immediately overlooks)

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Figure 4.2.4-22. A map showing the proposed Interstate 11 route, which would pass almost immediately adjacent to Saguaro National Park's Tucson Mountain District.

was initiated. It was a contested project – one of preservation versus development, but in the end, the Rincon Institute, which is a non-profit environmental group, was created to guide the development in a more environmentally mindful way. The original development plan was scaled back from 21,000-units to 2,000-3,000 homes, from four resorts to one, from three golf courses to one, and from 243 ha (600.5 ac) of shopping centers to a 20 to 30.4 ha (49.2 - 75.1 ac) commercial center and smaller areas of commercial developments (Davis 2013). In addition, the park purchased approximately 769 ha (1,900 ac) of high quality riparian habitat, which was originally part of the development, expanding its southern boundary to preserve and protect one of the highest priority riparian habitats in the county (Pima County n.d.).

Other potential developments mentioned during the park's NRCA scoping meeting that would potentially further degrade the park's veiwsheds include solar generating sites, which are proposed 80.5 km (50 mi) northwest of TMD; Central Arizona Project recharge ponds; land use conversions; and military fly overs, which also impact the soundscapes throughout the park.

And finally, how a view is perceived is quite subjective and will always have an element of uncertainty. The remoteness from occupied and modified areas outside the park's boundary varies depending upon the key observation point location, and due to Saguaro NP's complex management mandates that include preserving wilderness values and associated fauna, while also managing for park visitor access, considering different viewsheds from the perspective of the primary management objective would help focus the assessment.

A wide variety of views, ranging from high density urban to undeveloped, pristine vistas that include mountains and desert views are afforded from different observation points throughout the park, sometimes even within a given location. These views serve as landscape indicators for Saguaro NP, especially in terms of conserving its wilderness character. While scenic character or viewshed was not included as a wilderness character indicator in the park's wilderness report (Engebretson 2012), the views one sees while hiking in wilderness undoubtedly influences a visitor's experience. As Engebretson states (2012, p.15), "depending on the subjective experience of the wilderness user, seeing Tucson from the high country may elicit feelings of separation from the modern world and appreciation of the space that temporarily separates them from civilization. Others, however, may feel sights of modern development encroach on their views and degrade their wilderness experience. Nevertheless, the sights and sounds of modernity in wilderness are a constant reminder of the city below." Unfortunately, the loss of scenic viewsheds due to new developments occurring on "borrowed lands," are often beyond the park's ability to influence (NPS 2014a), which is why a working knowledge of high priority scenic areas and associated land management agencies who may be interested in partnering to protect these areas is imperative.

In this assessment, we have attempted to base our viewshed condition evaluation on an extensive body of literature studying people's visual preferences in natural areas. Given the fact that this assessment is based on both direct observations (i.e., panoramic photos) and GIS analysis, the overall confidence level is medium.

4.2.5. Sources of Expertise

For assessing the condition of this resource, we relied primarily on literature for this topic. Donna Shorrock, IMR NRCA Coordinator, provided initial GigaPan training. Saguaro NP staff took the panoramas from each observation point, and Scott Stonum, Saguaro National Park's Chief Science and Resource Management, provided additional details about the images photographed, selection of key observation points, and other needed information to facilitate the completion of this assessment. Kim Struthers performed the GIS analyses and authored this assessment.

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4.3. Night Sky

Indicators/Measures

- Sky Brightness (4 Measures)
- Sky Quality (1 Measure)

Condition – Trend – Confidence

Significant Concern - Insufficient Data - High

4.3.1. Background and Importance

Natural dark skies are a valued resource within the NPS, reflected in NPS management policies (NPS 2006), which highlight the importance of a natural photic environment to ecosystem function, and the importance of the natural lightscape for aesthetics. The NPS Natural Sounds and Night Skies Division (NSNSD) makes a distinction between a lightscape—which is the human perception of the nighttime scene, including both the night sky and the faintly illuminated terrain, and the photic environment—which is the totality of the pattern of light at night at all wavelengths (Moore et al. 2013).

Lightscapes are an aesthetic and experiential quality that is integral to natural and cultural resources. A 2007 visitor survey conducted throughout Utah national parks found that 86% of visitors thought the quality of park night skies was "somewhat important" or "very important" to their visit (NPS 2010). Additionally, in an estimated 20 national parks, stargazing events are the most popular ranger-led program (NPS 2010).

The value of night skies goes far beyond visitor experience and scenery (Figure 4.3.1-1). The photic environment affects a broad range of species, is integral to ecosystems, and is a natural physical process (Moore et al. 2013). Natural light intensity varies during the day--night (diurnal) cycle, the lunar cycle, and the seasonal cycle. Organisms, including humans, have evolved to respond to these periodic changes in light levels in ways that control or influence movement, feeding, mating, emergence, seasonal breeding, migration, hibernation, and dormancy. Plants also respond to light levels by flowering, vegetative growth, and their direction of growth (Royal Commission on Environmental Pollution 2009). Given the effects of light on living

NPS NATURAL SOUNDS AND NIGHT SKIES DIVISION

Figure 4.3.1- 1. View of the night sky as observed from the base of Wasson Peak in Saguaro National Park.

organisms, it is likely that the introduction of artificial light into the natural light/darkness regime will disturb the normal routines of many plants and animals (Royal Commission on Environmental Pollution 2009), as well as diminish stargazing recreational opportunities offered to national park visitors.

Regular monitoring of the night sky was identified in Saguaro NP's Foundation Document as a high priority and fundamental to protecting the wilderness character of the park. Saguaro NP's proximity to the large urban area of Tucson, AZ provides a unique opportunity to introduce many of the city's residents to the desert's unique environment. Saguaro NP hosts interpretive star gazing events and night walks that highlight the nocturnal landscape. On October 21-22, 2011 Saguaro NP hosted a 24-hour BioBlitz event, which coupled volunteers with scientists to better understand park resources including how night sky conditions vary across the park (NPS 2012). Information was collected in both of the park's two districts and while these data were not used for this assessment, the event helped to engage the community and raise awareness about the night sky resource at Saguaro NP.

The park also protects places important to American Indian cultural traditions (NPS 2014). Historically, American Indian's observation of the sun, moon and stars was essential for planning festivals and activities such as when to start planting and when to harvest (Aveni 2003). Protecting the night sky resources at Saguaro National Park benefits the natural resources, is important to protecting the wilderness character of the park, enriches the visitor experience, and has cultural significance.

4.3.2. Data and Methods

The NPS NSNSD goals of measuring night sky brightness are to describe the quality of the lightscape, quantify how much it deviates from natural conditions, and how it changes with time due to changes in natural conditions, as well as artificial lighting in areas within and outside of the national parks (Duriscoe et al. 2007).

Based on new guidance (Moore et al. 2013), the NPS NSNSD recommends the all-sky light pollution ratio (ALR) as the best single parameter for characterizing overall sky condition. However the utility of a single metric limits the ability to fully describe and manage the variations in resource quality that often exist within a park. Therefore, NSNSD recommends using a suite of metrics to describe and manage variations in night sky quality (see Table 4.3.2-1). When available, additional indicators and measures should also be considered in an assessment of night sky condition, but the ALR measure is the primary data source for condition assessment.

NSNSD conducted an assessment of the national park's night sky condition in Saguaro NP in multiple locations. The park is divided into two districts: the Tucson Mountain District (TMD) west of Tucson, AZ and the Rincon Mountain District (RMD) east of Tucson, AZ. The two districts each have distinct photic environments. Therefore, night sky conditions were assessed in both districts. In the TMD ground-based measurements were collected at the Desert View Discovery

Table 4.3.2- 1. Indicators and measures of the night sky and why they are important to resource condition.

Indicator	Measure	Description
Sky Brightness	All- sky Light Pollution Ratio, Vertical Maximum and Horizontal Illuminances and Zenith Sky Brightness	The all- sky light pollution ratio describes light due to man-made sources compared to light from a natural dark sky. Understanding the lightscape and sources of light is helpful to managers to maintain dark skies for the benefit of wildlife and people alike.
Sky Quality	Bortle Scale Class	The Bortle Dark Sky classification system describes the quality of the dark night sky by the celestial bodies and night sky features an observer can see. Observing the stars has been an enjoyable human pastime for centuries.

Nature Trail (southwest TMD) on March 13, 2007 and at Wasson Peak (southcentral TMD) on March 16, 2007 and on October 23, 2011. In the RMD ground-based measurements were collected from the Mica View picnic area (northwest RMD) on March 12, 2007 and from Rincon Peak (southwest RMD) on April 3, 2008. Ground-based measurements were collected after moonset using a using a CCD camera to assess the all-sky light pollution ratio, maximum vertical and horizontal illuminance, a sky quality meter to measure sky brightness, and the Bortle Dark Sky Scale, a qualitative assessment commonly used by amateur astronomers to evaluate the sky quality for star gazing.

Indicator/Measures

Sky Brightness (All-sky Light Pollution Ratio, Maximum Vertical Illuminance, Horizontal Illuminance, and Zenith Sky Brightness)

A CCD camera was used to measure both natural and anthropogenic light across the entire hemisphere. From the calibrated images collected by the CCD camera metrics including all-sky light pollution ratio and two measures of integrated sky brightness—horizontal and vertical illuminance—were derived.

All- sky Light Pollution Ratio

The all-sky light pollution ratio (ALR) is the average anthropogenic sky luminance presented as a ratio over natural conditions. A natural night sky has an average brightness across the entire sky of 78 nL (nanolamberts, a measure of luminance), and includes features such as the Milky Way, Zodiacal light, airglow, and other starlight. This is figured into the ratio, so that an ALR reading of 0.0 would indicate pristine natural conditions where the anthropogenic component was 0 nL. A ratio of 1.0 would indicate that anthropogenic light was 100% brighter than the natural light from the night sky. It is a useful metric to average the light flux over the entire sky (measuring all that is above the horizon and omitting the terrain). Recent advances in modeling of the natural components of the night sky allow the separation of anthropogenic light from natural features, such as the Milky Way. This metric is a convenient and robust measure and is most accurately obtained from ground-based measurements with the NPS Night Skies Program's photometric system, however, it can also be modeled with moderate confidence when such measurements are not available.

ALR was modeled for the entire park, 90% of the total wilderness area within the entire park, for each district, and for 90% of the wilderness area within each district. Measurements were made for 90% of wilderness areas because the NPS Night Skies Program recommends that the thresholds for lands managed as wilderness be met in more than 90% of the wilderness area (Moore et al. 2013). Modeled ALR was based on data from the 2001 World Atlas of Night Sky Brightness, which depicts zenith sky brightness (the brightness of the sky directly above the observer). A neighborhood analysis is then applied to the World Atlas to determine the anthropogenic sky brightness over the entire sky. Finally, the modeled anthropogenic light over the entire sky is presented as a ratio (ALR) over the natural sky brightness (Moore et al. 2013). While modeled data provide useful overall measurements, especially when site visits cannot be made, they are less accurate than ground-based measurements.

Maximum Vertical and Horizontal Illuminance

The maximum sky brightness is typically found in the core of urban light domes (i.e., the semicircular-shaped light along the horizon caused by the scattering of urban light). The minimum sky brightness is typically found at or near the zenith (i.e., straight overhead). The integrated night sky brightness is calculated from both the entire celestial hemisphere as well as a measure of the integrated brightness masked at the apparent horizon to avoid site-to-site variations introduced by terrain and vegetation blocking. Vector measures of illuminance (horizontal and vertical) are important in describing the appearance of three-dimensional objects on the landscape and their relative visibility.

Vertical illuminance is the integration of all light striking a vertical plane from the point

of the observer. In light-polluted areas, maximum sky brightness and maximum vertical illuminance will often measure the same area of sky, typically at the core of urban light domes. Vertical illuminance is an important metric when discussing night sky quality as it is easily noticeable to park visitors (since humans are oriented vertically). Even with dark conditions overhead, high vertical illuminance can hinder or inhibit dark adaptation of the eyes and cast visible shadows on the landscape. This is also an important ecological indicator, as many wildlife species base behavior on visual cues along the horizon. Horizontal illuminance is the amount of light striking a horizontal surface and is an important indicator of sky brightness (Cinzano and Falchi 2014). It is less sensitive in slightly impacted areas. This is because, even though the entire sky is considered, there is a rapid falloff in response to photons near the horizon, owing to Lambert's cosine law. At sites remote from cities, most of the anthropogenic sky glow occurs near the horizon.

Zentith Sky Brightness

Sky brightness describes the amount of light in the night sky. One method of assessing sky brightness uses a Unihedron Sky Quality Meter (SQM) that samples the night sky in a broad spectrum band roughly corresponding to the entire human visual range. The SQM measures an aggregate average brightness for the entire sky that is skewed to zenith brightness over an 80 degree field of view (Moore 2001).

Indicator/Measure

Sky Quality (Bortle Dark Sky Scale)

The Bortle Dark Sky Scale (Appendix C) was proposed by John Bortle (Bortle 2001) based on 50 years of astronomical observations. Bortle's qualitative approach uses a nine-class scale that requires a basic knowledge of the night sky and no special equipment (Bortle 2001, Moore 2001, White et al. 2012, Table 4.3.2-2). The Bortle scale uses both stellar objects and familiar descriptors to distinguish among the different classes. Another advantage of the Bortle scale is that it is suitable for conditions ranging from the darkest skies to the brightest urban areas (Moore 2001, Figure 4.3.2-1).

4.3.3. Reference Conditions

The ideal night sky reference condition, regardless of how it's measured, is one devoid of any light pollution. However, results from night sky data collection throughout more than 90 national parks suggest that a pristine night sky is very rare (NPS 2010). Of Saguaro NP's 91442.42 acres, 71,400 acres (78%) are designated as wilderness. Although the city of Tucson, Arizona is located between the park's two districts and the districts are bordered by residential development, Saguaro NP is considered a non-urban NPS unit, or area with at least 90% of its property located outside an urban area (Moore et al. 2013). For non-urban NPS units and those containing wilderness areas, the thresholds separating reference conditions of good, moderate, and significant concern are more stringent than those for urban NPS units because these areas are generally more sensitive to the effects of light pollution. For a summary of condition assessment categories for all night sky indicators for which thresholds have been identified, see Table 4.3.3-1.

All-sky Light Pollution Ratio

The threshold for night skies in good condition is an ALR <0.33 and the threshold for a moderate concern condition is ALR 0.33-2.0. An ALR >2.0 indicates significant concern (Moore et al. 2013).

Maximum Vertical Illuminance

The NPS Night Skies Division recommends a reference condition of 0.4 milli-Lux, since the average vertical illuminance experienced under the natural night sky on a moonless night is 0.4 milli-Lux (derived from Jensen et al. 2006, Garstang 1986, and unpublished NPS Night Skies Program data). No thresholds for condition rating have been set at this time. Vertical illuminance can also be expressed as a ratio to natural conditions, similar to ALR.

Horizontal Illuminance

The NPS Night Skies Division recommends a reference condition of 0.8 milli-Lux, since the average horizontal illuminance experienced under the natural night sky on a

Table 4.3.2- 2. Bortle Dark Sky Scale.*

Bortle Scale	Milky Way (MW)	Astronomical Objects	Zodiacal Constellations	Airglow and Clouds	Nighttime Scene
Class 1 Excellent Dark Sky Site	MW shows great detail, and appears 40° wide in some parts; Scorpio-Sagittarius region casts an obvious shadow	Spiral galaxies (M33 and M81) are obvious objects; the Helix nebula is visible with the naked eye	Zodiacal light is striking as a complete band, and can stretch across entire sky	The horizon is completely free of light domes, very low airglow	Jupiter and Venus annoy night vision, ground objects are barely lit, trees and hills are dark
Class 2 Typical Dark Site	MW shows great detail and cast barely visible shadows	The rift in Cygnus star cloud is visible; the Prancing Horse in Sagittarius and Fingers of Ophiuchus dark nebulae are visible, extending to Antares	Zodiacal band and gegenschein are visible	Very few light domes are visible, with none above 5° and fainter than the MW; airglow may be weakly apparent, and clouds still appear as dark voids	Ground is mostly dark, but object projecting into the sky are discernible
Class 3 Rural Sky	MW still appears complex; dark voids and bright patches and a meandering outline are visible	Brightest globular clusters are distinct, pinwheel galaxy visible with averted vision	Zodiacal light is easily seen, but band of gegenschein is difficult to see or absent	Airglow is not visible, and clouds are faintly illuminated except at zenith	Some light domes evident along horizon, ground objects are vaguely apparent
Class 4 Rural-Suburban Transition	MW is evident from horizon to horizon, but fine details are lost	Pinwheel galaxy is a difficult object to see; deep sky objects such as M13 globular cluster, Northern Coalsack dark nebula, and Andromeda galaxy are visible	Zodiacal light is evident, but extends less than 45° after dusk	Clouds are just brighter than the sky, but appear dark at zenith	Light domes are evident in several directions (up to 15° above the horizon), sky is noticeably brighter than terrain
Class 5 Suburban Sky	MW is faintly present, but may have gaps	The oval of Andromeda galaxy is detectable, as is the glow in the Orion nebula, Great rift in Cygnus	Only hints of zodiacal light may be glimpsed	Clouds are noticeably brighter than sky	Light domes are obvious to casual observers, ground objects are easily seen
Class 6 Bright Suburban Sky	MW only apparent overhead, and appears broken as fainter parts are lost to sky glow	Cygnus, Scutum, and Sagittarius star fields just visible	Zodiacal light is not visible; constellations are seen, and not lost against a starry sky	Clouds appear illuminated and reflect light	Sky from horizon to 35° glows with grayish color, ground is well lit
Class 7 Suburban-Urban Transition	MW may be just barely seen near the zenith	Andromeda galaxy (M31) and Beehive cluster (M44) are rarely glimpsed	Zodiacal light is not visible, and brighter constellations are easily seen	Clouds are brilliantly lit	Entire sky background appears washed out, with a grayish or yellowish color
Class 8 City Sky	MW not visible	Pleiades are easily seen, but few other objects are visible	Zodiacal light not visible, constellations are visible but lack key stars	Clouds are brilliantly lit	Entire sky background has uniform washed out glow, with light domes reaching 60° above the horizon
Class 9 Inner City Sky	MW not visible	Only the Pleiades are visible to all but the most experienced observers	Only the brightest constellations are discernible	Clouds are brilliantly lit	Entire sky background has a bright glow, ground is illuminated

*White et al. (2012)

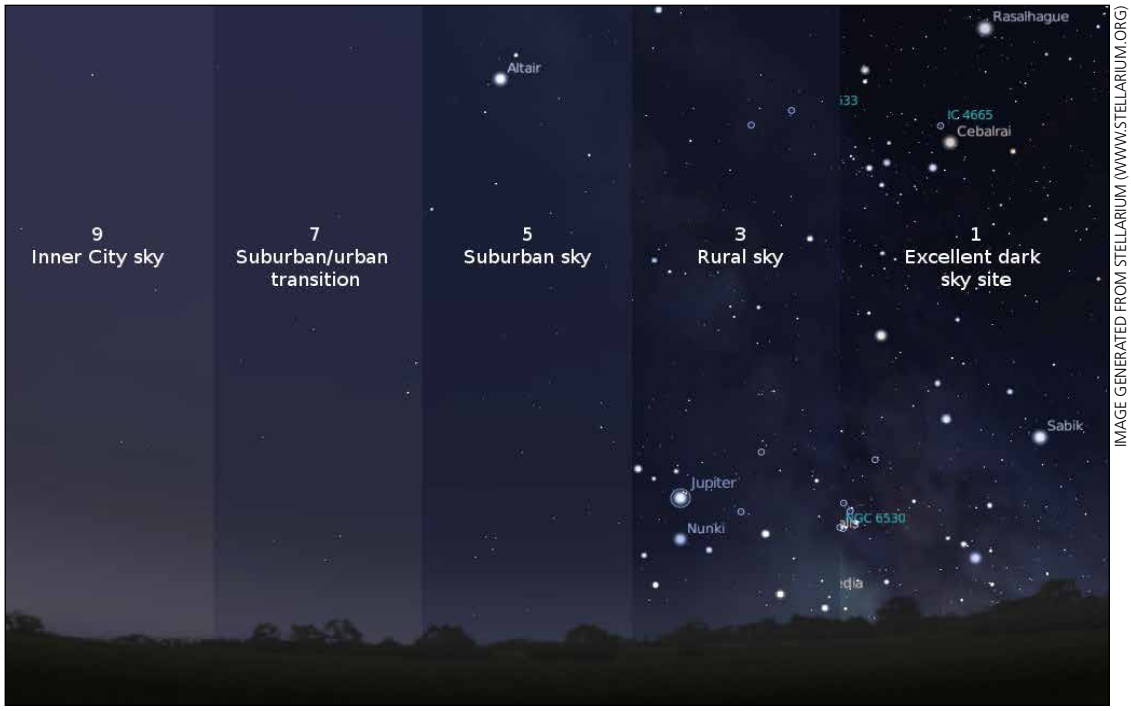

Figure 4.3.2- 1. Composite image illustrating the range of night sky conditions based on the Bortle Dark Sky Scale.

moonless night is 0.8 milli-Lux (derived from Duriscoe 2015 [submitted]). No thresholds for condition rating have been set at this time. Horizontal illuminance can also be expressed as a ratio to natural conditions, similar to ALR.

Zenith Sky Brightness

Reference conditions for night sky brightness can vary moderately based on the time of night (time after sunset), time of the month (phase of the moon), time of the year (the position of the Milky Way), and the activity of the sun which can increase "airglow"—a kind of faint aurora. For the minimum night sky brightness measure, the darkest part of a natural night sky is generally found near the zenith. A value of 22.0 magnitudes per square arc second (msa) is considered to represent a pristine sky, though it may vary naturally by more than +0.2 to -0.5 depending on natural conditions (Duriscoe 2013). Lower (brighter) values indicate increased light pollution and a departure from natural conditions. The astronomical magnitude scale is logarithmic, so a change of 2.50 magnitudes corresponds to a difference of l0x (100%); thus a 19.5 msa sky would be 10x brighter than natural conditions. Minimum night sky brightness values of 21.4 to 22.0 msa, are generally considered to represent natural (unpolluted) conditions (Duriscoe et al. 2007).

The maximum night sky brightness is often found within the Milky Way of a natural sky. A typical measurement from the Sagittarius region of the Milky Way in a natural sky yields 19.2 msa. Other regions of the Milky Way are somewhat dimmer, or around 20.0-21.0 msa. A value brighter than 19.0 msa will result in impairment to human night vision and may be noticeable by casting faint shadows or causing glare. A value lower (brighter) than 17.0 represents very bright areas of the night sky and would significantly impair human night vision and cast obvious shadows. Values for the brightest portion of the sky are of interest to the NPS because they represent unnatural intrusions on the nightscape, will prevent human dark-adapt vision, and may have effects on wildlife (Duriscoe et al. 2007).

Bortle Dark Sky Scale

A night sky with a Bortle Dark Sky Scale class 1 is considered in the best possible condition (Bortle 2001); unfortunately, a sky that dark is so rare that few observers have ever witnessed it (Moore 2001). Non-urban park skies with a Bortle class 3 or darker are considered to be in good condition, class 4 of moderate condition, and class 5 are considered poor condition. At class 4 and higher, many night-sky features are obscured from view due to artificial lights (either within or outside the park). Skies class 7 and higher have a significantly degraded

Table 4.3.3- 1. Night sky condition class summary for non- urban parks (i.e. parks with at least 90% of their property located outside an urban area).

Condition Class	ALR*	SQM	Bortle Scale
Good	ALR <0.33 (<26 nL average anthropogenic light in sky)	≥21.60	1- 3
Moderate	0.33- 2.0 (26- 156 nL average anthropogenic light in sky)	21.2- 21.59	4
Significant concern	ALR >2.0 (>156 nL average anthropogenic light in sky)	<21.2	5- 9

* At least half of the park's geographic area should meet the standard described.

aesthetic quality that may introduce ecological disruption (Moore et al. 2013). It is important to note that such degraded conditions may be restored toward a more natural state by modifying outdoor lighting, depending on the surrounding conditions that exist outside the national park.

4.3.4. Condition and Trend

All- sky Light Pollution Ratio

Modeling data by the NPS Night Skies Program shows a median ALR of 3.22 for the entire park (Table 4.3.4- 1). This is 322% brighter than average natural conditions. Figure 4.3.4- 1 shows the modeled ALR for the region surrounding Saguaro NP. ALR for 90% of the entire park's wilderness area is 4.99, or 499% brighter than average natural conditions. The TMD has a median ALR of 4.72, or 472% brighter than average natural conditions. For the wilderness area within the TMD, the ALR is 5.43, or 543% above average natural conditions. The RMD has a median ALR of 2.43, or 243% brighter than average natural conditions and about half as bright as in the TMD. For wilderness within the RMD, the ALR was 4.66 or 466% brighter than average natural conditions. The RMD has significantly darker and brighter areas than the TMD. The minimum ALR in the RMD is 1.35 (135% brighter) while the minimum ALR in TMD is only 2.85 (285% brighter).

Within the TMD the ground-based ALR from the Desert View Discovery Nature Trail produced an ALR of 2.96 (296% brighter than natural) (Table 4.3.4- 1). The ground-based data from Wasson Peak produced an ALR of 7.47 (747% brighter than natural) in 2007 and 6.46 (646% brighter than natural) in 2011. At Wasson Peak data were collected three hours later (00:21 local time) in 2011 compared with 2007. Within the RMD the ground-based ALR from Rincon Peak was 1.87 (187% brighter than natural) while the ground-based ALR at Mica View picnic area was 7.3 (730% brighter than natural). Ground-based data have a 90% confidence level of ±8 nL, or ±0.1 ALR. Figures 4.3.4- 2, - 3, - 4, - 5, and - 6 show the natural and anthropogenic light sources for each monitoring location and date of data collection.

Since the majority of all ALR measurements from each location, ground- based and modeled, were greater than 2.0, this measure warrants significant concern in Saguaro NP. Data to assess trends were not available. The confidence level is high since most measurements were ground- based.

Maximum Vertical Illuminance

In the TMD the Desert View Discovery Nature Trail had maximum vertical illuminance of 2.08 milli- Lux, or 520% brighter than average natural conditions (Table 4.3.4- 1). Maximum vertical illuminance on Wasson Peak in 2007 was 6.83 milli-Lux, or 1707% brighter than average natural conditions, while in 2011 it was 5.66 milli-Lux, or 1415% brighter than average natural conditions. On Rincon Peak maximum vertical illuminance was measured at 2.10 milli-Lux, or 525% brighter than average natural conditions. At Mica View picnic area maximum vertical illuminance was measured at 6.43 milli-Lux, or 1609% brighter than average natural conditions (Table 4.3.2-2).

Although specific benchmarks for condition classes have not been set;, the condition for this measure is estimated as significant

Table 4.3.4- 1. Night Sky Measurements at Saguaro NP.

Location	All- sky Light Pollution Ratio	Maximum Vertical Iluminance (milli- Lux)	Horizontal Illuminance (milli- Lux)	Zenith Sky Brightness (SQM)	Bortle Scale
Modeled Park- wide (wilderness[1])	3.22 (4.99)	- - -	- - -	- - -	- - -
Tucson Mountain District					
Median, Wilderness, Minimum	4.72, 5.43, 2.85	- - -	- - -	- - -	- - -
Desert View Discovery Nature Trail 2007	2.96	2.08	1.58	20.95	5
Wasson Peak 2007 (2011)	7.47 (6.46)	6.83 (5.66)	3.02 (2.80)	20.65 (20.63)	5
Rincon Mountain District					
Median, Wilderness, Minimum	2.43, 4.66, 1.35	- - -	- - -	- - -	- - -
Rincon Peak 2008	1.87	2.10	0.56	21.36[2]	4
Mica View picnic area 2007	7.3	6.43	3.67	20.43	6

[1] Calculated for 90% of the wilderness area.

[2] Estimated using imagery collected by the NPS Night Skies Program.

concern at both locations within the TMD (Desert View Discovery Nature Trail and Wasson Peak) and both locations within the RMD (Rincon Peak and Mica View picnic area) (J. White, personal communication, November 2015). Data to assess trends were not available. The confidence level is high.

Horizontal Illuminance

Within the RMD, horizontal illuminance ranged from 0.56 milli- Lux to 3.67 milli- Lux, which corresponds to 70% to 459% brighter than average natural conditions (Table 4.3.4- 1). In the TMD, horizontal illuminance ranged from 1.58 mill- Lux to 3.02 milli- Lux, which corresponds to 198% to 378% brighter than average naural conditions. All but one value exceeds the 0.8 milli- Lux. Although specific benchmarks for condition classes have not been set, the condition for this measure is estimated as significant concern within the TMD (Desert View Discovery Nature Trail and Wasson Peak). The measurements from Rincon Peak and at Mica View picnic area within the RMD were estimated to warrant moderate and significant concern, respectively (J. White, personal communication, November 2015). Data to assess trends were not available. The confidence level is high.

Zenith Sky Brightness

Within the TMD the SQM reading was 20.95 from the Desert View Discovery Trail (Table 4.3.4- 1). At Wasson Peak the SQM reading was 20.65 in 2007 and 20.63 in 2011. Within the RMD the ground-based SQM reading was 20.43 at Mica View picnic area and was estimated at 21.36 at Rincon Peak using imagery collected by the Night Skies Program (Table 4.3.2-2). Bsed on these data, zenith sky brightness warrants moderate to significant concern at Saguaro NP. The measurements from the Desert View Discovery Nature Trail and Wasson Peak within the TMD warrant significant concern. Within the RMD the measurement from Rincon Peak warrants moderate concern and measurement from the Mica View picnic area warrants significant concern. We could not determine trends based on these data. Confidence in this condition rating is high.

Bortle Dark Sky Scale

Within the TMD observers estimated the night sky quality to class 5 at both the Desert View Discovery Trail and at Wasson Peak which is consistent with a suburban sky (Table 4.3.4- 1). Within the RMD observers estimated the night sky quality class 4 at Rincon Peak (rural to suburban transition) and class 6 (bright

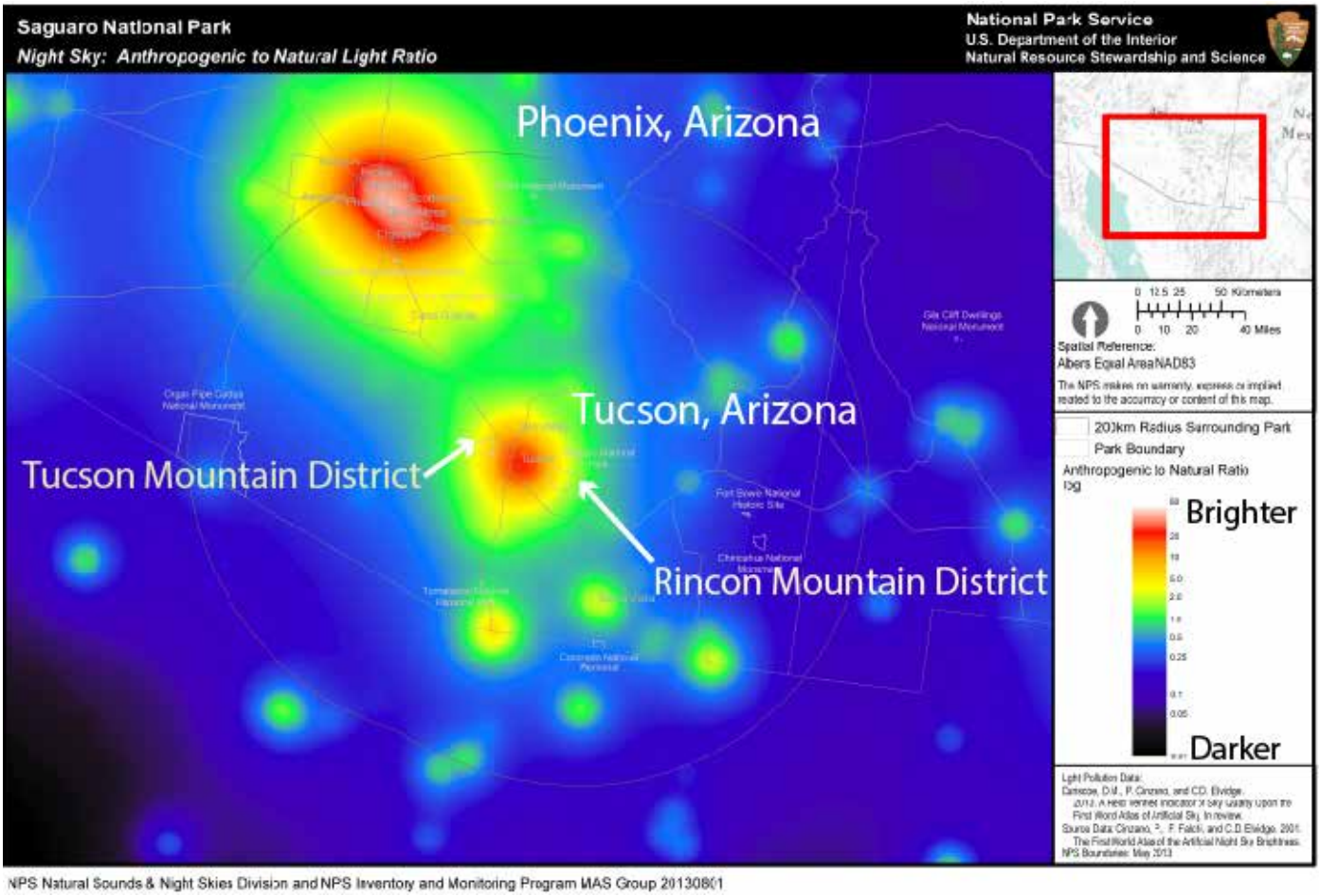

Figure 4.3.4- 1. Modeled ALR map for Saguaro National Park. A 200 km ring around the park illustrates the distance at which anthropogenic light can impact night sky quality within the park. Credit: NPS Natural Sounds and Night Skies Division.

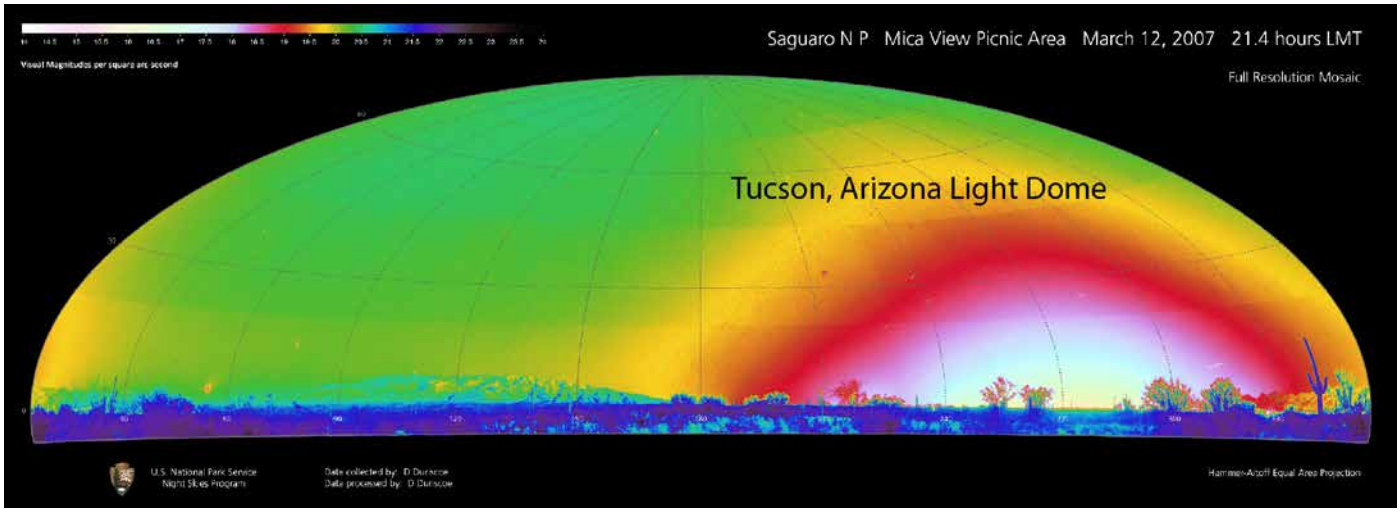

Figure 4.3.4-2. Panoramic (350°) all sky mosaic of all light sources (natural and anthropogenic) at Saguaro National Park from the Mica View picnic area within the Rincon Mountain District. Credit: NPS Natural Sounds and Night Skies Division.

suburban sky) at Mica View picnic area. Based on these data, sky quality as assessed by the Bortle dark sky scale warrants moderate to significant concern at Saguaro NP. Because this measure is qualitative, it has low confidence. Trend could not be determined.

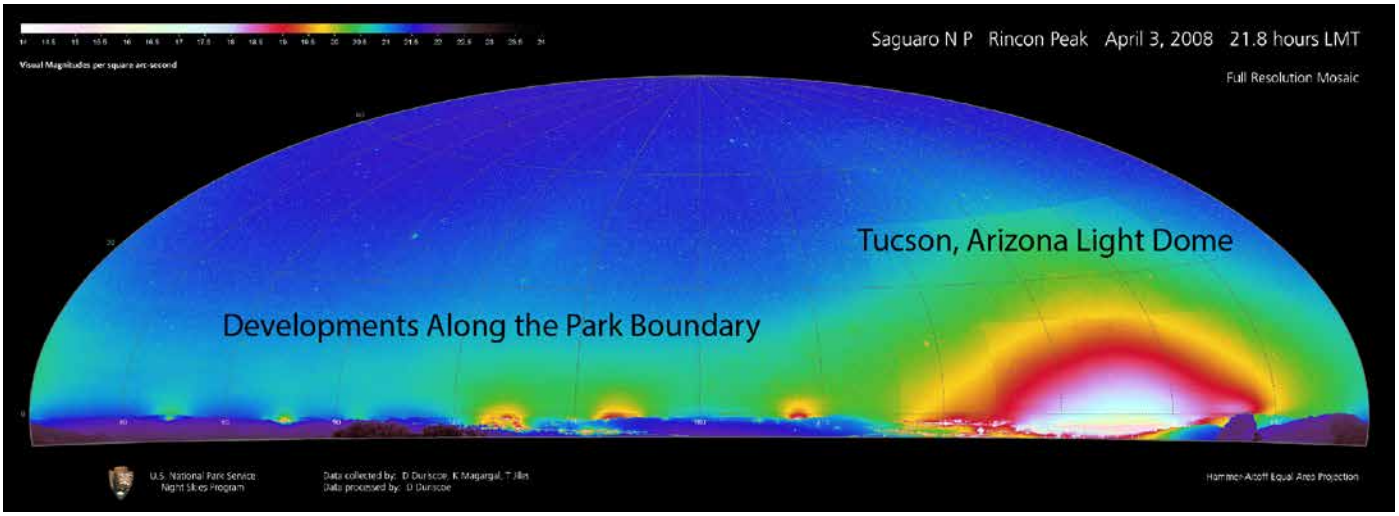

Figure 4.3.4-3. Panoramic (350º) all sky mosaic of all sources of light (natural and anthropogenic) at Saguaro National Park from Rincon Peak within the Rincon Mountain District. Credit: NPS Natural Sounds and Night Skies Division.

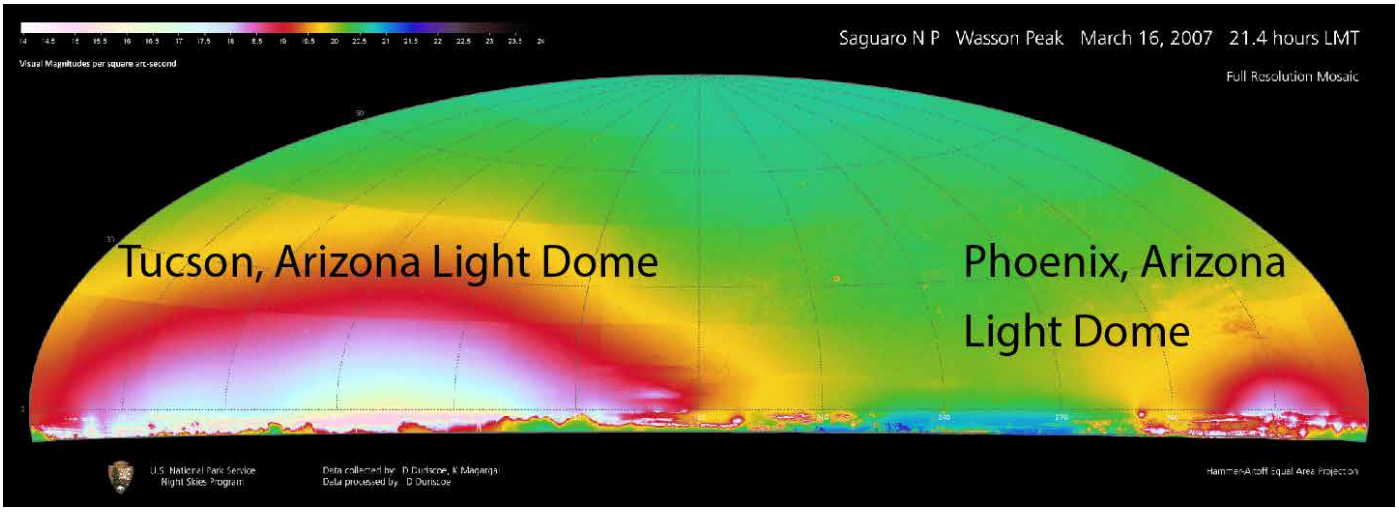

Figure 4.3.4-4. Panoramic (350º) all sky mosaic of all sources of light (natural and anthropogenic) at Saguaro National Park from Wasson Peak in 2007 within the Tucson Mountain District. Credit: NPS Natural Sounds and Night Skies Division.

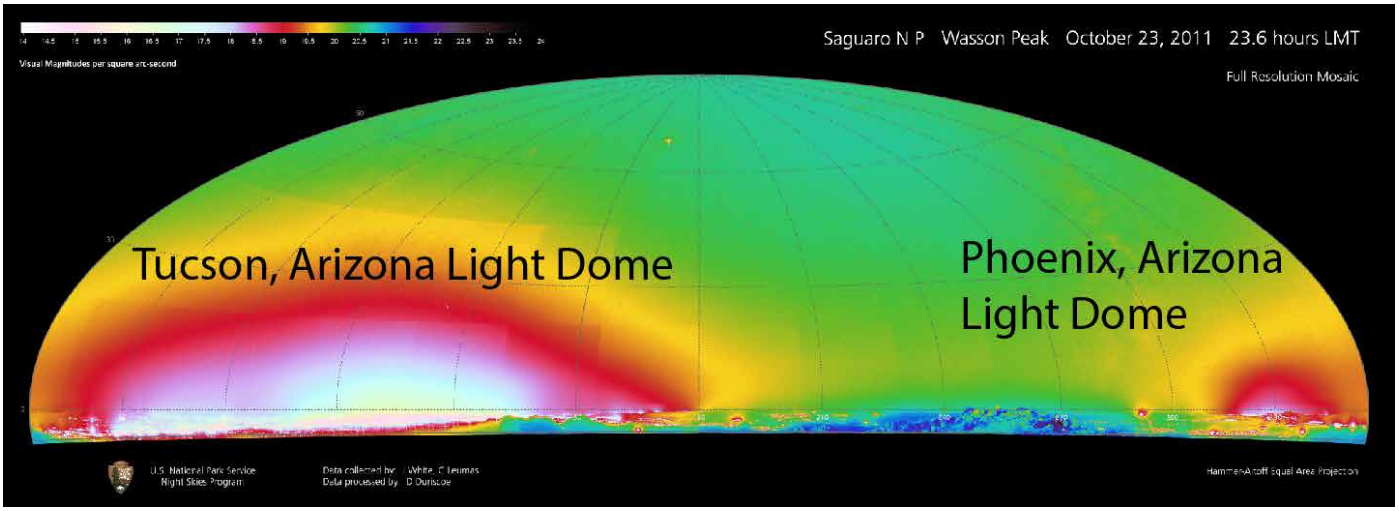

Figure 4.3.4-5. Panoramic (350º) all sky mosaic of all sources of light (natural and anthropogenic) at Saguaro National Park from Wasson Peak in 2011 within the Tucson Mountain District. Credit: NPS Natural Sounds and Night Skies Division.

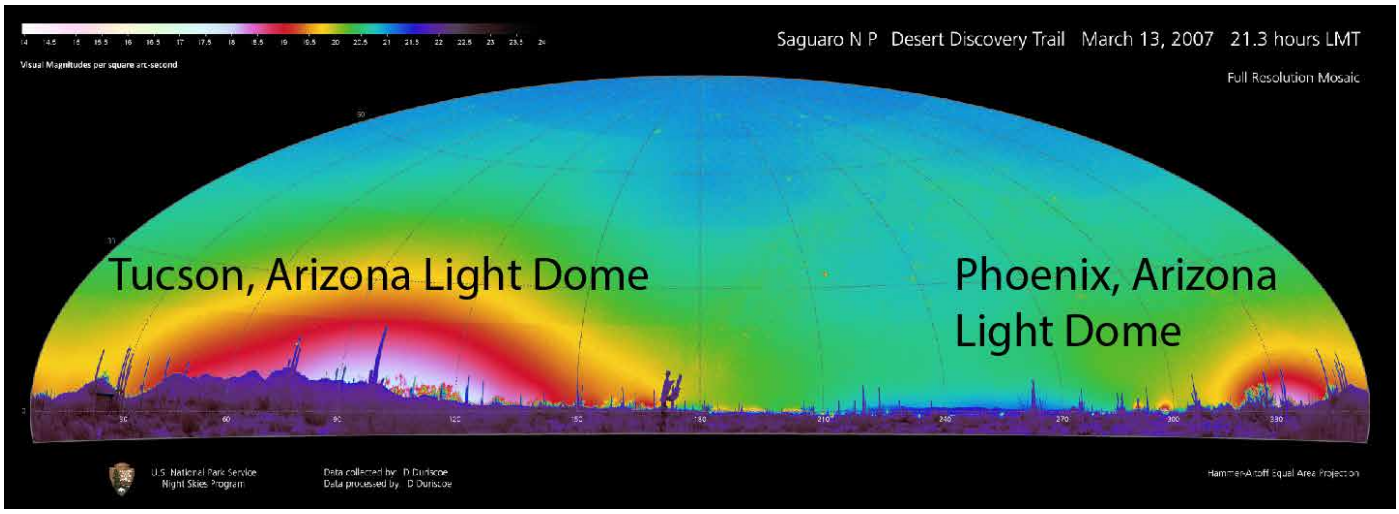

Figure 4.3.4-6. Panoramic (350°) all sky mosaic of all light sources (natural and anthropogenic) at Saguaro National Park from the Desert View Discovery Trail within the Tucson Mountain District. Credit: Natural Sounds and Night Skies Division.

Overall Condition

Quantitative measures of sky brightness (all-sky light pollution ratio, maximum vertical and horizontal Illuminance, and zenith sky brightness) and a qualitative assessment of sky quality (the Bortle Dark Sky Scale) were used to assess the condition of the night sky at multiple locations in Saguaro NP. These indicators and measures are summarized and interpreted in Table 4.3.4-2. Based on the park's non-urban character (see Figure 4.3.4-7) and the preponderance of wilderness in the park, the night sky resource condition at Saguaro NP is poor and warrants significant concern.

The majority of all ALR measurements collected in Saguaro NP and those that were modeled across specific areas within the park warrant significant concern (Figure 4.3.4-1). Within the RMD, the minimum ALR measurement and the measurement from Rincon Peak indicate moderate condition. Overall, RMD was less affected by anthropogenic light pollution than TMD. Although no thresholds have been established for maximum vertical illuminance or horizontal illuminance, the measurements warrant significant concern for both locations within each district, except for Rincon Peak where horizontal illuminance is estimated as moderate (J. White, personal communication, November 2015). The west and east facing slopes of Rincon Peak differ significantly in their overall night sky quality. Sky quality looking east is good to moderate, whereas sky quality looking west toward Tucson degrades considerably (J. White, personal communication, November 2015). Zenith sky brightness at Rincon Peak is moderate while readings at all other locations warrant significant concern. The qualitative Bortle Scale assessment indicates moderate night sky viewing conditions at Rincon Peak, whereas data for Mica View picnic area, Desert View Discovery Nature Trail and at Wasson Peak warrant significant concern. These data provide baseline information. No data on trends were available.

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Figure 4.3.4- 7. National Park Service staff enjoying a fire underneath the night sky in Saguaro National Park.

Table 4.3.4- 2. Summary of the night sky indicators, measures, and condition rationale.

Indicator	Measure	TMD Condition	RMD Condition	Condition Rationale
Sky Brightness	All- sky Light Pollution Ratio	Significant Concern		The majority of all ALR measurements from each location, ground-based and modeled, warrant significant concern in Saguaro NP. Within the TMD ALR was estimated as poor for all ground- based measurements and modeled data. Within the RMD the minimum ALR measurement and the median measurement from Rincon Peak warrants moderate concern while all other ALR estimates within the RMD warrant significant concern. These conditions are based on NPS Natural Sounds and Night Skies Division benchmarks for non- urban and parks managed as wilderness, ground- based measurements taken at four locations within the national park, and modeled estimates for specific areas within the park. Data to assess trends were not available. The confidence level is high. The ground-based data were collected by the NPS NSNSD.
	Maximum Vertical Illuminance	Significant Concern		Sky brightness as measured by maximum vertical illuminance warrants significant concern at Saguaro NP. Specific benchmarks for condition classes have not been set; however, condition is estimated as significant concern at both locations within the TMD (Desert View Discovery Nature Trail and Wasson Peak) and both locations within the RMD (Rincon Peak and Mica View picnic area) (J. White, personal communication, November 2015). Data to assess trends were not available. The confidence level is high. These data were collected by the NPS NSNSD.
	Horizontal Illuminance	Significant Concern	Moderate/ Significant Concern	Sky brightness as measured by horizontal illuminance warrants moderate to signfiicant concern at Saguaro NP. Specific benchmarks for condition classes have not been set; however, condition is estimated as significant concern within the TMD (Desert View Discovery Nature Trail and Wasson Peak). The measurement from Rincon Peak and at Mica View picnic area within the RMD were estimated to warrant moderate and significant concern, respectively (J. White, personal communication, November 2015). Data to assess trends were not available. The confidence level is high. These data were collected by the NPS NSNSD,
	Zenith Sky Brightness	Significant Concern	Moderate/ Significant Concern	Zenith sky brightness warrants moderate to significant concern at Saguaro NP. The measurements from the Desert View Discovery Nature Trail and Wasson Peak within the TMD warrant significant concern. Within the RMD the measurement from Rincon Peak warrants moderate concern and measurement from the Mica View picnic area warrants significant concern. These conditions are based on the NPS Natural Sounds and Night Skies Division benchmarks for non- urban parks and parks managed as wilderness, and on ground- based measures of zenith sky brightness measured at at four locations within the national park. Data to assess trends were not available. The confidence level is high.
Sky Quality	Bortle Dark Sky Scale	Significant Concern		Sky quality as assessed by the Bortle dark sky scale warrants moderate to significant concern at Saguaro NP. This condition is based on NPS Natural Sounds and Night Skies Division benchmarks for non- urban parks and parks managed as wilderness, and on the qualitative assessment of Bortle class 5 (significant concern) at both the Desert View Discovery Nature Trail and at Wasson Peak in the TMD, Bortle class 4 (moderate concern) at Rincon Peak and class 6 (significant concern) at Mica View picnic area within the RMD. These classes are consistent with a suburban sky at the Desert View Discovery Nature Trail and at Wasson Peak, a rural to suburban transition at Rincon Peak, and a bright suburban sky at Mica View picnic area. Because this measure is qualitative, it has low confidence.

Level of Confidence and Key Uncertainties
The Bortle Dark Sky Scale estimates have inherent uncertainties and error. The principle drawback of the Bortle Scale is that it relies upon human visual observers. Differences in visual acuity, experience and knowledge, as well as time and effort expended can influence the estimates (Bortle 2001, Moore 2001). Modeled data are based on 1996 satellite imagery, and ground-truthed with NPS ground-based measures. Changes in population levels, private and commercial building growth, and energy development could impact current ALR values.

Local and Regional Context
Dark night skies in Saguaro NP are threatened by the large and expanding urbanization and development surrounding the park. The park is divided into two districts separated by the city of Tucson, AZ (population 520,561) which is the largest light dome visible from both districts (U.S. Census Bureau 2010). The 30 miles separating the two park districts are now mostly filled in with urban development that abuts the park boundary in some locations (NPS 2014). In addition to the core city light dome of Tucson, AZ, sources of artificial light include residential development along the western, southwestern and northwestern boundary of the RMD and the northern, eastern and western boundary of the TMD. A planned construction project to widen Houghton Road approximately two miles outside of the entrance to RMD could further degrade night sky conditions in Saguaro NP. The City of Tucson Department of Transportation has been working to refine street lighting specifications along Houghton Road to minimize the impacts to night skies while maintaining safe roadways (M.J. Dillard, Houghton Road Corridor Project Manager, personal communication, November 2015). Furthermore, Pima County and the city of Tucson have implemented an outdoor lighting code to reduce the impacts of city lighting on dark night skies (Pima County 2015). The light domes of Phoenix, AZ (population 1,447,617) approximately 113 miles to the northwest; Nogales, AZ (population 20,837) approximately 66 miles to the south; and Sierra Vista, AZ (population 45,140) approximately 75 miles southwest of Tucson, AZ are also visible within the park.

Effects of Artificial Lighting on Wildlife
Studies show that artificial lighting reduces nocturnal foraging by rodents, modifies patterns of communication among coyotes, stimulates nocturnal activity in birds that are normally diurnal, disorients insects and birds that migrate at night, and alters patterns of pollination by nocturnal moths (Longcore and Rich 2004). Despite these studies, the effects of artificial lighting are not well understood for most species. Saguaro NP protects a prime example of the Sonoran Desert ecosystem that includes important habitat for many nocturnal species (NPS 2014). One study on the movements of the federally endangered lesser long-nosed bat in Tucson, AZ found that individuals moved through areas managed for lower light intensity and avoided areas of greater light intensity (Lowery et al. 2009). Given the poor night sky conditions in Saguaro NP, there is potential for adverse impacts to wildlife and disruption of ecological function.

4.3.5. Sources of Expertise

Jeremy White, Natural Sounds and Night Skies Division, part of the NPS Natural Resource Stewardship and Science Directorate, provided information pertaining to night sky data collection methodology and interpretation of results. White is a Physical Scientist with the Night Skies Program responsible for data collection and analysis, interpretation, and public outreach. Since 2001 the team has collected sky quality inventories at over 110 U.S. national parks.

This section was authored by biologist and writer Lisa Baril.

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4.4. Soundscape

Indicators/Measures

- Sound Level (2 Measures)
- Geospatial Model (1 Measure)

Condition - Trend - Confidence Level

Moderate to Significant Concern - Insufficient Data - Varied

4.4.1. Background and Importance

Our ability to see is a powerful tool for experiencing our world, but sound adds a richness that sight alone cannot provide. In many cases, hearing is the only option for experiencing certain aspects of our environment, and an unimpaired acoustical environment is an important part of overall National Park Service (NPS) visitor experience and enjoyment, as well as vitally important to overall ecosystem health.

In a 1998 survey of the American public, 72% of respondents identified opportunities to experience natural quiet and the sounds of nature as an important reason for having national parks (Haas and Wakefield 1998). Additionally, 91% of NPS visitors "consider enjoyment of natural quiet and the sounds of nature as compelling reasons for visiting national parks" (McDonald et al. 1995) (Figure 4.4.1-1). Despite this desire for quiet environments, noise continues to intrude upon natural areas and has become a source of concern in national parks (Lynch et al. 2011).

A park's natural soundscape is an inherent component of "the scenery and the natural and historic objects and the wildlife" protected by the Organic Act of 1916. NPS Management Policies (§ 4.9) (2006) require preservation of parks' natural soundscapes and restoration of degraded soundscapes to natural conditions wherever possible. Additionally, NPS is required to prevent or minimize degradation of the natural soundscapes from noise (i.e., any unwanted sound). Although the management policies currently refer to the term soundscape as the aggregate of all natural sounds that occur in a park, differences exist between the physical

Figure 4.4.1-1. Wildlife, such as Gila Woodpecker, and Red-spotted toad, [clock-wise from top left], and running water, and leaves, with perched Costa's Hummingbird, are some sources of natural sounds in Saguaro NP.

sound sources and human perceptions of those sound sources. The physical sound resources (e.g., wildlife, waterfalls, wind, rain, and cultural or historical sounds), regardless of their audibility, at a particular location, are referred to as the acoustical environment, while the human perception of that acoustical environment is defined as the soundscape. Clarifying this distinction will allow managers to create objectives for safeguarding both the acoustical environment and the visitor experience.

Sound also plays a critical role for wildlife communication. Activities such as courtship, predation, predator avoidance, and effective use of habitat rely on the ability to hear, with studies showing that wildlife can be adversely affected by intrusive sounds. While the severity of the impacts varies depending on the species and other conditions, documented responses of wildlife to noise include increased heart rate, startle responses, flight, disruption of behavior, separation of mothers and young, and interference with communication (Selye 1956, Clough 1982, USDA 1992, Anderssen et al. 1993, NPS 1994, Dooling and Popper 2007, Kaseloo 2006).

Although the soundscape is an important aspect of all parks, it takes on some added importance in Saguaro National Park (NP). Nearly 28,895 hectares (71,400 acres) within the park have been designated wilderness, and the park's soundscape has been identified as one of the measures by which the condition of Saguaro NP's wilderness will be monitored (Engebretson 2012). Wilderness is defined as "an area of undeveloped Federal land retaining its primeval character and influence without permanent improvements or human habitation…" in the Wilderness Act of 1964 (Public Law 88-577 [16 U.S.C. 1131- 1136]). A baseline assessment of each of the park's wilderness measures (approximately 38 in all, organized by indicator) was conducted in 2012, and a subsequent analysis is to be conducted every five years (Engebretson 2012). The report on the initial baseline assessment noted that the park did not yet collect soundscape monitoring data, but that such data would be collected in the future (Engebretson 2012). Due to a lack of information at the time, the soundscape measure could not be determined in the 2012 baseline assessment. Some of the sources of noise mentioned in the report, however, included traffic noise on roads bordering wilderness and aircraft noise from military and commercial overflights. Wilderness within Saguaro NP lies under the flight path of both the Tucson International Airport and Davis-Monthon Air Force Base (Engebretson 2012). In addition to the wilderness, Saguaro NP has a diverse array of native wildlife, including mammals, birds, and herpetofauna.

Although substantial portions of Saguaro NP are designated as Wilderness, the park is also adjacent to the growing city of Tucson, with the two districts forming "bookends" on either side of the city. As discussed in various sections of the overall condition assessment, the human population and development in the Tucson area are increasing. The greater Tucson metropolitan area is one of the fastest growing population centers in the United States. According to the 2010 census, Pima County's population was 980,263 and is projected to reach 1.45 million by 2041 (Pima Association of Governments 2016). In 2000, 55% of the private land surrounding Saguaro NP was undeveloped, but exurban development is expected to increase 38% by 2030 and 105% by 2060 (Hansen et al. 2014). Such increases in population and development surrounding the park may lead to a louder acoustical environment and soundscape, at least in the parts of the park bordering urban areas.

Sound Characteristics

Humans and wildlife perceive sound as an auditory sensation created by pressure variations that move through a medium such as water or air. Sound is measured in terms of frequency (pitch) and amplitude (loudness) (Templeton and Sacre 1997, Harris 1998).

Frequency, measured in Hertz (Hz), describes the cycles per second of a sound wave and is perceived by the ear as pitch. Humans with normal hearing can hear sounds between 20 Hz and 20,000 Hz and are most sensitive to frequencies between 1,000 Hz and 6,000 Hz. High frequency sounds are more readily

absorbed by the atmosphere or scattered by obstructions than low frequency sounds. Low frequency sounds diffract more effectively around obstructions, and, therefore, travel farther.

The amplitude (or loudness) of a sound, measured in decibels (dB), is logarithmic, which means that every 10 dB increase in sound pressure level (SPL) represents a tenfold increase in sound energy. This also means that small variations in SPL can have significant effects on the acoustical environment. For instance, a 6 dB reduction in background noise level would produce a 4x increase in listening area (Figure 4.4.1-2). Changes in the background noise level cause a change in listening opportunity. These lost opportunities will approach a halving of alerting distance and a 75% reduction of listening area for each 6 dB increase in affected band level (Barber et al. 2010).

SPL is commonly summarized in terms of dBA (A-weighted SPL). This metric significantly discounts sounds below 1,000 Hz and above 6,000 Hz to approximate the variation in human hearing sensitivity.

4.4.2. Data and Methods

For this soundscape assessment, we used acoustical monitoring data collected in 2016, as well as older data collected in 2004/2005 and 2011. None of the sites used in each of the three separate data collection efforts were the same, which are described in more detail below. It should also be noted that this condition assessment was completed prior to the completion of the full, detailed report of the 2016 data from the NPS Natural Sounds and Night Skies Division (NSNSD).

Sound levels at the park were evaluated in two ways for the purposes of this condition assessment: 1) using the on-site "snapshot" results from the acoustical monitoring effort in 2016 (NPS NSNSD 2016), as well as the older efforts, to determine percent time above reference sound levels, and the difference between natural ambient sound levels and sound levels exceeded 50% of the time at each location (to determine the reduction in listening area), and 2) using the geospatial sound modeling result for the impact between natural and existing acoustic conditions at the park (Mennitt et al. 2013). The indicators and measures are described in more detail later in this section.

Baseline acoustical monitoring data, including:

- sound level data in the form of A-weighted decibel readings (dBA) every second,
- continuous digital audio recordings, and in post processing, those data were converted to sound pressure level readings, ranging from 12.5 Hz to 6,300 Hz

were collected by Saguaro NP staff in coordination with the NPS NSNSD scientists during the months of February and April, 2016. Acoustical monitoring systems were deployed for approximately 30 days each at three locations within the national park: Discovery Trail (in the Tucson Mountain District [TMD]), and Tanque Verde Ridge Trail and Steel Tank (in the Rincon Mountain District [RMD] (Figure 4.4.2-1). All three of the sites are considered frontcountry and low-use, but they were close enough to higher-use areas within or outside of the park to be subject to human sound influences (Lauren Nichols,

Figure 4.4.1-2. A 6 dB reduction in background noise level would produce a 4x increase in listening area (NPS NSNSD 2014a).

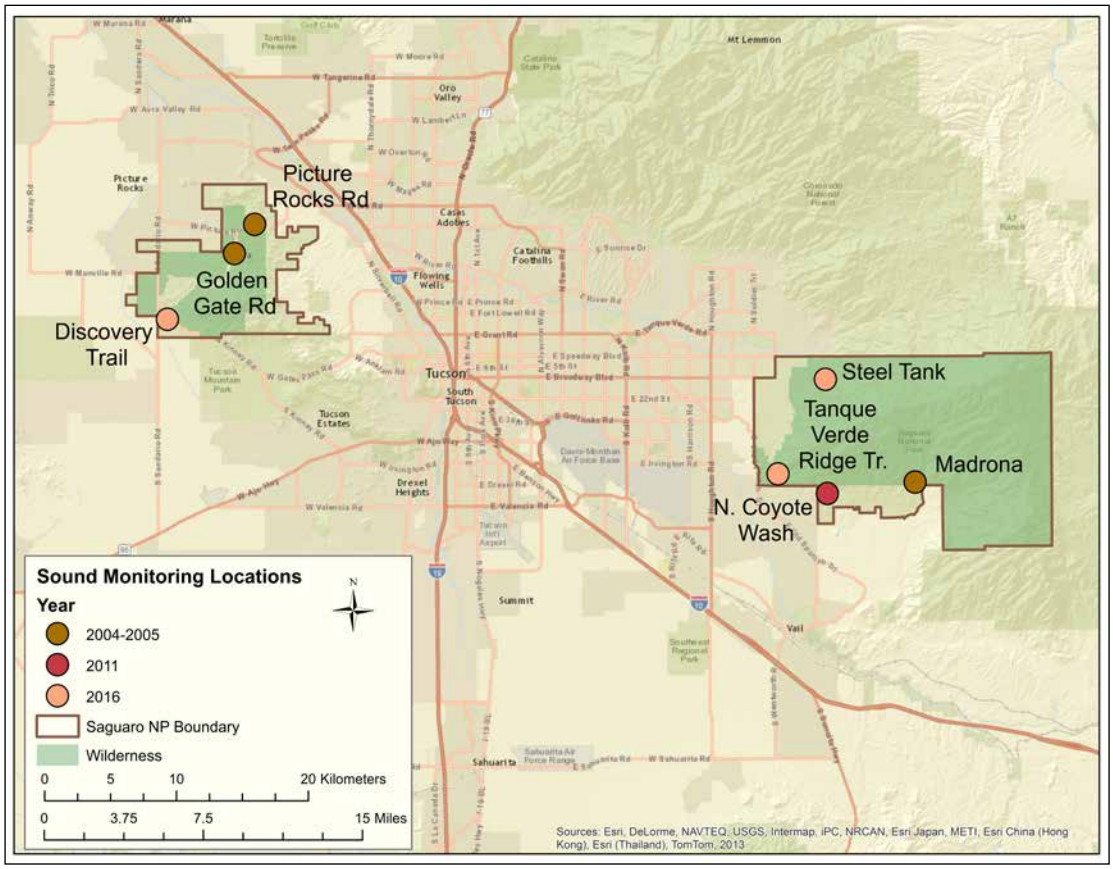


Figure 4.4.2-1. Locations of the acoustical monitoring sites at Saguaro NP.

Biological Science Technician, Saguaro NP, pers. comm.).

The characteristics of the three 2016 monitoring locations are summarized in Table 4.4.2-1. Both of the 2016 sites in the RMD were within designated wilderness. These two sites, as well as two additional, more remote sites will probably be used to monitor Saguaro NP's wilderness as described in Engebretson (2012) (Don Swann, Biologist, Saguaro NP, pers. comm.). The other site used in 2016, in the TMD, was not in designated wilderness.

The Discovery Trail site, in the southwest portion of the TMD, was located about 100 m (328 feet) south of Kinney Road, one of the main park roads. It was located within a triangle made by Kinney Road and two other main roads, Sandario and Mile Wide. The assessment point was also about 200 m (656 feet) away from the paved Desert Discovery Nature Trail. Human sounds that might be expected at this site include voices and related visitor noises from the paved nature trail, road traffic, and air traffic noise from personal or military aircraft which are known to fly directly overhead (L. Nichols, Biological Science Technician, Saguaro NP, pers. comm.).

The Tanque Verde Ridge Trail site, near the western corner of the RMD, was about 150 m (**429 feet**) from the trail and about 5 km (3.1 miles) from Old Spanish Trail Road (a busy road); the site was on a south-facing slope and looked down onto the Rincon Valley (L. Nichols, Biological Science Technician, Saguaro NP, pers. comm.). Potential sources

Table 4.4.2-1. Location characteristics of acoustical monitoring sites at Saguaro NP in 2016 (NPS-NSNSD 2016).

Site Name	Dates Deployed	Habitat	Elevation (m)
Discovery Trail (002; TMD)	2/3/2016-2/26/2016	Desert	735
Tanque Verde Ridge Trail (003; RMD)	2/2/2016-2/25/2016	Desert	1,077
Steel Tank (004; RMD)	4/4/2016-4/24/2016	Desert	946

of noise at this site are from the nearby trail, houses in the valley (including barking dogs), and air traffic. This site is subject to noise from both military and commercial air traffic.

The Steel Tank site was in the northern and western portion of the RMD. This site was located somewhat farther into the wilderness area than the other RMD site. A few trails are in the vicinity of the site, with the closest one being about 350 m (1,148 feet) away (L. Nichols, Biological Science Technician, Saguaro NP, pers. comm.). The nearest road is Speedway Blvd., which is less than 1.6 km (1 mile) away (with relatively slower traffic). In addition to sounds from hikers and possibly the road, military and commercial airline overflights occur.

As noted above, we also included the results of two past efforts of acoustical monitoring in the park. The two prior efforts were: 1) one site monitored by NSNSD in the RMD in 2011 (prior to the Bioblitz event in the park; NPS-NSNSD 2011a); and 2) three sites monitored in November 2004 or April 2005, one in the RMD and two in the TMD (Ambrose and Florian 2006).

The purpose of the acoustical monitoring by Ambrose and Florian (2006) was to: 1) establish natural ambient sound levels in the primary vegetation type in the TMD in areas near Picture Rocks Road (a busy road that bisects the northern part of the district), and 2) determine the influence of vehicle sounds on the natural ambient sound levels. Of these four additional acoustical monitoring locations, none were within designated wilderness, but the Golden Gate Road site was near the road and bordered wilderness. [Note that a map in Ambrose and Florian (2006) shows this site as being in wilderness, but the GIS data layer from the park shows it as being outside]. The Picture Rocks Road and Madrona sites were outside of but in close proximity to wilderness. Characteristics of the four additional (older) monitoring locations are summarized in Table 4.4.2-2. The monitoring equipment at Picture Rocks Road was placed 30.5 m (100 feet) from the centerline of the road, and that at Golden Gate Road was placed 76 m (250 feet) from the centerline of the road. Ambrose and Florian (2006) provided statistics on Picture Rocks Road indicating that it was used by approximately 7,000 vehicles a day in 2004 (and this was projected to double by 2025). Traffic along Golden Gate Road was approximately 90 vehicles a day.

Indicator/Measures

Sound Level (% Time Above Reference Sound Levels and % Reduction in Listening Area)

% Time Above Reference Sound Levels

The percent time above reference sound levels is a measure of the amount of time that the sound level exceeds specified decibel values (NPS-NSNSD 2014b). Human responses to sound levels can serve as a proxy for potential impacts to other vertebrates, because humans have more sensitive hearing at low frequencies than most species (Dooling and Popper 2007). Therefore, these values can be used to address potential impacts to both humans and wildlife. Table 4.4.2-3 summarizes sound levels that relate to human health and speech, as documented in the scientific literature. Note that there is additional discussion on the impact of noise on wildlife in the Threats and Issues section at the end of the assessment.

The first, 35 dBA, is designed to address the health effects of sleep interruption. Recent studies suggest that sound events as low as 35 dBA can have adverse effects on blood pressure while sleeping (Haralabidis 2008).

Table 4.4.2-2. Location characteristics of acoustical monitoring sites at Saguaro NP in 2004/2005 (Ambrose and Florian 2006) and 2011 (NPS-NSNSD 2011a).

Site Name	Dates Deployed	Habitat	Elevation (m)
Picture Rocks Road. (001; TMD)	11/11/2004-11/15/2005	Desert	737
Golden Gate Road (002; TMD)	11/11/2004-11/15/2005	Desert	809
Madrona (003; RMD)	4/6/2005-4/11/2005	Desert	994
N. Coyote Wash (RMD)	July 2011 (30 days)	Desert	968

Table 4.4.2-3. Explanation of reference sound level values.

Sound Levels (dBA)	Relevance
35	Blood pressure and heart rate increase in sleeping humans (Haralabidis et al. 2008)
45	World Health Organization's recommendation for maximum noise levels inside bedrooms (Berglund et al. 1999)
52	Speech interference for interpretive programs (U.S. EPA 1974)
60	Speech interruption for normal conversation (U.S. EPA 1974)

The second value addresses the World Health Organization's recommendations that noise levels inside bedrooms remain below 45 dBA (Berglund et al. 1999). Park visitors camping in or near the park could experience either of these two effects. The third value, 52 dBA, is based on the U.S. Environmental Protection Agency's (USEPA's) speech interference threshold for speaking in a raised voice to an audience at 10 meters (32.8 ft) (USEPA 1974). This threshold addresses the effects of sound on interpretive presentations in parks. The final value, 60 dBA, provides a basis for estimating impacts on normal voice communications at 1 meter (3.28 ft). Hikers and visitors viewing scenic vistas in the park would likely be conducting such conversations. For the 2016 and 2011 data, the NSNSD determined the percent of time sound levels were above these four decibel levels for both day (7:00 am to 7:00 pm) and night (7:00 pm to 7:00 am).

% Reduction in Listening Area

A one decibel change is not readily perceivable by the human ear, but any addition to this difference could begin to impact listening ability. To assess the condition of the acoustic environment, it is useful to consider the functional effects that increases in sound level might produce. For instance, the listening area, the area in which a sound can be perceived by an organism, will be reduced when background sound levels increase. Seemingly small increases in sound level can have substantial effects, particularly when quantified in terms of loss of listening area (Barber et al. 2010). Each 3 dB increase in the background sound level will reduce a given listening area by half.

Failure to perceive a sound because other sounds are present is called masking. Masking interferes with wildlife communication, reproductive and territorial advertisement, and acoustic location of prey or predators (Barber et al. 2010). However, the effects of masking are not limited to wildlife. Masking also inhibits human communication and visitor detection of wildlife sounds. In urban settings, masking can prevent people from hearing important sounds like approaching people or vehicles, and interfere with the way visitors experience cultural sounds or interpretive programs.

For this measure, we set out to calculate the percent reduction in listening area from the natural ambient sound level for each monitoring location using data provided by the corresponding acoustical monitoring effort. The natural ambient sound level refers to all naturally occurring sounds and excludes all anthropogenic noise; it is an estimate of the L_{50} that would occur in the absence of human-caused noise (NPS-NSNSD 2014b). L_{50} refers to the level of sound exceeded fifty percent of the time at a given location. Note, however, that the natural ambient sound level was not available for the 2016 monitoring (at this point in time) or the 2004/2005 monitoring. Therefore, we used the existing ambient L_{90} level as the natural ambient level, which is an acceptable practice (ANSI S12.9-1998 (2003), Quantities and Procedures for Description and Measurement of Environmental Sound Part 1; Ambrose and Florian 2006). The L_{90} value refers to the level of sound exceeded 90% of the time at a given location; it is an estimate of the background against which individual sounds are heard (NPS-NSNSD 2014b). Residual sound may be approximated by the percentile sound level exceeded during 90-95 percent of the measurement period. We calculated reduction in listening area by determining the difference between the L_{50}

and L_{90} values, using a formula provided by NPS-NSNSD to calculate the reduction in listening area.

Existing ambient conditions include all sounds in a given area, natural and anthropogenic. The three monitoring efforts (2004/2005, 2011, 2016) reported data for both day (7:00 am to 7:00 pm) and night (7:00 pm to 7:00 am), and we calculated reduction in listening area using both daytime and nighttime sound levels (separately).

Indicator/Measure
Geospatial Model (L_{50} Impact [Mennitt et al. 2013])

Geospatial Model- L_{50} Impact (Mennitt et al. 2013)
The geospatial model estimated sound pressure levels for the continental United States by using actual acoustical measurements combined with a multitude of explanatory variables, such as location, climate, landcover, hydrology, wind speed, and proximity to noise sources (e.g., roads, railroads, and airports; Mennitt et al. 2013). The 270-m-resolution model predicts daytime sound levels during midsummer. Each square of color on the map represents 270 m^2, and each pixel on the map represents a median sound level (L_{50}). It should be noted that while the model excels at predicting acoustic conditions over large landscapes, it may not reflect recent localized changes such as new access roads or development.

Model parameters useful for assessing a park's acoustic environment include the understanding of: a) natural conditions, b) existing acoustic conditions, including both natural and human-caused sounds, and c) the impact of human-caused sound sources in relation to natural conditions. The L_{50} impact condition demonstrates the influence of human activities to the acoustic environment and is calculated by subtracting the natural condition from the existing condition. The three models are run separately, and NSNSD "zeroes" out all anthropogenic contributions like roads, development, and cities to predict impact, but the impact statistics will not always be exactly equal to existing minus natural (E. Brown, NSNSD pers. comm.).

4.4.3. Reference Conditions
Reference conditions for the indicators/measures used in this condition assessment are presented in Table 4.4.3-1 for measures in good condition, those warranting moderate concern, and those warranting significant concern.

<u>% Time Above Reference Sound Levels</u>
We used decibel levels presented in Table 4.4.2-3 as thresholds to separate the three reference conditions displayed in Table 4.4.3-1. If sound levels were below the World Health Organization's recommended maximum noise level in bedrooms (45 dB), then we considered the condition to be good. If sound levels were above that which is expected to cause speech interference for

Table 4.4.3-1. Reference conditions used to assess sound levels at Saguaro NP.

Indicator	Measure	Good	Moderate	Significant Concern
Sound Level	% Time Above Reference Sound Levels	The majority of sound levels recorded were <44.99 dBA.	The majority of sound levels recorded were between 45 - 51.99 dBA.	The majority of sound levels recorded were >52 dBA.
	% Reduction in Listening Area (for non-urban parks)	Listening area reduced by ≤30% (Difference between L_{50} & L_{90} is ≤ 1.5)	Listening area reduced by 30-50% (Difference between L_{50} & L_{90} is >1.5 and ≤ 3.0)	Listening area reduced by > 50% (Difference between L_{50} & L_{90} is >3.0)
Geospatial Model	L_{50} Impact for non-urban parks (Mean L_{50} impact [dBA])	≤ 1.5 Listening area reduced by ≤30%	>1.5 and ≤ 3.0 Listening area reduced by 30-50%	>3.0 Listening area reduced by > 50%

interpretive programs, we considered the condition to warrant significant concern.

% Reduction in Listening Area

Turina et al. (2013) developed two categories, urban and non-urban, of L_{50} impact reference conditions based on the proximity of a park to urban areas as identified by the U.S. Census Bureau (2010). The urban criteria are applied to park units that have at least 90% of the park property within an urban area. Non-urban parks have at least 90% of their areas outside designated urban areas (Turina et al. 2013). Based on these criteria, Saguaro NP is considered a non-urban park (Emma Brown, NSNSD, pers. comm.).

Sound levels at non-urban parks most often exhibit less divergence between existing and natural sound levels, making them quieter areas that are more susceptible to noise. Visitors likely have a greater expectation for quiet at non-urban parks, and wildlife are likely more adapted to a noise-free environment. Therefore, the reference conditions (or thresholds) for non-urban parks are more stringent than for those located in urban areas. Although Saguaro NP is considered a non-urban park, it should also be noted that some areas of the park (e.g., in the western RMD and the eastern TMD) are in relatively close proximity to the City of Tucson and its expanding borders.

For this measure, a reduction in listening area of 30% or less would indicate good condition, while a more than 50% reduction in listening area would warrant significant concern (Turina et al. 2013). As noted previously, to arrive at these listening area reductions, we used the corresponding differences between the existing ambient L_{50} and L_{90} sound levels (with the L_{90} representing the natural ambient sound level). The difference is referred to as the impact, and the impact values were also based on Turina et al. (2013).

Geospatial Model (L_{50} Impact [Mennitt et al. 2013])

Reference conditions for this measure were developed by Turina et al. (2013) and are presented in Table 4.4.3-1, using non-urban park thresholds.

4.4.4. Condition and Trend

% Time Above Reference Sound Levels

Figure 4.4.4-1 shows the percent time sound levels were above the reference sound levels at each monitoring location during day (7 a.m. - 7 p.m.) and nighttime (7 p.m. - 7 a.m.) hours for the three sites monitored in 2016. Sound levels mainly exceeded the 35 dBA metric, with 3.9 to 11.4% of daytime hours above this level, and the Steel Tank site representing the highest percent time above the reference. Sound levels exceeded the 45 dBA metric 0.6 to 2.6% of the daytime hours, once again with the Steel Tank site representing the highest

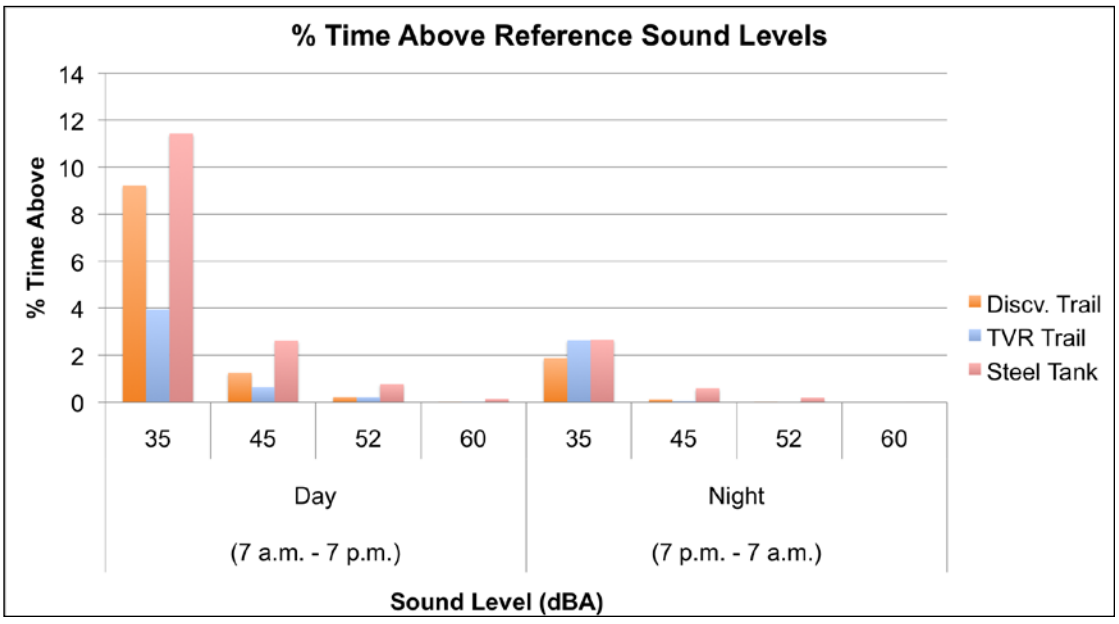


Figure 4.4.4-1. Percent time above reference sound levels recorded at Discovery Trail, Tanque Verde Ridge Trail, and Steel Tank acoustical monitoring sites.

percent time above the reference level. Sound levels at all three sites rarely exceeded 52 dBA during day or night (and again, sound levels were the highest at the Steel Tank site, with levels above 52dBA 0.8% of daytime hours and 0.2% of nighttime hours).

As might be expected, sound levels were lower at night than during the day. Nighttime sound levels only exceeded the 35 dBA reference value 1.9% to 2.7% of the time. During the nighttime hours, sound levels exceeded the 45 dBA reference level for recommended maximum noise levels inside bedrooms only 0.05 to 0.6% of the time, suggesting a quiet environment.

Low frequency sounds (20-1250 Hz), of which transportation noises are often a major contributor, comprised more of the sound heard at the sites during both day and nighttime hours, with the exception of the Tanque Verde Ridge Trail site during the night at the 35 dBA percent exceedence level (NPS-NSNSD 2016). Note that the metrics presented in the 2016 snapshot report did not identify sound sources; sound sources will be identified in the full report that will be prepared by NSNSD. However, the data sheets completed by Saguaro NP staff at the acoustical monitoring locations included some notes about sounds heard. For example, the Discovery Trail site was about 100 m (328 feet) from Kinney Road, and light traffic was heard on the acoustical equipment deployment and/or retrieval date. At the Tanque Verde Ridge Trail site, which was about 5 km (3.1 miles) from Old Spanish Trail Road, "constant air traffic" was heard on the deployment and/or retrieval date. The Steel Tank site, which was less than 1.6 km (1 mile) from Speedway Blvd., was also subject to aircraft overflights.

Although we did not include results from the acoustical monitoring in RMD in 2011 (i.e., North Coyote Wash site) in Figure 4.4.4-1, similar data are available from that monitoring effort. Note that we did not include the 2011 results in the figure due to the difference in the values (and the scales of the values). However, the results are shown in Table 4.4.4-1. Percent time above the metrics (during summer) was higher at this site compared to the three 2016 sites (in February or April), especially for percent time above 35 dBA at night (i.e., this level was exceeded 84.8% of the time at the N. Coyote Wash site) and 45 dBA at night (i.e., exceeded 21.4%). Even with these results, the majority of sound levels were below 45 dBA, especially during the day. Also note that it is possible that some of the daytime and nighttime sounds were natural (e.g., insects, wind).

Relative to the percent time above reference sound levels measure, all 2016 monitoring locations are considered to be in good condition using our reference conditions. Although the sound levels were higher at the N. Coyote Wash site, especially at night, the measure is still in good condition based on the reference conditions. We have high confidence in the assessment under this measure. Trends cannot be determined at this time.

<u>% Reduction in Listening Area</u>

We had data from each of the three different acoustical monitoring efforts (2004/2005, 2011, 2016) to assess this measure. We calculated the percent reduction in listening area for each site by determining the impact (in dB), or the difference between the L_{50} sound level and the L_{90} sound level. In each case, we used the L_{90} sound level to represent natural sound levels. Although it would have been preferable to use the L_{nat} sound level rather than the L_{90}, this level was not available except in the case of the North Coyote Wash site. For this one site, we also calculated the impact using the L_{nat} value for comparison, but we used the impact from the L_{90} level to be consistent with how we conducted the other

Table 4.4.4-1. Percent time above four reference sound level values as measured by NSNSD in 2011 at North Coyote Wash in the RMD (NPS- NSNSD 2011b).

	Perccent Time Above (%)			
	35dBA	45 dBA	52 dBA	60 dBA
Day	13.60	3.02	1.09	0.34
Night	84.82	21.47	1.16	0.04

site comparisons. Upon completion of the full analysis by NSNSD of the 2016 monitoring data, L_{nat} values will be available from this most recent monitoring effort. Again, note that the reference conditions (or thresholds) used were for non-urban parks.

L_{50} and L_{90} values were provided by NSNSD for both day and night hours, but for the 2004/2005 effort, we had to calculate each of the daytime and nighttime averages from tables in Ambrose and Florian (2006) showing mean hourly L_{50s} and L_{90s}.

The reduction in listening area analysis is shown in Table 4.4.4-2. The table shows the L_{50} and L_{90} sound levels for each site, for both daytime and nighttime hours, as well as the impact value (i.e., the difference), reduction in listening area, and condition. We also grouped results by district. Based on the analysis, during the daytime hours, the reduction in listening area was greater in the TMD than in the RMD, with an overall district condition of significant concern for the TMD and moderate concern for the RMD. Individual reduction in listening area values ranged from 36.9-60.0% in the TMD

Table 4.4.4-2. Results of the % reduction in listening area analysis for each site monitored for both daytime and nighttime hours.

Year	District	Site Name	L_{50} (dBA)	L_{90} (dBA)	Impact (dBA)	Reduction in Listening Area	Condition	Summary by District
Daytime Hours (7 am - 7 pm)								
2004	TMD	Picture Rocks Rd. [1]	40.6	38.6 [1]	2.0	36.9%	Moderate	Significant Concern
2004		Golden Gate Rd. [1]	34.1	30.8 [1]	3.3	53.2%	Significant	
2016		Discovery Trail	25.8	21.8	4.0	60.0%	Significant	
2004	RMD	Madrona	28.0	25.0	3.0	49.9%	Moderate	Moderate Concern
2011		**N. Coyote Wash [2]**	**25.6**	**23.4 [2]**	**2.2**	**39.7%**	**Moderate [2]**	
2011		N. Coyote Wash	25.6	20.8	4.8	66.9%	Significant	
2016		Tanque Verde Ridge Trail	22.7	20.7	2.0	37.0%	Moderate	
2016		Steel Tank	27.8	26.2	1.6	30.8%	Moderate	
Nighttime Hours (7 pm - 7 am)								
2004	TMD	Picture Rocks Rd. [1]	50.2	31.8 [1]	18.4	98.6%	Significant	Moderate Concern
2004		Golden Gate Rd. [1]	35.4	32.4 [1]	3.0	49.9%	Moderate	
2016		Discovery Trail	20.4	18.6	1.8	33.9%	Moderate	
2004	RMD	Madrona	22.8	20.2	2.6	45.0%	Moderate	Moderate Concern
2011		**N. Coyote Wash [2]**	**41.4**	**40.0 [2]**	**1.4**	**27.6%**	**Good [2]**	
2011		N. Coyote Wash	41.4	38.7	2.4	42.5%	Moderate	
2016		Tanque Verde Ridge Trail	21.3	19.1	2.2	39.7%	Moderate	
2016		Steel Tank	26.4	25.2	1.2	24.1%	Good	

[1] Ambrose and Florian (2006) reported the L_{90} for this site was not a good indicator of true natural ambient sound levels because non-natural sounds were audible throughout the measurement period. Using the L_{90} in this case would probably lead to an underestimate of the reduction in listening area.

[2] Note that the numbers for these rows use the Lnat, which was provided by NSNSD, rather than the L90. Using one vs. the other changes the impact level and condition category. While using the Lnat for each site would be preferable, we only had the Lnat for N. Coyote Wash. To use the same approach for all sites, we used the conclusion based on the L90 for the summary conditions.

Note: The rows in bold for 2011 show the numbers using the Lnat for comparison, but the L90 was used for the assessment.

and 30.8-66.9% in the RMD. Among all the sites, the three highest daytime L_{50s} were at Picture Rocks Rd., Golden Gate Rd., and Madrona, respectively.

During nighttime hours, the overall district condition was similar for both districts (i.e., moderate concern), but the reduction in listening area at individual sites was smaller for some sites in the RMD. For example, the range in the reduction in listening area for the TMD was 33.9-98.6%, while that in the RMD was 24.1-45.0%. Among all of the sites, the three highest nighttime L_{50s} were at Picture Rocks Rd., North Coyote Wash, and Golden Gate Rd., respectively.

Overall, we consider the condition for the TMD using the percent reduction in listening area measure as moderate to significant concern (considering day and nighttime sound levels, with 3 values of moderate concern and 3 values of significant concern). We consider condition for the RMD using this measure as moderate concern (with 6 values of moderate concern and 1 each of significant concern and good condition).

Although we have high confidence in the three acoustical monitoring efforts/data, our use of the L_{90} values to represent natural sound levels somewhat lowers our confidence in the assessment. For example, we determined the impact level for the North Coyote Wash site using both the L_{90} and L_{nat} sound levels. Using the L_{90} for daytime hours, the impact value was 4.8 dB (which corresponds to a 66.9% reduction in the listening area and a condition of significant concern). Using the L_{nat}, impact was 2.2 dB, which corresponds to a 39.7% reduction in listening area and a moderate concern condition. Also, Ambrose and Florian (2006) suggested that the L_{90} values for the two sites in the TMD were not good estimations of the natural ambient sound level in these areas because non-natural sounds, primarily vehicles, could be heard throughout the measurement period. Both sites were near roads, with the Picture Rocks Road site only 30.5 m (100 ft) from the centerline of the roadway. Ambrose and Florian (2006) also indicated that sounds (traffic) from Picture Rocks Road affected the ambient sound level at the Golden Gate Road site, 1.4 km (0.9 miles) away. The authors believed that the L_{90} at the Madrona site was probably a more accurate estimate of the natural ambient at the Madrona site (and the other two sites [which have similar vegetation]).

NPS-NSNSD (2011a) reported the five most common human-caused sounds identified at the N. Coyote Wash site during the day. These five sound sources were jets, propeller planes, helicopters, automobiles, and trains. They found that the longest-lasting individual noise events were from trains (running south of the monitoring site and park; on average about 22 minutes), but that trains were identified 12 times per day compared to jets, which were identified an average of 58 times per day. The results also indicated that individual events from the four other sources (excluding trains) lasted on average about 6.5 minutes for automobiles; 4 minutes for helicopters; 3 minutes for propeller planes; and 2.5 minutes for jets (NPS-NSNSD 2011a).

Geospatial Model (L_{50} Impact [Mennitt et al. 2013])

The modeled difference between the existing and predicted natural sound level (L_{50} impact) provides a measure of how much anthropogenic noise is increasing the existing sound level above the natural sound level, on average. Figure 4.4.4-2 shows the modeled median impact sound level map for the park, which was 4.1 decibels (dBA) above natural conditions, ranging from 0.5 dBA in the least impacted areas to 19.9 dBA in the most impacted areas. The map depicts the area most influenced by human-caused sounds (i.e., lighter colored areas), which is the City of Tucson. The existing and natural acoustic environment condition maps for the park are included in Appendix D.

Summary statistics of the L_{50} values for the natural, existing, and impact conditions are provided in Table 4.4.4-3. Average values represent the median L_{50} value occurring within the park boundary, and visitors may experience sound levels higher and lower than the average L_{50}.

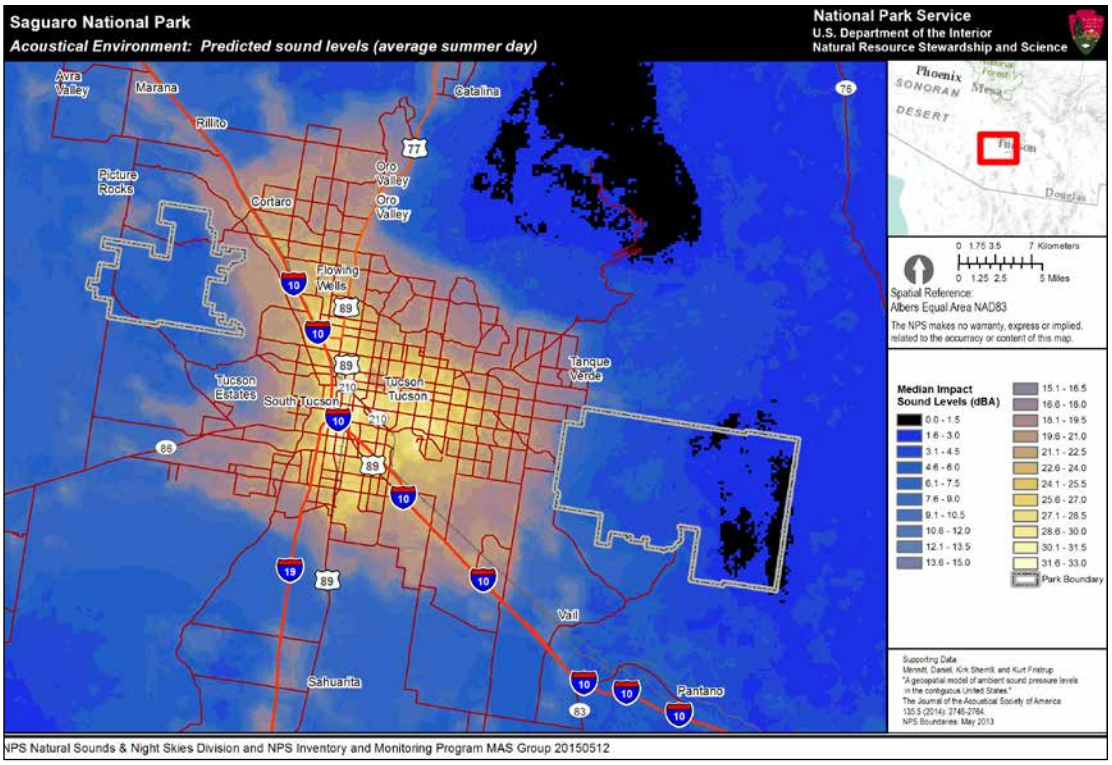


Figure 4.4.4-2. The modeled L_{50} impact sound level at Saguaro NP and vicinity (Mennitt et al. 2013). Lighter colors represent higher impact areas.

Table 4.4.4-3. Summary of the modeled minimum, maximum, and median L_{50} measurements in Saguaro NP. Data provided by E. Brown, NPS- NSNSD.

Acoustic Environment Condition	L_{50} Values (dBA)		
	Min.	Max.	Median
Natural	25.7	29.0	32.6
Existing	30	46.3	32.6
Impact	0.5	19.9	4.1

This modeled metric (4.1 dBA) is similar to the measured difference between natural (i.e., L_{90}) and existing ambient sound levels (L_{50}) at the park, which generally ranged from 1.2 to 4.8 dBA (for both daytime and nighttime, excluding the highest level at Picture Rocks Rd. at night). A one decibel change in sound level is not readily perceivable by the human ear, but any addition to this difference could begin to impact a visitor's listening ability to hear natural sounds or interpretive programs.

Mennitt et al. (2013) suggest that in a natural environment, the average summertime L_{50}, which is the sound level exceeded half of the time (and is a fair representation of expected conditions) is not expected to exceed 41 dBA. Except for the maximum L_{50}, the modeled estimates for Saguaro NP were below 33 dBA, with the median L_{50} being 32.6. However, the average impact level (4.1 dBA) was considered to be of significant concern according to the reference thresholds developed by Turina et al. (2013).

Discussion of Acoustical Monitoring Sites in Wilderness

As discussed previously in the assessment, two of the sites in the RMD are within Saguaro NP's designated wilderness. These sites are the Tanque Verde Ridge Trail and Steel Tank sites. Of the sites outside of wilderness, all are in fairly close proximity to wilderness. However, some are also in close proximity to the urban environment of Tucson (e.g., Picture Rocks Road site).

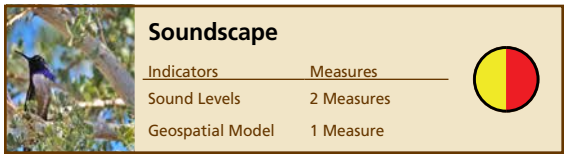
The Wilderness Act "requires that a wilderness provide opportunities for solitude and a primitive and unconfined recreation" (Leslie 2014). Leslie (2014) discussed two common audibility metrics that are useful in examining the condition of the soundscape in wilderness; these metrics are percent time audible and noise free interval (Miller 2008, as cited in Leslie 2014). Percent time audible

refers to the percentage of time a source or category is audible relative to the length of total observation, while the noise free interval is the length of time that a particular source or category is not audible during an observation period. These metrics are not currently available for the acoustical monitoring locations in Saguaro NP's wilderness because the method used to calculate audibility of sound sources does not produce these metrics (E. Brown, NPS NSNSD, pers. comm.). Although we did not have these metrics available for this assessment, we summarize below the results for the two wilderness sites (that were presented earlier).

Comparing daytime existing ambient sound levels (i.e., L_{50s}), the Tanque Verde Ridge Trail site was quietest among all of the sites at 22.7 dBA, and the Steel Tank site was the third most quiet (at 27.8 dBA). Acoustic conditions at the sites differed slightly between day and night. At night, the Tanque Verde Ridge Trail site was the second most quiet (at 21.3 dBA; see Table 4.4.4-2). Recall, however, that these numbers include both natural and human-made sounds. The estimates of the L_{nat} (not available at this time), will give a clearer picture of the natural sound levels in the absence of human-related sounds.

Recall the figure showing the time sound levels were above the reference sound levels (i.e., 35, 45, 52, and 60 dBA) at the two sites in the RMD during day (7 a.m. - 7 p.m.) and nighttime (7 p.m. - 7 a.m.) hours. Sound levels exceeded the 35 dBA metric only 3.9% of daytime hours at Tanque Verde Ridge Trail and 11.4% of daytime hours at the Steel Tank site. Sound levels exceeded the 45 dBA metric only 0.6% and 2.6% of the daytime hours, respectively. Sound levels rarely exceeded 52 dBA during day or night. At night, sound levels only exceeded the 35 dBA reference level 2.6% and 2.7% of the time at the two sites, respectively. This reference value was for addressing the health effects of sleep interruption; studies suggest that sound events as low as 35 dBA can have adverse effects on blood pressure while sleeping (Haralabidis 2008). For these sites, condition was judged to be good based on these percent time above metrics.

The forthcoming, detailed report of the 2016 data from NSNSD will provide estimates of the natural ambient sound levels (L_{nat}) at the sites, sources of natural and anthropogenic sounds during the day and night for the sites, and percent audibility of natural and anthropogenic sounds. This information will provide a clearer picture of the soundscape in the wilderness locations, as well as the overall sites. At this time, the soundscape at the two sites appears to be in good condition to moderate concern, based on the two sound level measures discussed here. However, it is clear that anthropogenic noise is a significant problem throughout Saguaro NP, and it is very rare that visitors experience time anywhere in the park when they are completely free of noise from automobiles, airplanes, trains, and local industry (D. Swann, biologist, pers. comm.)



Overall Condition and Trend

For assessing the condition of the national park's soundscape, we used two indicators and three measures that are summarized in Table 4.4.4-4. Overall, based on the sites monitored and the information available, we consider the soundscape at Saguaro NP to be of moderate to significant concern, with an unknown trend.

This assessment was based on data from three sites in 2016, one site in 2011, and three sites in 2004/2005. Overall, three of the sites were in the TMD, and four of the sites were in the RMD. Of the seven sites, two were in designated wilderness. The forthcoming, detailed report on the 2016 data will provide additional information, but information to date indicates vehicles on roadways (e.g., Picture Rocks Rd.), trains, and aircraft overflights contribute to noise levels in the park at some sites. It is possible that the additional analysis may lead to some different condition conclusions.

Note that as of December 2016, Saguaro NP's Natural Resource Report on soundscape that is currently in review (Job, in review) states, "Noise was very prominent at SAGU002 (Discovery Trail) and SAGU003 (Tanque Verde Ridge Trail) 99.7% and 98.2% of the time….

Table 4.4.4-4. Summary of the soundscape indicators, measures, and condition rationale.

Indicators of Condition	Measures	Condition	Rationale for Condition
Sound Levels	% Time Above Reference Sound Levels	Good	The majority of existing sound levels heard at all sites for which data were available (i.e., 2011 and 2016) were <44.99 dBA, suggesting a relatively quiet environment, so we consider this measure to be in good condition. Confidence in the data and the assessment is high. However, 2004/2005 data were not available for inclusion.
	% Reduction in Listening Area (for non-urban parks): TMD	Moderate to Significant	Analysis for the TMD is based on two sites monitored in 2004/2005 and one site monitored in 2016. Considering both day and night sound levels, three impact values led to a reduction in listening area of 33.9-49.9% (moderate concern) and three a 53.5-98.6% reduction (significant concern). Therefore, overall, we considered condition under this measure as moderate to significant concern. No data are available for trends. Our confidence in the assessment is medium (see text for explanation). In the TMD, existing ambient sound levels (L_{50s} and L_{90s} for day and night) were lowest in the Discovery Trail site.
	% Reduction in Listening Area (for non-urban parks): RMD	Moderate	Analysis for the RMD is based on one site monitored in 2004/2005, one site monitored in 2011, and two sites from 2016. Considering both day and night sound levels, six impact values led to a reduction in listening area of 30.8-49.9% (each moderate concern), one a 24.1% reduction (good condition), and one a 66.9% reduction (significant concern). Therefore, overall, we considered condition under this measure as moderate concern. No data are available for trends. Our confidence in the assessment is medium (see text for explanation). In the RMD, existing ambient sound levels (L_{50s} and L_{90s} for day and night) were lowest in the Tanque Verde Ridge Trail site.
Geospatial Model	L_{50} Impact	Significant Concern	The modeled median impact sound level for the national park was 4.1 dBA, which is considered to be of significant concern based on threshold values for non-urban parks (Turina et al. 2013). This level of sound impact corresponds to a reduction in listening area of >50%. This measure is based on modeled sound levels (rather than on-site measurements), resulting in a medium confidence level.

from these results, it is unlikely that a visitor to Saguaro can experience a significant time period completely free from anthropogenic noise, with this possibility being highly unlikely at SAGU0002 and SAGU0003." As the author of this assessment stated, the full report will likely further inform the soundscape condition status at the park.

Level of Confidence and Key Uncertainties

Confidence in the quality of the data is high. However, our overall confidence in the assessment is medium for the following reasons. First, data for three of the monitoring sites are more than a decade old, and data for one of the sites are five years old. Although the acoustical environment has probably not become more quiet in these sites due to human population growth and development in the Tucson area, this is uncertain. Second, the same data and analyses were not available from each of the three monitoring efforts and for each of the sites. For example, data on the percent time above the reference levels (first measure of first indicator) was not available for the 2004/2005 sites. If it had been, as at least two of these sites were among the highest in existing ambient sound levels, the use of such data may have lowered the condition for this measure. Also, as mentioned previously, we also used the L_{90} to represent natural ambient sound levels at the sites (for the second measure of first indicator), because the L_{nat} level was only available for one of the sites (in

2011). Using the natural ambient sound levels at the sites may lead to some different results and condition conclusions. The natural ambient sound levels will be estimated for the three sites monitored in 2016 in the full report by NSNSD.

NPS

Figure 4.4.4-3. Helicopter flying over Saguaro NP in 2016.

Threats and Issues

Although the data from 2016 are not yet available regarding sources of sounds within the national park, the 2004/2005 and 2011 data indicated that, for the sites monitored, some of the main sources of anthropogenic sound were vehicle/roadway traffic, aircraft overflights (Figure 4.4.4-3), and trains. Based on descriptions of the sites from park personnel, aircraft overflights will probably be one of the important sources of noise for the 2016 sites as well. Most of the monitoring sites used in the assessment (from all efforts) are considered frontcountry, so they are in closer proximity to the City of Tucson, which has been undergoing substantial growth for a number of years (see background section). As development continues, increases in anthropogenic sounds, at least at some of the sites, are likely to occur. We were unable to assess trends in condition of the soundscape at Saguaro NP because none of the sites monitored in the three acoustical monitoring efforts were in the same location. However, in the future, the wilderness monitoring that will be conducted approximately every five years in the park (Engebretson 2012) will provide information on trends in the soundscape for the sites monitored.

In addition to influencing the human experience of the landscape, anthropogenic sounds can influence the behavior and ability of wildlife to function naturally on the landscape. With respect to the effects of noise, there is compelling evidence that wildlife can suffer adverse behavioral and physiological changes from noise and other human disturbances, but the ability to translate that evidence into quantitative estimates of impacts is presently limited (Shannon et al. 2015). In a synthesis of wildlife response to noise, researchers found that many species of terrestrial wildlife respond to noise as low as 40 dBA (Shannon et al. 2015). One of the most common and readily observed biological responses to human noise is changes in vocal communication. Birds use vocal communication primarily to attract mates and defend territories, but anthropogenic noise can influence the timing, frequency, and duration of their calls and songs (Shannon et al. 2015). Similar results have been found for some species of mammals, amphibians, and insects, which also rely on vocal communication for breeding and territorial defense. Other changes include changes in time spent foraging, ability to orient, and territory selection (Shannon et al. 2015, McClure et al. 2013).

Several recommendations have been made for human exposure to noise, but no guidelines exist for wildlife, such as the lesser long-nosed bat (*Leptonycteris yerbabuenae*) (Figure 4.4.4-4) and the habitats we share. The majority of research on wildlife has focused on acute noise events, so further research needs to be dedicated to chronic noise exposure (Barber et al. 2010). In addition to wildlife,

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Figure 4.4.4-4. Lesser long-nosed bat (*Leptonycteris yerbabuenae*).

standards have not yet been developed to assess the quality of physical sound resources (the acoustic environment), separate from human or wildlife perception. Scientists are also working to differentiate between impacts to wildlife that result from the noise itself or the presence of the noise source (Barber et al. 2010).

4.4.5. Sources of Expertise

The NPS Natural Sounds and Night Skies Division (NSNSD) scientists help parks manage sounds in a way that balances the various expectations of park visitors with the protection of park resources. They provide technical assistance to parks in the form of acoustical monitoring, data collection and analysis, and in developing acoustical baselines for planning and reporting purposes. For more information, see http://nps.gov/nsnsd.

Emma Brown, Acoustical Resource Specialist with the NSNSD, provided an NRCA soundscape template used to develop this assessment and the sound model statistics and maps. She also reviewed a draft of the assessment.

This section was authored by writer and biologist Patty Valentine-Darby. Lisa Baril, also a writer and biologist, authored parts of the Threats and Issues section at the end of the assessment.

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4.5. Air Quality

Indicators/Measures

- Visibility (1 Measure)
- Level of Ozone (2 Measures)
- Wet Deposition (4 Measures)

Condition – Trend – Confidence

Moderate to Significant Concern - Varied - Varied

4.5.1. Background and Importance

Under the direction of the National Park Service's (NPS) Organic Act, Air Quality Management Policy 4.7.1 (NPS 2006), and the Clean Air Act (CAA) of 1970 (P.L. 94-567; U.S. Federal Register 1970), the NPS has a responsibility to protect air quality and any air quality related values (e.g., scenic, biological, cultural, and recreational resources) that may be impaired from air pollutants.

One of the main purposes of the CAA is "to preserve, protect, and enhance the air quality in national parks" and other areas of special natural, recreational, scenic or historic value. The CAA includes special programs to prevent significant air quality deterioration in clean air areas and to protect visibility in national parks and wilderness areas (NPS-ARD 2006a).

Different categories of air quality areas have been established through the authority of the CAA: Class I and II. The air quality classes are allowed different levels of permissible air pollution, with Class I receiving the greatest protection and strictest regulation. The CAA gives federal land managers responsibilities and opportunities to participate in decisions being made by regulatory agencies that might affect air quality in the federally protected areas they administer (NPS-ARD 2005).

Class I areas include parks that are larger than 2,428 ha (6,000 acres) or wilderness areas over 2,023 ha (5,000 acres) that were in existence when the CAA was amended in 1977 (NPS-ARD 2015a). Saguaro National Park is designated as a Class I airshed (Figure 4.5.1-1) and clean air is identified as one of the park's fundamental resources and values (NPS 2014).

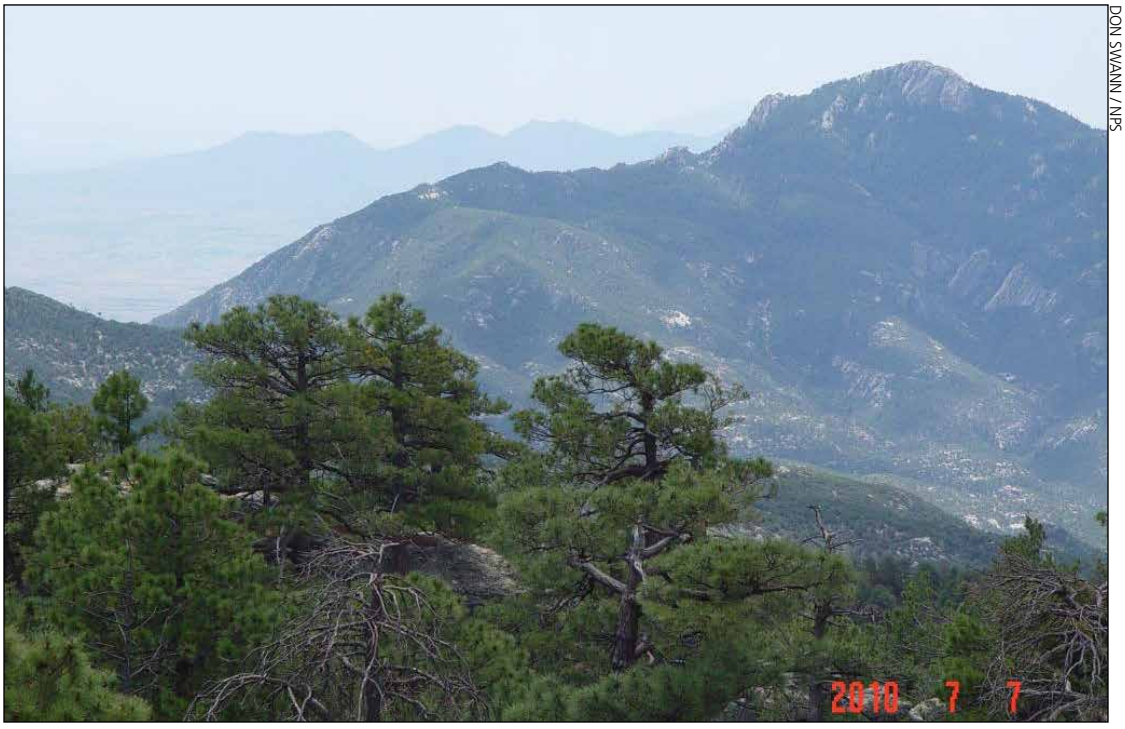

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Figure 4.5.1-1. Saguaro National Park is designated as a Class I airshed.

Air Quality Standards

Air quality is deteriorated by many forms of pollutants that either occur as primary pollutants, emitted directly from sources such as power plants, vehicles, wildfires, and wind-blown dust, or as secondary pollutants, which result from atmospheric chemical reactions. The CAA requires the United States Environmental Protection Agency (EPA) to establish National Ambient Air Quality Standards (NAAQS) (40 CFR part 50) to regulate these air pollutants that are considered harmful to human health and the environment (EPA 2015). The two types of NAAQS are primary and secondary.

Primary standards establish limits to protect human health, and secondary standards establish limits to protect public welfare from air pollution effects, including decreased visibility, damage to animals, crops, vegetation, and buildings (EPA 2015). The NPS' Air Resources Division (NPS-ARD) air quality monitoring program uses EPA's NAAQS, natural visibility goals, and ecological thresholds as benchmarks to assess current conditions of visibility, ozone, and atmospheric deposition throughout parks.

Visibility

Visibility affects how well (acuity) and how far (visual range) one can see (NPS-ARD 2002), but air pollution can degrade visibility. Both particulate matter (e.g. soot and dust) and certain gases and particles in the atmosphere, such as sulfate and nitrate particles, can create haze and reduce visibility.

Visibility can be subjective and value-based (e.g. a visitor's reaction viewing a scenic vista while observing a variety of forms, textures, colors, and brightness) or it can be measured objectively by determining the size and composition of particles in the atmosphere that interfere with a person's ability to see landscape features (Malm 1999). The NRCA's viewshed section (4.1) addresses the subjective aspects of visibility, whereas, this section (4.5) addresses measurements of particles and gases in the atmosphere affecting visibility.

Ozone

Ozone is a gaseous constituent of the atmosphere produced by reactions of nitrogen oxides (NO_x) from vehicles, powerplants, industry, and fire and volatile organic compounds from industry, solvents, and vegetation in the presence of sunlight (Porter and Biel 2011). It is one of the most widespread air pollutants and the major constituent in smog (NPS-ARD 2003). Ozone can be harmful to human health, and it is also phytotoxic, causing foliar damage to plants (NPS-ARD 2003). The foliar damage requires the interplay of several factors, including the interaction of the plant to the ozone, the level of ozone exposure, and the exposure environment. The highest ozone risk exists when the species of plants are highly sensitive to ozone, the exposure levels of ozone significantly exceed the thresholds for foliar injury, and the environmental conditions, particularly adequate soil moisture, foster gas exchange and the uptake of ozone by plants (Kohut 2004).

Ozone penetrates leaves through stomata (openings) and oxidizes plant tissue, which alters the physiological and biochemical processes (NPS-ARD 2013a). Once the ozone is inside the plant's cellular system, the chemical reactions can cause cell injury or even death (NPS-ARD 2013a), but more often reduces the plant's resistance to insects, diseases, growth, and reproductive capability (NPS-ARD 2015b).

Atmospheric Deposition

Airborne pollutants can be atmospherically deposited to ecosystems through rain and snow (wet deposition) or dust and gases (dry deposition). Nitrogen, sulfur, and mercury air pollutants can have a variety of effects on ecosystem health, including acidification, fertilization or eutrophication, and accumulation of toxins (NPS-ARD 2010). Atmospheric deposition can also change soil pH, which in turn, affects microorganisms, understory plants, and trees (NPS-ARD 2010). Certain ecosystems are more vulnerable to pollutants than others, including high-elevation ecosystems in the western United States, upland areas in the eastern part of the country, areas on granitic

bedrock, coastal and estuarine waters, arid ecosystems, some grasslands, and many surface waters (NPS-ARD 2013b).

According to the EPA (2012), in the United States roughly two thirds of all sulfur dioxide (SO_2) and one quarter of all NO_x come from electric power generation that relies on burning fossil fuels. Sulfur dioxide and nitrogen oxides are released from power plants and other sources, and ammonia is released by agricultural activities, feedlots, fires, and catalytic converters. In the atmosphere these transform to sulfate, nitrate, and ammonium and can be transported long distances across state and national borders, with the potential to negatively impact resources (EPA 2012).

Mercury and other toxic pollutants (e.g., pesticides, dioxins, PCBs) accumulate in the food chain and can affect both wildlife and human health. Sources of atmospheric mercury include by-products of coal-fire combustion, municipal and medical incineration, mining operations, volcanoes, and geothermal vents. High mercury concentrations in birds, mammals, amphibians, and fish can result in reduced foraging efficiency, survival, and reproductive success (NPS-ARD 2015c).

4.5.2. Data and Methods

The approach used for assessing the condition of air quality parameters at the park was developed by the NPS-ARD for use in Natural Resource Condition Assessments (NPS-ARD 2015c,d). NPS-ARD uses all available data from NPS, EPA, state, and/or tribal monitoring stations to interpolate air quality values, with a specific value assigned to the maximum value within each park. Even though the data are derived from all available monitors, data from the closest stations will "outweigh" the rest. ARD only uses monitor values for parks that are outside the contiguous U.S. (K. Pugacheva, pers. comm. 2015).

Trends are computed from data collected over a 10-year period at on-site or nearby representative monitors. Trends are calculated for sites that have at least 6 years of annual data and an annual value for the end year of the reporting period.

Indicators/Measures

Visibility (Haze index)

Visibility is monitored through the Interagency Monitoring of Protected Visual Environments (IMPROVE) Program (NPS-ARD 2010) and annual average measurements for Group 50 visibility are averaged over a 5-year period at each visibility monitoring site with at least 3-years of complete annual data. Five-year averages are then interpolated across all monitoring locations to estimate 5-year average values for the contiguous U.S. The maximum value within Saguaro NP boundaries is reported as the visibility condition from this national analysis.

Visibility trends are computed from the Haze Index values on the 20% haziest days and the 20% clearest days, consistent with visibility goals in the CAA and Regional Haze Rule, which include improving visibility on the haziest days and allowing no deterioration on the clearest days. Although this legislation provides special protection for NPS areas designated as Class I, the NPS applies these standard visibility metrics to all units of the NPS. If the Haze Index trend on the 20% clearest days is deteriorating, the overall visibility trend is reported as deteriorating. Otherwise, the Haze Index trend on the 20% haziest days is reported as the overall visibility trend.

For visibility trend analyses, monitoring data from the IMPROVE SAWE1 site (operating since October 2001) was used to represent the Tucson Mountain District (TMD) and IMPROVE site SAGU1 (operating since June 1988) represented the Rincon Mountain District (RMD).

Indicators/Measures

Level of Ozone (Human Health: Annual 4th-highest 8hr concentration and Vegetation Health: 3-month maximum 12hr W126)

Ozone is monitored across the U.S. through air quality monitoring networks operated by

the NPS, EPA, states, and others. Aggregated ozone data are acquired from the EPA Air Quality System (AQS) database. Note that prior to 2012, monitoring data were also obtained from the EPA Clean Air Status and Trends Network (CASTNet) database.

Human Health: Annual 4th-highest 8-hr Concentration

The primary NAAQS for ground-level ozone is set by the EPA, and is based on human health effects. The 2008 NAAQS for ozone was a 4th-highest daily maximum 8-hour ozone concentration of 75 parts per billion (ppb). On October 1, 2015, the EPA strengthened the national ozone standard by setting the new level at 70 ppb (EPA 2016). The NPS-ARD assesses the status for human health risk from ozone using the 4th-highest daily maximum 8-hour ozone concentration in ppb. Annual 4th-highest daily maximum 8-hour ozone concentrations are averaged over a 5-year period at all monitoring sites. Five-year averages are interpolated for all ozone monitoring locations to estimate 5-year average values for the contiguous U.S. The ozone condition for human health risk at the park is the maximum estimated value within park boundaries derived from this national analysis.

Vegetation Health: 3-month Maximum 12-hr W126)

Exposure indices are biologically relevant measures used to quantify plant response to ozone exposure. These measures are better predictors of vegetation response than the metric used for the human health standard. One annual index is the W126, which preferentially weighs the higher ozone concentrations most likely to affect plants and sums all of the weighted concentrations during daylight hours (8am-8pm). The highest 3-month period that occurs during the ozone season is reported in "parts per million-hours" (ppm-hrs), and is used for vegetation health risk from ozone condition assessments. Annual maximum 3-month 12-hour W126 values are averaged over a 5-year period at all monitoring sites with at least three years of complete annual data. Five-year averages are interpolated for all ozone monitoring locations to estimate 5-year average values for the contiguous U.S. The estimated current ozone condition for vegetation health risk at the park is the maximum value within park boundaries derived from this national analysis.

Ozone trend analyses at the park were based on data collected at the local monitoring site, which is operated by the Arizona Department of Environmental Quality (ADEQ) and Pima County personnel. The monitoring station, Saguaro Park East, is located adjacent to RMD's western boundary (AQS Site: 04-019- 0021) and has been in operation year-round since January 1, 1992 (Pima County 2015, NPS-ARD 2015c,d). Annual fourth-highest daily maximum 8-hour average ozone concentrations (ppb) are used to calculate human health based ozone trends. Trends for vegetation-based ozone trends use annual 3-month maximum 12-hour W126 statistic.

Indicators/Measures

Wet Deposition (Nitrogen, Sulfur, and Mercury)

Atmospheric wet deposition is monitored across the United States as part of the National Atmospheric Deposition Program/National Trends Network (NADP/NTN) for nitrogen and sulfur wet deposition and at the Mercury Deposition Network (MDN) for mercury wet deposition.

Wet deposition is used as a surrogate for total deposition (wet plus dry), because wet deposition is the only nationally available monitored source of nitrogen and sulfur deposition data. Values for nitrogen (N) from ammonium and nitrate and sulfur (S) from sulfate wet deposition are expressed as amount of N or S in kilograms deposited over a one-hectare area in one year (kg/ha/yr). For nitrogen and sulfur condition assessments, wet deposition was calculated by multiplying nitrogen (from ammonium and nitrate) or sulfur (from sulfate) concentrations in precipitation by a normalized precipitation. Annual wet deposition is averaged over a 5-year period at monitoring sites with at least 3 years of annual data. Five-year averages are then interpolated across all monitoring locations to estimate 5-year average values

for the contiguous U.S. For individual parks, minimum and maximum values within park boundaries are reported from this national analysis. To maintain the highest level of protection in the park, the maximum value is assigned a condition status.

Wet deposition trends are evaluated using pollutant concentrations in precipitation (micro equivalents/liter) so that yearly variations in precipitation amounts do not influence trend analyses. There are no on-site or nearby representative monitors to assess wet deposition trends for Saguaro NP. The closest monitoring stations for nitrogen and sulfur are located at Oliver Knoll, 132 km (82 mi) northeast of the park; at Organ Pipe Cactus National Monument, 187 km (116 mi) southwest of the park; and at Chiricahua National Monument, 180 (112 mi) east of the park (NPS ARD 2015a).

The condition of mercury was assessed using estimated 3-year average mercury wet deposition (μg/m2/yr) and the predicted surface water methylmercury concentrations at NPS Inventory and Monitoring parks. It is important to consider both mercury deposition inputs and ecosystem susceptibility to mercury methylation when assessing mercury condition because atmospheric inputs of elemental or inorganic mercury must be methylated before it is biologically available and able to accumulate in food webs (NPS-ARD 2015c). Thus, mercury condition cannot be assessed according to mercury wet deposition alone. Other factors like environmental conditions conducive to mercury methylation (e.g., dissolved organic carbon, wetlands, pH) must also be considered (NPS 2015b).

Annual mercury wet deposition measurements are averaged over a 3-year period at all NADP-MDN monitoring sites with at least 3 years of annual data. Three-year averages are then interpolated across all monitoring locations using an inverse distance weighting method to estimate 3-year average values for the contiguous U.S. For individual parks, minimum and maximum values within park boundaries are reported from this national analysis. There are no on-site or nearby representative monitors to assess a trend for mercury wet deposition at Saguaro NP. The closet monitoring stations are Converse Flats in San Bernardino County, California and Mesa Verde National Park in Montezuma County, Colorado.

Conditions of predicted methylmercury concentration in surface water are obtained from a model that predicts surface water methylmercury concentrations for hydrologic units throughout the U.S. based on relevant water quality characteristics (i.e., pH, sulfate, and total organic carbon) and wetland abundance (USGS 2015). The predicted methylmercury concentration at a park is the highest value derived from the hydrologic units that intersect the park.

4.5.3. Reference Conditions

The reference conditions against which current air quality indicators and measures were assessed are identified by NPS ARD (2015d) for condition assessments and are listed in Table 4.5.3-1.

Table 4.5.3-1. Reference conditions for air quality parameters.

Air Quality Indicator/Measure	Very Good	Good	Moderate Concern	Significant Concern
Visibility/Haze Index (dv)	n/a	< 2	2-8	>8
Ozone: Human Health (ppb)	n/a	≤ 54	55-70	≥ 71
Ozone: Vegetation Health (ppm-hrs)	n/a	<7	7-13	>13
N and S Wet Deposition (kg/ha/yr)	n/a	< 1	1-3	>3
Mercury Wet Deposition (μg/m2/yr)	< 3	≥ 3 and < 6	≥ 6 and < 9	≥ 9 and < 12
Predicted Methylmercury Concentration (ng/L)	< 0.038	≥ 0.038 and < 0.053	≥ 0.053 and < 0.075	≥ 0.075 and < 0.12

Data Sources: NPS-ARD (2015d), EPA (2016)

Visibility

A visibility condition estimate of less than 2 dv above estimated natural conditions indicates a "good" condition, estimates ranging from 2-8 dv above natural conditions indicate "moderate" condition, and estimates greater than 8 dv above natural conditions indicate "significant concern." The NPS-ARD chose reference condition ranges to reflect the variation in visibility conditions across the monitoring network.

Ozone

The human health ozone condition thresholds are based on the ozone standard set by the EPA at a level to protect human health: 4th-highest daily maximum 8-hour ozone concentration of 75 ppb, The NPS-ARD rates ozone condition as "good" if the ozone concentration is less than or equal to 60 ppb, which is 80% of the human health-based NAAQS; "moderate" if the ozone concentration is between 61 and 75 ppb; and of "significant concern" if the concentration is greater than or equal to 76 ppb.

The W126 condition thresholds are based on information in EPA's Policy Assessment for the Review of the Ozone National Ambient Air Quality Standards (EPA 2014). Research has found that for a W126 value of:

- ≤ 7 ppm-hrs, tree seedling biomass loss is ≤ 2 % per year in sensitive species; and
- ≥13 ppm-hrs, tree seedling biomass loss is 4–10 % per year in sensitive species.

ARD recommends a W126 of < 7 ppm-hrs to protect most sensitive trees and vegetation and is considered good; 7-13 ppm-hrs to be in "moderate" condition; >13 ppm-hrs is considered to be of "significant concern" (NPS-ARD 2015d).

N and S Wet Deposition

The NPS-ARD selected a wet deposition threshold of 1.0 kg/ha/yr as the level below which natural ecosystems are likely protected from harm, based on studies linking early stages of aquatic health decline correlated with 1.0 kg/ha/yr wet deposition of nitrogen both in the Rocky Mountains (Baron et al, 2011), and in the Pacific Northwest (Sheibely et al. 2014). Parks with less than 1 kg/ha/yr of atmospheric wet deposition of nitrogen or sulfur compounds are assigned "good" condition, those with 1-3 kg/ha/yr are assigned "moderate" condition, and parks with depositions greater than 3 kg/ha/yr to be of "significant concern."

Mercury Wet Deposition and Predicted Methylmercury Concentration

Ratings for mercury wet deposition and predicted methylmercury concentrations were evaluated using the mercury condition assessment matrix shown in Table 4.5.3-2 to identify one of three condition categories. Condition adjustments can be made if the presence of park-specific data on mercury in food webs are available and/or data are lacking to determine the wet deposition rating (NPS-ARD 2015c).

4.5.4. Condition and Trend

The values used to evaluate conditions for all air quality indicators and measures are listed in Table 4.5.4-1 and in Table 4.5.4-2 for trends.

Visibility

The maximum Haze Index value (6.9 dv) within Saguaro NP boundaries based on the estimated 5-year (2009-2013) average warranted a visibility condition status of moderate concern. The long-term visibility trends from 1988-2015 at the RMD monitor, SAGU1, (Figure 4.5.4-1) and from 2001-2015 at the TMD monitor, SAWE1, (Figure 4.5.4-2) improved on both the 20% clearest days and on the 20% haziest days, resulting in an

Table 4.5.3-2. Mercury condition assessment matrix (NPS-ARD 2015d).

Predicted Methylmercury Concentration Rating	Mercury Wet Deposition Rating				
	Very Low	Low	Mod-erate	High	Very High
Very Low					
Low					
Moderate					
High					
Very High					

Condition: Green = Good, Yellow = Moderate, Red = Significant Concern

Table 4.5.4-1. Condition results for air quality measures at Saguaro National Park.

Data Span	Ozone: Human Health (ppb)	Ozone: Vegetation Health (ppm-hrs)	Visibility (dv)	Total N (kg/ha/yr)	Total S (kg/ha/yr)	Mercury (µg/m2/yr)	Mercury (ng/L)
Condition: 2009-2013	Moderate (70.9)	Significant Concern (14.7)	Moderate (6.9)	Significant Concern (3.6)	Moderate (1.6)	Unknown	Significant Concern (0.037 to 0.24)

Data Source: NPS-ARD (2013c)

overall improving visibility trend for Saguaro NP (Colorado State University [CSU] 2015).

The 2003 Haze Index spike shown in the long-term trend trend graphs coincides with increased organic carbon that resulted from the Helen's II fire, which burned during June 2003 in RMD and also from the Aspen wildfire that burned in the Santa Catalina Mountains northeast of Tucson between June and July 2003 (ADEQ 2011).

Table 4.5.4-2. Trends for ozone and visibility at Saguaro National Park (NPS-ARD 2013c).

Air Quality Indicator / Monitor	Trend Years	Trend Result
Ozone: Human and Vegetation Health - 040190021, AZ	2004-2013	Unchanging; no significant trend
Visibility - SAGU1	1988-2015	Improving; significant trend for both clearest and haziest days at both monitors
Visibility - SAWE1	2001-2015	

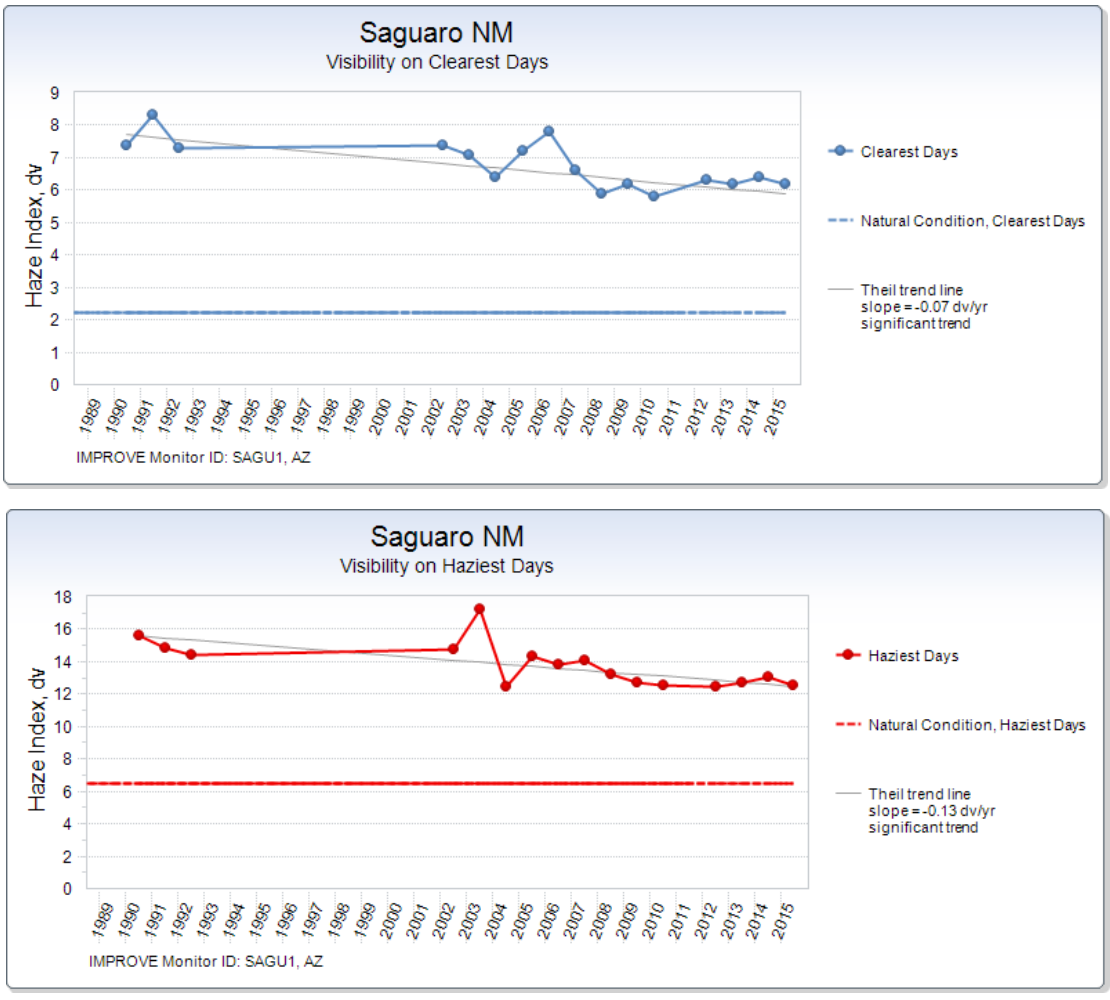


Figure 4.5.4-1. The long term (1988-2015) visibility trends improved for both the 20% clearest (top) and 20% haziest (bottom) days at Rincon Mountain District IMPROVE monitor SAGU1. Figure Credit: Colorado State University (2015).

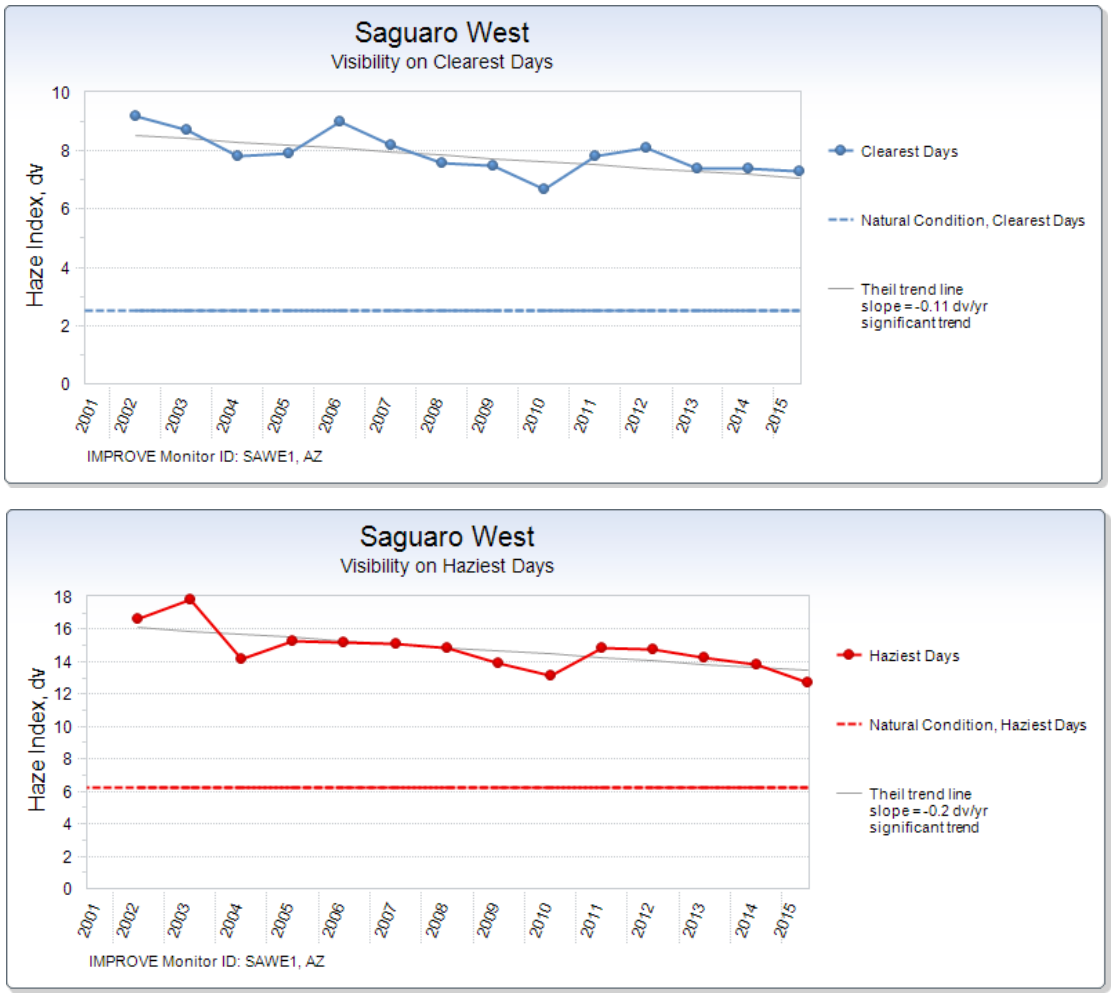


Figure 4.5.4-2. The long term (2001-2015) visibility trends improved for both the 20% clearest (top) and 20% haziest (bottom) days at Tucson Mountain District IMPROVE monitor SAWE1. Figure Credit: Colorado State University (2015).

In 2015, the National Parks Conservation Association (NPCA) released a new air quality analysis of 48 national parks, including Saguaro NP, which was ranked as the twelfth most harmed park for poor air quality related to the inability for "seeing clearly" (NPCA 2015).

The CAA visibility goal requires states to demonstrate reasonable progress towards improving visibility and to remedy any existing impairment, as well as to prevent any future impairments resulting from man-made air pollution (ADEQ 2015). The Arizona Department of Environmental Quality (ADEQ) developed an Arizona Regional Haze State Implementation Plan and established baseline visibility goals for the best and worst days for each class I area using IMPROVE monitoring station data from 2000-2004 and natural conditions estimates using EPA's Regional Haze Rule guidance (ADEQ 2011). ADEQ's 2018 projected visibility estimate during the 20% clearest days (only) suggests the goal will not be met at the RMD monitor, SAGU1. The RMD IMPROVE monitor is very close to Tucson's city limits and more likely influenced by urban emissions than the monitor in TMD since no obstructions are located between the city and RMD where SAGU1 is located (ADEQ 2015). The TMD IMPROVE monitor, SAWE1, is located west of Tucson and separated from the city by the Tucson Mountains, which provide a buffer from pollution sources originating from the city.

Visibility impairment primarily results from small particles in the atmosphere that include natural particles from dust and wildfires and anthropogenic sources from organic compounds, NO_x and SO_2. The contributions to haze made by different classes of particles and monthly distributions on the clearest days and on the haziest days are shown in Figures 4.5.4-3, -4, and -5 for RMD monitor

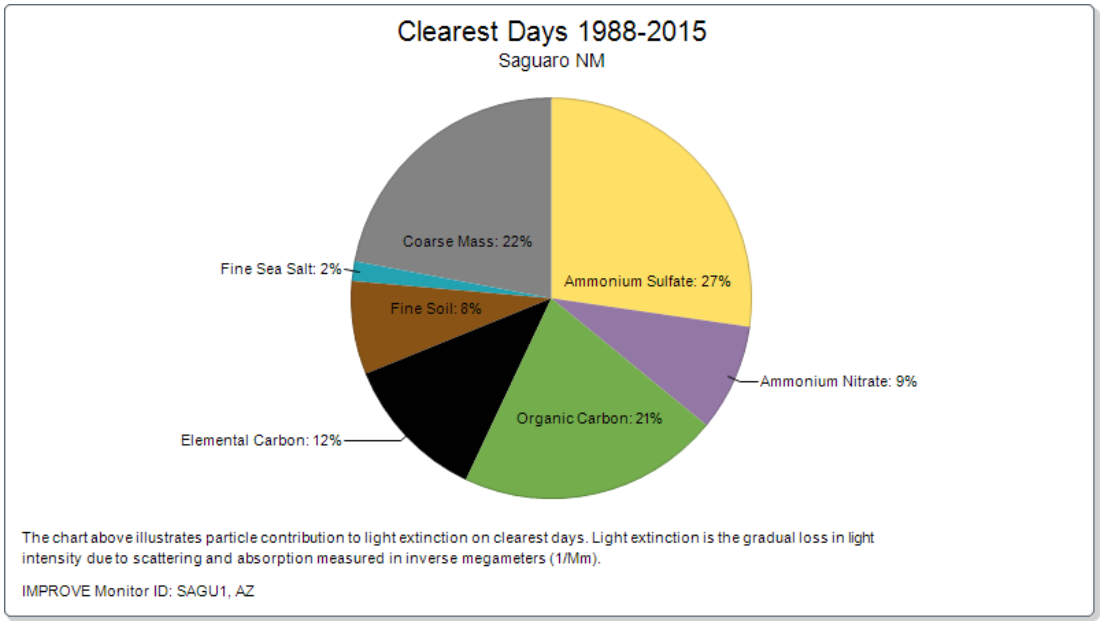


Figure 4.5.4-3. Visibility data collected at RMD's IMPROVE station, SAGU1, showing the composition of particle sources contributing to haze during the clearest days from 1988-2015 (Colorado State University 2015).

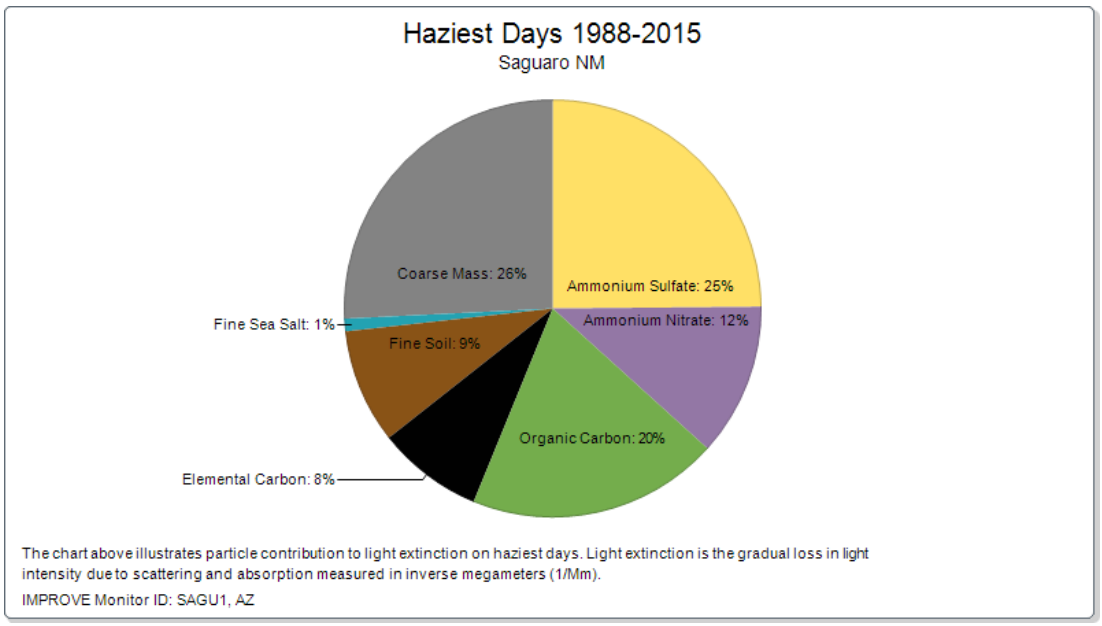
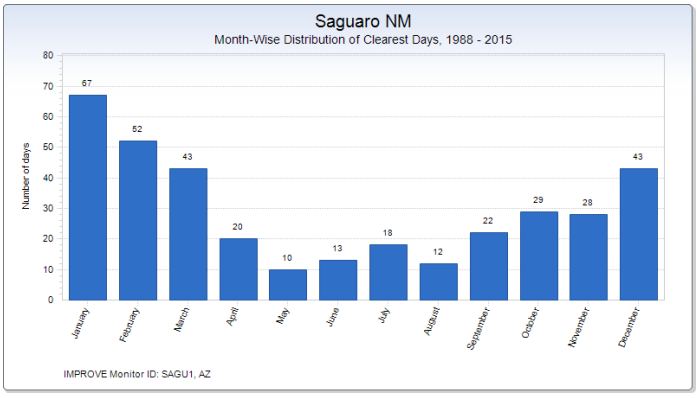


Figure 4.5.4-4. Visibility data collected at RMD's IMPROVE station, SAGU1, showing the composition of particle sources contributing to haze during the haziest days from 1988-2015 (Colorado State University 2015).



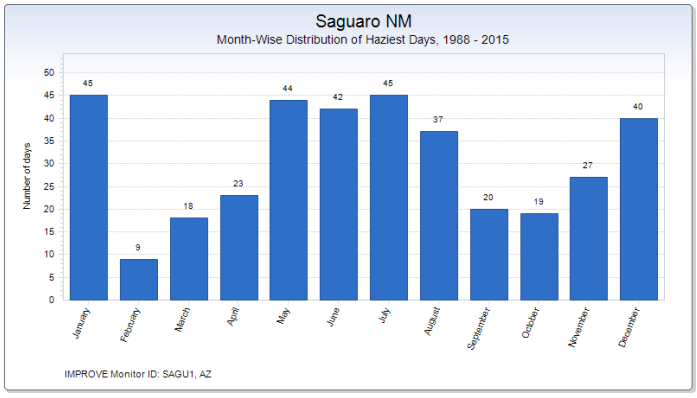


Figure 4.5.4-5. Monthly distribution of clearest days (left) and haziest days (right) from 1988-2015 at RMD's IMPROVE station, SAGU1 (Colorado State University 2015).

SAGU1 and in Figures 4.5.4-6, -7, and -8 for TMD monitor SAWE1.

The primary visibility impairing pollutants at both IMPROVE monitors for the clearest and haziest days were ammonium sulfate, coarse mass, and organic carbon (NPS-ARD 2013c). Ammonium sulfate originates mainly from coal-fired power plants and smelters; coarse mass consists of wind-blown dust, while organic carbon originates primarily from combustion of fossil fuels and vegetation. In general, the clearest days occur during the winter months (Nov.-March) at the two monitors while the haziest days occur from May-August at the RMD SAGU1 monitor and from January - April at the TMD SAWE1 monitor.

According to NPS Air Resources Division (2015e), the high Haze Index at Saguaro NP results in the following impacts:

- reduced visibility, at times, due to human-caused haze and fine particles of air pollution, including dust;
- reduction of the average natural visual range from about 257.5 km (160 mi) (without pollution) to about 161 km (100 mi) because of pollution at the park;
- reduction of the visual range to below 113 km (70 mi) on high pollution days.

The ADEQ monitors progress towards the state's visibility goal and will periodically reevaluate progress towards reaching the goal as new visibility data become available. At present, ADEQ's most current visibility trend (2004-2013) suggests an overall improvement (NPS-ARD 2013c).

Ozone

Ozone data used for the condition assessment were derived from estimated five year average values (2009-2013) of 70.9 parts per billion (ppb) and of 14.7 parts per million-hours (ppm-hrs), which resulted in a moderate condition rating for human health and significant concern for vegetation health, respectively. The ozone trends for human and vegetation health are shown in Figures 4.5.4-9 and 4.5.4-10. For 2004–2013, the trend in 4th highest 8-hour ozone concentration and the W126 metric at Saguaro NP remained relatively unchanged (no statistically significant trend) (AQS Monitor ID: 040190021, AZ).

An ozone risk assessment was conducted by Kohut (2004) for Sonoran Desert parks and concluded that plants in Saguaro NP were at low risk of foliar ozone injury. However, ozone concentrations and cumulative doses at the park are high enough to induce foliar injury to sensitive vegetation under certain conditions (NPS-ARD 2010). Surveys in the early 1990s found slight ozone injury on ponderosa pines (Miller 1996), but the typical dry conditions in the park cause plant stomata to close, limiting ozone uptake. In other parks, scientists have found that in moist areas along streams and seeps, plants may keep stomata open more often, allowing ozone uptake and subsequent injury (Kohut et al. 2012). The nine plants identified as ozone sensitive at the park during the Kohut (2004) effort are listed in Table 4.5.4-3.

An additional 13 plants have also been identified as ozone sensitive at the park and are listed in Table 4.5.4-2 (Bell In Review, NPSpecies 2015). Of the 22 ozone-sensitive plant species, 15 (68.2%) are bioindicators, which can reveal ozone stress in ecosystems by producing distinct visible and identifiable injuries to plant leaves (NPS-ARD 2006b). These species are noted the table.

Wet N Deposition

Wet N deposition data used for the condition assessment were derived from estimated five year average values (2009-2013) of 3.6 kg/ha/yr, which resulted in a significant concern status. No trend could be determined given the lack of nearby monitoring stations (NPS-ARD 2013c).

Ecosystems in the park were rated as having very high sensitivity to nutrient-enrichment effects from nitrogen relative to all Inventory and Monitoring parks (Sullivan et al. 2011 a,b,c,d). Using three data sets, Landscape Fire and Resource Management Planning Tools Project (LANDFIRE), National Wetlands Inventory, and National Land Cover Data, nitrogen-sensitive vegetation for

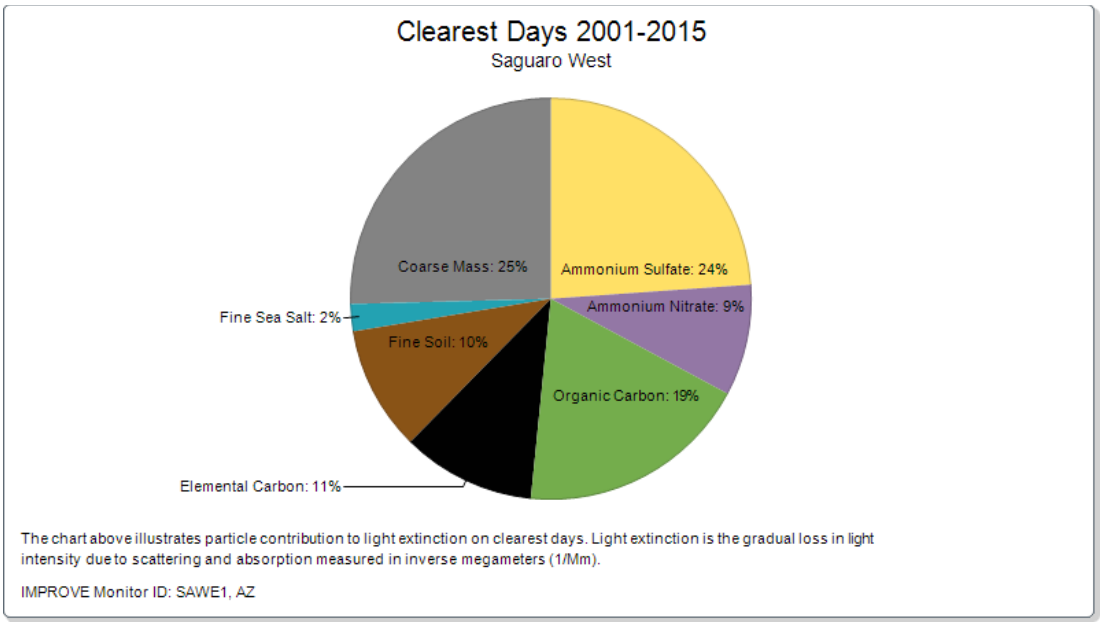


Figure 4.5.4-6. Visibility data collected at TMD's IMPROVE station, SAWE1, showing the composition of particle sources contributing to haze during the clearest days from 2001-2015 (Colorado State University 2015).

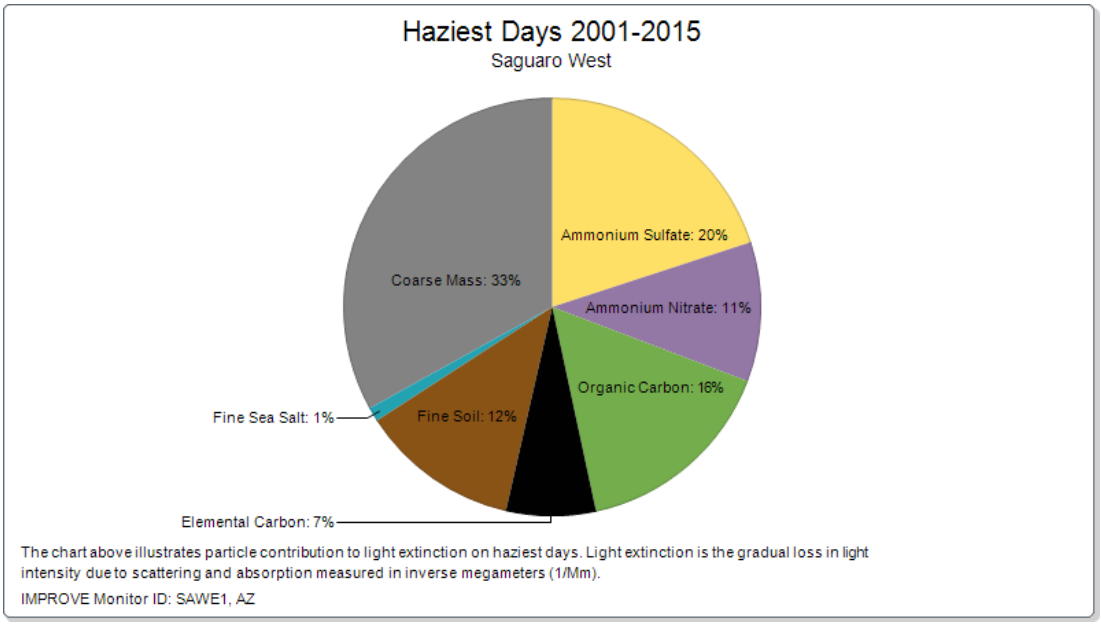


Figure 4.5.4-7. Visibility data collected at TMD's IMPROVE station, SAWE1, showing the composition of particle sources contributing to haze during the haziest days from 2001-2015 (Colorado State University 2015).

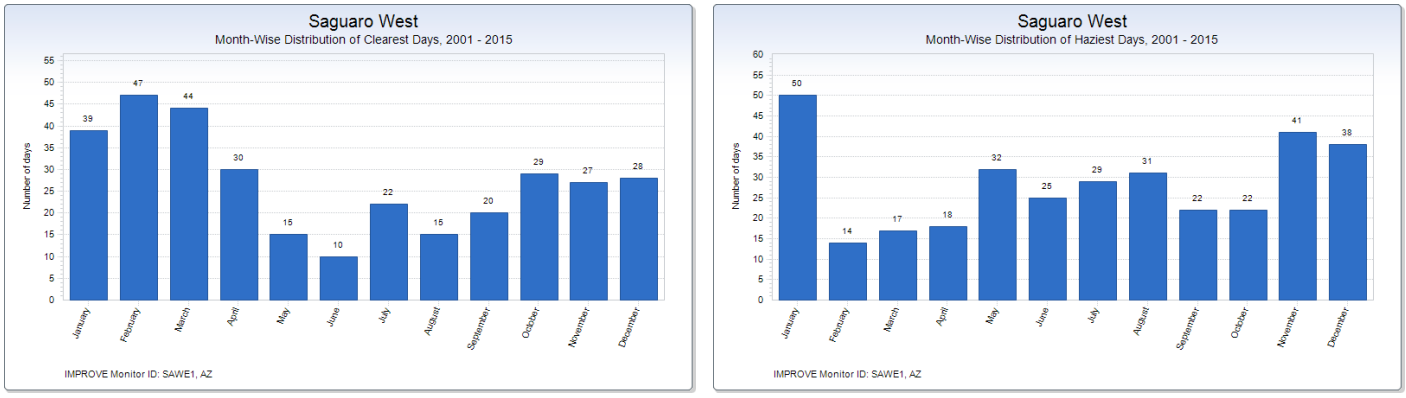


Figure 4.5.4-8. Monthly distribution of clearest days (left) and haziest days (right) from 2001-2015 at TMD's IMPROVE station, SAWE1 (Colorado State University 2015).

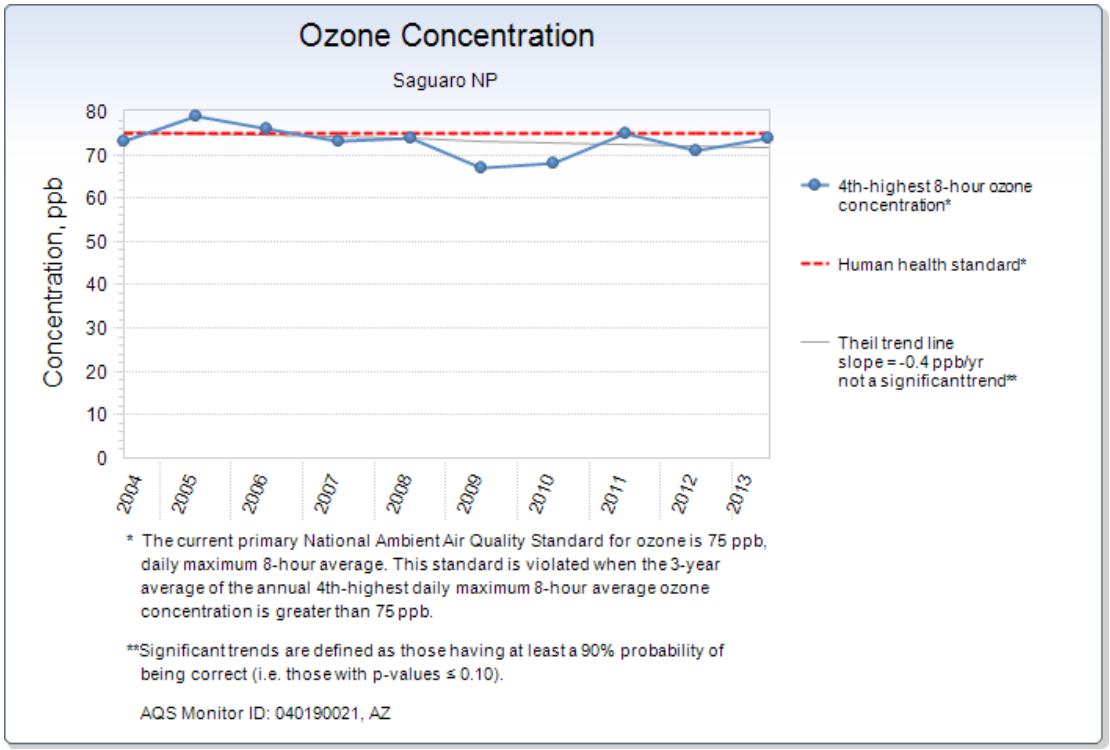


Figure 4.5.4-9. Ozone trend (2004-2013) for human health at Saguaro NP monitor site 040190021. The trend is not statistically significant but is considered to be stable (NPS-ARD 2013c).

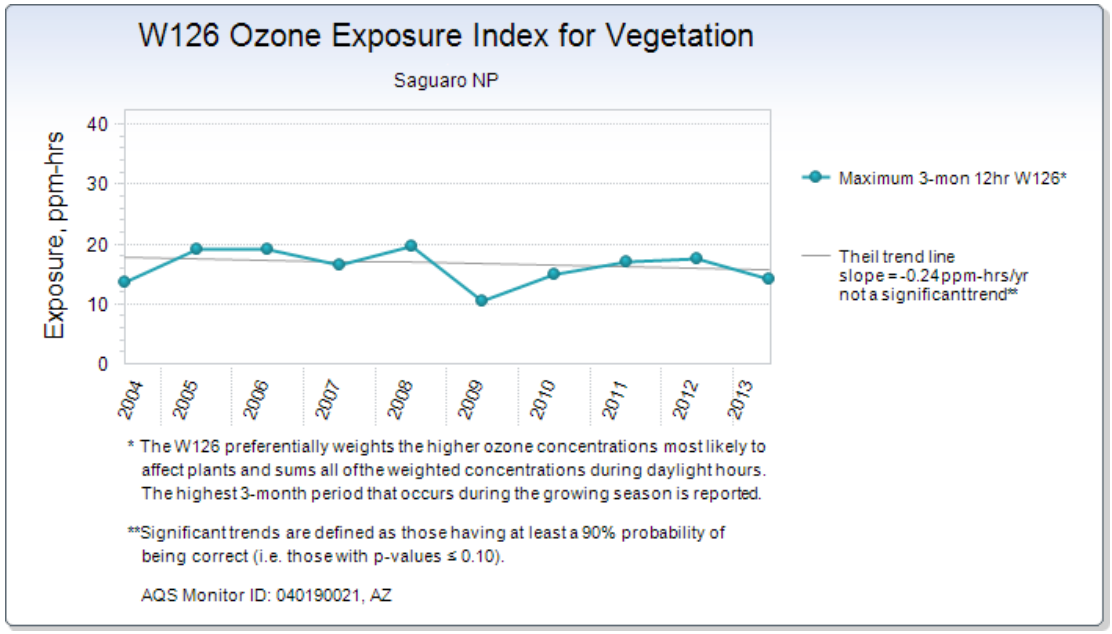


Figure 4.5.4-10. Ozone trend (2004-2013) for vegetation at Saguaro NP monitor site 040190021. The trend is not statistically significant but is considered to be stable (NPS-ARD 2013c).

the park was identified (E&S Environmental Chemistry, Inc. 2009). The LANDFIRE data set was the only one that contained N sensitive communities, arid and semi-arid and grassland and meadows, for the park and locations of these communities within each park district are shown in Figure 4.5.4-11.

In addition to assessing wet deposition levels, critical loads can also be a useful tool in determining the extent of nitrogen deposition impacts (i.e., nutrient enrichment) to park resources. A critical load is defined as a level of deposition below which harmful effects to the ecosystem are not expected. For Saguaro NP, Pardo et al. (2011) suggested following critical load ranges for total nitrogen deposition in the North American Desert Ecoregion:

- 3.0–3.0 kg/ha/yr to protect lichen
- 3.0–8.4 kg/ha/yr to protect herbaceous vegetation

Table 4.5.4-3. Ozone sensitive plants at Saguaro National Park.

Scientific Name	Common Name	Bioindicator
Acer negundo	boxelder	Yes
Achillea millefolium[1]	western yarrow	No
Apocynum androsaemifolium[2]	spreading dogbane	Yes
Apocynum cannabinum	Indianhemp	No
Artemisia ludoviciana	white sagebrush	Yes
Cephalanthus occidentalis	common buttonbush	Yes
Fraxinus anomala	singleleaf ash	Yes
Mentzelia albicaulis	smallflower blazing star	Yes
Oenothera elata[2]	Hooker's evening primrose	Yes
Parthenocissus quinquefolia	American ivy	No
Parthenocissus vitacea	Virginia creeper	No
Pinus ponderosa[2]	ponderosa pine	Yes
Populus fremontii	Fremont cottonwood	Yes
Populus tremuloides[2]	quaking aspen	Yes
Prunus serotina	black cherry	Yes
Prunus virginiana	chokecherry	No
Rhus aromatica[2,3]	Sumac	Yes
Rudbeckia laciniata[2]	cutleaf coneflower	Yes
Salix exigua	narrowleaf willow	No
Salix gooddingii[2]	Goodding's willow	No
Salix scouleriana[2]	Scouler's willow	Yes
Sambucus nigra[2,4]	black elderberry	Yes

Data Sources: Bell, In Review; Kohut (2004), and NPSpecies (2015).

[1] This is a non-native species.

[2] These species were identified by Kohut (2004) as ozone sensitive.

[3] Kohut (2004) identified this as *Rhus trilobata*.

[4] Kohut (2004) identified this as *Sambucus mexicana*.

To maintain the highest level of protection in the park, the minimum of the critical load ranges (3.0 kg/ha/yr) is an appropriate management goal.

While nitrogen is necessary for plants to grow, too much of it can disrupt the balance of vegetation communities. Nitrogen deposition may also disrupt soil nutrient cycling and affect biodiversity of some plant communities, including arid and semi-arid grasslands. Invasive non-native grasses tend to thrive in areas with elevated nitrogen deposition, displacing native vegetation adapted to low nitrogen conditions. In nearby desert ecosystems, an increase in nitrogen has been found to promote invasions of fast-growing exotic annual grasses (e.g., cheatgrass (*Bromus tectorum*)) and forbs (e.g., Russian thistle (*Salsola kali*)) at the expense of native species (Brooks 2003; Allen et al. 2009; Schwinning et al. 2005).

Buffelgrass (*Pennisetum ciliare*) is an invasive non-native grass of particular concern at the park and throughout the Sonoran Desert ecosystem. Nitrogen favors buffelgrass over native species in similar ecosystems, as it is able to rapidly absorb and assimilate nitrogen (Lyons et al. 2013). Greater cover of non-native invasive grasses, including buffelgrass, has been shown to increase fire risk in arid areas (Rao et al. 2010). Interactions between nitrogen, invasive annual grasses, and fire have profound implications for changes to biodiversity in non-fire adapted ecosystems (e.g., Sonoran Desert). Saguaros and many

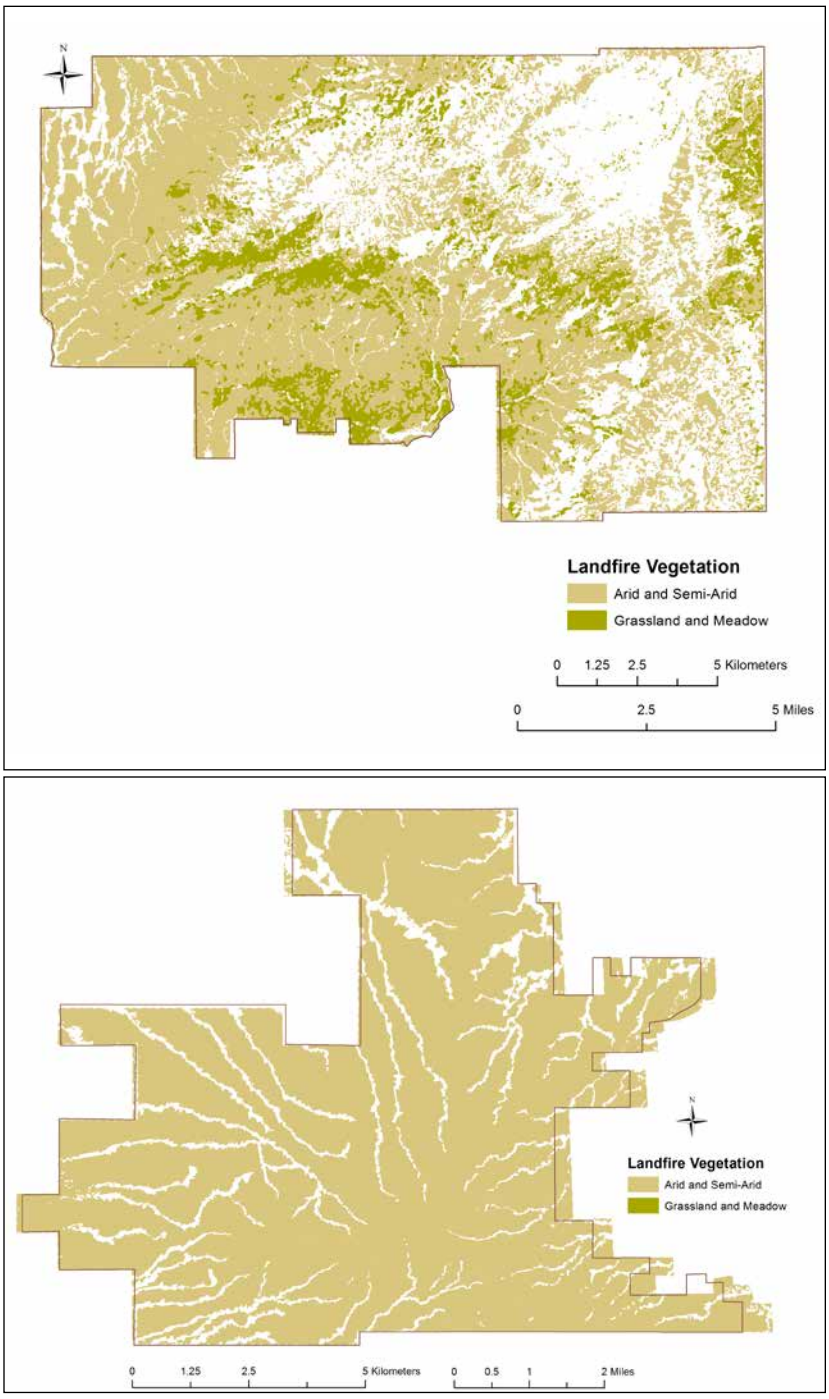


Figure 4.5.4-11. Locations of LANDFIRE nitrogen sensitive vegetation in Saguaro National Park's Rincon Mountain District (top) and Tucson Mountain District (bottom).

other native plants and animals did not evolve with fire and can die from hot intense fires.

Wet S Deposition

Wet S deposition data used for the condition assessment were derived from estimated five year average values (2009-2013) of 1.6 kg/ha/yr, which resulted in a moderate concern status. No trend could be determined given the lack of nearby monitoring stations (NPS-ARD 2013c).

Ecosystems in the park were rated as having high sensitivity to acidification effects relative to all Inventory & Monitoring parks (Sullivan et al. 2011 a,b). Acidification effects can include changes in water and soil chemistry that impact ecosystem health. Small streams with steep-sided canyon walls in higher elevations of the park - far from the park's popular cactus forests - have little ability to retain nutrients and water, offering the landscape little opportunity to buffer potentially acidic run-off. Perennial pools in lush desert oases in the park may also be sensitive to acid deposition, but there is no evidence that acidification has occurred in streams or pools, and many areas of the park are well-buffered from acidification (NPS-ARD 2013c).

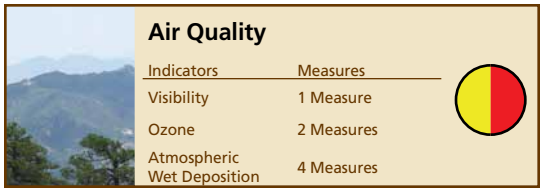
In general, nitrate, sulfate, and ammonium deposition levels have changed over the past 20 years throughout the United States. Regulatory programs that mandated a reduction in emissions have proven effective for decreasing both sulfate and nitrate ion deposition primarily through reductions from electric utilities, vehicles, and industrial boilers, although a rise in ammonium ion deposition has occurred in large part due to the agricultural and livestock industries (NPS-ARD 2009). A study conducted by Lehmann and Gay (2011) showed a decrease in sulfate concentrations but an increase in nitrate concentrations from 1985-2009 in the area surrounding the park. Only the sulfate trend was statistically significant (Lehmann and Gay 2011). It seems reasonable to expect a continued improvement in sulfate deposition levels because of Clean Air Act requirements, however, at this time, ammonium levels are not regulated by the EPA and may continue to rise as a result (NPS-ARD 2010).

Wet Deposition: Mercury and Predicted Methylmercury Concentration

While the 2011–2013 estimated wet mercury deposition value was not available due to lack of monitoring coverage in the area, the predicted methylmercury concentration in park surface waters was very high, ranging

from 0.037 to 0.24 nanograms per liter (USGS 2015) and of significant concern. Although surface waters are limited within the park, there are ephemeral surface waters and springs, and the predicted concentrations of methylmercury are very high as compared to other NPS units (USGS 2015). A recent study found elevated mercury levels in small prey fish (speckled dace) in desert rivers at Zion and Capitol Reef national parks (Eagles-Smith et al. 2014). The predicted high concentrations at Saguaro NP warrant further study for levels in park biota (NPS-ARD 2013c).

Beginning in 2014, up to 50 national parks, including Saguaro NP, participated in a citizen science study, Dragonfly Mercury Project (DMP). Students and volunteers collected dragonfly larvae from sampling sites, and the samples were sent to the University of Maine, US Geological Survey, or Dartmouth College laboratories for mercury analyses. According to NPS ARD, "the study will provide baseline data to better understand the spatial distribution of mercury contamination in national parks" (NPS-ARD 2016). Sampling continued in 2016 and the DMP is expected to continue into the future (NPS-ARD 2016).



Overall Condition and Trend

For assessing the condition of air quality, we used three air quality indicators, which are summarized in Table 4.5.4-4. We consider the overall condition of air quality at Saguaro National Park to be of moderate to significant concern, with unchanging trends for ozone and an improving trend for visibility on both the clearest and haziest days at both monitoring locations. Trends for the wet deposition measures could not be determined since no monitoring sites are located within the requisite distances to be representative of the conditions at the park.

Level of Confidence/Key Uncertainties

A key uncertainty of the air quality section is knowing the effect(s) of air pollution, especially nitrogen and mercury deposition, on ecosystems at the park. Additional uncertainties associated with air quality impacts include increasing urbanization surrounding Tucson, local and regional mining operations (e.g., Rosemont Copper Mine), continued spread of buffelgrass, and climate change. Air quality will also likely be adversely impacted from fires at least on a short-term basis (Figure 4.5.4-12) (refer to visibility discussion, which includes air quality impacts from the 2003 wildfires). While the park has a cooperative agreement with Pima County for monitoring some of the air quality parameters, staff have identified a medium priority need for an air quality management plan and/or increased collaboration with surrounding cities to be more proactive with managing air quality issues (NPS 2014).

Since there are representative visibility and ozone monitors, we have more confidence in the ozone and visibility condition estimates (i.e. high confidence) since closer monitors have a higher weight in the estimate determination, whereas there is more uncertainty when using interpolated estimates for condition assessments for wet deposition (i.e. medium confidence).

4.5.5. Sources of Expertise

The National Park Service's Air Resources Division oversees the national air resource management program for the NPS. Together with parks and NPS regional offices, they monitor air quality in park units and provide air quality analysis and expertise related to all air quality topics. They also provide condition assessment guidance, data, and trend analysis, routinely updating the 5-year averages from which air quality conditions are evaluated. This section was authored by Kim Struthers.

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Figure 4.5.4-12. Smoke from Helen's II 2003 wildfire in Rincon Mountain District.

Table 4.5.4-4. Summary of the air quality indicators, measures, and condition rationale.

Indicator	Measure(s)	Condition	Condition Rationale
Visibility	Haze Index	Moderate	Visibility warrants moderate concern at Saguaro NP based on NPS ARD benchmarks and the 2009–2013 estimated visibility on mid-range days of 6.9 deciviews (dv) above estimated natural conditions. The trend in visibility improved on the 20% clearest days and improved on the 20% haziest days at both monitors (IMPROVE SAGU1 and SAEW1). The Clean Air Act visibility goal requires visibility improvement on the 20% haziest days, with no degradation on the 20% clearest days. The confidence level is high due to the proximity of the monitoring station.
Level of Ozone	Human Health: Annual 4th-Highest 8-hour Concentration	Moderate	Human health risk from ground-level ozone warrants moderate concern at Saguaro NP. This condition is based on NPS ARD benchmarks and the 2009–2013 estimated ozone of 70.9 parts per billion (ppb). For 2004–2013, the trend in ozone concentration at Saguaro NP remained relatively unchanged and was not statistically significant. The confidence level is high since there is an on-site or nearby ozone monitoring station.
	Vegetation Health (ppm-hrs)	Significant Concern	Vegetation health risk from ground-level ozone warrants significant concern at Saguaro NP. This condition is based on NPS Air Resources Division benchmarks and the 2009–2013 estimated W126 metric of 14.7 parts per million-hours (ppm-hrs). The W126 metric relates plant response to ozone exposure, however, a risk assessment concluded that plants in Saguaro NP were at low risk for ozone damage (Kohut 2007; Kohut 2004). See list of ozone-sensitive plant species. For 2004–2013, the trend for W126 remained relatively unchanged and was not statistically significant trend. The degree of confidence in the evaluation is high because there is an on-site or nearby ozone monitor.
Wet Deposition	Total Nitrogen	Significant Concern	From 2009-2013, the average estimated wet nitrogen deposition was 3.6 kilograms per hectare per year, warranting significant concern based on NPS ARD benchmarks. No NPS-ARD trend information is available for nitrogen because there are not sufficient on-site or nearby deposition monitoring sites, and as a result, the confidence level for the assessment is medium.
	Total Sulfur	Moderate	From 2009-2013, the average estimated wet sulfur deposition was 1.6 kilograms per hectare per year, warranting moderate condition based on NPS ARD benchmarks. No NPS-ARD trend information is available for sulfur because there are not sufficient on-site or nearby deposition monitoring sites, and as a result, the confidence level for the assessment is medium.
	Mercury	Unknown	No data exist for the park to evaluate this measure resulting in an unknown condition.

Table 4.5.4-4. Summary of the air quality indicators, measures, and condition rationale continued.

Indicator	Measure(s)	Condition	Condition Rationale
Wet Deposition	Predicted Methylmercury Concentration	Significant Concern	The predicted concentrations of methylmercury in surface waters at the park are very high as compared to other NPS units, warranting significant concern. No NPS-ARD trend information is available because there are insufficient on-site or nearby deposition monitoring sites. As a result, the confidence level for the assessment is low.

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4.6. Surface Water Quantity in the Middle Reach of Rincon Creek

Indicators/Measures

- Water Quantity (4 Measures)

Condition – Trend - Confidence

Moderate to Significant Concern-Deteriorating-High

4.6.1. Background and Importance

Streams and rivers are the integrators within a landscape. Inputs, such as energy and nutrients, provide a wide variety of ecosystem services including habitat for plants and animals, and recreational opportunities and water supplies for humans. Since streams and rivers are generally sensitive to stressors, both locally and at the watershed-level, they are one of the most useful ecosystems to monitor to determine long-term conditions and trends (NPS I&M 2012).

A significant determinant of the health of riparian areas is streamflow. In Saguaro National Park's subtropical desert environment, streamflow is greatest during the months of July-September and December-March, but some flow occurs at other times of the year due to groundwater inputs (groundwater will be addressed in a separate assessment) (Perger 2014b). Approximately half of the annual precipitation in Saguaro NP arrives during the monsoon months of July-September, usually in the form of violent, localized storms resulting in flash flood events (Perger 2014b). An additional 25% of precipitation falls as snow during December-February. In spring, snowmelt provides more gradual and consistent surface water to streams and rivers than monsoon rains, but both are important components to regional hydrology (Perger 2014b).

Rincon Creek (Figure 4.6.1-1) is an intermittent stream located in Saguaro National Park's Rincon Mountain District (RMD) and on private lands. The creek's watershed extends into the high elevations of the Rincon Mountains up to 2,585 m (8,482 feet). The creek flows through the park before entering private lands, and then re-enters the park in what is known as the

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Figure 4.6.1-1. Middle reach of Rincon Creek in Saguaro National Park.

expansion area (NPS 2008a). The 1,664 ha (4,111 acre) expansion area was added to Saguaro NP in 1991, when the park was still a national monument; it was designated a national park by Congress on October 14, 1994 (NPS 2014). The expansion area was added because of the exceptional quality of the riparian area along Rincon Creek. The riparian corridor provides habitat for a wide variety of flora and fauna, many of which depend on the creek for water, food, breeding habitat, and refuge from predators (NPS 2014).

The Rincon Creek watershed covers a 11,655 ha (28,800 acre) upstream of the USGS gage, approximately half of which lies within the RMD (Swann et al. 2014). The watershed includes three major tributaries (Chimenea Creek, Madrona Creek and the main stem of Rincon Creek) which drain into an area known as the middle reach of Rincon Creek (Figure 4.6.1-2) (Swann et al. 2014).

Rincon Creek is the largest and most well developed riparian woodland in Saguaro NP with Freemont cottonwood (*Populus*

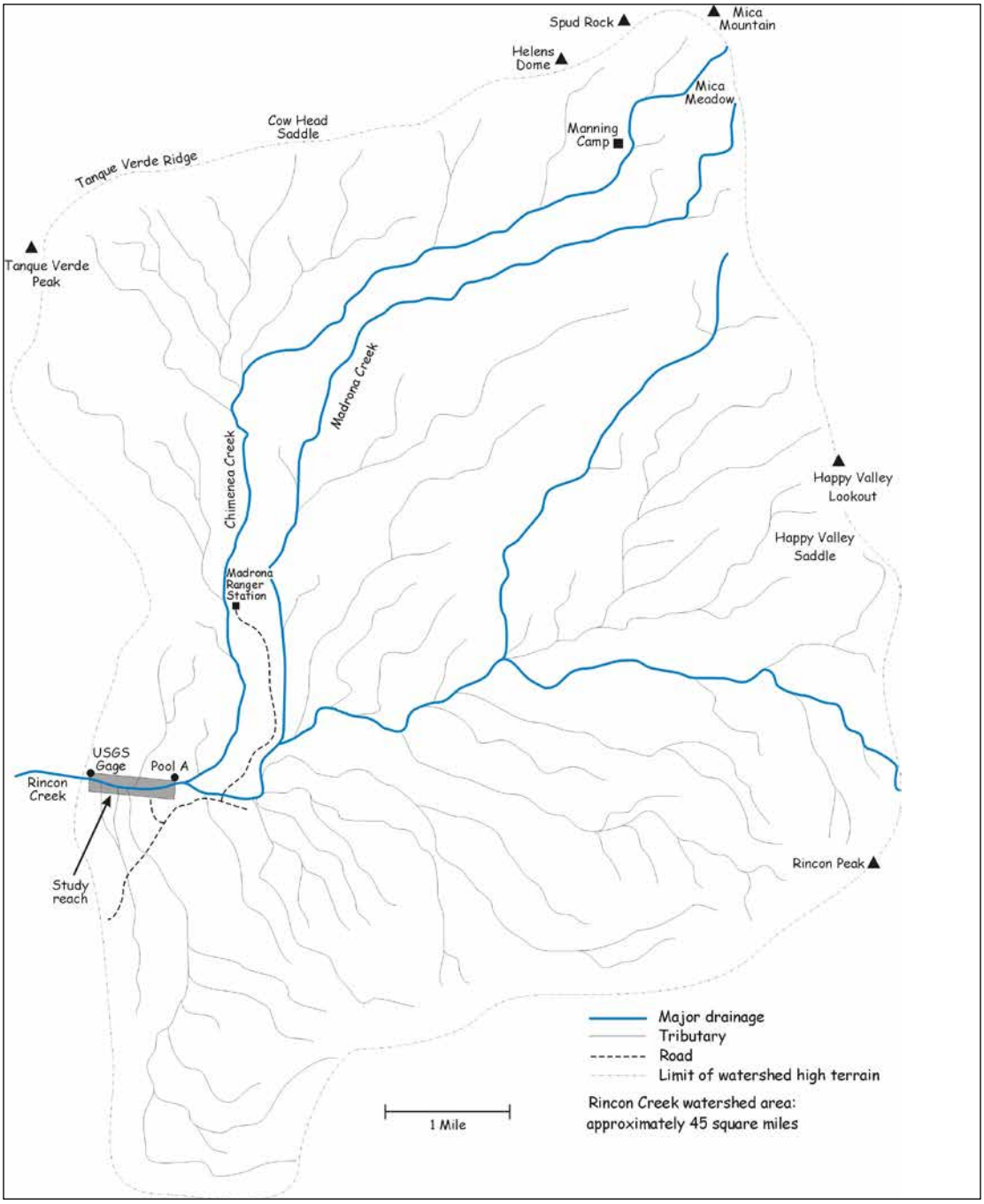

Figure 4.6.1-2. Map of the Rincon Creek watershed showing the USGS Gage and Pool A in the middle reach of Rincon Creek. Figure excerpted from Perger 2014b.

fremonti), Arizona sycamore (*Platanus wrightii*), velvet ash (*Fraxinus velutina*), willow (*Sailix* spp.), and netleaf hackberry (*Celtis reticulata*) growing along its banks (Baird et al. 2001). Riparian woodlands represent only 0.5% of the landscape in Arizona, yet they represent some of the most diverse plant and animal communities in the region, especially with respect to birds (Johnson et al. 1977). Bird diversity tends to increase with increasing structural complexity of vegetation, but surface water is also important because it attracts a higher diversity of invertebrate prey (Kirkpatrick et al. 2009). Amphibians require persistent pools of water in Rincon Creek for breeding and many species of mammal rely on surface water for drinking and foraging (NPS 2008, Stitt et al. 2008).

National Park Service (NPS) management policies (2006) state that parks must "perpetuate surface waters and groundwaters as integral components of park aquatic and terrestrial ecosystems." To this end, NPS policy is that the agency should consider all available and legal options in order to protect water-related resources within the park (NSP 2008a).

Protecting the surface water in Rincon Creek is considered very important to the park for a number of reasons, especially its great value for wildlife (Figure 4.6.1-3). While not perennial, Rincon Creek is the most reliable in the park, flowing in some years during the entire year. The riparian woodland in the creek contains the greatest diversity of birds in the park, including breeding populations of species such as Yellow-billed Cuckoo (*Coccyzus americanus*) and Gray Hawk (*Buteo plagiatus*), and is considered one of the most significant areas for birds in the Tucson area (Powell 2004, Conway et al. 2012). The creek and its tributaries also contain some of the regions's most stable populations of the lowland leopard frog (*Rana* [or *Lithobates] yavapaiensis*) as well as other aquatic species such as Sonoran mud turtles (*Kinosternon sonoriense*), and supports an important mammal community that includes coati (*Nasua narica*), black

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Figure 4.6.1-3. Rincon Creek supports a variety of wildlife as shown clockwise from upper left: mule deer, Black Phoebe, Sonoran mud turtle and lowland leopard frog.

bear (*Ursus americanus*), and mountain lions (*Puma concolor*).

On July 13, 2001, The Arizona Department of Water Resources issued a Certificate of Assured Water Supply No. 27-400201 to Mountain Creek Ranch (a subdivision) near Rincon Creek (NPS 2008a). The Certificate was for a three-fold increase in water withdrawal from the Rincon Creek watershed (NPS 2008a). The park became concerned about the effects this increase would have on wildlife, plants, and the recreational value of the creek. To determine the amount of water needed to support the riparian and aquatic ecosystems within the middle reach, the NPS conducted hydrologic studies beginning in 2003 (NPS 2008a). Data collected during these studies were used to complete a water right application (No. 33-96733), requesting instream-flow maintenance from the Arizona Department of Water Resources (NPS 2008a,b). The status of the water right application has not been resolved; however, the NPS has continued hydrologic studies in the middle reach to monitor long-term changes in water resources and their effects on wildlife and plants. Data from the NPS hydrologic studies were used in this assessment.

4.6.2. Data and Methods

This assessment is based on one indicator with four measures. The indicator is water quantity and the four measures are trend in mean annual discharge, minimum daily discharge per month, number of dry days per year in Pool A, and number of dry days per year at the USGS gage.

Data used in this assessment were obtained from two locations in the middle reach of Rincon Creek: the USGS gaging station (No. 09485000) and Pool A. The USGS station Station, located at the mid-point of the reach, has been operated by the USGS from October 1952 through September 1974 and from October 1988 to the present. Pool A, located at the upstream end of the reach, has been operated by the NPS since June 2003 (NPS 2008a). Pool A is approximately 23 m (77 feet) long with a maximum depth of 0.6 m (1.9 feet) and a surface area of about 102 square meters (1,100 square feet) (NPS 2008).

Indicator/Measures

Water Quantity (Trend in Mean Annual Discharge, Minimum Daily Discharge per Month, Number of Dry Days Per Year in Pool A, and Number of No-Flow Days Per Year at the USGS gage)

Trend in Mean Annual Discharge

To assess the trend in mean annual discharge we downloaded mean monthly discharge data (1952-2013) from the USGS's National Water Information System website on January 21, 2016 (http://waterdata.usgs.gov/nwis). We excluded all years with fewer than 12 months of data (20 years) then calculated the mean annual discharge in acre feet/yr for the remaining 44 years and examined trends over time.

Minimum Daily Discharge Per Month

In the the water right application the NPS requested a minimum daily discharge per month, or the natural flow whenever the natural flow is less than the requested minimum daily discharge (Table 4.6.2-1; NPS 2008). These recommendations ensure that water is available in Rincon Creek for wildlife and recreational purposes.

To assess the current condition of stream discharge in Rincon Creek we downloaded daily mean discharge data from January 2003 through December 2014 from the USGS's National Water Information System website on January 21, 2016 (http://waterdata.usgs.gov/nwis). We removed all days for which there were no data available and determined the number of days which met the recommended mean daily discharge for each month during the 12-year period. We then calculated the proportion of days per month for each year during the 12-year period that met the minimum daily discharge recommendations. We used the proportion of days rather than the number of days to control for missing daily data.

Since the minimum recommendations for water discharge in Rincon Creek are on a daily basis, any one day could be dry as a

Table 4.6.2-1. Requested minimum daily discharge to maintain resource condition within the middle reach of Rincon Creek (NPS 2008a, page 27).

Month	Minimum Daily Discharge (ft^3/s)
January	1.50
February	1.50
March	3.00
April	2.00
May	1.00
June	0.50
July	0.20
August	1.00
September	1.00
October	0.50
November	0.50
December	0.50

result of natural variation in flow due to precipitation, snowmelt, or groundwater recharge; domestic use of water through private wells, ranches, and subdivisions; or a combination of these factors. Therefore, we obtained water use data from the Rincon Water Company (RWC) (data provided by Colleen Filippone, NPS Intermountain Region hydrologist) to determine if water withdrawal has changed between two time periods: 1986-2001 (prior to the Certificate of Assured Water Supply) and 2002-2014 (after the Certificate of Assured Water Supply) (NPS 2008a). We compared the mean water withdrawal between these two time periods. If water use did not differ between these two time periods, we attributed days with lower than the recommended flow as natural flow; however, we acknowledge that private wells located in the watershed were not accounted for in the Rincon Water Company data.

Number of Dry Days Per Year

To determine the average number of dry days per year in Pool A we used Table 2 in Perger 2014a. The wet/dry data presented in Table 2 were extracted from the Pool A data logger installed in June 2003. Readings were recorded in 15-minute intervals (Perger 2014b). The data logger may have recorded water in the pool even when the pool appeared dry. This is because water was present below the sediment level, as was often the case (Perger 2014a).

Number of No-Flow Days/Year

Since the USGS gage may not register discharge when the Pool A data logger records water in the pool or vice versa, we also determined the number of no-flow days per year at the USGS gage. We downloaded daily mean discharge data for calendar years 2003 through 2014 from the USGS's National Water Information System website on January 21, 2016 (http://waterdata.usgs.gov/nwis). We excluded all days with no data and all days where the flow was greater than 0.0 ft^3/s to determine the number of no-flow days per year.

4.6.3. Reference Conditions

Reference conditions for this assessment are shown in Table 4.6.3-1. Reference conditions are described for resources in good condition, moderate concern, and significant concern for the four measures of water quantity in the middle reach of Rincon Creek.

4.6.4. Condition and Trend

Trend in Mean Annual Discharge

Mean annual discharge, as measured at the USGS gage, exhibited high variability from year to year (Figure 4.6.4-1). The mean discharge was 4,207 A-ft per year and the median discharge was 2,899 A-ft per year. The maximum discharge was 21,703 A-ft per year and occurred during 1993 while the minimum discharge was 14 A-ft per year and occured during 1956. Between 1953 and 1973 (21 years), annual discharge averaged 3,907 A-ft per year. Between 1988 and 2014 (23 years), annual discharge averaged 4,480 A-ft per year, but declined throughout the time period. Four of the years during the 1990s had higher mean annual discharge than during any other decade in the time series, but during six of the last eight years of data (2007-2014), mean annual discharge was below both the historical mean and the median. Although there is high variability in the data, the recent decline in this measure warrrants moderate to significant concern.

Table 4.6.3-1. Reference conditions for water quantity measures (NPS 2008).

Water Quantity Measure	Good	Moderate	Significant Concern
Trend in Mean Annual Discharge (1952-2013)	Trend in annual discharge is stable or increasing.	Trend in annual discharge has declined somewhat.	Trend in annual discharge had declined significantly.
Minimum Daily Discharge/Month (2003-2014)	Instream flow meets the requested minimum discharge for each month of the year.	Instream flow meets the requested minimum discharge but during months that are less critical for aquatic herpetofauna and macroinvertebrate needs.	Instream flow is less than the requested minimum discharge, especially during months that are most critical for aquatic and herpetofauna and macroinvertebrate needs.
Number of Dry Days/Year in Pool A (2003-2013)	The number of dry days per year has declined.	The number of dry days per year has remained stable or increased slightly.	The number of dry days per year has increased significantly.
Number of Dry Days/ Year at USGS Gage (2003-2013)			

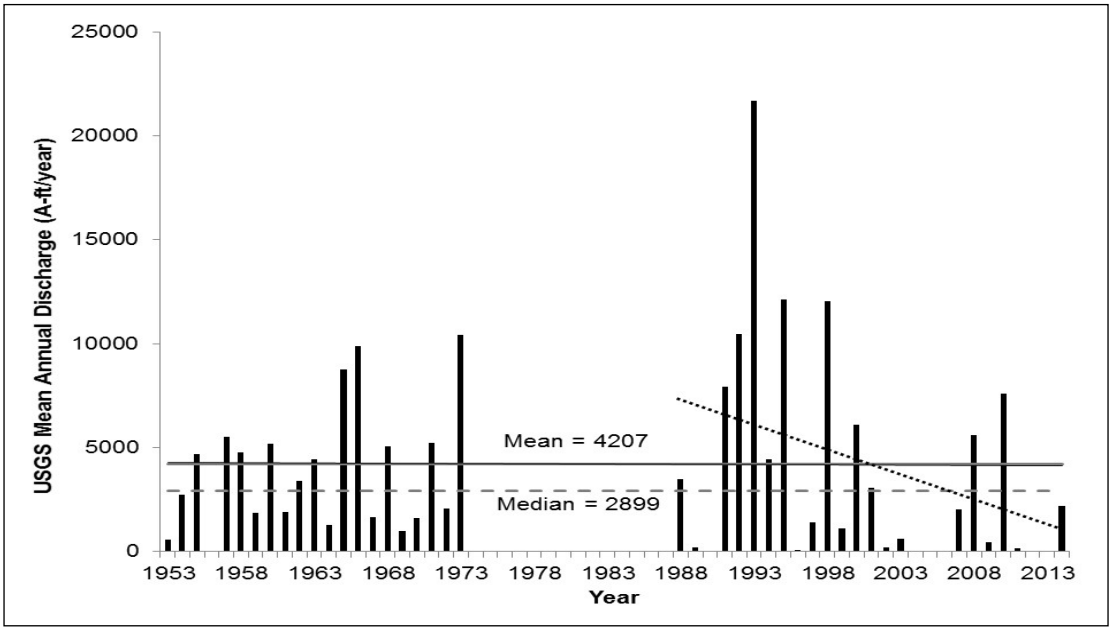


Figure 4.6.4-1. Trend in mean annual discharge as measured at the USGS gage in the middle reach of Rincon Creek from 1953-2014 showing the mean and median during 1953-2014 and the trend during 1988-2014.

Minimum Daily Discharge Per Month

The proportion of days per month during the 12-year period where discharge, as measured at the USGS gage, met the minimum recommendations in the NPS water right application ranged from 0% in June to 29% in February (Table 4.6.4-1). In 2008 and 2003, discharge met the minimum requirements 33% of the time. Aside from years with incomplete data, 2011 and 2012 met the minimum requirements only 4 and 2% of the time, respectively. Overall, February-March and July-September were the wettest months of the year. These months coincide with spring snowmelt during the earlier period and monsoon rains during the later period. Only four of the 124 months during the 12-year period met the minimum daily recommendation.

According to RWC data, mean water use during 1986-2001 (prior to the certificate of assured water supply) was 24 A-ft per year (Figure 4.6.4-2). During 2002-2014 (after RWC issued the certificate of assured water supply), mean water use was 24 A-ft per year. This suggests that months which did not meet the minimum recommendation was a result of natural variation in flow; however, there are several private wells in the area and a change in their water usage could have influenced water availability in

Table 4.6.4-1. The percentage of days per month from 2003-2014 where mean daily discharge met the recommended minimum daily discharge (NPS 2008a).

Year	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	Annual Average
2003	---	---	---	---	---	0	0	0	0	0	0	0	0
2004	0	17	68	47	0	0	3	3	0	---	---	---	15
2005	---	---	---	---	---	---	---	---	---	0	0	0	0
2006	0	0	0	0	0	0	7	100	80	0	77	29	24
2007	0	0	0	0	0	0	26	52	0	10	0	74	13
2008	45	100	26	0	0	0	87	29	90	10	0	3	33
2009	35	68	0	0	0	0	0	0	3	0	0	0	9
2010	29	100	97	97	10	0	19	39	0	0	0	0	33
2011	0	0	0	0	0	0	26	10	7	0	0	0	4
2012	10	0	0	0	0	0	13	0	0	0	0	0	2
2013	0	0	0	0	0	0	0	0	0				0
2014	0	0	0	0	0	0	3	16	57	100	53	45	23
Monthly Average	12	29	19	14	1	0	17	23	22	12	13	15	13

Rincon Creek. Furthermore, although there is no difference in the mean between the two time periods, the amount of water use has increased since 2003 (Figure 4.6.4-2). This is supported by the observed decline in mean annual discharge in recent years as described in the previous measure. The observed decline in discharge could also be due to the recent drought or a combination of these two factors.

Given the language of "natural" flow in the NPS water right application, it is difficult to determine if these data meet the minimum daily recommendations; however, since only 4 of 104 months for which there were data met the minimum requirements, and the trend in water use since 2003 has increased, the condition for this measure warrants moderate to significant concern.

Number of Dry Days Per Year in Pool A

As with mean annual discharge, the number of dry days in Pool A was variable (Table 4.6.4-2). The average number of dry days during the 11-yr period averaged 146, or 40% of the year. In both 2007 and 2008, no dry days were recorded. In 2013, 270 dry days were recorded and this was the highest number of dry days during the 11-yr period. There were four years where the number of dry days exceeded 200, or 55% of the year. After the wet years of 2007 and 2008, the number of dry days in Pool A increased indicating a trend toward drier conditions. Because of the variability in data and the two years with no dry days, there is no trend in the number of dry days in Pool A; however, because of the increased number of dry days in recent years, this measure warrants moderate concern.

Average Number of No Flow Days Per Year at the USGS Gage

The number of no-flow days recorded at the USGS gage averaged 214, or 65% of total days reported the from 2003-2013 (Table 4.6.4-2). In contrast to Pool A, there were no years where water was present every day. In most years the number of no-flow days was greater than in Pool A, indicating drier conditions as recorded by the USGS gage.

The greatest number of dry days was recorded in 2011 and the year with the fewest number of dry days was 2005. Overall, the trend in no-flow days at the USGS gage has increased during 2003-2013. Because of the increased number of dry days in recent years, this measure warrants moderate concern.

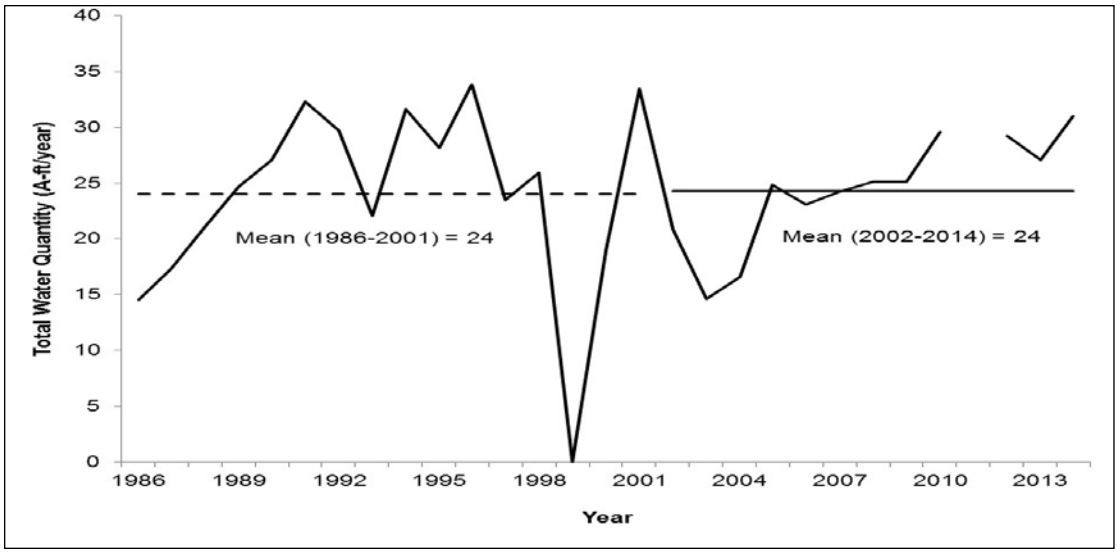
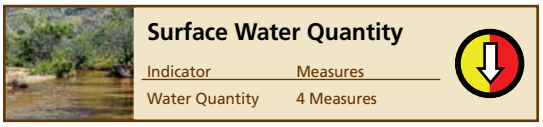


Figure 4.6.4-2. Trend in total water use by the Rincon Water Company during 1986-2014.



Overall Condition and Trend

For assessing water quantity at Rincon Creek in Saguaro NP, we used one indicator with four measures. A summary of each measure and its contribution to the overall water quantity condition along the middle reach of Rincon Creek is listed in Table 4.6.4-3.

The overall condition for water quantity in the middle reach of Rincon Creek warrants moderate to significant concern. None of the measures were considered good based on the reference conditions outlined previously. Assigning conditions was somewhat difficult because of high variability in the data, but all measures indicate a trend toward drier conditions in recent years.

Level of Confidence/Key Uncertainties/ Threats

Long-term hydrologic data collected by the USGS since 1952 provide important information regarding changes in stream discharge. The data collected by the NPS since 2003 supplements the USGS data (Figure 4.6.4-3). Together they constitute a robust source of information regarding surface water quantity in Rincon Creek's middle reach, and the confidence in these data is high; however, the NPS water right application has not been resolved and development along the southwestern boundary of the RMD has increased dramatically in recent years, adding pressure on already limited park water resources in the park (NPS 2014, Briggs 2008). Furthermore, climate change threatens water resources in Rincon Creek and elsewhere in Saguaro NP. A recent study shows that the desert southwest has shifted to an overall drier climate pattern than what is normal (Prein et al. 2016). Changes in surface water quantity along Rincon Creek could be the result of regional drought, which in turn may be caused by climate change; however, more data are needed to determine the long-term consequences.

Table 4.6.4-2. Number of dry days per calendar year at Pool A and no-flow days at the USGS gage during 2003-2013.

Year	Dry Days at Pool A	No FLow Days at USGS Gage*
2003	---	274 of 365
2004	232	182 of 274
2005	190	92 of 92
2006	215	207 of 364
2007	0	158 of 365
2008	0	154 of 366 (leap yr)
2009	102	235 of 365
2010	84	196 of 365
2011	237	347 of 365
2012	125	272 of 365
2013	270	242 of 365
Mean	146	214

* Number of no flow days per year. Note that data were not collected every day for certain years.

Table 4.6.4-3. Summary of the surface water quantity indicators, measures, and condition rationale.

Indicator of Condition	Measure	Condition	Rationale for Condition
Water Quantity	Trend in Mean Annual Discharge	Moderate to Significant Concern	Although there is high variability in the data, the recent decline in this measure warrants moderate to significant concern.
	Minimum Daily Discharge per Month	Moderate to Significant Concern	Given the language of "natural flow" in the NPS water right application, it is difficult to determine if the data meet the minimum recommendations because the natural flow is not known; however, since only 4 of 104 months for which there were data met the minimum requirements and the trend in water use since 2003 has increased, the condition for this measure warrants moderate to significant concern.
	Number of Dry Days per Year in Pool A	Moderate Concern	Because of variability in the data and the two years with no dry days in Pool A, there is no trend; however, because of the increased number of dry days in recent years, the condition for this measure warrants moderate concern.
	Number of No-Flow Days/ Year at USGS Gage	Moderate Concern	Overall, the trend in no-flow days at the USGS gage has increased during 2003-2013. Because of the increased number of no-flow days in recent years, this measure warrants moderate concern.

Effects of Water on Wildlife and Plants

The occurrence of wildlife and plants along and in the middle reach of Rincon Creek depends on streamflow and pools located within the creek. While surface water quantity is important for all wildlife and plants, some species are more dependent on reliable water sources than others. The wetland plant community is dependent on near-surface soil saturation; however, mature trees and other vegetation in Rincon Creek already show signs of water stress and there is a general lack of seedling recruitment (Baird et al. 2001). Vegetation structure and health play a key role in bird species diversity and abundance and the loss of complex vegetation structure could influence these metrics along Rincon Creek.

Amphibians are particularly dependent on pools within Rincon Creek. Pools often maintain water long after streamflow ceases and represent important breeding habitat (Briggs 2008). For example, the canyon tree frog (*Hyla arenicolor*) and Sonoran Desert toad (*Bufo alvarius*) rely on surface water in these pools for breeding and recruitment, but in dry years, neither species is able to breed (Stitt et al. 2008). Dry periods not only affect breeding and recruitment but also survival. Mortality of the Sonoran mud turtle was higher in dry years. The lowland leopard

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Figure 4.6.4-3. Chuck Perger and Colleen Filippone measuring water level (left) and USGS gage (right), both in Rincon Creek.

frog, a species of concern due to a few small, localized populations, is considered rare in Rincon Creek and is usually only observed during wet years when most of the creek bed contains surface water (Stitt et al. 2008). Macroinvertebrates are an important food source for herpetofauna and birds. Goforth and Walker (2008) found that the number of taxa and diversity of macroinvertebrates was inversely related to the magnitude of flow. During peak flows (Figure 4.6.4-4) many are swept downstream which may be an important mode of dispersal (Goforth and Walker 2008). Many species of mammal are attracted to Rincon Creek because of reliable sources of drinking water, foraging (i.e. insectivorous bats), and for refuge (e.g. white-nosed coatis) (Powell et al. 2006).

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Figure 4.6.4-4. High water level in Rincon Creek.

4.6.5. Sources of Expertise

Colleen Filippone, a hydrologist for the Intermountain Region of the National Park Service, provided data and advice on various aspects of this assessment. Assessment author is Lisa Baril, biologist and science writer, Utah State University.

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4.7. Tinajas, Springs, and Seeps (Rincon Mountain District only)

Indicators/Measures

- Water Availability (4 Measures)
- Water Quality (6 Measures)

Condition – Trend - Confidence

Moderate Concern- Unknown - Low

4.7.1. Background and Importance

Tinajas and springs are perennial or intermittent pools of water on which aquatic and riparian wildlife and plants depend. Seeps are small seasonally wet areas with minimal pooled water which support plants and animals adapted to drier conditions (Gaun et al. 2016). Tinajas, a word used to describe stream channel pools, means "earthen jar" in Spanish and occur in drainages throughout the Rincon Mountains, usually in clusters associated with outcrops of metamorphic bedrock (Figure 4.7.1-1; Gaun et al. 2016).

While a few seasonal seeps occur in the Tucson Mountain District (TMD), Saguaro National Park (NP), springs and tinajas are only found within the Rincon Mountain District (RMD) (Gaun et al. 2016). Tinajas are filled by precipitation and runoff, but many are also groundwater-fed and thus retain water year-round (Aldred et al. 2014).

Perennial tinajas are critical water resources for wildlife, plants and humans in the NP. Tinajas usually occur along a fracture in the bedrock that is associated with groundwater and may form as a result of stream erosion along these fractures, although exactly how tinajas are created and the source of their water is not well understood (Aldred et al. 2014).

Tinajas and springs serve as breeding pools and refugia for reptiles and amphibians, including lowland leopard frog (*Rana* [or *Lithobates] yavapiensis*), canyon treefrog (*Hyla arenicolor*), and Sonoran mud turtle (*Kinosteron sonoriensis*) (Swann et al. 2008). Other wildlife are also attracted to tinajas and springs because they provide reliable sources of drinking water, foraging opportunities, and refuge from predators (Swann et al. 2008). Many mammals, including mountain

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NPS

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Figure 4.7.1-1. Tinajas, springs, and seeps are important resources for wildlife and plants in Saguaro National Park. Clockwise from upper left: Madrona Pools, black bear (*Ursus americanus*) recorded via camera trap, black-necked garter snake (*Thamnophis cyrtopsis*), and water at Italian Spring.

lion (*Puma concolor*), white-nosed coati (*Nasua narica*), and several species of bat have been documented using tinajas (Sidner 2003, Swann et al. 2008). Birds also forage and nest in vegetation associated with these areas (Boyle and Conway 2003). In addition to the benefits these surface waters provide to wildlife and plants, tinajas, springs and seeps serve as recreational areas and sources of drinking water for many of Saguaro NP's visitors and backcountry users (NPS 2014).

However, human disturbance of tinajas may alter animal behavior, trample plants and introduce bacteria such as *Escherichia coli*, which may have unwanted effects on water quality (NPS 2014). Other impacts to water resources include urbanization and development surrounding the park, groundwater pumping, livestock trespass, and introduction of non-native plants (NPS 2014). Because of their reliance on water in bedrock, which is related to precipitation quantity and intensity, tinajas are considered highly vulnerable to climate change. A recent study shows that the desert southwest, which is already a dry region, has become drier and warmer over the last several decades (Prein et al. 2016). Furthermore, an altered fire regime as a result of climate change, fire suppression and/or non-native plants has led to increased sedimentation in some tinajas and streams destroying important habitat for aquatic wildlife and plants (Parker 2006).

National Park Service (NPS) management policies (2006) state that parks must "perpetuate surface waters and groundwaters as integral components of park aquatic and terrestrial ecosystems." To this end, the park has been monitoring surface water resources and its effects on wildlife since the mid-1990s, with particular emphasis on lowland leopard frog habitat (Swann et al. 2013). In 2014, Saguaro NP launched the "Year of Water," a campaign to synthesize all that is known about water resources in the park (D. Swann, NP, pers. comm.). As part of this initiative, The George Wright Society Park Break program addressed the general question, "What drives the dynamics of rare and sensitive waters in Saguaro National Park?" The program took place March 10-14th, 2014 and involved nine graduate students from all over the U.S. (Aldred et al. 2014). The result of these efforts was a better understanding of surface water resources in Saguaro NP, including their underlying geology, origin of water and water chemistry, and associated wildlife and plant health; however, much still remains unknown about this critical resource. Tinajas, springs and seeps represent a small fraction of Saguaro NP's total land area yet are an important component of the arid landscape in which they are embedded (Figure 4.7.1-2; NPS 2014).

4.7.2. Data and Methods

This assessment is based on two indicators, which have a total of ten measures. The indicators are water availability (four measures) and water quality (six measures). The four water availability measures are trend in water presence among tinajas, water persistence within tinajas, the Palmer Hydrological Drought Index (PHDI), and percent sediment volume in tinajas. Anecdotal evidence suggests that springs, especially high elevation springs, have decreased flow from historical levels, but no monitoring data are available. Because high elevation springs are clearly dependent on recent precipitation in the form of winter snow and summer rain (see RMD groundwater assessment), the PHDI is the most appropriate index to evaluate potential changes in springs. The six water quality measures are 1) temperature, 2) specific conductance, 3) turbidity, 4) pH, 5) dissolved oxygen, and 6) bacterial occurrence from human recreational use of tinajas, specifically, *E. coli*.

Indicator/Measures

Water Availability (Trend in Water Presence Among Tinajas; Persistence of Water Within Tinajas; Palmer Hydrological Drought Index; and Percent Sediment Volume)

Trend in Water Presence Among Tinajas

Saguaro NP has recorded the presence and absence of water in more than 400 tinajas in the park's RMD since 1996 as part of long-term leopard frog monitoring (Swann et al. 2013). Surveys typically took place in

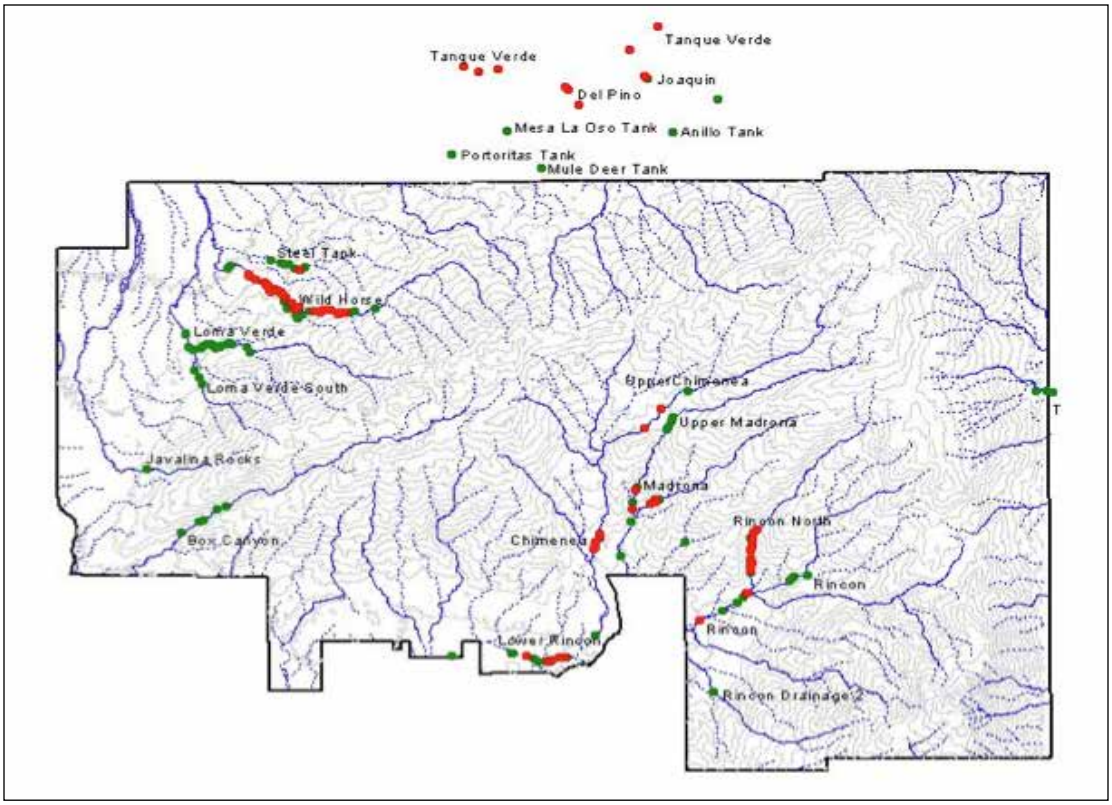


Figure 4.7.1-2. The location of approximately 240 tinajas, within and near the boundaries of Saguaro National Park, Rincon Mountain District. Red dots represent prime lowland leopard frog habitat. Figure Credit: Swann et al. 2013.

spring (May-June) and autumn (October-November); however, not all pools were sampled every year. For this measure we included only those pools surveyed at least once per year. This resulted in 127 pools sampled during 2004-2013 (10 years). We did not include data from 1996-2003 since pools were not consistently monitored during that time.

Persistence of Water Within Tinajas

The previous measure indicates whether water was present over the long-term across 127 pools; however, it does not indicate whether particular tinajas are reliable sources of water. Because pools were visited at least once per year, and usually more than once per year, we determined the proportion of pools that contained water in each of three reliability classes. The classes are:

Reliable: water was present between 50% and 100% of all site visits during 2004-2013;

Moderately Reliable: water was present between 25% and 49% of all site visits during 2004-2013;

Unreliable: water was present < 25% of all site visits during 2004-2013.

Palmer Hydrological Drought Index

The PHDI indicates the severity of a wet or dry spell based on the principles of environmental water supply and demand, and is a good indicator of groundwater conditions (NOAA 2016). The index generally ranges from -6 to +6, with negative values denoting dry spells, and positive values indicating wet spells (Table 4.7.2-1). During extremes the index may reach +7 or -7.

PHDI data were provided by Colleen Filippone (NPS Intermountain Region

Table 4.7.2-1. Palmer Hydrological Drought Index summary.

PHDI Index	NOAA Description
> -0.5	normal
-0.5 to -2.5	incipient to mild drought
< -2.5	moderate drought to extreme drought

*Note that NOAA separates mild and moderate drought at -3.0 rather than -2.5. The more stringent threshold of -2.5 is thought to capture the effects of drought on wildlife in Saguaro NP (Professional opinions of D. Swann and C. Filippone, NPS, personal communication, 2016).

Hydrologist), but were originally extracted from the National Atmospheric and Oceanic Administration's National Climatic Data Center (https://www.ncdc.noaa.gov/). To determine the condition of PHDI, we used monthly data from January 2004 through December 2014 (11 years, or 132 months). This time period roughly coincides with the time frame used in the previous two measures.

Percent Sediment Volume

Beginning in 2005, Saguaro NP began monitoring percent sediment volume in 23-29 tinajas in the RMD to determine the effects of wildfires on pool sediment loads. Five fires occurred within the watersheds of pools sampled between 1989 and 2003 (O'Brien et al. 2015). The pools are located within eight drainages originating at or above 1829 m (6000 ft) with the exception of one stream.

The tinajas surveyed were located in the upper portion of the stream channel where bedrock plays a significant role in their overall structure. The tinajas ranged from 2 to 10 m across (6 to 30 ft) with depths of 0.3 to 3 m (1 to 9 ft) deep (O'Brien et al. 2015). Drainages were selected based on Saguaro NP's monitoring program for the lowland leopard frog and tinajas within streams were selected based on historical leopard frog occupancy and distribution (O'Brien et al. 2015). We used Table 1 from O'Brien et al. 2015 to determine the current condition of the 29 tinajas surveyed (see O'Brien et al. 2015 for details on data collection methods).

Although percent sediment volume is reported for 2005-2006, 2007 and 2010, we restricted our analysis to tinajas sampled in 2013 only. We did not include the earlier data since this assessment is meant to address current condition for sediment volume.

Indicator/Measures

Water Quality (temperature, pH, specific conductance, turbidity, dissolved oxygen, and *E. coli*.)

Temperature, pH, Specific Conductance, Turbidity, and Dissolved Oxygen

To assess temperature, pH, specific conductance, turbidity, and dissolved oxygen in tinajas we used data collected from 13 tinajas located in Chimenea Creek (data were provided by NPS staff and were reported in Culbert and Swann 2015). Collectively, these tinajas are referred to as Madrona Pools.

The Madrona Pools were visited weekly from June through October 2014 by NPS staff and interns (Culbert and Swann 2015). Temperature, specific conductance, pH, and dissolved oxygen data were collected using YSI Professional Series (ProPlus model) automated water quality probes (sondes). Turbidity was determined by using a HACH 2100P turbidimeter, and the pools were sampled between 0600 hrs and 1000 hrs.

We also include data for nine high elevation springs and five low elevation springs as reported in Gaun et al. 2016. High elevation springs are those located >1829 m (6000 ft.) and low elevation springs are located <1829 m (Gaun et al. 2016). Data on temperature, specific conductance, and pH were collected during June 2010 and October 2011 for high elevation springs and June 2010 and November 2011 for low elevation springs. Dissolved oxygen was only collected for the five low elevation springs.

The pH of a water body affects the organisms living within and around it. It is a measure of how acidic or basic a water body is and ranges on a scale from 0 to 14 of decreasing acidity with 7 being neutral. Because pH is reported in logarithmic units, each number is a 10-fold difference along the acidity-basicness spectrum. The pH of water determines the solubility and availability of compounds and minerals to organisms. The more acidic water is the greater the amount of dissolved material, including heavy metals, and is therefore, an indicator of a change in water chemistry and pollution (USGS 2016).

Specific conductance (also referred to as conductivity) is the ability of water to conduct an electrical current and is dependent on the amount of dissolved solids in the water such as salts (USGS 2016). Turbidity is the relative clarity of water. Water clarity is affected by rainstorms, which wash particles from the surrounding landscape into a water

body, and high velocity flows, which stir up sediments from the bottom of a water body (USGS 2016). Suspended particles include clay, silt, sand, algae, plankton and other organic and inorganic matter. High turbidity affects drinking water and provides food and shelter for pathogens, which have been known to cause severe gastroenteritis outbreaks throughout the U.S. and the world (USGS 2016).

Dissolved oxygen is crucial for wildlife living in pools (e.g., amphibians). Oxygen enters a water body from both the atmosphere and groundwater discharge. Temperature is an important factor in controlling the amount of dissolved oxygen in a water body. The colder the water, the more oxygen it can retain. Therefore, dissolved oxygen exhibits both daily and seasonal cycles (USGS 2016). The rate of photosynthesis is also an important driver of dissolved oxygen and the rate of photosynthesis is in turn affected by turbidity (USGS 2016).

Bacterial Occurrence by *E. coli*

We used *E. coli* as an indicator of pathogenic contamination of tinajas. Data were collected monthly during September 2003 through December 2004 from one pool located in each of three creeks in Saguaro NP: Chimenea Creek, Rincon Creek, and Wildhorse Creek (Storrer et al. 2005). *E. coli* were enumerated using the Quanta Tray method to count the Most Probable Number (MPN) per 100 ml (Storrer et al. 2005). Although data included in this report are thirteen years old and limited in geographic extent, they represent the most recent data available on bacterial occurrence in Saguaro's tinajas.

4.7.3. Reference Conditions

Reference conditions for this assessment are shown in Table 4.7.3-1. Reference conditions are described for resources in good, moderate concern and significant concern conditions for the ten measures of water availability and quality of tinajas and springs in Saguaro NP's Rincon Mountain District.

Water Availability - Trend in Water Presence Among Tinajas

We plotted the proportion of site visits during which water was present from 2004 to 2013 for 127 tinajas, and examined trends over time. No trend, or an increase in water presence, would indicate good condition while a decline in water presence would warrant moderate or significant concern.

Water Availability - Persistence of Water Within Tinajas

We determined the proportion of the 127 pools that fell within each of the three persistence classes: reliable, moderately reliable and unreliable. If at least 75% of the pools are considered reliable, the condition for this measure is good; if 75% of pools are considered moderately reliable, the condition for this measure warrants moderate concern; and if 75% of pools are considered unreliable, the condition for this measure warrants significant concern.

Water Availability - PHDI

Using data from 2004-2014, we determined the number and duration of three PHDI drought condition classes: non-drought (or normal), incipient to mild drought, and moderate to extreme drought. In general, we followed the index thresholds developed by NOAA, but used a slightly more stringent threshold between mild and moderate drought that is thought to represent the point at which aquatic wildlife will respond to drought conditions in Saguaro NP (professional opinions of D. Swann and C. Filippone, NPS, personal communication, 2016).

Water Availability - Percent Sediment Volume

Using data from 2013, we calculated the proportion of pools in which sediment volume was less than 30% (good condition), the proportion of pools in which sediment volume was between 30% and 50% (moderate concern), and the proportion of pools in which sediment volume was greater than 50% (significant concern). These percent thresholds for each condition class are based on the professional opinions of Don Swann, biologist at Saguaro NP and Colleen Filippone, hydrologist at NPS Intermountain Region Office.

Water Quality - Core Parameters

We compared water quality data for tinajas and

Table 4.7.3-1. Reference conditions for tinajas in Saguaro NP. Water quality measurements were compared to Arizona Department of Environmental Quality standards for warm (i.e., below 5124 m (5000 ft.)) and cold water (i.e., above 5124 m (5000 ft.)) (AZDEQ 2009) depending on the elevation of the surface water measured.

Indicators	Measures	Good	Moderate Concern	Significant Concern
Water Availability	Trend in Water Presence Among Tinajas during 2004-2013 (127 pools).	No change, or an increase in the proportion of site visits during which water was present.	A moderate decline in the proportion of site visits during which water was present.	A significant decline in the proportion of site visits during which water was present.
	Persistence of Water Within Tinajas	Seventy-five percent of pools are considered reliable (i.e., contain water at least 50% of all site visits).	Seventy-percent of pools are considered moderately reliable (i.e., contain water between 25% and 49% all site visits).	Seventy-five percent of pools are considered unreliable (i.e., contain water < 25% of all site visits).
	Palmer Hydrological Drought Index (PHDI)	Normal (non-drought) conditions predominate and are interrupted only by mild drought conditions of short duration.	Normal (non-drought) conditions predominate, but incipient to mild drought conditions of several months are common with periods of moderate to extreme drought of short duration.	Drought conditions predominate with limited periods of normal (non-drought) conditions of short duration.
	Percent Sediment Volume	The majority of all tinajas measured are < 30% sediment volume.	The majority of tinajas measured are between 30% and 50% sediment volume.	The majority of tinajas measured are >50% sediment volume.
Water Quality	Temperature °C	AZDEQ standards not established.		
	pH (SU)	The pH in tinajas and springs is between 6.5 and 9 SU.	The pH in tinajas and springs do not meet AZDEQ water quality standards.	
	Specific Conductance µS/cm	AZDEQ standards not established.		
	Turbidity (NTU)	AZDEQ standards not established.		
	Dissolved Oxygen (mg/L)	Dissolved oxygen is 6 mg/L for warm water and 7.0 mg/L for cold water.	Dissolved oxygen does not meet AZDEQ water quality standards.	
	s(MPN)	AZDEQ standards not established for tinajas.		

springs to reference conditions for Aquatic and Wildlife warm and Aquatic and Wildlife cold using water quality standards developed by the Arizona Department of Environmental Quality (AZDEQ 2016).

4.7.4. Condition and Trend

Water Availability-Trend in Water Presence Among Tinajas

Water was recorded on 74% of all site visits to the 127 pools during 2004 to 2014 (Figure 4.7.4-1). The minimum proportion of site visits during which water was recorded occurred in 2005 (59%) and the maximum occurred in 2008 (89%). Overall, there was a slight increase in water presence. Since the proportion of site visits during which water was recorded remained relatively stable over time, the condition for this measure is good.

Water Availability - Persistence of Water Within Tinajas

Of the 127 tinajas included in this analysis, 87% (n = 111) were considered reliable, or

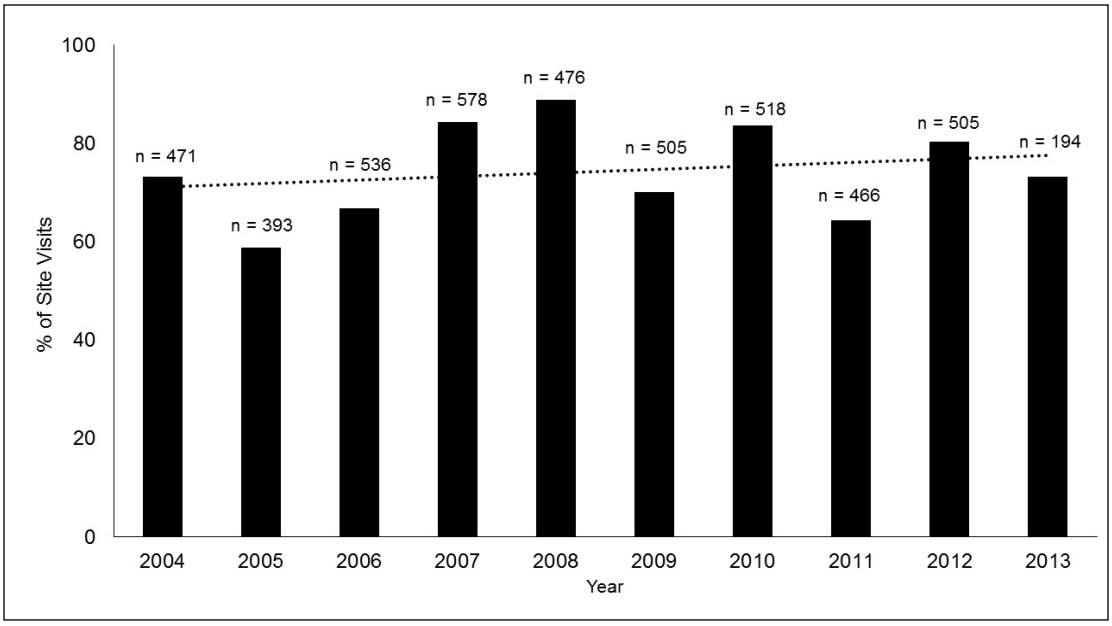


Figure 4.7.4-1. The proportion of site visits during which pools were observed as containing water from 2004 to 2013 (*n* indicates the number of site visits per year).

Table 4.7.4-1. The number and duration of drought periods during 2004-2014 when the Palmer Hydrological Drought Index met the reference conditions. Green indicates normal, light red indicates incipient to mild drought, and dark red indicates moderate to extreme drought.

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
2004	-3.23	-2.89	-2.61	-1.77	-2.35	-2.8	-3.02	-3.15	-2.81	-2.59	-2.11	-1.91
2005	-0.94	1.9	1.63	1.74	2.36	2.18	1.16	1.27	-1.07	-1.33	-1.93	-2.52
2006	-3.13	-3.76	-3.65	-4.09	-4.47	-4.4	-3.02	-2.38	-1.5	-1.42	-2.01	-2.35
2007	-1.9	-2.08	-1.99	-2.32	-2.66	-2.89	-2.16	-2.09	-2.18	-2.6	-2.55	-1.83
2008	-1.57	-1.54	-1.88	-2.22	-1.93	-1.99	1.31	1.65	1.34	0.63	-0.88	-0.98
2009	-1.31	-1.71	-2.39	-2.75	-2.8	-2.6	-3.12	-3.93	-3.97	-4.06	-4.21	-4.16
2010	-2.3	-1.5	-1.17	-0.64	2.24	2.21	2.35	1.95	1.19	0.74	-1.37	-1.65
2011	-2.27	-2.45	-3.25	-3.66	-3.91	-4.3	-3.99	-4.01	-3.58	-3.84	-3.31	-2.47
2012	-2.83	-2.98	-3.18	-3.56	-3.66	-3.91	-3.09	-3.34	-2.67	-3.2	-3.44	-3.14
2013	-2.92	-2.74	-3.07	-3.46	-3.75	-4.16	-3.09	-2.84	-2.21	-2.63	-1.75	-1.92
2014	-2.65	-3.43	-3.58	-3.95	-4.27	- 4.74	-4.03	-2.82	-1.27	-1.06	-1.44	-1.31

observed as containing water on at least half of all site visits during 2004-2013. Sixteen, or 13%, of all pools were perennial (i.e., contained water on 100% of all site visits). Eleven percent of pools (n = 14) were considered moderately reliable (i.e., contained water between 25% and 49% of all site visits), and 2% (n = 2) were considered unreliable (i.e., contained water <25% of all site visits). All pools contained water during at least 18% of all site visits. Since more than 75% of all pools are considered reliable, the condition for this measure is good.

Water Availability-Palmer Hydrological Drought Index

During January 2004 through December 2014, there were three normal (non-drought) periods, 11 periods of incipient to mild drought, and nine periods of moderate to extreme drought (Table 4.7.4-1). Normal periods (i.e., PHDI > -0.5) ranged between four and seven consecutive months and occurred prior to 2011. The eleven periods of incipient to mild drought (i.e., PHDI between -0.5 to -2.5) lasted between two and nine months each, while the nine periods of moderate to extreme drought (i.e., PHDI <

-2.5) lasted between two and 20 consecutive months each. Since 2011 the number and duration of moderate to extreme drought conditions increased. Because of the large number and relatively long duration of drought periods and increasing drought severity in recent years, this measure warrants significant concern.

Water Availability-Percent Sediment Volume

All but one of the 29 pools surveyed exhibited at least some sedimentation (Table 4.7.4-2). Sediment volume averaged 28.3% over all pools and ranged from 0% in Wild Horse 8 to 95.9% in Loma Verde AV2. Of the 29 pools, 15 (52%) held less than 30% sediment volume, or were in good condition; 10 (34%) held between 30% and 50% sediment volume, which warrants moderate concern; and 4 (14%) pools held greater than 50% sediment volume, which warrants significant concern.

Overall, 86% of all pools exhibited less than 50% sediment volume, therefore we consider the condition for this measure to be good to moderate. Although we did not determine trends over time for this assessment, O'Brien et al. (2015) reported percent sediment volume increased in most stream channels and pools from 2005-2006 to 2007 then declined from 2010 to 2013, and of all years sampled, percent sediment volume was lowest in 2013 (O'Brien et al. 2015). There were five major fires which affected sedimentation in the eight drainages sampled. The Chiva Fire (1989) was the earliest and the most recent fire (Helen's II) occurred in 2003 (O'Brien et al. 2015). The impact of fires varied by drainage, with tinajas in one drainage still exhibiting the effects of sedimentation 16 years post-fire, which indicates a long recovery time (O'Brien et al. 2015).

Water Quality - Core Parameters in Tinajas

Temperature (°C)

Temperature in all pools was relatively stable from early June through early September and then declined until the end of the sampling period in late October (Figure 4.7.4-2). AZDEQ has not defined water

Table 4.7.4-2. Percent of tinaja volume filled with sediment in 29 tinajas (pools) in the Rincon Mountain District of Saguaro NP. Data were extracted from O'Brien et al. 2015.

Category	Pool	% Sediment Volume
<30% Sediment Volume	Wild Horse 8	0
	Box Canyon 6	4.1
	Steel Tank 4	4.2
	Wild Horse 13	5.5
	Chimenea 1L	6.8
	Madrona 13	7.3
	Loma Verde 9	9
	Wild Horse 15	9.5
	Madrona 2	9.6
	Chimenea 1C	10.4
	Loma Verde 4	11.7
	Upper Chimenea 8	15.4
	Chimenea 2J	17.9
	Chimenea 1E	20.7
	Upper Madrona 7	22.2
Subtotal & Average Sedimentation	**15 pools (52% of 29 pools)**	**10.3**
30-50% Sediment Volume	Wild Horse 19	30.1
	Upper Madrona 1	30.8
	Box Canyon 1	32.6
	Wild Horse 4	33.2
	Rincon Creek 5	36.5
	Rincon North 14	36.9
	Loma Verde 2	40.2
	Loma Verde 1	40.5
	Miller 3	44.3
	Loma Verde 6	48.7
Subtotal & Average Sedimentation	**10 pools (34% of 29 pools)**	**37**
>50% Sediment Volume	Loma Verde 10	51.5
	Rincon North 2	55.1
	Upper Miller 4	90.6
	Loma Verde AV2	95.9
Subtotal & Average Sedimentation	**4 pools (14% of 29 pools)**	**73.3**
Total	**29 Pools**	**28.3**

quality standards for temperature except for water bodies influenced by thermal discharge, which does not apply in Saguaro NP. Therefore, condition for temperature is unknown, however, seasonal variation in water temperature is expected and is not a cause for concern. These data will provide baseline information to compare future temperature measurements to determine change in water quality.

pH (SU)

pH was highly variable, but generally declined from June through October (Figure 4.7.4-3). The AZDEQ minimum standard was met in all pools on each sampling date, however, the pH was greater than the AZDEQ threshold of 9 on ten sampling occasions in six pools. The highest pH was 9.88 in Pool 1E on July 7, 2014. The spike toward increasing alkalinity occurred from early June to early July then fell to slightly above neutral during the remainder of the survey period.

Rather than pollution, the pH of tinajas may be affected by the composition of rocks in the flow path and the underlying bedrock of the tinajas themselves. Natural variation in pH is expected over time and although six pools exceeded AZDEQ pH standards during June, values outside the standards

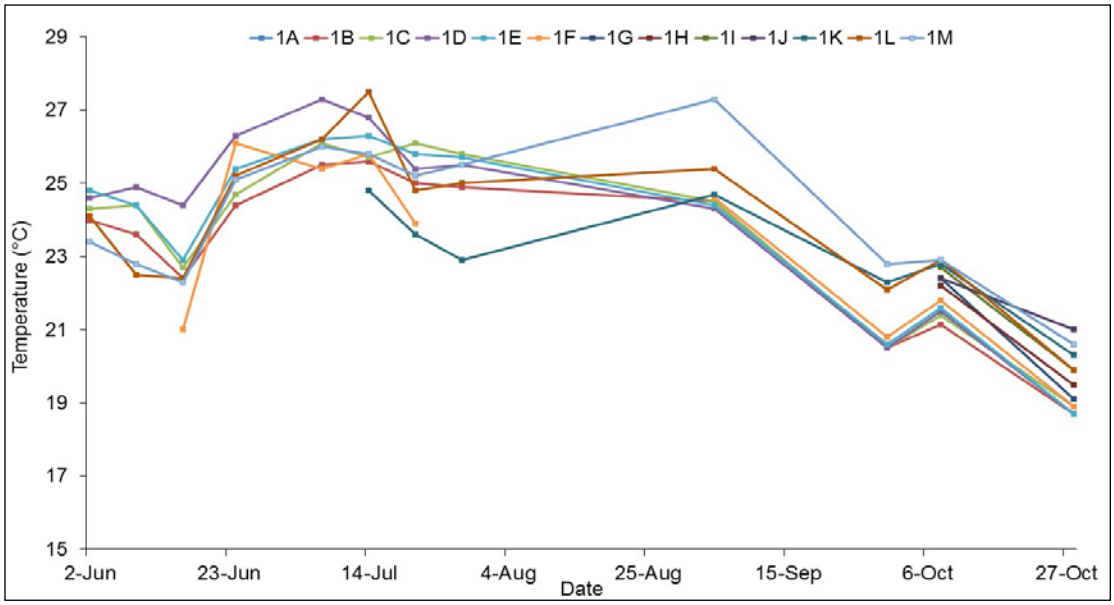


Figure 4.7.4-2. Trend in temperature during June through October 2014 in Madrona Pools. Data were provided by Culbert and Swann 2015.

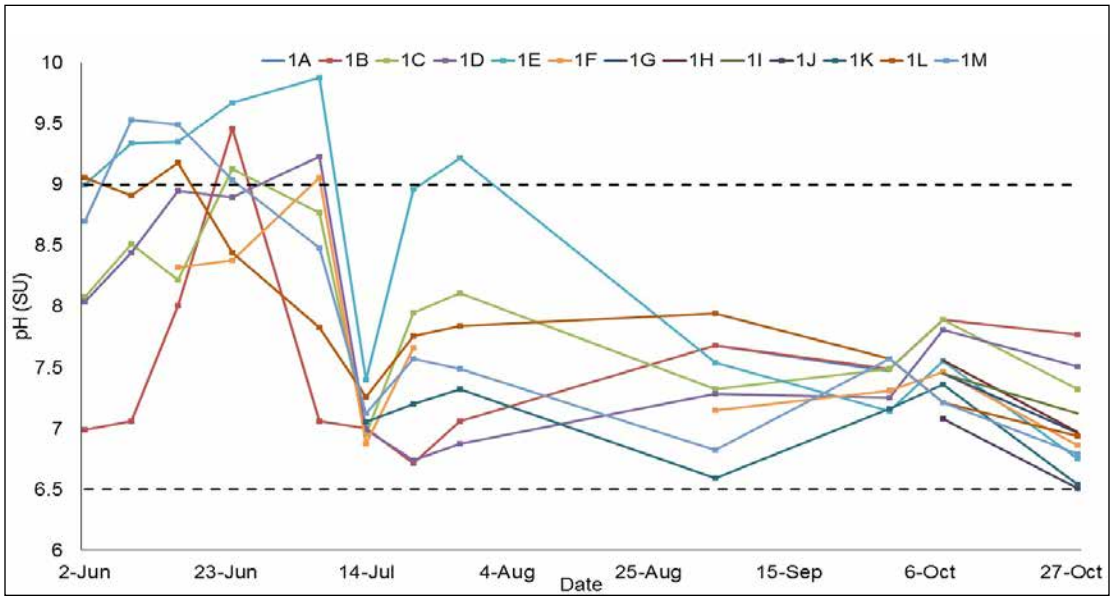


Figure 4.7.4-3. Trend in pH during June through October 2014 in Madrona Pools. The dotted lines represent the maximum and minimum AZDEQ pH standards developed for warm water. Data were provided by Culbert and Swann 2015.

set by AZDEQ could be a result of natural variation in water chemistry; however, because this is unknown we did not assign a condition for this measure.

Specific conductance (µs/cm)

The pattern of specific conductance over time was similar between pools (Figure 4.7.4-4). Conductance was highest from about June 9 through July 14 then tapered until about September 4, after which conductance leveled off. AZDEQ has not defined water quality standards for specific conductance; therefore, we were unable to assess the condition of this measure and it is currently unknown.

Turbidity (NTU)

Turbidity was low throughout the sampling period except for a spike late June to mid-July after which, turbidity was at nearly zero until a smaller spike in two pools during October (Figure 4.7.4-5). AZDEQ has not defined water quality standards for turbidity; therefore, we were unable to assess the condition of this measure.

Dissolved Oxygen (mg/L)

Dissolved oxygen remained below the AZDEQ standard of 6 mg/L for most pools during July, after which, dissolved oxygen increased to at or above 6 mg/L during late August through October; however, four pools were below the AZDEQ threshold

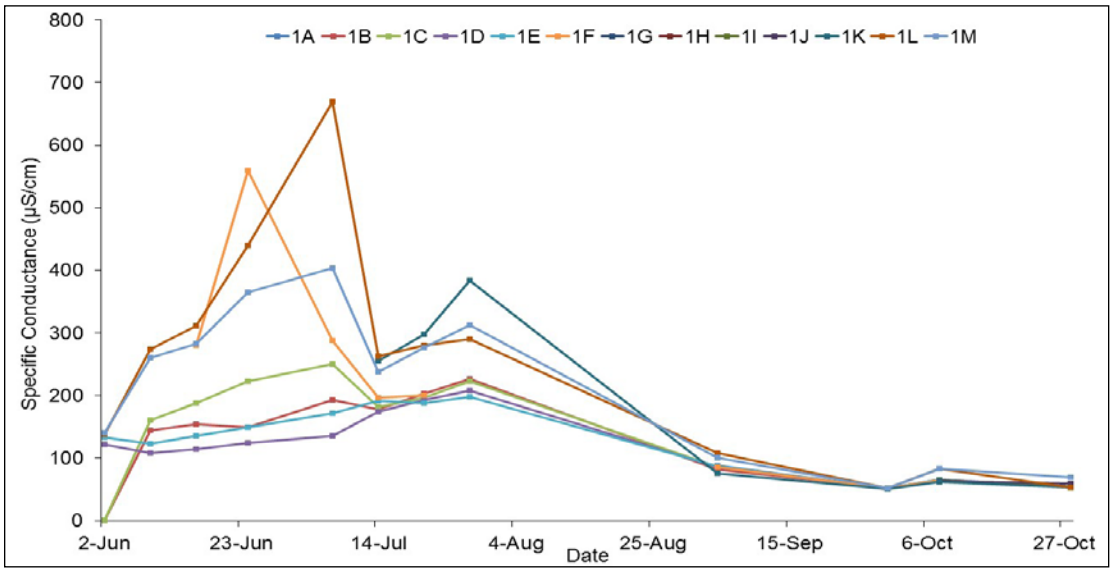


Figure 4.7.4-4. Trend in specific conductance during June through October 2014 in Madrona Pools. Data were provided by Culbert and Swann 2015.

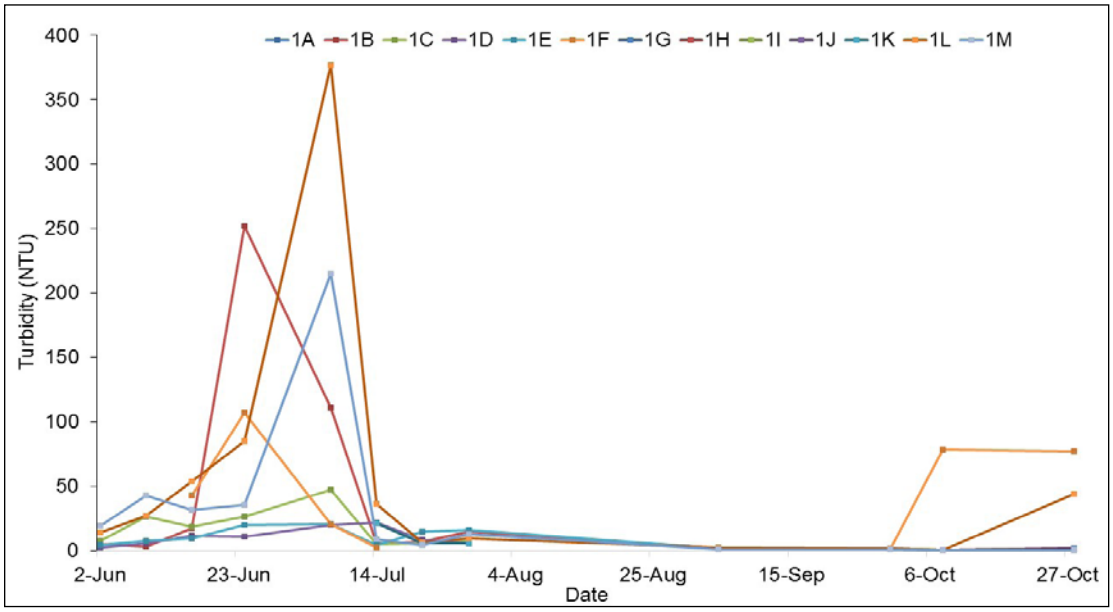


Figure 4.7.4-5. Trend in turbidity during June through October 2014 in Madrona Pools. Data were provided by Culbert and Swann 2015.

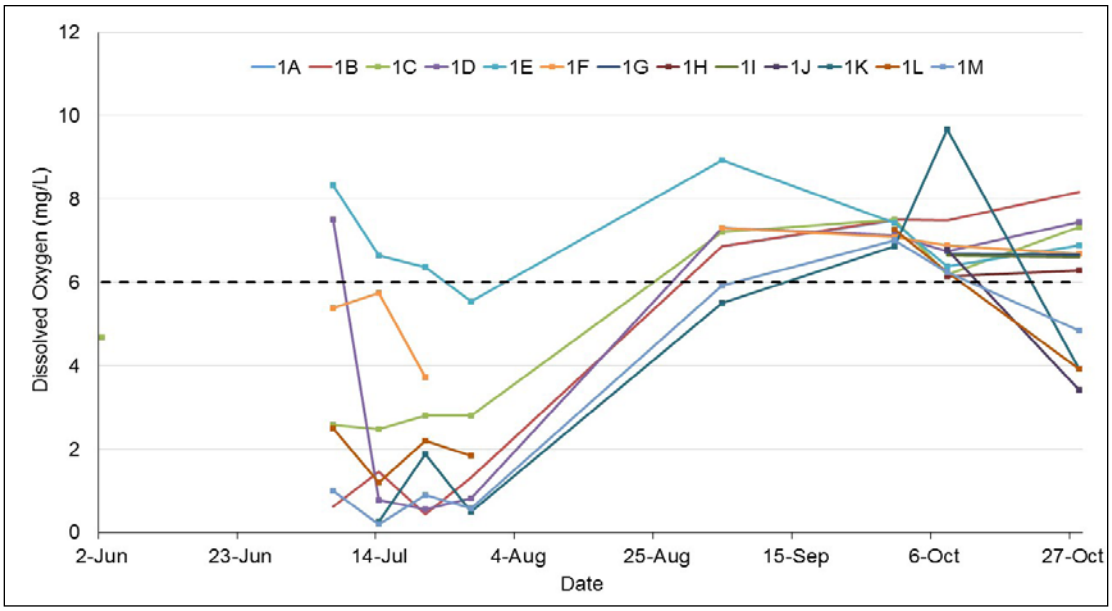


Figure 4.7.4-6. Trend in dissolved oxygen during June through October 2014 in Madrona Pools. The dotted line represents the AZDEQ minimum standard for warm water (i.e., 6 mg/L dissolved oxygen meets AZDEQ standards). Data were provided by Culbert and Swann 2015.

by late October (Figure 4.7.4-6). Pools were closest to meeting the standard from early September through late October. The amount of dissolved oxygen was lowest during July when water temperature was high. Although all tinajas failed to meet AZDEQ criteria at least some of the time, natural variation in dissolved oxygen is a reasonable explanation; however, because this is unknown, we did not assign a condition for this measure.

Bacterial occurrence by E. Coli

Average *E. coli* in tinajas was below 10 MPN, however there are no AZDEQ standards for which to compare this measure (Storrer et al. 2005). AZDEQ standards for E. coli do not apply to this water body type; therefore, we were unable to determine the condition of this measure. Furthermore, these data are 13 years old and were only collected in three pools of limited recreational use. The Wildhorse Canyon pool is accessible via a 2.6 km (1.6 miles) hike while Chimenea Creek and Rincon Creek can be accessed via a 16 km (10 miles) hike and 21.2 km (13.2 miles) hike, respectively.

Water Quality - Core Parameters in Springs

Temperature (°C)

Temperature in high elevation springs was generally low while temperature in low elevation springs was significantly higher (Figures 4.7.4-7 and 4.7.4-8). In low elevation springs average temperature was higher during November than during June, while the difference between seasons in high elevation springs was much smaller. Since AZDEQ has not established water quality standards for temperature, the condition for this measure is unknown.

pH (SU)

Average pH in both low and high elevation springs was below 9, but at or above 6.5 (Figures 4.7.4-7 and 4.7.4-8). Low elevation spring exhibited greater seasonal variability than high elevation springs. Because there are limited data and natural variation in pH is expected, we did not assign a condition for this measure.

Specific conductance (µs/cm)

Specific conductance, or conductivity, in low elevation springs was much greater than in high elevation springs (Figures 4.7.4-7 and 4.7.4-9). Furthermore, the seasonal difference in low elevation springs was greater than the seasonal difference in high elevation springs. Gaun et al. (2016) suggested the difference in conductivity between high and low elevation springs was the result of the longer flow path of water in low elevation springs and/or the result of greater evaporation potential in low elevation springs, which increases the concentration of ions and thus the conductivity of water. Increases in suspended sediment following surface flows will significantly increase

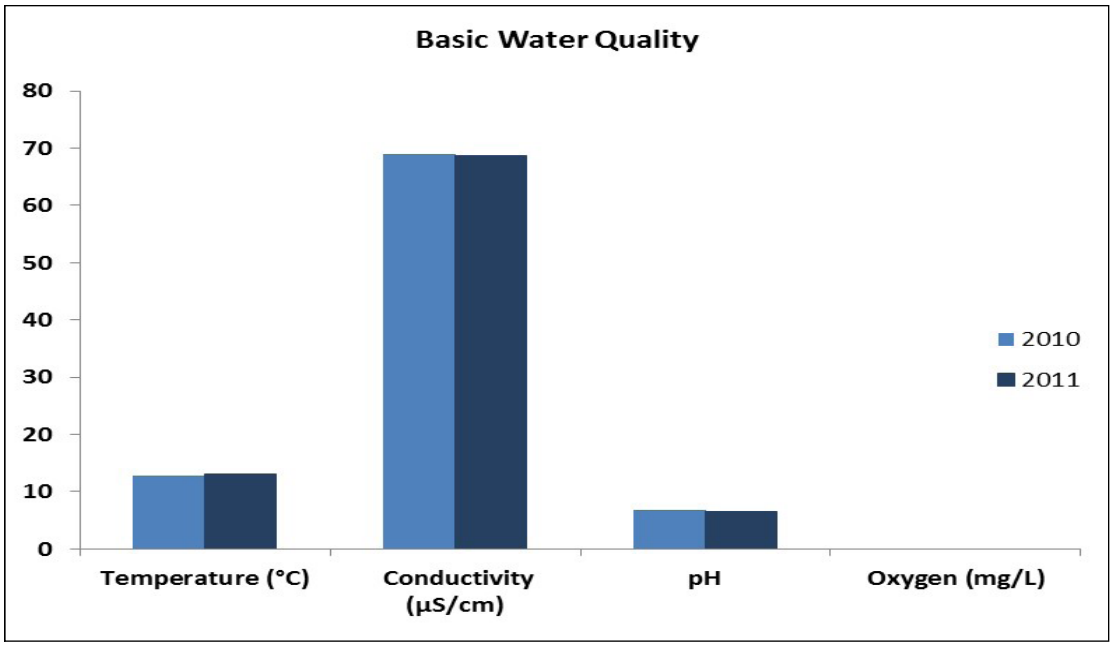


Figure 4.7.4-7. Core water quality parameters for nine high elevation, cold water springs in June 2010 and October 2011. Oxygen was not sampled at any of the springs. Figure excerpted from Gaun et al. 2016.

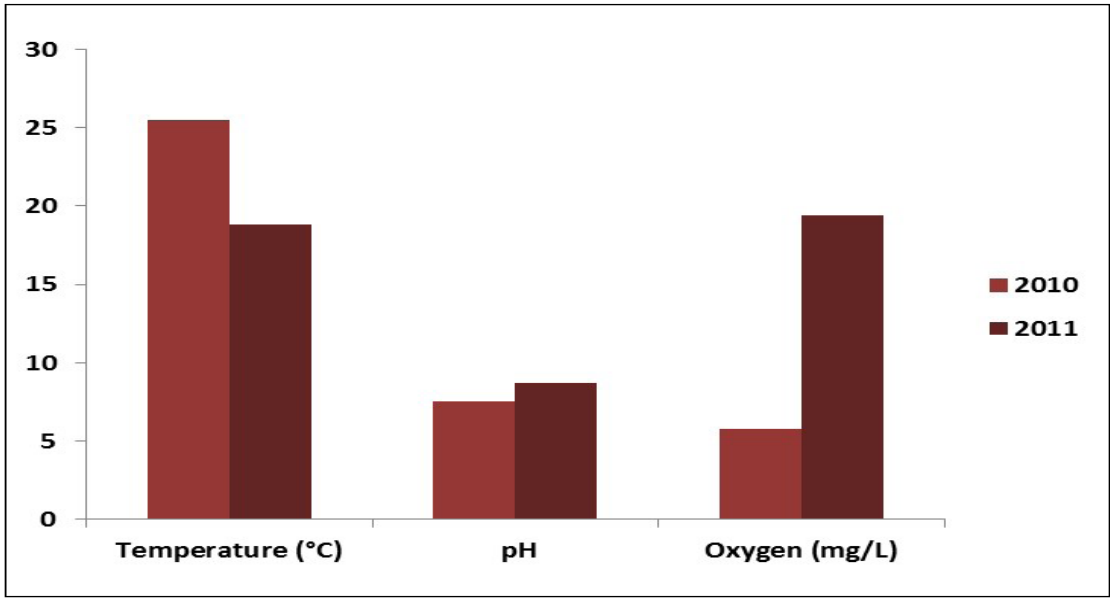


Figure 4.7.4-8. Core water quality parameters for five low elevation, warm water springs in June 2010 and November 2011. Figure excerpted from Gaun et al. 2016.

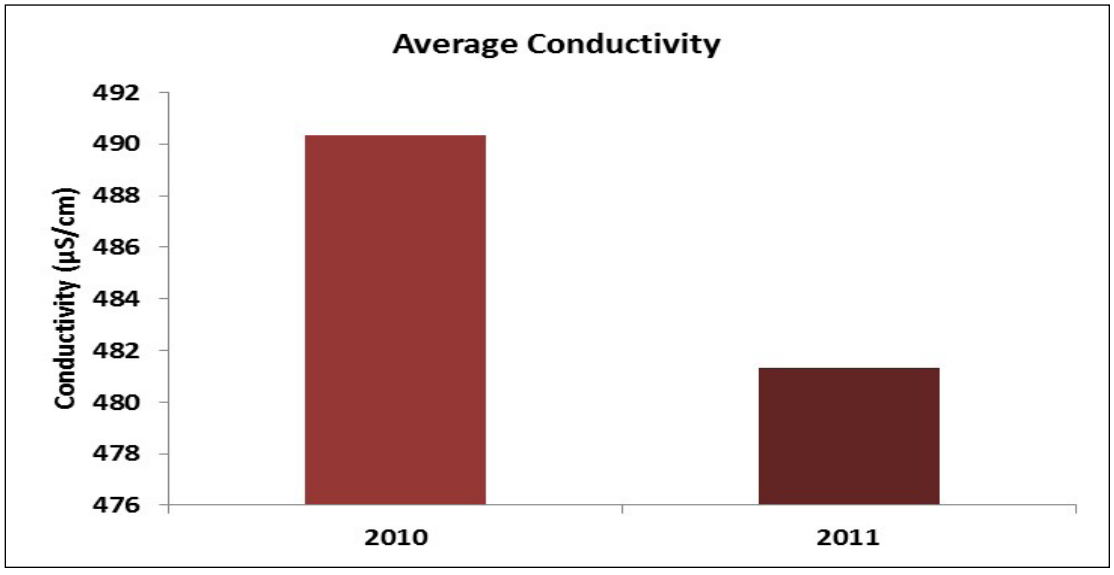
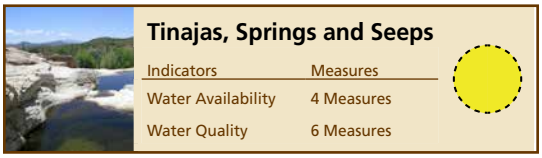


Figure 4.7.4-9. Specific conductance for five low elevation springs in June 2010 and November 2011. Figure excerpted from Gaun et al. 2016.

conductivity. Furthermore, three of the low elevation springs were measured just after a rainstorm, and surface water runoff mixed with spring water, which may have increased conductivity there. The AZDEQ has not established water quality standards for conductivity; therefore, we did not assign a condition for this measure.

Dissolved Oxygen (mg/L)
Dissolved oxygen in low elevation springs exceeded the AZDEQ standard of 6.0 mg/L in November but not in June (Figure 4.7.4-8). Higher water temperature during summer is a likely explanation. As with pH, we did not assign a condition for this measure because of limited data and because natural variation in dissolved oxygen is expected.



Overall Condition and Trend
For assessing water availability and quality in tinajas and springs in Saguaro NP, we used two indicators with a total of ten measures. A summary of each measure and its contribution to the overall water availability and quality condition is listed in Table 4.7.4-3. Overall, the condition for tinaja and spring water quality in Saguaro NP is largely unknown. The condition of water availability is in good condition for trend in water presence and water persistence in tinajas, but the PHDI warrants significant concern. Percent sediment volume is in good to moderate concern condition and has improved over time.

We could not assign a condition to four of the water quality measures because Arizona has not set standards for temperature, specific conductance, turbidity, and *E. coli* for tinajas. Rather, these data provide a baseline condition with which to compare future measurements. For those parameters for which AZDEQ has set standards, the condition was not met in at least some of the time for pH and on nearly all sampling occasions for dissolved oxygen. As with the other measures of water quality however, pH and dissolved oxygen are expected to vary naturally over time and failure to meet AZDEQ standards does not necessarily warrant concern. However, the limited amount of data prevented us from assigning a condition for these measures.

We based our overall condition rating on the four measures of water availability and assigned a condition of moderate concern. The percent sedimentation in tinajas has improved over time as the tinajas surveyed recover from increased sedimentation following fires located in their watersheds (O'Brien et al. 2015). Some tinajas are supplied by groundwater. The fact that there are some perennial tinajas indicates that groundwater storage in those areas is sufficient to recharge those pools during periods when flowing surface water is not available. However, persistent drought conditions have the potential to reduce stored groundwater reserves below needed levels to maintain perennial tinajas in some areas.

Level of Confidence/Key Uncertainties
The level of confidence in water quality is low given that the data are limited in temporal and spatial extent, and confidence in the water availability data are medium given the limited temporal nature of data collection. Although these data are long-term, water presence/absence data were collected only a handful of times each year and water availability may have changed between sampling dates. Water quality measures were generally measured during one season for a limited number of tinajas and springs. Due to limited data for springs and seeps and few long-term datasets for tinajas, there is significant uncertainty regarding their condition. The remote location of many tinajas, especially those at higher elevations, hampers repeated monitoring efforts.

Threats to Tinajas, Springs and Seeps
Tinajas, springs and seeps are some of the most important natural resources in Saguaro NP. Despite their importance, there is relatively little information on water availability and quality of these resources partly because of their remote location. The few water quantity and availability data that exist for springs indicate that in both high elevation and low elevation areas in the park, springs have

Table 4.7.4-3. Summary of the tinajas, springs, and seeps indicators, measures, and condition rationale.

Indicator of Condition	Measure	Condition/ Confidence Level	Rationale for Condition
Water Availability	Trend in Water Presence Within Tinajas	Good/Medium	Since the proportion of site visits during which water was recorded remained relatively stable over time and averaged 74% during 2004 to 2014, the condition for this measure is good.
	Persistence of Water Within Tinajas	Good/Medium	Since more than 75% of all pools are considered reliable (i.e., contain water on at least 50% of all site visits), the condition for this measure is good.
	Palmer Hydrological Drought Index	Significant Concern/ Medium	During January 2004 through December 2014, there were three normal periods, 11 periods of incipient to mild drought and nine periods of moderate to extreme drought. Drought periods lasted between two and 20 months, while non-drought periods lasted between four and six months. Because of the large number and relatively long duration of drought periods compared with non-drought periods, as well as increasing drought severity in recent years, this measure warrants significant concern.
	Percent Sedimentation	Good to Moderate/ High	Just over half (52%) of the 29 tinajas exhibited less than 30% sediment volume, and 86% of all tinajas exhibited less than 50% sediment volume. Only four of the 29 pools exhibited greater than 50% sediment volume, therefore, we consider the condition of this measure as good to moderate.
Water Quality	Temperature	Unknown/Low	AZDEQ do not apply to water bodies sampled in Saguaro NP; therefore, we cannot assess the condition of this measure.
	pH	Unknown/Low	The AZDEQ minimum standard was met in all tinajas on each sampling date; however, the pH was greater than the AZDEQ threshold of 9 on ten sampling occasions in six tinajas. All springs were within the range of variation established by AZDEQ. Due to limited data and expected variability over time we did not assign a condition for this measure.
	Specific Conductance	Unknown/Low	AZDEQ has not defined water quality standards for specific conductance; therefore, we were unable to assess the condition of this measure.
	Turbidity	Unknown/Low	AZDEQ has not defined water quality standards for turbidity; therefore, we were unable to assess the condition of this measure.
	Dissolved Oxygen	Unknown/Low	Dissolved oxygen in tinajas and springs was variable, but the standard of 6mg/L was met some of the time. Although natural variation in dissolved oxygen is a reasonable explanation, we consider the condition unknown because of limited data.
	Bacterial Contamination by *E. coli*	Unknown/Low	Average *E. coli* in tinajas was below 10 MPN, which is well below AZDEQ standard of 126 MPN; however, these data are 13 years old. Therefore, the condition for this measure is unknown.

potentially reduced flows, or in some cases, complete loss of flowing water (Gaun et al. 2016). While the associated habitat is smaller for low elevation springs than high elevation springs, which support greater plant species diversity, the low elevation springs were important historical water resources in the park. Water in high elevation springs originates principally from recent precipitation events while it is believed that lower elevation springs and tinajas have longer flow pathways with water originating from precipitation events that occurred decades earlier (Gaun et al. 2016). Climate change may be one driver for reduced flows in springs. Prien et al. (2016) found a trend toward drier and warmer conditions in the southwest. This is supported by our examination of the Palmer Hydrological Drought Index. Other drivers may include altered fire regime and changes in how NPS manages and maintains springs (Gaun et al. 2016).

Pressures on water resources in the park are increasing as development surrounding the park increases. The greater Tucson metropolitan area is one of the fastest growing population centers in the U.S. In 2000, 55% of the private land surrounding Saguaro NP was undeveloped, but exurban development is expected to increase 38% by 2030 and 105% by 2060 (Hansen et al. 2014). Some evidence suggests that water in low-elevation tinajas may be threatened by groundwater pumping outside the park, because they may derive water from an aquifer associated with the regional detachment fault (see RMD groundwater assessment).

An altered fire regime may also influence the health of tinajas, springs and seeps. The Box Canyon Fire in 1999 led to complete sedimentation of nearly all tinajas in Loma Verde Canyon (Figure 4.7.4-10) and to the extirpation of the lowland leopard frog in that drainage (Parker 2006). Increased sedimentation following the 2003 Helen's II Fire led to declines in leopard frogs in Joaquin Canyon and other tributaries of Tanque Verde Creek (O'Brien et al. 2015). Pools that filled with sediment following fires can take decades to recover (Parker 2006); however, the processes of sedimentation, fire, and its effects on wildlife are not well understood.

4.7.5. Sources of Expertise

Colleen Filippone, a hydrologist for the Intermountain Region of the National Park Service, provided data and advice on various aspects of this assessment. Don Swann, Saguaro NP biologist, provided data and advice in developing indicators, measures, and condition thresholds.

Assessment author is Lisa Baril, biologist and science writer, Utah State University.

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Figure 4.7.4-10. Loma Verde Pool 1 before (left) and after (right) the 1999 Box Canyon Fire, showing pool sedimentation following large wildfires.

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4.8. Groundwater - Tucson Mountain District

Indicators/Measures

- Groundwater Level in Avra Valley Aquifer (1 Measure)
- Groundwater Flow Direction in Avra Valley Aquifer (1 Measure)
- Groundwater Level in Shallow Alluvial Wells (1 Measure)

Condition – Trend - Confidence

Moderate Concern – Unchanging – Medium

4.8.1. Background and Importance

Groundwater is vital to the ecosystem integrity and operations of both the Tucson and Rincon Mountain units of Saguaro National Park (NP). In the Rincon Mountain District (RMD), the few perennial pools and tinaja upon which wildlife and aquatic plants and animals depend for survival through the hottest and driest times of year are sustained by groundwater. In the Tucson Mountain District (TMD), perennial natural surface water is unknown (Mott 1997), and a small number of wildlife watering facilities supplied by groundwater have been developed (Figure 4.8.1-1). At Saguaro NP, in addition to location-specific physical characteristics, groundwater availability to ecosystems is dependent on climatic variables, including the quantity and timing of precipitation as well as whether the precipitation falls as rain or as snow. Atmospheric factors that influence snow melt and the rate of evaporation, including temperature, wind speed and direction, and relative humidity, play a significant role. Potential human-related impacts to available groundwater, in particular groundwater declines associated with pumping and/or climate change, are discussed in the following sections.

Potable groundwater availability to park operations at both units is affected by the factors discussed above but is strongly moderated by the importation of Colorado River water via the Central Arizona Project (CAP) aqueduct and the ability to pump and transport stored groundwater from hundreds of feet below the surface in the central groundwater basins to points of use throughout the area.

NPS

Figure 4.8.1-1. Wildlife watering station supplied by TMD water supply well.

With the exception of the eastern slopes of the RMD, both units are located within the Tucson Active Management Area (AMA) (Figure 4.8.1-2), and as such, the potable water supply future of both units is linked to overall groundwater status within the Tucson AMA. The Tucson AMA is one of five designated planning areas in the State of Arizona within which groundwater use is subject to an extensive regulatory framework aimed at controlling groundwater depletion and allocating limited groundwater resources (Arizona Department of Water Resources [ADWR] 2015a). The AMA system was established under the 1980 Groundwater Management Act, also known as the Groundwater Management Code, which includes rules intended to move the AMAs toward the goal of reaching safe-yield by 2025. Within the Tucson AMA, groundwater is used at twice the rate it is replenished naturally, and the total volume of existing groundwater rights and withdrawal permits exceeds natural and incidental recharge by a factor of 2.8 (ADWR 1999).

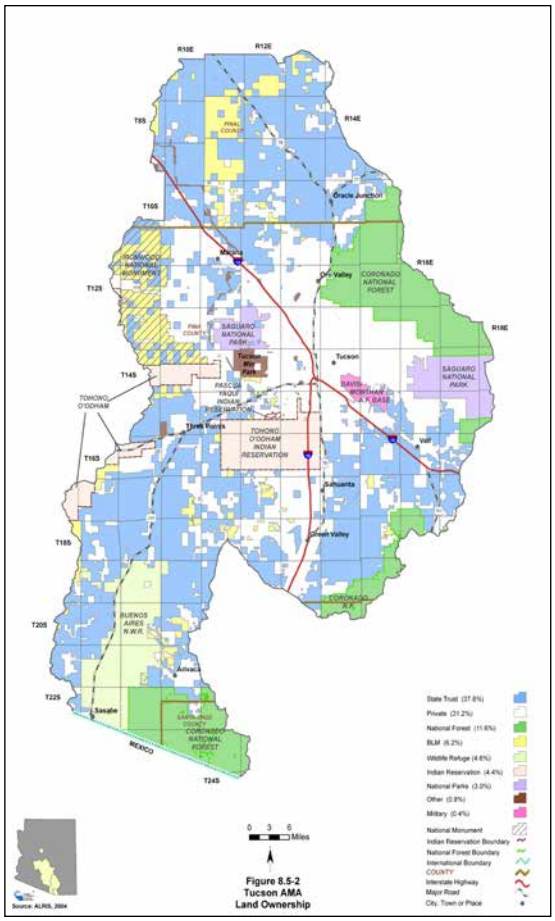


Figure 4.8.1-2. Tucson Active Management Area (ADWR 2010). Different colors denote land ownership agencies.

All facilities within the TMD are supplied by groundwater pumped by the park from the Avra Valley aquifer. Annual water usage at TMD is about 300,000 gallons, or 0.92 acre-feet. Operations at the RMD receive potable water distributed by the City of Tucson's water department, Tucson Water. Annual water usage by RMD is around 441,000 gallons, or 1.35 acre-feet. Tucson Water is supplied by groundwater pumping of well fields within the Tucson AMA, including but not limited to wells in Avra Valley, west of TMD.

The Avra Valley aquifer, located west of the Tucson Mountains, was severely overdrafted between the 1940s and the 1990s but has since been supplemented by recharge from the Colorado River delivered via the Central Arizona Project (ADWR 2016). CAP water deliveries have been recharged at the Central Avra Valley Storage and Recovery Project (CAVSARP) since about 1997, resulting in water level increases of nearly 100 feet from lows occurring in the late 1990s and early 2000s. CAVSARP is located approximately 1.5 miles west of the TMD boundary. The gleaming recharge ponds are a highly visible element of the westward viewshed at TMD. Due to inflows to the Tucson AMA via recharge of Colorado River water brought by CAP, there is a disconnect between natural groundwater availability to ecosystems in the basin and water availability for human uses, some of which originates as Colorado River surface water outside of the basin.

Tucson Mountain District Physical Setting

The TMD of Saguaro NP lies entirely within the Tucson AMA, including two groundwater subbasins, the Avra Valley subbasin to the west and the Upper Santa Cruz subbasin to the east (Figure 4.8.1-3).Geologic history of the Tucson Mountains is complex and includes submersion in shallow Mesozoic seas, violent volcanic eruption, translocation of upper plate sedimentary rocks from above the Catalina detachment fault, periods of erosion, and high-angle normal block faulting that formed the basin and range province (Bezy 2005). Most of the TMD is underlain by hardrock, including crystalline granites and granodiorites, welded volcanic tuffs,

remnants of lava flows, and sedimentary rocks. Capacity to store or transmit groundwater in these rocks is limited to localized joints and fractures, and available groundwater is minimal. (Figure 4.8.1-4) illustrates the distribution of near-surface hardrock substrate at TMD (ADWR 2015b). Figure 4.8.1-5 (left) shows typical hardrock uplands as seen along the Hugh Norris Trail at TMD, and Figure 4.8.1-5 (right) shows north-facing slopes with pediment colluvium and alluvial fan sediments below Wasson Peak at TMD. Along the mid-slopes of the Tucson Mountains, available water is limited to storage in thin surficial sediments, present at greatest depth within drainages. Where near-surface hardrock is present, most precipitation will evaporate, infiltrate thin soils and be absorbed by plants or move downslope within sediments, or flow downslope on the surface in one of the numerous ephemeral washes that drain the Tucson Mountains (Figure 4.8.1-3). Only a negligible amount is retained as stored groundwater. Isotope studies indicate that water within bedrock fractures of the Tucson Mountains originates from winter precipitation almost exclusively (C. Eastoe, personal communication). Estimates of recharge from the Tucson Mountains to the Avra Valley aquifer range from negligible to 9,000 acre-feet per year (Mason and Bota 2006), but isotopes studies show no evidence that a significant amount of recharge to the Avra Valley aquifer originates in the Tucson Mountains (Dody et al. 2001). Beneath the Tucson Mountains, isotope analyses also indicate the presence of older and sometimes warmer water moving upward in some areas, but insufficient data are available to more fully characterize this phenomenon (Dody et al. 2001, Hahman and Allen 1981).

Along the lower slopes of the near-surface hardrock areas delineated in Figure 4.8.1-4, pediment alluvium channel, alluvial fan, terrace deposits and colluvium grade toward the bounding valleys to the east and west (Pearthree and Biggs 1999, Andrews 1937). These slopes are underlain by hardrock at shallow depths on the mountain slopes, covered with increasing thickness of alluvium towards the basins. Figure 4.8.1-6 illustrates the surface topography in and around the park and shows the locations of wells and a watering facility within that topography. The alluvium and colluvium is derived from the Tucson Mountains, and deepens toward the basin centers, as illustrated in the cross-section of Avra Valley west of TMD shown in Figure 4.8.1-7.

4.8.2. Data and Methods

As discussed above, groundwater availability varies greatly within TMD. For the purposes of this discussion, a well may be either a drilled or a hand-dug excavation that provides access to subsurface groundwater. Mine adits that may intercept groundwater were not assessed for this report and are not included here. Figure 4.8.1-4 illustrates the location of wells present at TMD, and Figure 4.8.1-6 shows the situation of these same sites within the

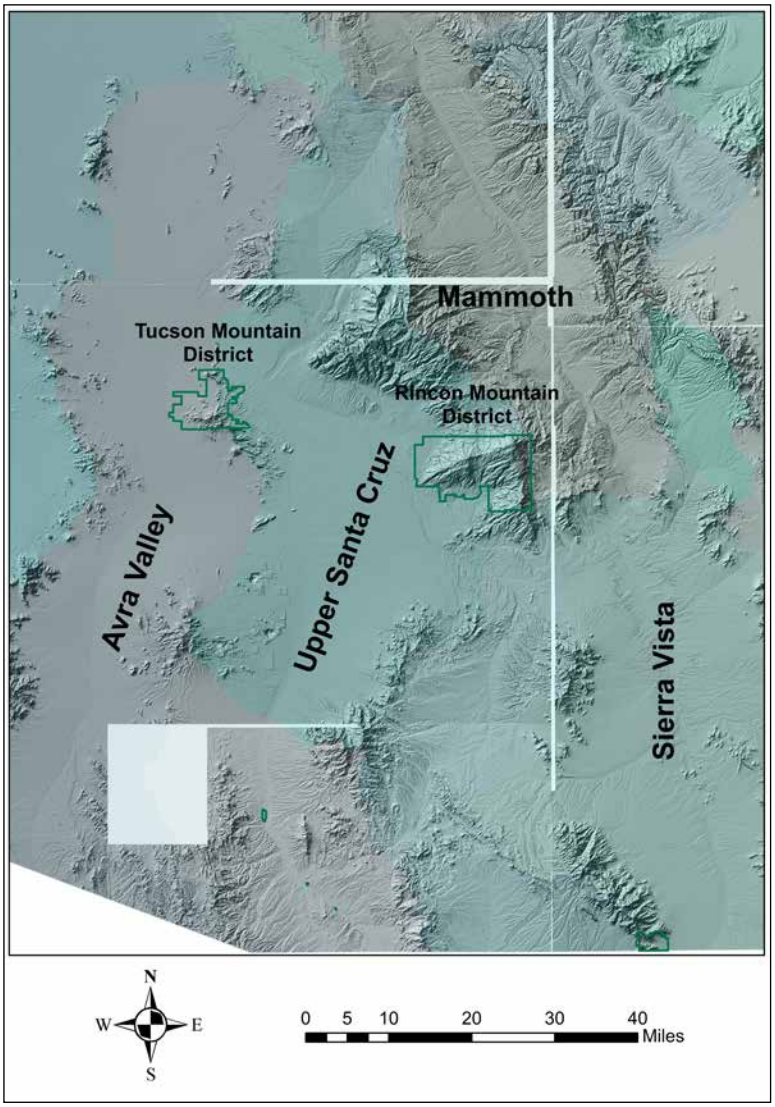


Figure 4.8.1-3. Groundwater sub-basins around Saguaro NP.

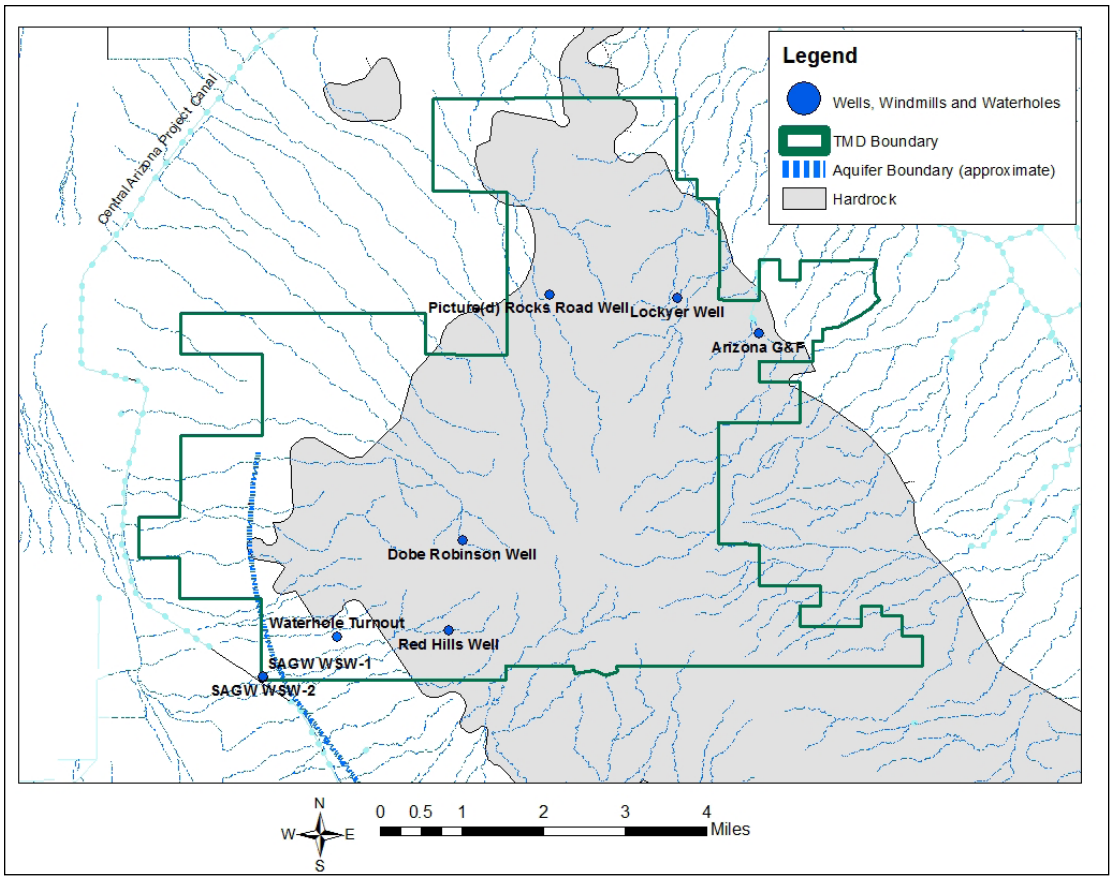


Figure 4.8.1-4. Map of Saguaro NP TMD showing areas with hardrock substrate and groundwater well locations (ADWR 2015 hardrock shapefile).

topography at TMD and the greater Tucson Mountains. These are listed in Table 4.8.2-1.

Sources of groundwater data for TMD include historical and recent records in park files, the State of Arizona Department of Water Resources (ADWR) well registry, and the Sonoran Desert Network groundwater database. Due to fundamental differences, the following sections discuss the potable water sources connected with the Avra Valley aquifer separate from those located in the hardrock areas.

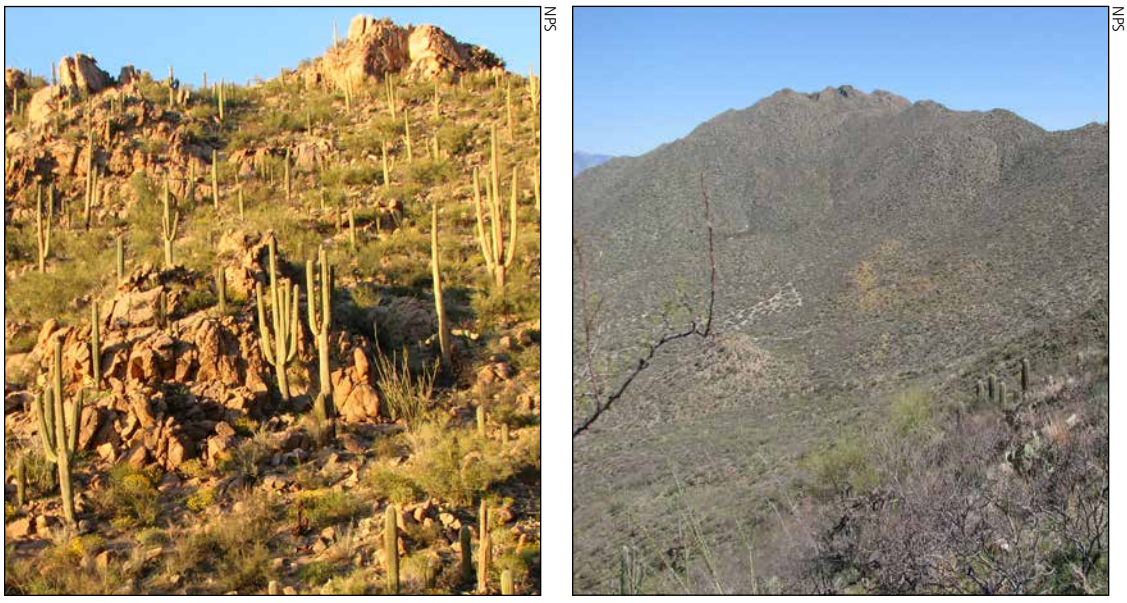


Figure 4.8.1-5. Typical hardrock upland at TMD as seen along the Hugh Norris Trail (left), and north-facing Tucson Mountain slopes grade to pediment below Wasson Peak at TMD (right).

Potable Water at TMD

Since 1964, potable water supply to TMD facilities have been pumped from a well located within the park near the northeast corner of the intersection of Mile Wide Road and Sandario Road in the far southwestern corner of the park (Figures 4.8.1-4 and -6). The original water supply well, ADWR 55-629094 (SAGW WSW-1) was replaced in 2009 by a newly constructed well, ADWR 55-910129 (SAGW WSW-2), located about 50 feet north of the original well. Of the sites listed in Table 4.8.2-1, only SAGW WSW-1 and SAGW WSW-2 are situated within the boundary of the Avra Valley aquifer delineated by the blue dashed aquifer boundary line in Figure 4.8.1-4. Available groundwater resources are shallow and very limited east of the aquifer boundary. Figure 4.8.2-1 provides a view of the Tucson Mountains from the area of the water supply wells near the southwest boundary of the park.

In Spring 2015, water levels in the two park wells were around 380 feet below ground surface (ft bgs; water level elevation 1956 feet; SODN). However, during drilling each of the two wells, water was not encountered until 550 ft bgs, indicating that the groundwater intercepted by these wells is confined within bedrock fractures or rubblized zones connected with the main aquifer, and rises to the piezometric level of the aquifer only when intercepted by an opening such as a well. Figure 4.8.1-7 illustrates a generalized geologic cross-section of Avra Valley with the approximate location of the park's water supply well noted. The park wells intercept a fractured zone hydraulically connected to the Avra Valley aquifer (not shown on Figure 4.8.1-7). Due to the depth to water, these groundwater resources are not available to support surface ecosystems without intervention in the form of pumping and distribution. The wildlife watering hole shown in Figure 4.8.1-1 is supplied by deep groundwater. Table 4.8.2-2 summarizes subsurface conditions encountered during the construction of SAGW WSW-2 in 2008.

Since the construction of WSW-2 in 2008, WSW-1 has been reconfigured as a monitoring well. Repeated water level measurements in wells WSW-1 and WSW-2 indicate that these

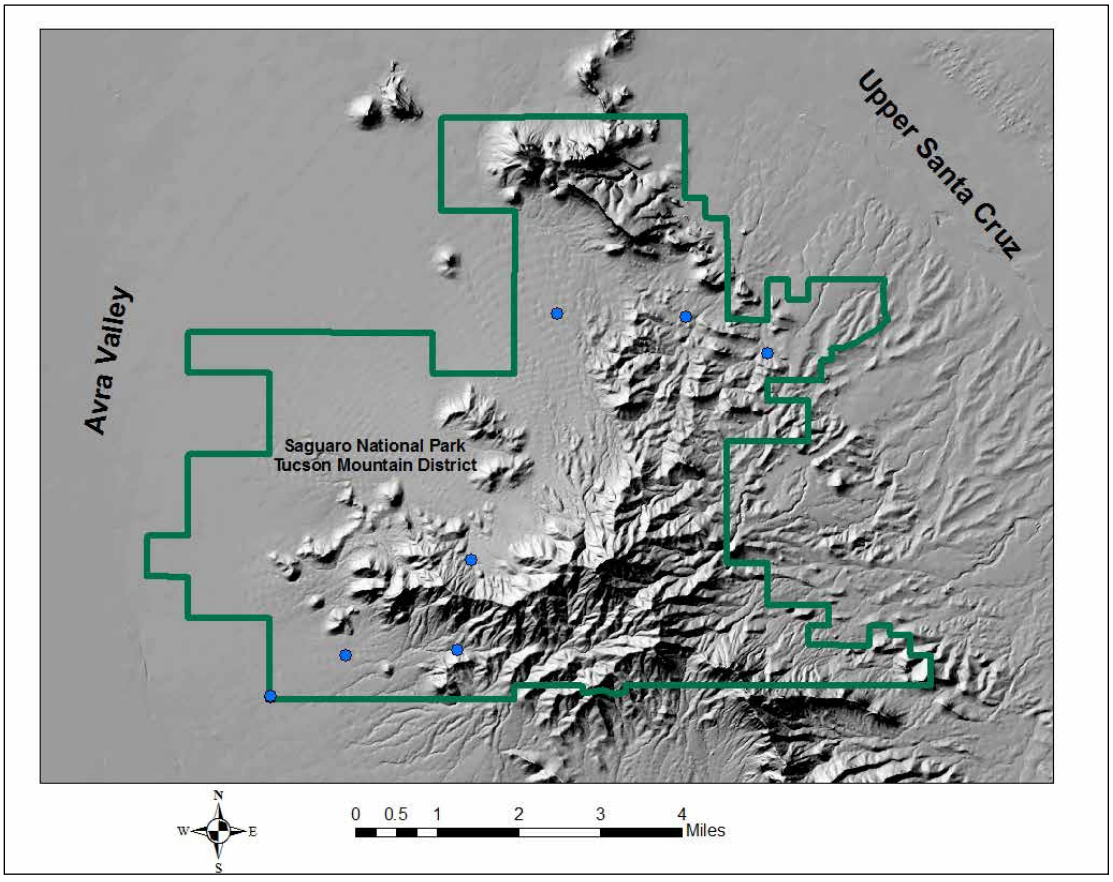


Figure 4.8.1-6. Topography and well locations at Saguaro NP Tucson Mountain District.

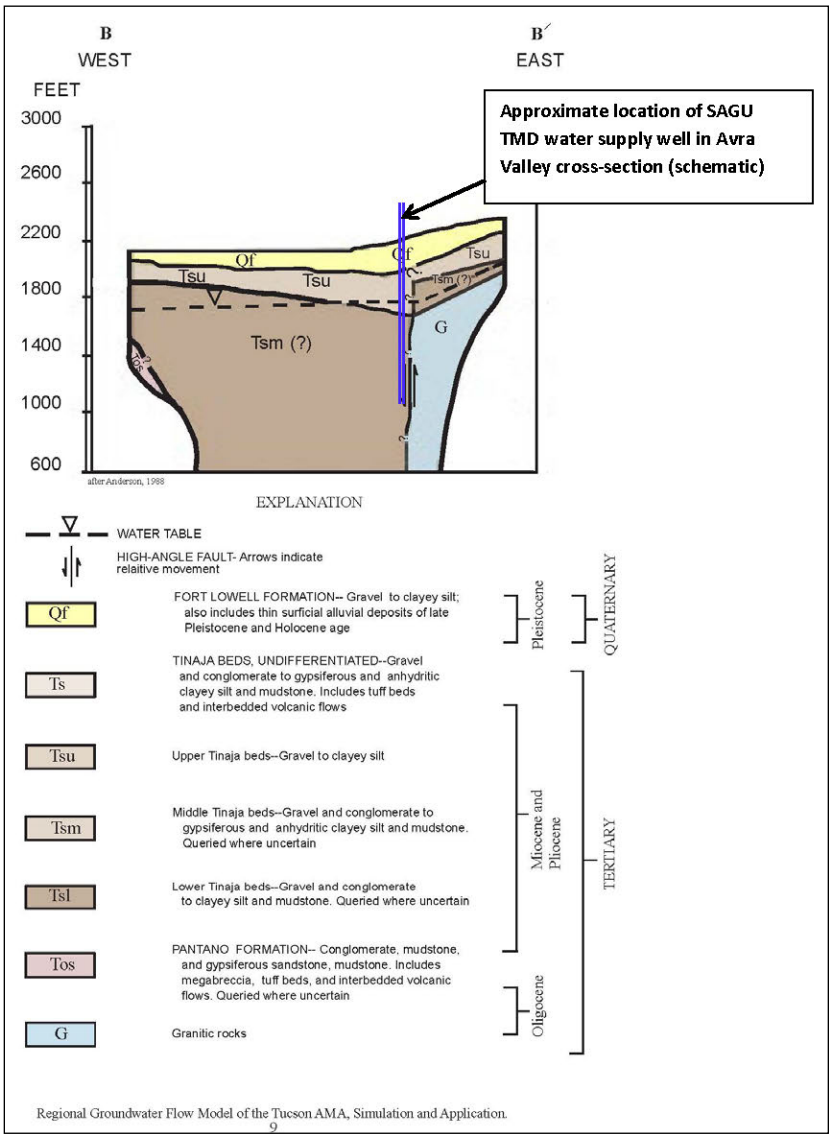


Figure 4.8.1-7. Generalized geologic cross-section of Avra Valley groundwater basin. Figure Credit: Mason and Bota 2006.

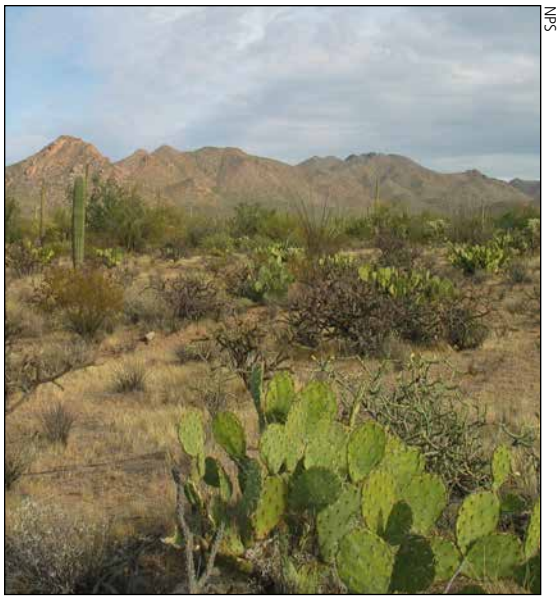

NPS

Figure 4.8.2-1. View of the Tucson Mountains from the gently sloping lower pediment near the west boundary of the park.

wells intercept the same water source. Figure 4.8.2-2 is a map generated by Tucson Water staff showing wells, the aquifer boundary, the Central Arizona Project aqueduct, and the CAVSARP recharge ponds located within a two-mile radius of the park water supply wells. Figure 4.8.2-3 shows the record of water levels at WSW-1 since 1963 together with water levels at a nearby City of Tucson monitoring well, ADWR 55-620255, located about 0.9 mile southwest of the park monitoring well and shown on Figure 4.8.2-2. Figure 4.8.2-3 includes water levels measured at the park monitoring well since 2010 as part of the Sonoran Desert Inventory and Monitoring Network groundwater protocol.

Groundwater elevations shown in Figure 4.8.2-3 track closely over the period of record, indicating that these two wells are in hydraulic communication with the same water source. Figure 4.8.2-3 indicates water levels about five feet higher nearer the valley center than at the park well even decades prior to the introduction of recharge by CAVSARP. This may be attributed to lack of accuracy in relative elevations of the two wells, or it may be consistent with minimal recharge contributed from the Tucson Mountains and the majority of recharge to the basin taking place below Brawley Wash near the valley center, and, since the 1990s, below CAVSARP. Groundwater also flows into the Avra Valley basin from the Altar Valley to the south. The natural groundwater flow direction in the Avra Valley subbasin is from south to north as shown in Figure 4.8.2-4 .

Declining water levels between the 1950s and 1990s reflect groundwater mining for agricultural uses in Avra Valley over that time period. In 1980, the City of Tucson began to purchase land in Avra Valley to retire agricultural water consumption. Development of CAVSARP and pilot testing of recharge began in 1996 and continued through 2002. Full-scale operation of the facility began in 2003 and continues today (ADWR 2016). This history is reflected in

Table 4.8.2-1. Groundwater wells at Saguaro National Park Tucson Mountain District.

Common Name(s)/ PLSS Location	Description (total depth)	Depth to Water (ft) (2015)	State Registration Number
SAGW WSW-1/ D(13-11)34CCC	Monitoring well, [Former water supply 1964-2008] (560 ft)	~380	55-629094
SAGW WSW-2/ D(13-11)34CCC	Potable water supply well 2009-present (660 ft)	~380	55-910129
Red Hills Section 36 well / D(13-11) 36BDC	Windmill-wildlife well; out of service (36 ft)	10	55-629095
Picture(d) Rocks Road Section 7 well*/ D(13-12) 7BDA	Not located (94 ft)*	Unknown*	55-629096
Dobe Robinson/ North Slope Section 25 Well/ D(13-11) 25BDA	Windmill-wildlife well; out of service (36 ft)	32.9	55-629097
Lockyer Well/ D(13-12) 9BCC	In wash ~76 m WSW of dome foundation (77 ft)	53.7	55-629098
Arizona Game & Fish/ D(13-12) 10CDB1	Windmill-wildlife well/ aka Barrel Spring (30 ft)	10.2	55-628185
Wildlife Watering Hole	Wildlife watering facility supplied by potable water system (n/a)	n/a	n/a

*Picture(d) Rocks Road Section 36 well was not located for field verification of location, total depth or 2015 depth to water prior to development of this text. Information shown in table is from ADWR well registration records as well as NPS and USGS field measurements.

Table 4.8.2-2. Geologic log of materials encountered during construction of well SAGW WSW-2 in 2008 (ADWR well registration records).

Depth from Surface		Description	Interval Where Water Was Encountered
From (ft)	To (ft)		
0	5	Top soil	
5	18	Clay and boulders	
18	60	Rock	
60	550	Conglomerate	
550	560	Gravel	Water
560	568	Rock	
568	660	Fractured rock	Water

Figure 4.8.2-3, and water levels in the basin near CAVSARP have risen to levels similar to those present in the early 1950s.

Groundwater in Hardrock Terrain

The remaining five groundwater wells listed in Table 4.8.2-1 are situated within the area characterized by a near-surface hardrock substrate. All of these wells are completed in "shallow" groundwater, where the definition of shallow groundwater here varies between 10 and 54 feet below ground surface. Since water level measurements at these sites are few, depths to water are not well characterized, but where measured have been found to vary seasonally depending on the climatic factors discussed above in combination with local site factors including contributing surface drainage area, soil texture, depth and volume of alluvium, hydraulic properties of sediments, bedrock slope and vegetation.

Describing groundwater conditions in the Avra Valley area, Andrews (1937, p. 171) notes that "available ground water beneath the upper slopes is scanty". He goes on to describe the presence of "shallow water in small quantities in washes where the rock is sufficiently fractured and disintegrated to serve as a storage reservoir for rain or run-off water that penetrates below the surface." Andrews further illustrates this in his Plate 41, in which he identifies the substrate at TMD as "mountain area (very little ground water)", "pediment zone (small amounts of shallow ground water)", and "upper

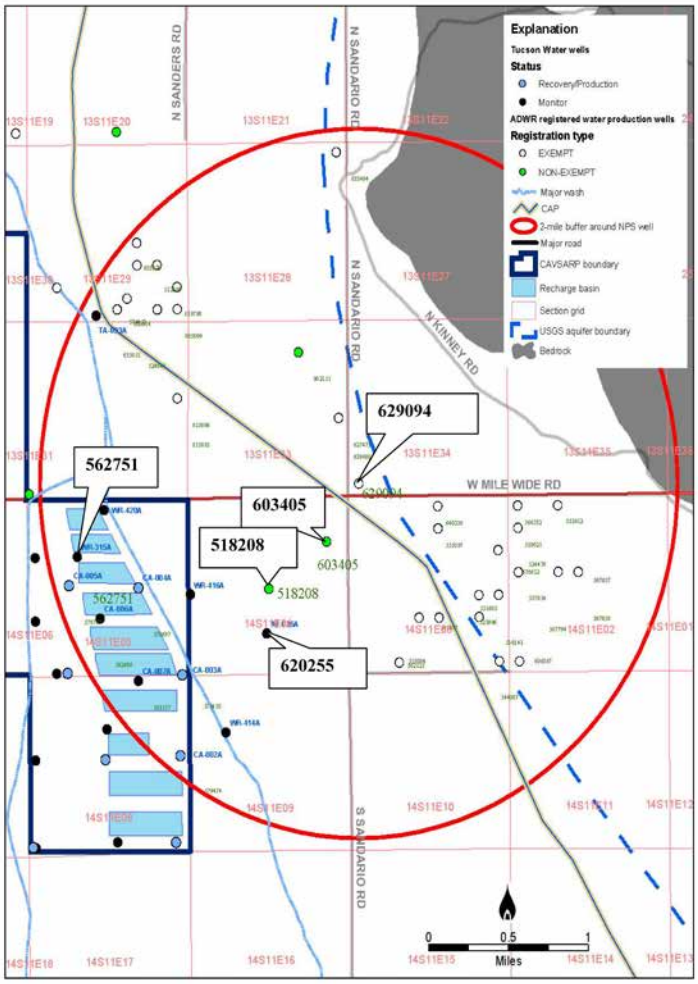


Figure 4.8.2-2. Map of water infrastructure and aquifer boundary within a two-mile radius of SAGW WSW-1 (ADWR 55-629094). Figure Credit: Tucson Water 2003.

alluvial land (fair amounts of ground water but rather deep)" (Andrews 1937; see Plate 41). These notes are descriptive of the sites known as Dobe Robinson and Red Hills, located in the pediment zone where shallow alluvial fan, terrace and colluvium sediments cover bedrock, and the Arizona Game & Fish, Lockyer, and Picture(d) Rocks wells, located on lower slopes in channel and low terrace deposits and alluvium (Figure 4.8.1-4) (Pearthree and Biggs 1999). The shallow groundwater sites at Dobe Robinson, Red Hills and Arizona Game & Fish were developed for the purpose of supplying perennial water to wildlife via windmills and surface catchments. The Dobe Robinson and Red Hills wells were developed as wildlife watering facilities by the Civilian Conservation Corps in the 1930s and were upgraded in 1989 as part of the Central Arizona Project Canal wildlife mitigation (Kline et al. 1998), but they are not currently functioning. The Arizona Game & Fish windmill was developed and continues to be maintained by the State of Arizona Department of Game and Fish.

The Lockyer well (shown in Figure 4.8.2-5 (left) and Picture(d) Rocks Road well are deeper (94 ft and 77 ft, respectively) and are not currently in use. As of this writing, the Picture(d) Rocks Road well has not been located by NPS or USGS staff. Table 4.8.2-3 summarizes known water level measurements at these three shallow wells.

Dobe Robinson

Dobe Robinson well shown in Figure 4.8.2-5 (right) was visited most recently in May 2016 and found to have less than a couple of feet of water present. The windmill and associated hardware were not functional at the time of the visit. Water level monitoring at Dobe Robinson between 2013 and 2016 has shown that available water at this site is not reliable, and the well is dry during the times of year when its water is most needed by wildlife. Figure 4.8.2-6 shows the record of depth of water in the bottom of the Dobe Robinson well together with precipitation between 2013 and 2015. These data show a lack of available water through the summer months. The Dobe Robinson well is situated in alluvium overlying crystalline rocks formed along the roof of the Amole pluton, including aplite and granodiorite. These rocks typically have little to no capacity for water storage except for within joints and fractures, which do not appear to be widely present in this area. Beckwith (2015a) documents the loss of a rock dam, Rincon Dam 4, constructed in the wash to facilitate retention of water in the sediments. For these reasons, it is not surprising that during the extended drought now occurring, water presence is ephemeral in this well. Loss of sediment in the drainage may also be a contributing factor to the apparent reduction in available water at this location.

Red Hills

The 32.4-foot deep Red Hills well, shown in Figure 4.8.2-7, was last visited in May 2016. No water level data were found for the period between 1982 and 2015 (Table 4.8.2-3). The

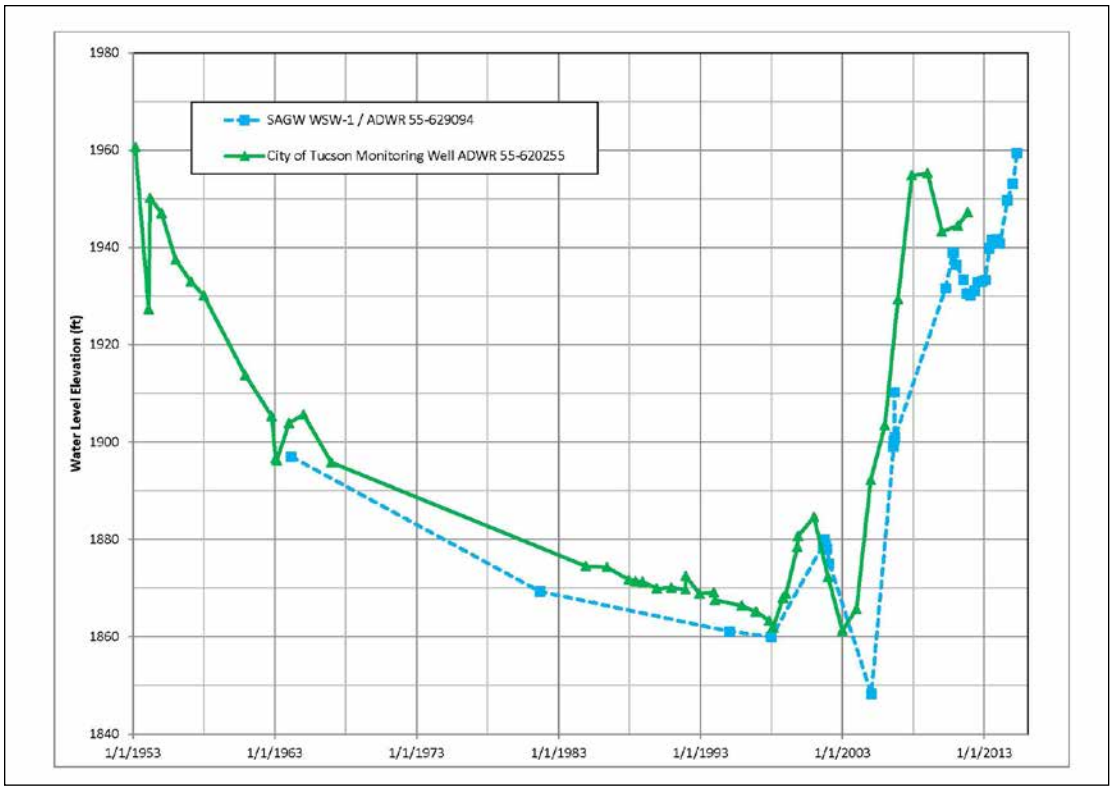


Figure 4.8.2-3. Elevation of historical and recent water levels measured at Tucson Water monitoring well (#620255) and SAGW WSW-1 (#629094). Data from ADWR online database and NPS field measurements..

windmill and associated hardware at this site were also not functioning when visited in January 2015, however a significant amount of water was present in the well (Table 4.8.2-3) and a water level recording sensor was installed on this visit. This logger was downloaded in May 2016 and provides a record of available water in the well throughout that time period, shown in Figure 4.8.2-8. Figure 4.8.2-8 shows that between January 2015 and May 2016, depth to water below the cover of the well was never more than about 13 feet, indicating that this location holds promise for supporting a small wildlife watering facility. Beckwith (2015b) documents the intact presence of Javelina Wash Dam 2 adjacent to the well and windmill. Red Hills well is located in a wash that has formed along a contact between granite of the Amole pluton and the sandstone, shale and conglomerate of the Recreation Red Beds (NPS 2009). About 300 m east and upgradient of the well, these two units come into contact with the Amole Arkose Formation, including siltstone, arkosic sandstone, conglomerate and limestone. The Red Hills well is located near the northwest terminus of the Museum Fault Zone, separating the Cretaceous

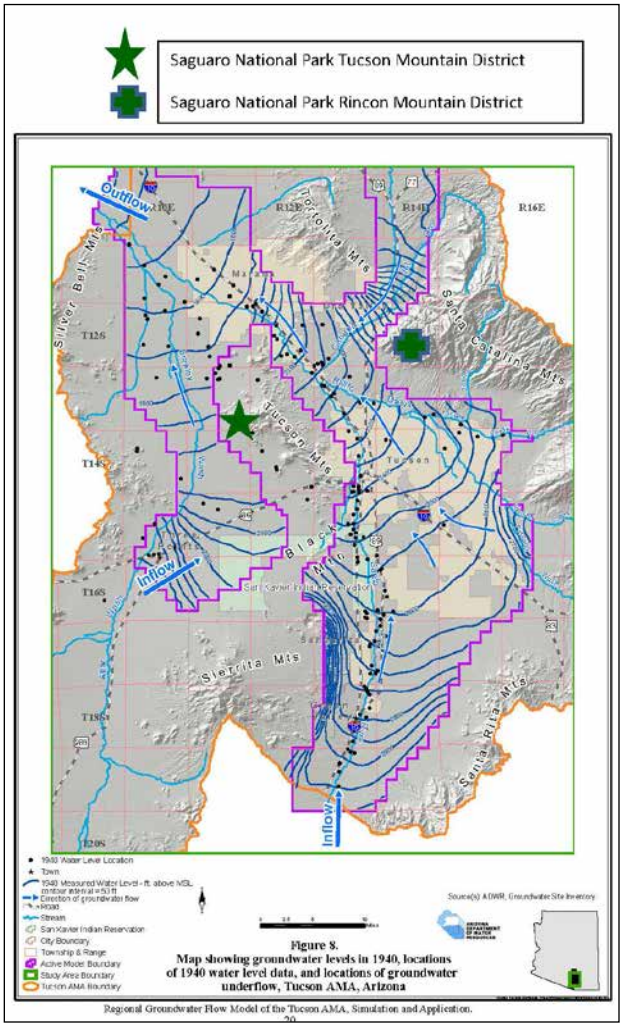


Figure 4.8.2-4. Water levels in the Tucson AMA circa 1940s. Figure Credit: Mason and Bota 2006.

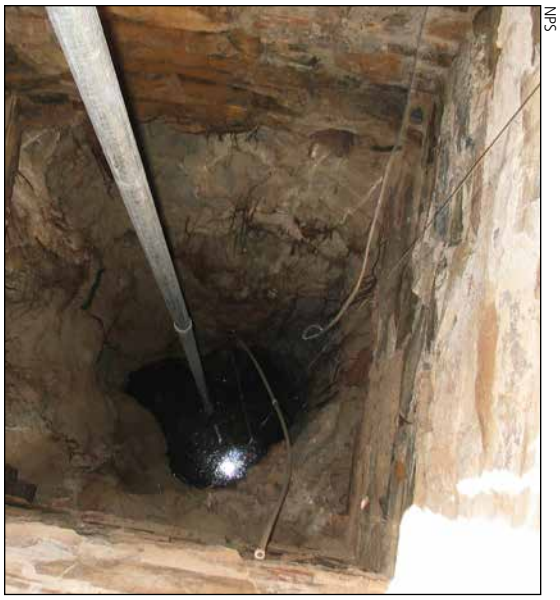


Figure 4.8.2-5. Lockyer Well in 2015 (left) and interior view of Dobe Robinson dug well (right).

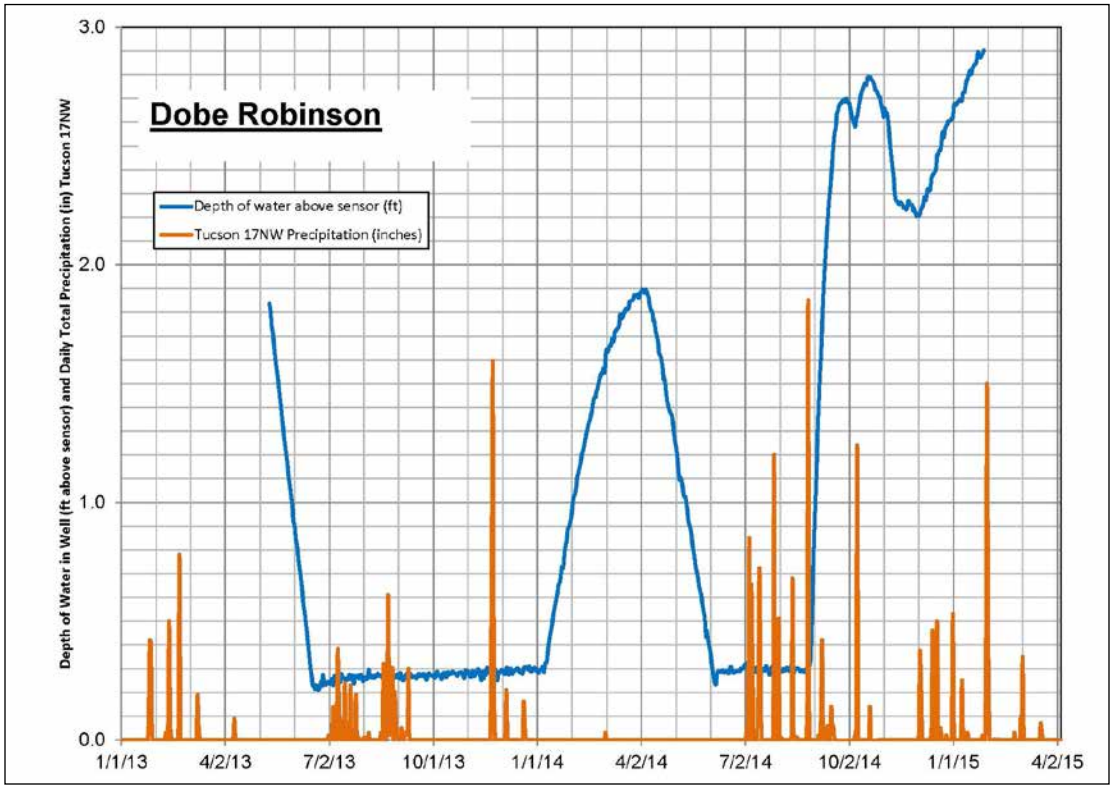


Figure 4.8.2-6. Water levels measured at Dobe Robinson well 2013 to 2015 (as depth of water above sensor in well bottom).

arkose and the older Jurassic Recreation Red Bed units in this area. The unique position of the Red Hills well in respect to these features in combination with the limited potential for greater water storage capacity of the sedimentary rock units, the presence of alluvial fan and colluvial sediments, and the intact dam structure explain the greater availability of water at this location compared with Dobe Robinson.

Arizona Game & Fish (sometimes referred to as Barrel Spring)

Although few water level data are available for this site, recent data are promising and indicate possible year-round water availability at the Arizona Game & Fish site. The windmill and wildlife watering facilities are maintained by the Arizona Game and Fish Department and were functioning when visited in December 2014 and April 2015 (Beisner, personal communication; Figure 4.8.2-9. The

Table 4.8.2-3. Groundwater level data for three shallow wells in the Tucson Mountain District.

Measurement Date	Location	Water Level Depth Below Measuring Point (ft)	Source
6/2/1983	Dobe Robinson	14.5	document from R. Beckwith; states depth of well is 17.4 ft
10/15/1988	Dobe Robinson	19.5	Beckwith
5/15/2007	Dobe Robinson	32	Ward
6/20/2007	Dobe Robinson	33	Ward
7/16/2007	Dobe Robinson	33.75	Ward
10/29/2007	Dobe Robinson	33.5	Ward
11/14/2007	Dobe Robinson	33.5	Ward
7/17/2008	Dobe Robinson	32.75	Ward
11/13/2008	Dobe Robinson	34.4	Ward
3/9/2009	Dobe Robinson	31.4	Ward
4/16/2009	Dobe Robinson	32	Ward
4/19/2012	Dobe Robinson	32.6	Ward
1/23/2013	Dobe Robinson	34.5	Ward
5/10/2013	Dobe Robinson	34.18	Perger
1/29/2015	Dobe Robinson	32.88	Ward/Perger
5/12/2016	Dobe Robinson	35.64	Perger
1930	Red Hills	5.5	ADWR well record
??	Red Hills	4.2	Mott p.19 no date
6/15/1982	Red Hills	29.4	Beckwith
1/29/2015	Red Hills	9.95	Ward/Perger
5/12/2016	Red HIlls	11.8	Perger
1/1/1953	Arizona Game &Fish	variable to 18	ADWR registry record
1/26/1995	Arizona Game &Fish	1.2	ADWR GWSI database
12/17/2014	Arizona Game &Fish	10.24	Beisner USGS
4/1/2015	Arizona Game &Fish	10.30	Beisner USGS

Figure 4.8.2-7. Red Hills well and dam (Beckwith 2015b).

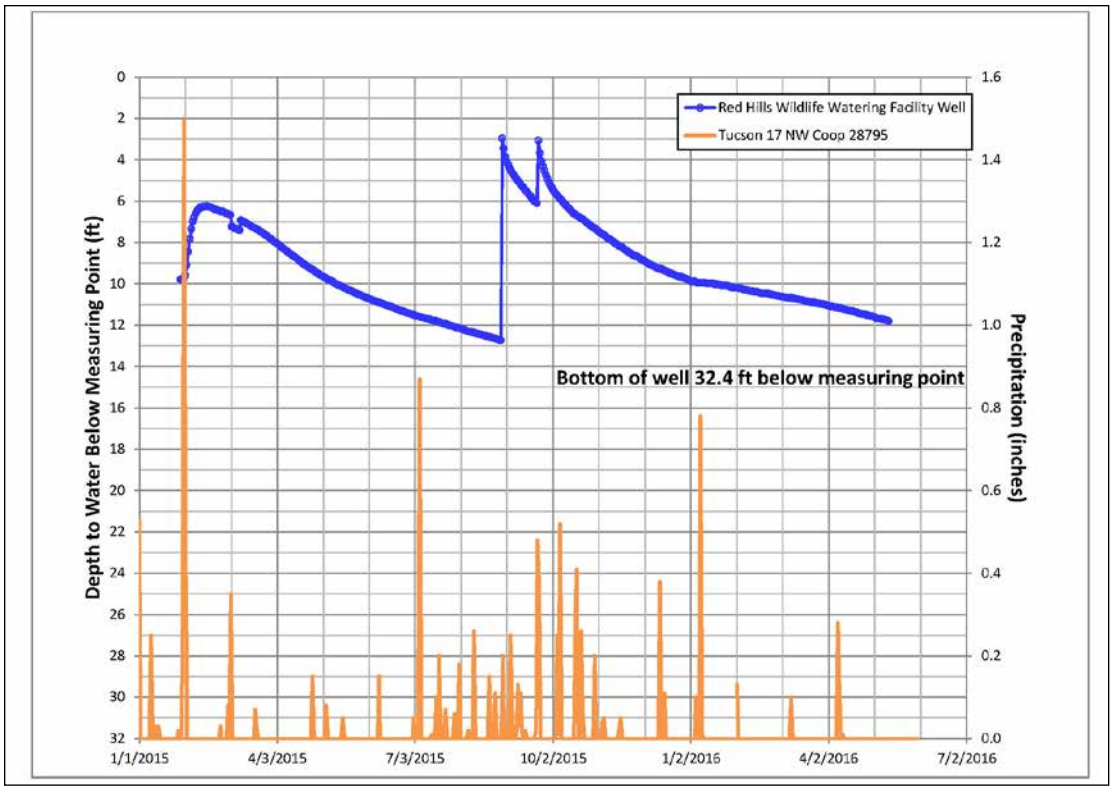


Figure 4.8.2-8. Depth to water in Red Hills wildlife water facility well 2015-May 2016.

Arizona Game and Fish staff do not measure water levels (Ed Jahrke, AZ G&F, personal communication). The well is located in a wash that drains a larger area than either of the other two windmill sites discussed above, and occupies a lower position in the landscape (refer to Figures 4.8.1-4 and -6). Geologically, the well is situated in alluvium overlying an andesitic lava flow that is one member of the thick, northward-tilting sequence known as the Volcanics of Yuma Mine (Lipman 1993, NPS 2009). While the host rocks in this sequence may not possess significant primary porosity capable of storing water, a secondary porosity of joints and fractures developed during the tilting and repositioning of these rocks may have developed, providing additional storage capacity and facilitating year-round availability of near-surface groundwater at this location.

Groundwater Usage

Between 2012 and 2015, groundwater pumped by the TMD averaged 300,000 gallons per year (0.92 acre-feet per year). This water is pumped from the water supply well SAGW WSW-2 (ADWR 55-910129), supplying all operations at TMD as well as a wildlife viewing area watering facility formerly known as Windmill #1 (Boy Scout), located northwest of the visitor center along Kinney Road (refer to Figures 4.8.1-1 and -4. An unknown percentage of the potable water used by the park is returned to the groundwater system via the park's leach field, located west of the visitor center. The former water supply well, SAGW WSW-1 (ADWR

NPS

Figure 4.8.2-9. USGS hydrologist measuring water level at the Arizona Game & Fish windmill.

55-629094), was in use through 2008 and has been converted to a monitor well since SAGW WSW-2 was brought on line in 2009.

Of the three wildlife watering facilities, only the Arizona Game & Fish windmill facility remains operational. Arizona Game and Fish staff maintain this watering facility but do not measure water levels at the site (E. Jahrke, personal communication). The other two shallow wells, although equipped with windmills for wildlife watering purposes, are not in service. Dobe Robinson well may have insufficient water to be serviceable as a water source in the future, but Red Hills well shows promise as a year-round wildlife water source. Repairing the Rincon Dam 4 at Dobe Robinson may improve groundwater retention at that location. Monitoring by NPS staff to better understand these two sites is ongoing. Neither Lockyer or Picture(d) Rocks wells are in use at this time. The Lockyer well has potential as a wildlife watering facility source, but the Picture(d) Rocks well is not located at this time and may or may not be in usable condition.

4.8.3. Reference Conditions

Deep Groundwater Reference Conditions

Reference conditions for groundwater levels in the Avra Valley basin are available from several sources. Mason and Bota (2006) indicate that in 1940, water level elevations in the area of the park's water supply well were around 1950 feet (Figure 4.8.2-4). Mason and Hipke (2013) report water level elevations in the area of the park wells also around 1950 feet in 2010 (Figure 4.8.3-1). Osterkamp (1973) shows a depth to water in the area of the park wells of between 400 and 500 feet, which would translate to water level elevations between 1836 feet and 1936 feet. These levels are consistent with the water levels shown at the park well and a nearby City of Tucson well in Figure 4.8.2-3. Beginning around 1940, increasing groundwater pumping in the Avra Valley aquifer put the system into an overdraft condition that increased in severity into the mid-1970s (Mason and Bota 2006). Reductions in agricultural water demand after the 1970s were offset by increases in municipal use by the City of Tucson, and water levels did not begin to increase until the arrival of Central Arizona Project water and the initiation of aquifer recharge at the CAVSARP facilities in Avra Valley in the late 1990s. Today, the Avra Valley groundwater system is highly managed by the City of Tucson and dependent on CAP inflow, such that the concept of reference condition is somewhat moot. For our purposes, the predevelopment 1940 water level elevation of 1950 feet and overall south to north groundwater flow conditions in the Avra Valley aquifer are identified as meaningful reference states for the aquifer supplying potable water to the park. Since the ground surface elevation where the monitoring well SAGW WSW-1 is located is about 2,336 feet, and the reference condition water level is 1,950 feet, a depth to water around 385 feet or less is considered to be a good condition. In addition, reference conditions for deep groundwater are also associated with the regional groundwater flow regime. In Avra Valley, the predevelopment groundwater flow pattern was uniformly south to north as shown in Figure 4.8.2-4.

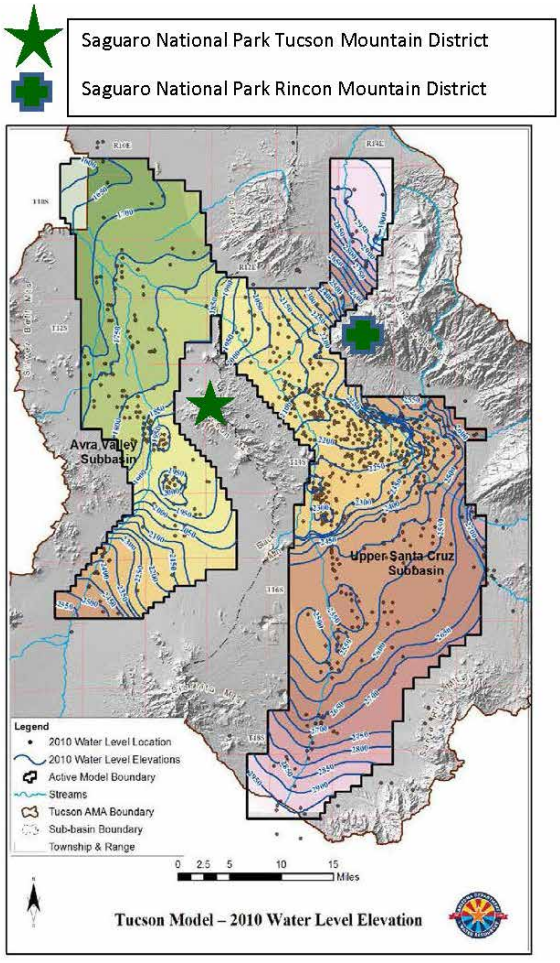


Figure 4.8.3-1. Groundwater levels in the Tucson AMA circa 2010 (Mason and Hipke 2013).

Shallow Groundwater Reference Conditions

Groundwater availability in the shallow alluvium of ephemeral drainage channels is closely associated with seasonal climatic cycles in the Sonoran Desert. When adequate sediment is present and conditions are right, winter season infiltration will produce sufficient groundwater storage in sediments to sustain shallow water levels and springs through the hot dry season. The bimodal winter rains and summer monsoon precipitation pattern and annual peak in potential evapotranspiration shown in Figure 4.8.3-2 result in cycles of high and low water levels in shallow alluvium where measurements have been made. Figures 4.8.2-6 and -8 illustrate this type of seasonal pattern at Dobe Robinson and Red Hills. Persistence of groundwater availability within the channel alluvium between wet seasons depends on a number of physical factors unique to each location. In the case of both Dobe Robinson and Red Hills wells, the presence of sufficient water to sustain wildlife watering facilities throughout the year is the reference condition. Exactly what this translates to in terms of water levels throughout the year within the respective wells is not quantified at this time, but efforts to determine just that are underway.

At Dobe Robinson well, the water levels listed in Table 4.8.2-3 suggest that water levels were higher in the 1980s, although the number of water level data are limited. While data from the CCC era or from the 1990s were not located, the more recent measurements beginning in 2007 indicate that water availability at Dobe Robinson is much reduced relative to the 1980s levels. Since 2007, no water level measurements have shown depth to water less than 31 feet, while the two 1980s data show depths to water under 20 feet, one of these in June. In the case of Dobe Robinson, reference conditions similar to those of the 1980s seem reasonable, since available water capable of sustaining wildlife watering facilities through the spring and summer period would be required to justify the effort involved in developing the facility initially, and then restoring it in 1989. When available water is relatively low in June, the ability of the well to sustain a water supply to a surface catchment without restoration of the dam at a minimum, is doubtful. Continued water level monitoring and eventual testing of this source will be needed prior to committing

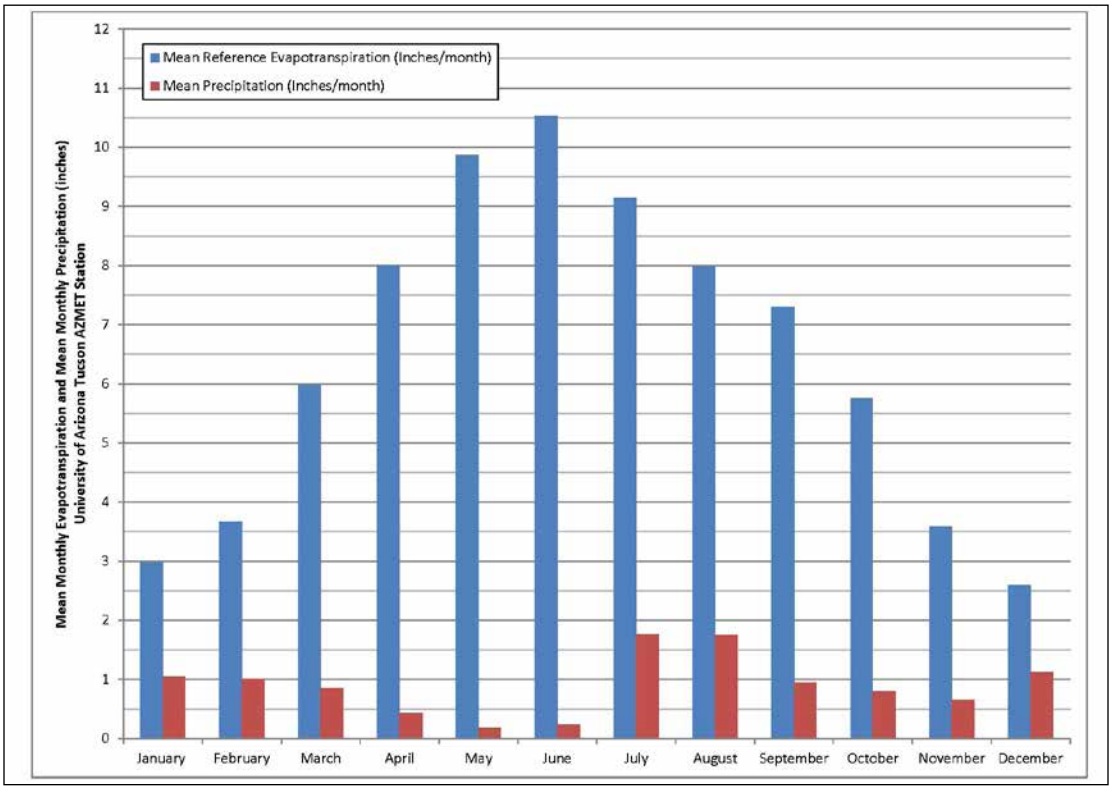


Figure 4.8.3-2. Monthly mean potential evapotranspiration and precipitation at The University of Arizona's Arizona Meteorological Network (AZMET) Tucson station.

substantial maintenance resources at this site. While it is not possible at this time to specify a quantitative reference condition with confidence, it is possible to state qualitatively that the current condition is below the reference condition, is not adequate to sustain established uses, and is reasonable assigned to a condition class warranting significant concern.

At the Red Hills well, a depth to water of 5.5 feet in the 1930s is recorded in state records. A depth to water of 4.2 feet at Red Hills is reported by Mott (1997), and depths to water ranging between 3 feet and 12.7 feet were recorded between January 2015 and May 2016 (Figure 4.8.3-1). A June 1982 measurement at Red Hills indicated a depth to water of 29 feet. More recent measurements at Red Hills, shown in Table 4.8.2-3 and in Figure 4.8.3-1, indicate that this well contains a fair amount of water during both the winter and summer months, at least for the relatively short 2015-2016 monitoring period. In 2015, water levels at Red Hills reached their lowest point in late August, after which time recharge from the summer monsoons appears to have replenished storage in the well, which then declined steadily through the winter months. No increase in storage was observed during the 2015-2016 winter season, which was abnormally warm and dry. The limited data available are not sufficient to arrive at a firm conclusion about long-term reference state, especially since there are no dates associated with the early measurement data. Variability throughout the years is unknown, and how much water is sufficient to sustain a wildlife watering facility is undetermined at this time. A longer period of monitoring is needed, but the presence of water throughout the year is encouraging. The reference conditions for TMD's groundwater resource are summarized in Table 4.8.3-1.

4.8.4. Condition and Trend

Avra Valley Aquifer

Condition and trend in the Avra Valley aquifer are assessed on the basis of water level elevation at the park water supply well and on aquifer-wide water level maps developed by Tucson Water staff. The current status of water levels in the area of the TMD water supply well is comparable with pre-development (1940) water levels of around 1,950 feet altitude. As shown in Figure 4.8.2-3, water levels at the park water supply well have recovered from declines of as much as 100 feet in recent years. However, overall aquifer status is not directly comparable with predevelopment conditions since the increased water levels starting in the late 1990s at TMD are attributed to the introduction of CAP recharge at CAVSARP. Figures 4.8.2-4 and 4.8.3-1 show Avra Valley water level contours for 1940 (Mason and Bota 2006) and 2010 (Mason and Hipke 2013). Examination of these two figures reveals the localized influence of recharge in the development of groundwater mounds beneath the CAVSARP and its sister project to the south, the Southern Avra Valley Storage and Recovery Project (SAVSARP). The recharge facilities substantially perturb natural groundwater flow patterns in Avra Valley, and have not restored depressed water table levels in the north of the basin. Taking into account the intensely managed nature of this aquifer near the park, the condition is assessed as moderate at this point in time. Trend for groundwater in this aquifer is assessed as stable, but confidence in this assessment is medium due to long-term uncertainty around the effects of continuing drought, dependence on water imports from outside the watershed, and potential for CAP water delivery reductions in future years.

Shallow Alluvial Groundwater

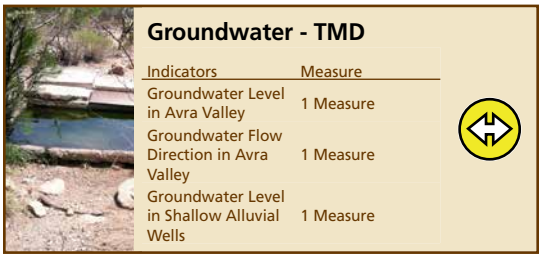
Available data for the two wildlife watering wells in the shallow pediment alluvium are limited. At Dobe Robinson, there are sufficient recent measurements (Figure 4.8.2-6) to indicate that water levels at that location have declined substantially since the 1980s, to the point that the site may no longer be functional as a water source for wildlife without intervention, such as restoration of the dam. Condition of groundwater at this location is of significant concern. Due to the limited data available but knowing that the site functioned as a water source in past years, trend in condition is assessed as deteriorating. Confidence in this assessment is medium.

At Red Hills, insufficient data exist to understand whether or not water availability

Table 4.8.3-1. Reference classes for assessing groundwater condition at Saguaro NP.

Condition Class	Description
Good	In the Sonoran Desert, a good reference condition consists of a water balance that sustains park operations and ecosystem integrity in keeping with established uses without threat of interruption or long-term declining trends in groundwater levels. Water level variability reflects a system in dynamic equilibrium, characterized by natural short-term variation in environmental inflows and outflows, but with sufficient reserves remaining in storage to supply wildlife watering facilities and park operations through low water level cycles of normal magnitude and duration.
Moderate Concern	A moderate groundwater condition exists when natural groundwater levels are capable of meeting established operational and/or ecosystem needs but evidence of imbalance is present. For example: • A long-term declining trend in groundwater levels is present. • Fluctuating water levels are regularly reaching lower levels than were previously observed. • Periods of low water levels are longer in duration than were previously observed • Average groundwater levels are significantly lower than previously observed and are approaching a condition that is marginally sufficient to maintain established uses. In this scenario, prolonged drought or increase in runoff, lack of snow, excessive or new groundwater withdrawals, or physical alteration of the surface environment such as loss of water-bearing soils and sediments by erosion, diversion of runoff by road entrenchment, or streambed channelization, interrupt the hydrologic processes supporting established uses. Where groundwater availability is deemed adequate but is fundamentally dependent on water imported from sources from outside the watershed, a moderate condition assignment is warranted. Alternatively, a moderate condition is indicated before marginal levels are reached when long-term (multi-year) declines in water levels occur regardless of the origin of the negative water balance.
Significant Concern	A condition of significant concern exists when groundwater supplies are marginally adequate, are intermittently inadequate, or are consistently inadequate to sustain established uses.

is currently adequate to sustain wildlife watering facilities, which is the reference condition. Depth to water through the summer months for several years will be a key measure to inform on condition at this location, and testing to determine if water pumped from the well during dry periods will be recharged is needed. Ongoing monitoring will provide improved understanding of this important water source. On the basis of data for 2015-2016, condition at Red Hills is tentatively assessed as moderate, pending results of long-term monitoring and recharge capacity testing during dry periods. Trend in condition is tentatively assessed as stable, and confidence in this assessment is medium.



Overall Condition and Trend

A summary of each indicator and measure and their contribution to the overall water quality condition within TMD is listed in Table 4.8.4-1.

Overall condition of deep groundwater at TMD is assessed as one of moderate concern. At present, water levels in the Avra Valley groundwater subbasin near the park are comparable to predevelopment conditions. However, current water levels near the park are dependent on continued inflow of Tucson's allocation of CAP water. This is a concern because shortages in CAP delivery to the state are projected, although in the near

term, shortages are not projected to be passed on to municipal users (Central Arizona Project 2014). While local-scale water flow patterns are perturbed by recharge facilities, overall water flow direction remains south to north, and trend is assessed as stable at this point in time.

Groundwater in the shallow alluvium at TMD is less well characterized than deep groundwater in the Avra Valley subbasin, but is more threatened by the effects of drought due to limited storage capacity, rapid drainage following infiltration, increased evapotranspiration and absence of supplemental sources compared to deep groundwater. Southern Arizona has been in a long-term drought condition since the late 1990s and is currently experiencing abnormally dry conditions as shown in Figure 4.8.4-1. Drier than normal conditions stress shallow groundwater reserves through decreased infiltration, increased plant water uptake, and increased evaporation when it does rain. Drier conditions also facilitate wind-induced surface soil losses, leading to increased surface armoring and runoff. Condition status of shallow groundwater is assessed as one of moderate concern, while trend is deteriorating and confidence in assessment is medium due to the need for additional monitoring results.

Overall condition of groundwater at TMD is assessed as moderate, with an unchanging trend and medium confidence level.

Key Uncertainties/Threats

Key uncertainties in groundwater condition arise from unquantified changes in water balances in response to future climatic conditions and to concomitant changes in ecosystem and human consumption. Projected increases in temperature and decreases in precipitation as well as projected increases in extreme winter precipitation events (Garfin et al. 2013) have the potential to result in added stress to shallow groundwater reserves when infiltration is reduced and plant transpiration demands are increased. Soil losses that occur during extreme events reduce the ability of watersheds to retain water and deteriorate groundwater conditions. Within the Avra Valley groundwater subbasin, sustainability depends upon continued inflows from the Colorado River, a source that depends on many factors outside of the control of the end user (Bureau of Reclamation 2012).

Table 4.8.4-1. Summary of the groundwater indicators, measures, and condition rationale.

Indicator of Condition	Measure	Condition	Rationale for Condition
Groundwater Level in Avra Valley aquifer west of the park	Depth to Water <385 feet at park monitoring well ADWR 55-629094	Moderate Concern	Current water levels at the park monitoring well are similar to the reference period; however, dependence of aquifer water levels on imported Colorado River water and projected shortages in delivery of Colorado River water, in combination with over-allocation of groundwater in Tucson AMA, create uncertainty going forward.
Groundwater flow direction in Avra Valley aquifer	Groundwater flow lines similar to pre-development south to north pattern	Moderate Concern	Overall groundwater flow follows a south to north trajectory, but is significantly perturbed by recharge facilities, recovery wells and continued aquifer depletion to the north.
Groundwater level in shallow alluvial wells	Depth of water in shallow wells during dry season >20 feet above the well bottom	Moderate Concern	One of two shallow wells used for providing water to wildlife is no longer capable of supplying the facility during the driest times of year when it is most needed; the second well meets the measure criteria but it is unknown if this would be sustained if water was pumped for supplying wildlife.

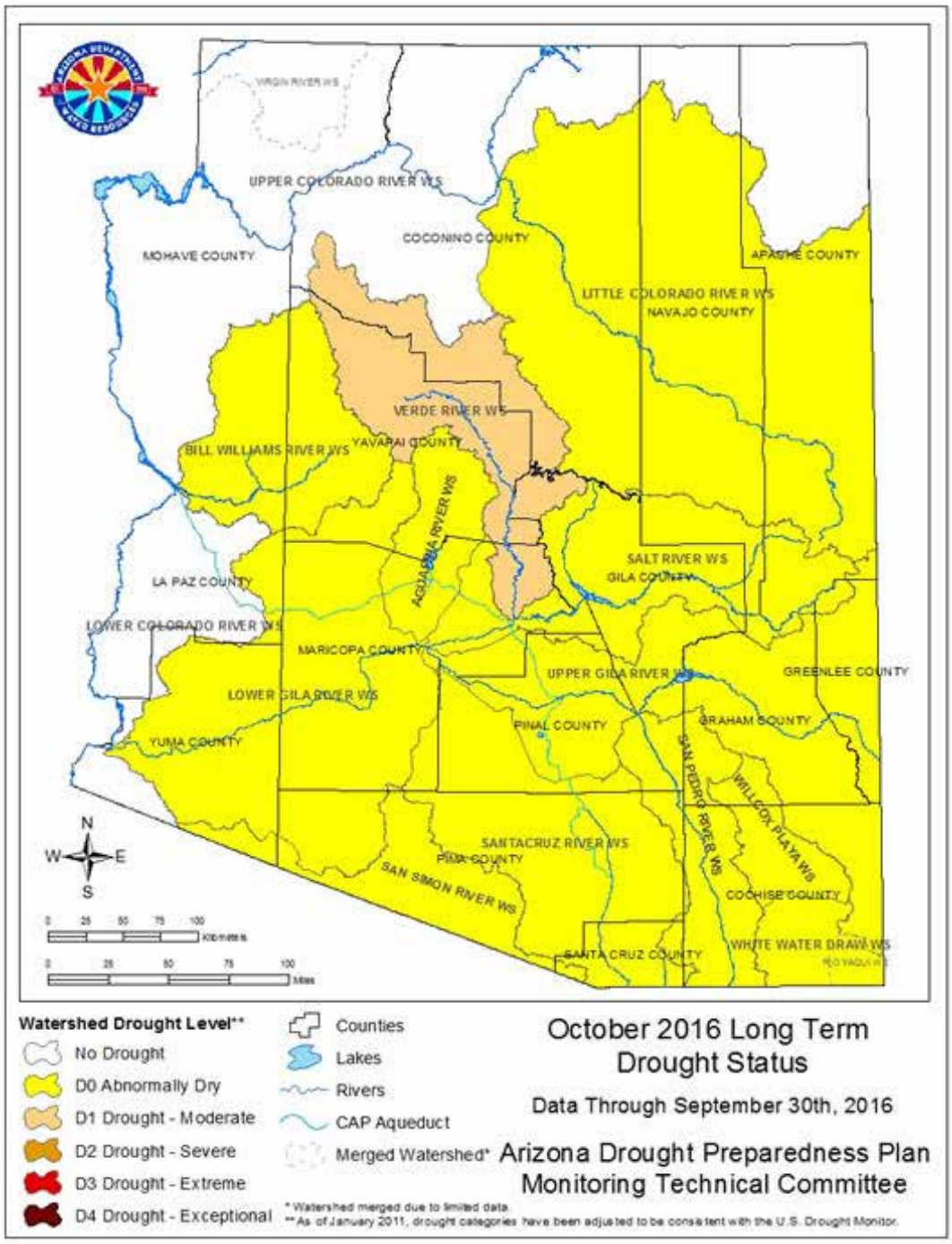


Figure 4.8.4-1. Map of Arizona long-term drought status as of October 2016 (ADWR 2015a).

4.8.5. Sources of Expertise

The groundwater assessment for Saguaro NP was developed by Colleen Filippone, NPS Intermountain Region hydrologist and groundwater protocol lead for the Sonoran Desert Inventory and Monitoring Network. The interpretation and assessment presented here are derived from personal experience at the park, discussions with Saguaro National Park and U.S. Geological Survey Arizona Water Science Center staff, the data cited, and from supporting information in the cited literature. This work could not have been conducted without the assistance of Saguaro NP facilities and resource staff and volunteers, whose data collection and contributions over the years are the foundation of the preceding discussions. Thanks are extended to Chuck Perger, Chris Eastoe, Steven Rice and Jennifer Back for their thoughtful reviews of this chapter.

Ms. Filippone holds a Master of Science degree in Hydrology and Water Resources from The University of Arizona in Tucson. Her areas of expertise include groundwater hydrology, water quality and unsaturated zone hydrology.

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4.9. Groundwater - Rincon Mountain District

Indicators/Measures

- Groundwater Supplying Perennial High Elevation Springs (1 Measure)
- Groundwater Occurring in Mountain Block Regional-scale Fractures (1 Measure)
- Groundwater Supplying Low Elevation Springs, Pools, and Tinajas (1 Measure)
- Shallow Alluvial Aquifer In Rincon Valley And Upper Pantano Formation (1 Measure)
- Detachment Fault Related Groundwater (1 Measure)
- Upper-plate Groundwater (1 Measure)

Condition – Trend - Confidence

Moderate Concern – Deteriorating – Medium

4.9.1. Background and Importance

Groundwater is vital to the ecosystem integrity and operations of both the Tucson and Rincon Mountain units of Saguaro National Park (NP). In the Rincon Mountain District (RMD), the few perennial springs and bedrock pools (tinajas) upon which wildlife and aquatic ecosystems depend for survival through the hottest and driest times of year are sustained by groundwater (Figure 4.9.1-1). The potential loss of groundwater in the park due to long-term concerns such as climate change and groundwater withdrawal outside park boundaries is of significant concern to park managers. At Saguaro NP, in addition to location-specific physical characteristics of soils and bedrock, groundwater availability to ecosystems is dependent on climatic variables, including evaporation and the quantity and timing of precipitation as well as whether the precipitation falls as rain or as snow.

Rincon Mountain District Physical Setting

The Upper Santa Cruz subbasin portion of RMD occupies the northwestern, western and southwestern slopes of the Rincon Mountains and lies within the Tucson Active Management Area (AMA). Eastern flanks of the Rincons include drainages to the east and southeast included in the Mammoth subbasin to the east-northeast and the Sierra Vista subbasin to the southeast (Figure

NPS

Figure 4.9.1-1. Lowland leopard frogs in a pool along Chimenea Creek, Rincon Mountain District.

4.9.1-2). The Mammoth and Sierra Vista subbasins are not included in the Tucson AMA. Present-day physical characteristics of RMD are dominated by the development of the Catalina-Rincon metamorphic core complex between 25 and 18 million years ago (Davis 2013). During that period of regional crustal extension, Paleozoic limestone, Proterozoic granite and Cenozoic basin-fill rocks in the upper 6-8 km of crust were tilted and sheared, causing them to separate from granitic rocks that had intruded deep below the surface. The separation occurred along the Catalina-Rincon detachment fault surface/fault zone. The trace of this fault zone passes through RMD and is exposed along the Cactus Forest Loop Drive (Figure 4.9.1-3; Davis 1987). The overlying upper plate (hanging wall) rock units moved down and slid to the west and southwest, unroofing the granitic basement (footwall) rocks, which were altered below the primary fault surface. These footwall rocks migrated to the northeast and were uplifted and arched, becoming the present day Rincon and Catalina Mountains. The Catalina-Rincon fault zone includes the subparallel subdetachment Javelina fault as well as minidetachment surfaces and microfaults, which can also be observed along the Cactus Forest Loop Drive (Davis 2013, Force 2002). Figure 4.9.1-4 shows the boundaries of the level 12 (HUC-12) surface watersheds in and around the park.

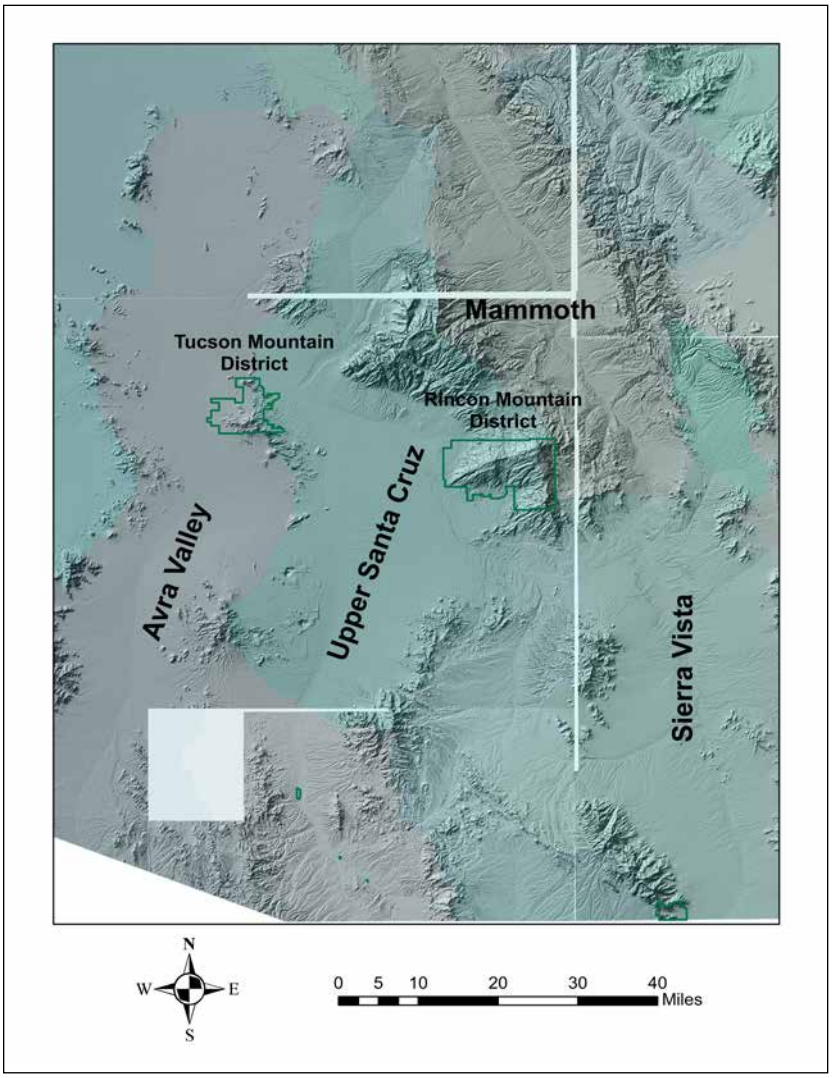


Figure 4.9.1-2. Groundwater sub-basins around Saguaro National Park districts (ADWR 2015 GIS dataset).

A direct result of the core complex development is that a majority of RMD is underlain by crystalline igneous and metamorphic rocks. Capacity to store or transmit groundwater in these rocks is limited to joints, faults and preferentially weathered foliation planes - sheet-like planar structures (Marshak 2009) formed along shear zones within the rock fabric. Where there is no soil, alluvium or weathered bedrock at the surface, groundwater storage is restricted to rock fractures. Figure 4.9.1-5 illustrates wells at RMD and areas within the Tucson AMA identified by ADWR as "hardrock", i.e., non-water bearing areas outside of any designated aquifer (the shape file shown in the figure covers only areas within the Tucson AMA, in fact the entire east side of the park is underlain by the same types of hardrock and has similarly limited ability to store groundwater). Within the park, upper plate (hanging wall) rocks are found west and south of the Catalina-Rincon detachment fault. Upper plate bedrock is also characterized by minimal water storage capacity, and in most areas, is buried beneath relatively shallow sediments eroded from the nearby mountains (Bezy 2005).

Rock fractures, including joints and faults, control subsurface flow pathways in the otherwise impermeable granitic, gneissic and schistose hardrocks at RMD. Understanding groundwater movement at RMD is linked to understanding the occurrence and characteristics of these features in the park. While rock fractures are necessary for groundwater storage and flow in hardrock terrain (away from near-surface flow in soils,

alluvium, colluvium, etc.), these features alone are not sufficient. Connectivity of fractures having sufficient aperture for flow to occur is a required condition that is present locally in some sections of some drainages. There is no evidence that hydraulic connectivity in the sense of an equivalent porous medium is widely or locally present in the Rincon Mountains at Saguaro NP. In other words, there is no evidence for a bedrock aquifer at the park. Groundwater in the crystalline bedrock occurs in discrete fractures present at both local and regional scales or within limited local- and regional-scale fracture networks. Infiltrated groundwater is also stored in pore spaces within soils, alluvium, colluvium, debris flows and bedrock-weathered-in-place where these occur in drainages and on protected slopes.

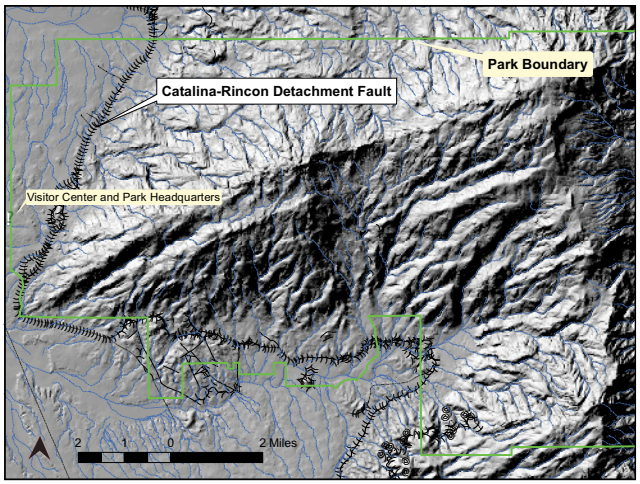


Figure 4.9.1-3. Map showing location of the Catalina-Rincon detachment fault and drainages at Rincon Mountain District.

Studies of joint, fault and foliation characteristics on Tanque Verde Ridge, the most prominent landform in the park, have concluded that these features of the ridge exhibit structural control on the landscape form and evolution on all scales, from the ridge itself to microtopographic features, including the striking drainage patterns shown so vividly on imagery as seen in Figure 4.9.1-3 (Leger 1967, Miksa 1993, Rodriguez-Guerra 2000). Four vertical joint sets were identified in the field by Leger and confirmed by Miksa. These local-scale features were also identified by Rodriguez-Guerra using remote sensing, who also documented the presence and orientations of three systems of larger-scale penetrative lineaments on the basis of analysis of Landsat Thematic Mapper imagery (Landsat TM), Digital Orthophoto Quarter

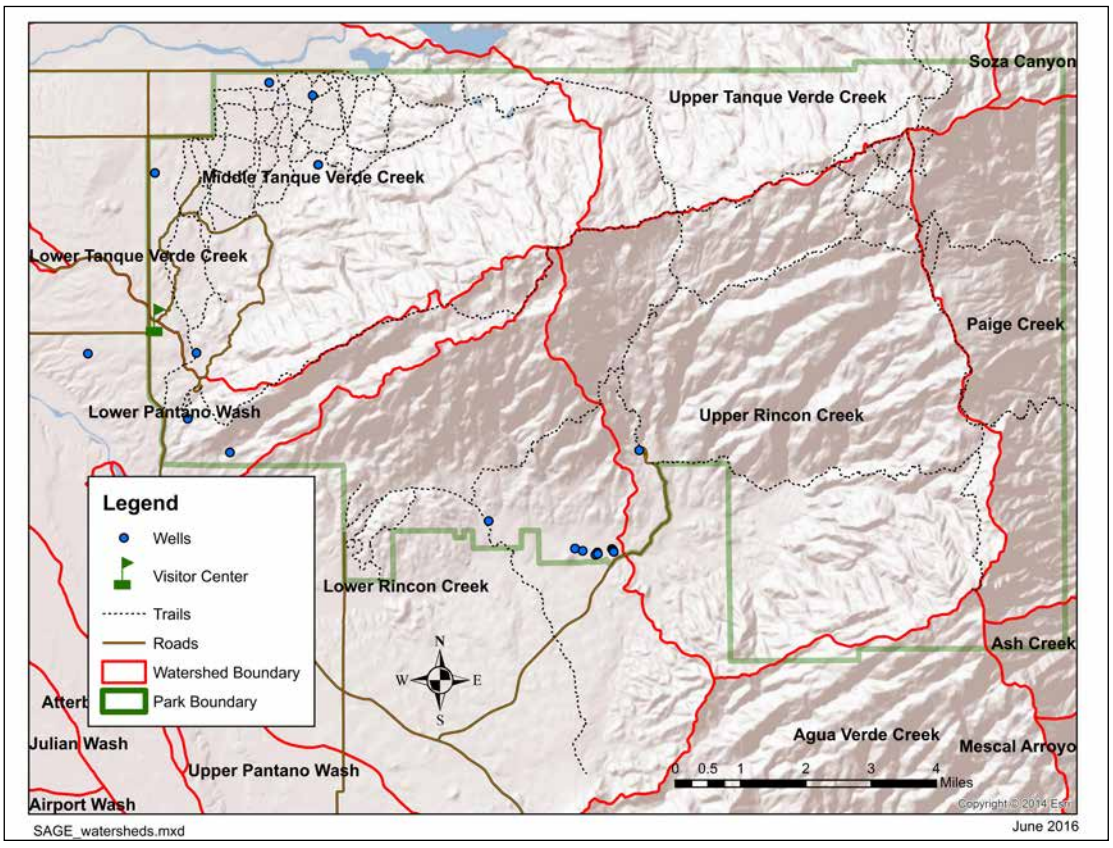


Figure 4.9.1-4. Location of HUC level 12 watershed boundaries at Rincon Mountain District.

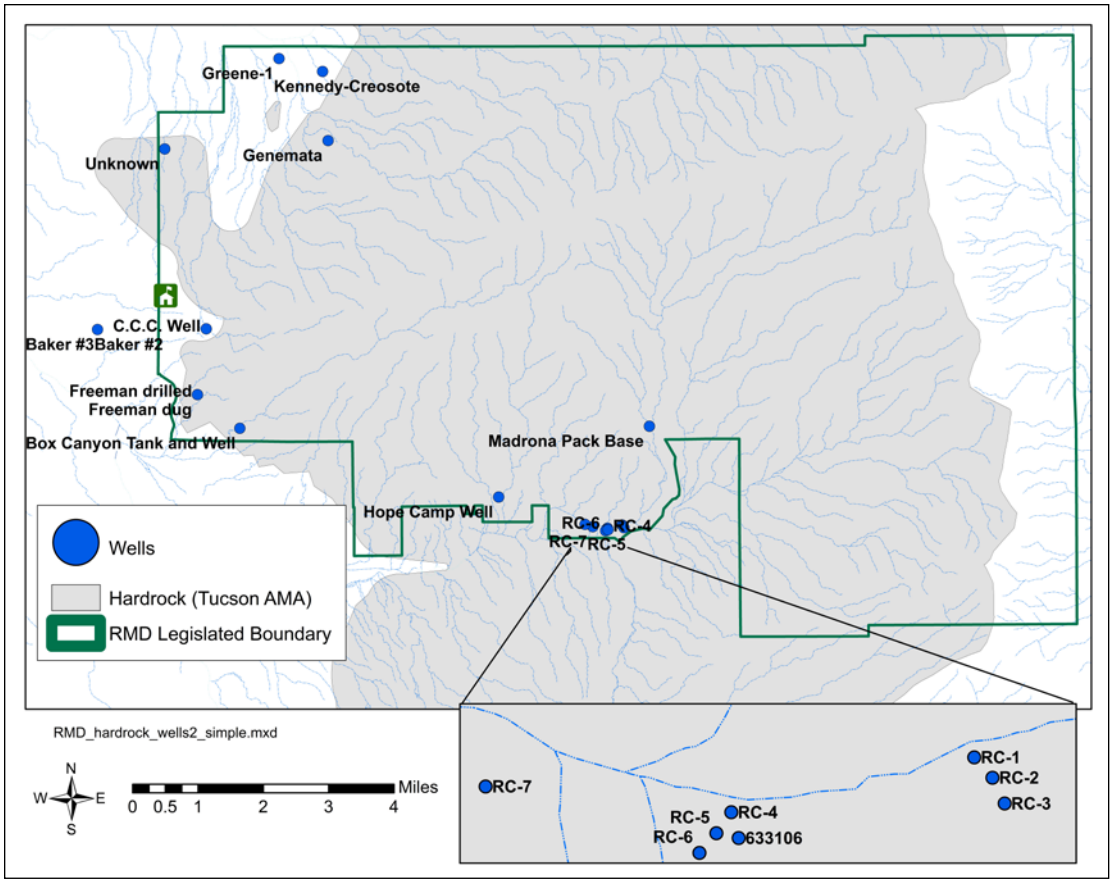


Figure 4.9.1-5. Map of Rincon Mountain District showing areas underlain by hardrock substrate and groundwater well locations.

Quadrangles (DOQQ) and USGS Digital Elevation Models (DEM)(Rodriguez-Guerra 2000). Rodriguez-Guerra (2000) confirmed the presence of two of these systems in the field and verified that one of the sets identified as small-scale joints by previous investigators was actually a system of large-scale faults.

The first of these three sets is a steeply westward dipping to vertical penetrative fault system striking North 10-30° West with a spacing of between 0.5 and 2 km, present along Tanque Verde Ridge, Mica Mountain and the Rincon Peak area (Rodriguez-Guerra 2000). This system is analogous to Miksa's J1 joint set, but in contrast with the conclusions of previous studies (Leger 1967, Miksa 1993), was field-verified to be a penetrative fault system. This first system is oriented perpendicular to the direction of tectonic denudation and is interpreted as originating in response to isostatic uplift and doming of the metamorphic core complex (Rodriguez-Guerra 2000). Within this fault system, a 2-km wide graben was identified at Cow Head Saddle, separating Tanque Verde Ridge and Mica Mountain, with a possible displacement on the order of several hundred meters (Figure 4.9.1-6; from Rodriguez-Guerra 2000). A Google Earth image of the Cow Head Saddle graben viewed from the south is shown in Figure 4.9.1-7. The eastern boundary of this graben was named by Rodriguez-Guerra as the Cabeza de Vaca fault. On the north side of Tanque Verde Ridge, the Douglas Spring Trail follows a canyon with this orientation between Douglas Spring and Cow Head Saddle. Interestingly, a line drawn between Douglas Spring and the spring-pool known as Rincon-1 or the Grotto falls along the same orientation as the Cowhead Saddle graben Cabeza de Vaca fault.

The second system described by Rodriguez-Guerra is a steeply dipping penetrative open joint system striking North 60-75° East in parallel with mylonitic lineation in the footwall. These features were previously described as joints and penetrative brittle structures on smaller scales by Leger and were referred to by Miksa as joint set J4 (Miksa 1993). Identification and field verification of these larger-scale features is of considerable significance owing to the implied

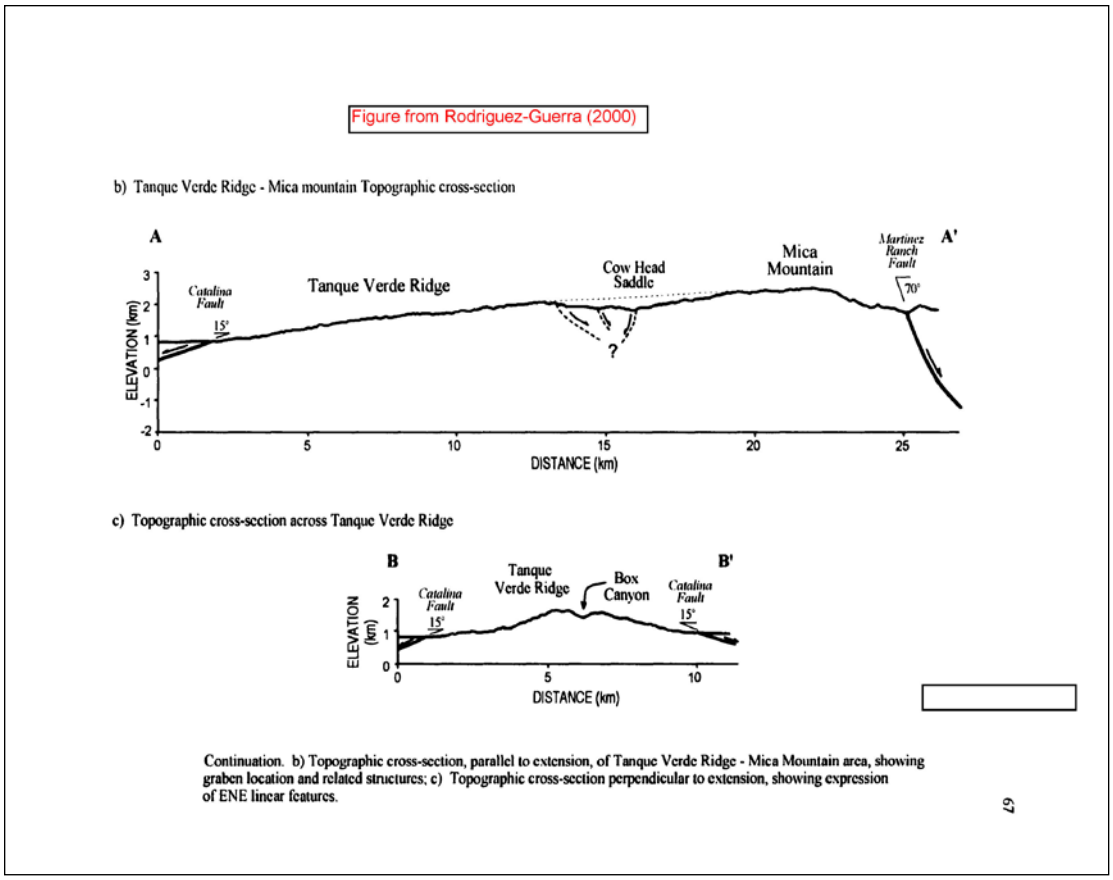


Figure 4.9.1-6. Conceptual model of Cow Head Saddle graben. Figure Credit: Rodriguez-Guerra, 2000.

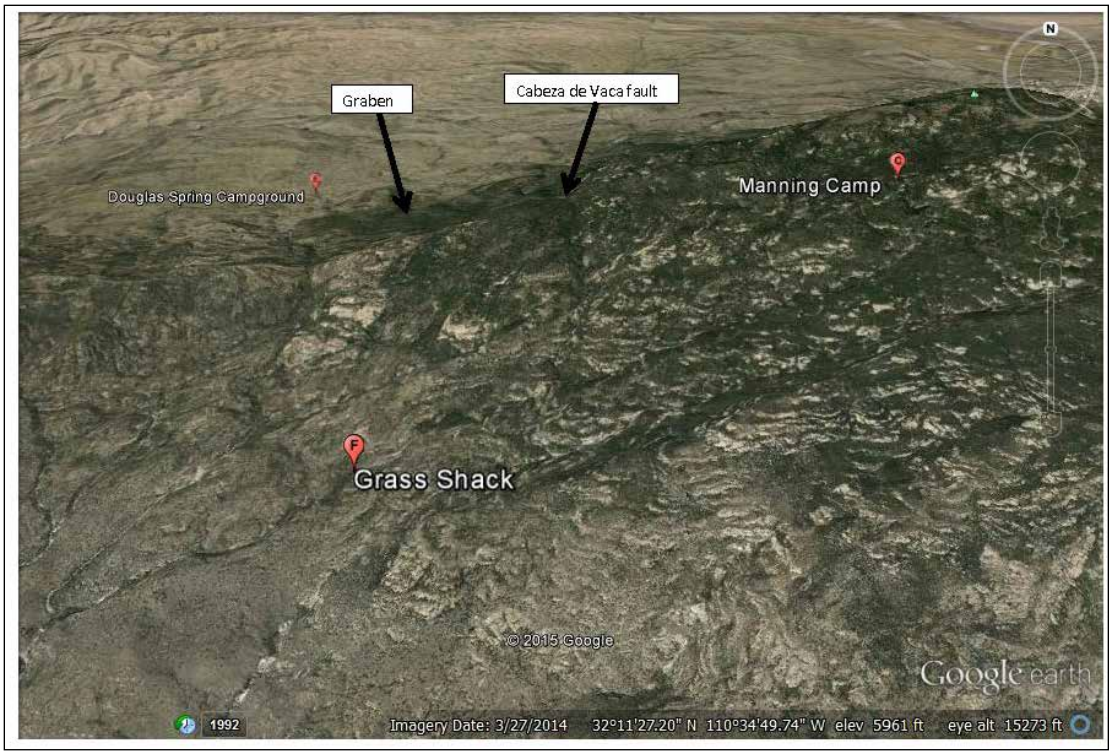


Figure 4.9.1-7. Google Earth view of Cow Head Saddle graben on Tanque Verde Ridge.

deep penetration into the footwall rocks of the metamorphic complex, previously thought to be for the most part massive (solid; unbroken by joints or faults) at larger scales. Examples of canyons following the orientation of this joint system on the southwest flanks of Mica Mountain include the upper reaches of Chimenea and Madrona drainages between Grass Shack and the Devil's Bathtub Trail and Box Canyon on Tanque Verde Ridge.

Figure 4.9.1-8 illustrates detailed and regional lineaments identified by Rodriguez-Guerra at Saguaro National Park following analysis of Landsat TM and DEM imagery (Rodriguez-Guerra 2000). A productive exercise that is beyond the scope of the present work would be to overlay the lineaments in these figures with a map showing the locations of canyons, pools and springs. Figure 4.9.1-9 shows a map detailing the location of mapped subdetachment faults occurring in the Middle Tanque Verde watershed area (Force 2002) together with the locations of surface water features in this area. These deeply penetrating faults dip to the northwest.

The presence of penetrative joints and faults in the hardrock terrain at RMD does not by itself imply that water flows in them. Miksa (1993) identified a strong correlation between local-scale joint direction and the surficial drainage net, i.e., the landscape has developed in such a way that flowing surface water has carved channels largely along the weaker rocks broken by joints or faults, working its way in zigzag patterns downhill along the intersecting features under the influence of gravity. When water flows along these pathways on the surface, where there is aperture allowing water penetration and there is connectivity with other permeable pathways, water will also move along these fracture-controlled subsurface routes under the influence of gravity.

While it is not possible to know the detailed nature of flow pathways in fractured rocks below the ground surface, where perennial springs or bedrock pools are present along joint or fault lines, and where alternative potential groundwater sources (such as substantial sediment lenses) are absent, it may be reasonably inferred that these water bodies intercept seepage along fractured bedrock pathways from higher-elevation sources of a more regional scale, or from a more localized fracture reservoir of sufficient storage to

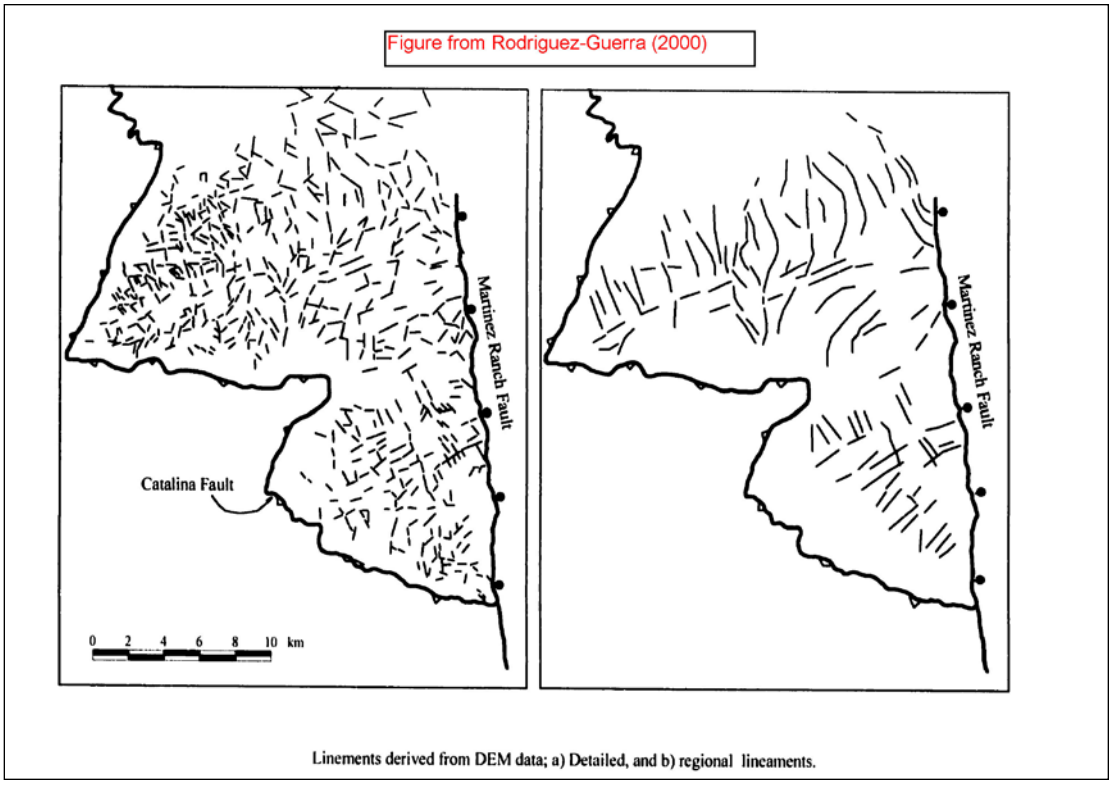


Figure 4.9.1-8. Maps showing local and regional lineaments identified by Landsat Thematic Mapper analysis. Figure Credit: Rodriguez-Guerra, 2000).

maintain supply to the pool(s) throughout extended dry periods. Whether such pathways are local (water originating relatively nearby in the immediate watershed) or of more remote origin is not easily determined, and a number of springs and pools show evidence of a combination of sources. The application of isotope methods and the interpretation of water quality analyses for the estimation of water source and age has been conducted on a limited basis at RMD by Eastoe (2012) and in this document.

Springs and pools that harbor perennial water are important in that a connection with a significant source of groundwater is implied by their perennial nature. Perennial water in some pools and springs is found in drainages around the park including Chimenea, Rincon, Rincon North, Wildhorse, Madrona, Box Canyon and Steel Tank (Swann et al. 2013). As shown in Figure 4.9.1-9, a number of these drainages are co-located with rock fractures (faults or joints) identified by Rodriguez-Guerra (2000) and Force (2002). Overlaying Rodriguez-Guerra's maps of lineaments (Figure 4.9.1-8) onto a map of perennial springs and tinaja would provide valuable insight into the correlation between perennial water and the faults and open joints described in her dissertation. Force's mapping inside Saguaro NP RMD reveals the co-location of the lower Loma Verde pools (none perennial) with a sub-detachment fault east of the primary Catalina-Rincon detachment fault. Likewise, perennial pools in Wildhorse Canyon and the Steel Tank area may be sourced at least in part from water routed along sub-detachment surfaces/faults identified by Force (2002).

4.9.2. Data and Methods

Groundwater Conceptual Model

Before status of groundwater resources at RMD can be assessed, it is necessary to understand as well as possible what may be the unique groundwater systems present and, to the extent currently possible, how each functions. A review of available data including isotopic, water quality and geological, together with limited data about surface water and water levels in wells inside and outside

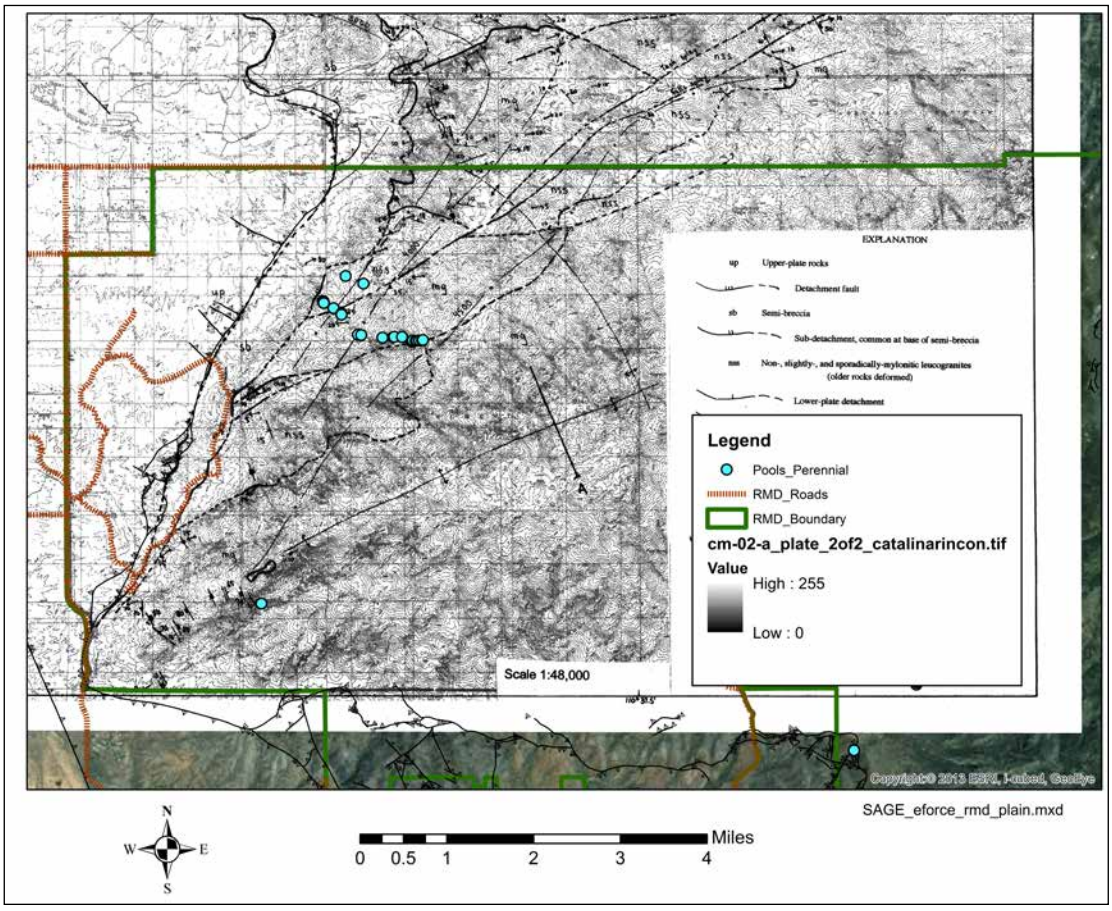


Figure 4.9.1-9. Map showing structural features of lower-plate rocks along the Catalina-Rincon range front (Force, 2002) together with Saguaro National Park Rincon Mountain District boundary, perennial pools and tritium sample results for selected locations. Solid and dashed black lines are known and inferred faults.

the park, was conducted for the purpose of developing conceptual models. The key goal of the models is to capture those features that are, on the basis of available data, the primary sources of groundwater in wells, springs and tinajas at RMD. These data are summarized in the sections that follow. The groundwater systems identified:

Mountain-block regional-scale groundwater
Groundwater recharged to hydrologically independent penetrating fractures (faults, joints) present in the mountain-block. This includes penetrating, large-scale to regionally extensive independent fractures or interconnected fracture systems described by authors including Rodriguez-Guerra and Force. This model is consistent with the high total dissolved solids, dominant sodium-sulfate, elevated fluoride class of deeply circulating water infiltrated to fractures in the crystalline mountain mass described by Olson (1982) and Mohrbacher (1984) for the Tanque Verde canyon watershed and the eastern Santa Catalinas. Isotopically older water (submodern) sampled from the deep groundwater in the Rincon Valley and at a few springs/tinajas in the park is believed to derive from this source. Water levels in private wells penetrating the detachment fault in Rincon Valley represent the potentiometric surface in the Rincon Valley at around 3,100 feet above sea level. Figure 4.9.2-1 illustrates this conceptual model overlain on a part of cross-section C-C' of Drewes (1977).

Mountain-block local-(drainage) scale groundwater
Groundwater originating as infiltrated rainfall or snowmelt that flows through and is stored in shallow (~<10 m), local-scale fracture (fault, joint) systems, weathered rock zones, foliation planes, and/or sediment deposits. Local-scale groundwater daylights where it intercepts the surface at bedrock pools (tinajas) in drainages or is routed to the surface as springs. This water is isotopically modern and is consistent with Olson (1982) and Mohrbacher's (1984) sodium-calcium-bicarbonate water type, lower in fluoride and most other ions than the regional-scale waters discussed above. Conceptual models for this type are shown in Figures 4.9.2-2, -3, -4, and -5.

Mixed regional- and local-scale mountain block groundwater
Groundwater in the mountain block proper that is of mixed origin including contribution from both local and regional sources described above.

Upper-plate groundwater
Groundwater in alluvium and upper-plate rocks comprising the hanging wall (carapace) above the Catalina-Rincon detachment fault. Upper-pate groundwater includes water in the shallow alluvial aquifer in the Rincon Valley as well as water in shallow wells constructed within the current park boundary prior to transfer to the National Park Service. The primary source of recharge to upper-pate groundwater is infiltration of local and mountain surface runoff. s

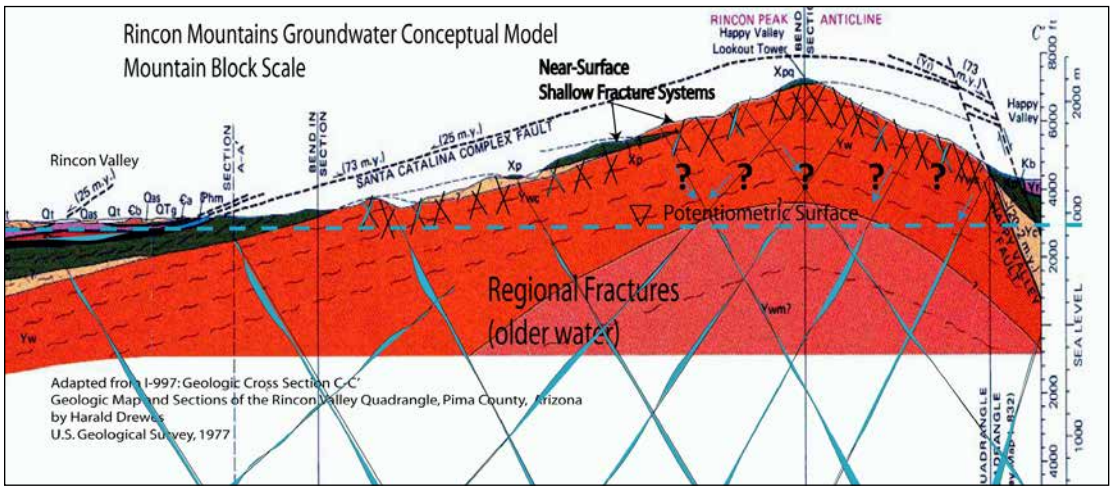


Figure 4.9.2-1. Conceptual model of mountain-block scale groundwater overlaid on Rincon Valley cross-section.

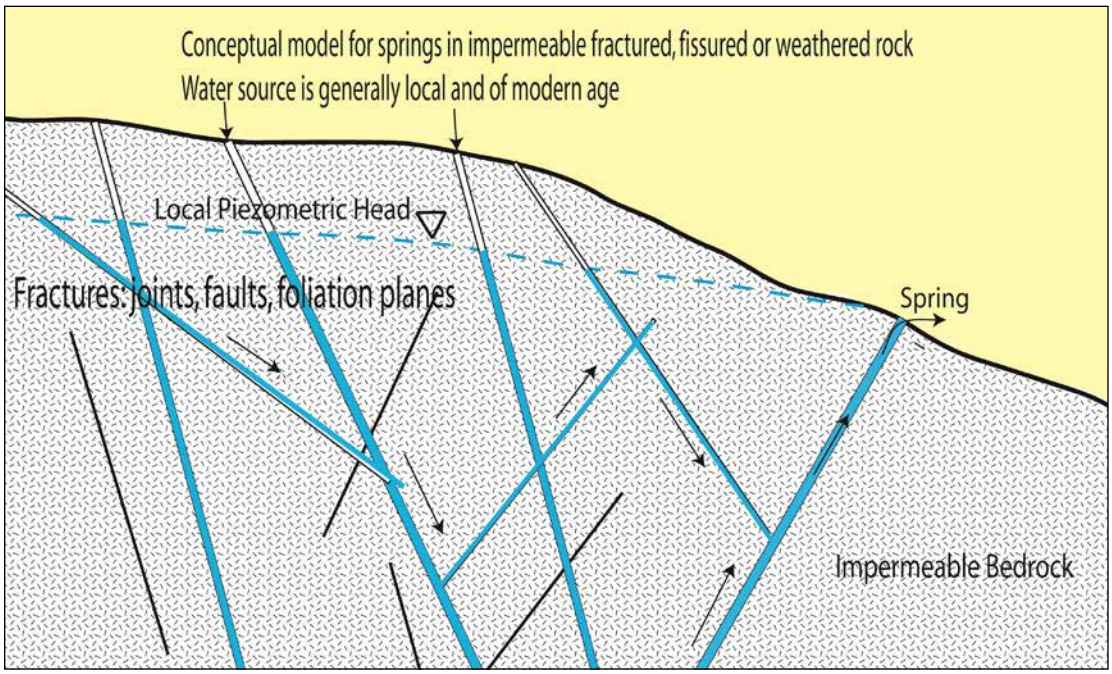


Figure 4.9.2-2. Conceptual model for groundwater flow to springs in impermeable fractured, fissured or weathered rock.

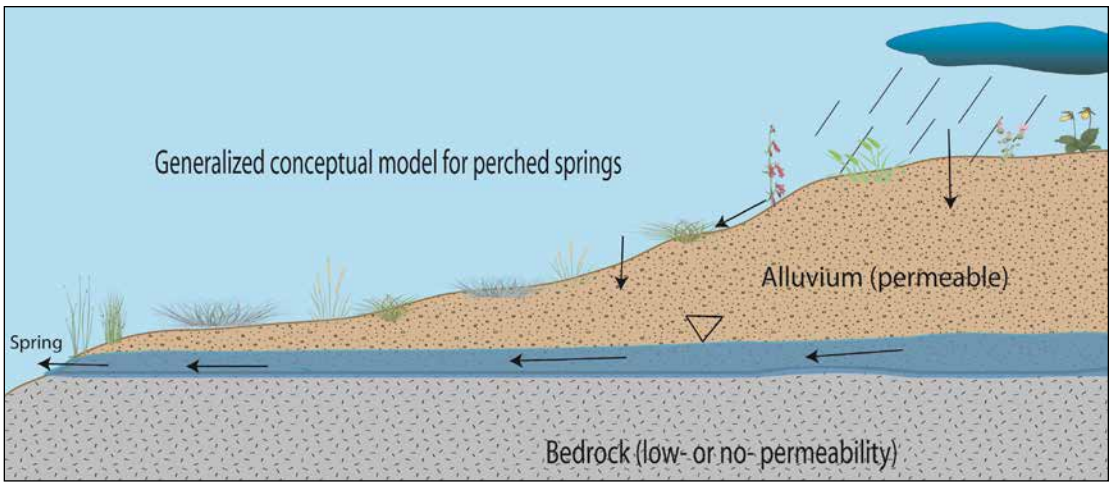


Figure 4.9.2-3. Simplified conceptual model for groundwater flow to springs under perched conditions.

Detachment-fault groundwater

Detachment-fault groundwater is conceptualized as a permeable zone of rubblized and crushed rock occurring below a low-permeability feature, possibly mylonite fault gouge, of the low-angle Catalina-Rincon detachment fault. Detachment-fault groundwater may be continuous along the length of the fault, which has uninterrupted continuity (Davis, 2013). Water infiltrating regional-scale mountain block in the footwall of the fault (the Rincon Mountains) is thought to be the primary source of recharge to this zone at the park. Apart from groundwater pumping, the only documented natural discharge of detachment-fault groundwater occurs at springs at Agua Caliente and La Cebadilla. Piezometric head in wells decreases along the western Rincon Mountains from 3100 feet in the Rincon Valley to 2756 at Agua Caliente spring. Detachment-fault groundwater is characterized similarly to that of that described in (1) above: originates at high-elevation, has a sodium-sulfate water type with elevated fluoride, and is thousands of years old (Eastoe 2012).

The following sections summarize analyses of isotope and water quality data that have provided clues to groundwater processes active at RMD.

Isotopes

The following paragraphs describe key results and conclusions arising from analysis of stable (^{2}H and ^{18}O) and radioactive (tritium, ^{3}H)

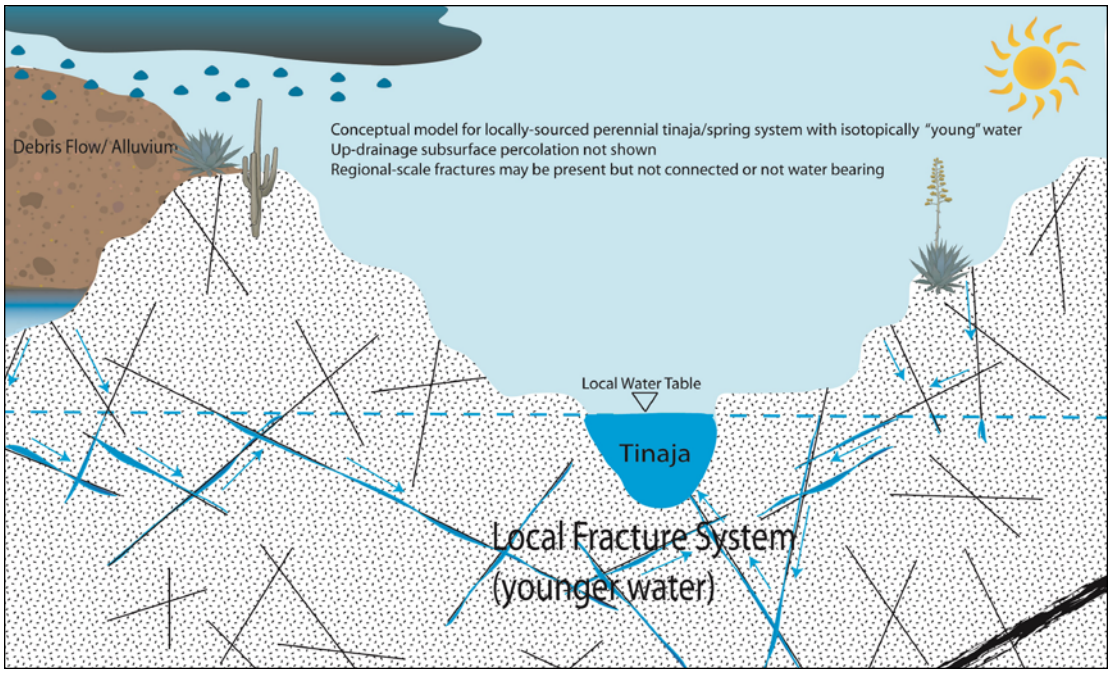


Figure 4.9.2-4. Conceptual model for groundwater flow to locally-sourced perennial or intermittent tinajas.

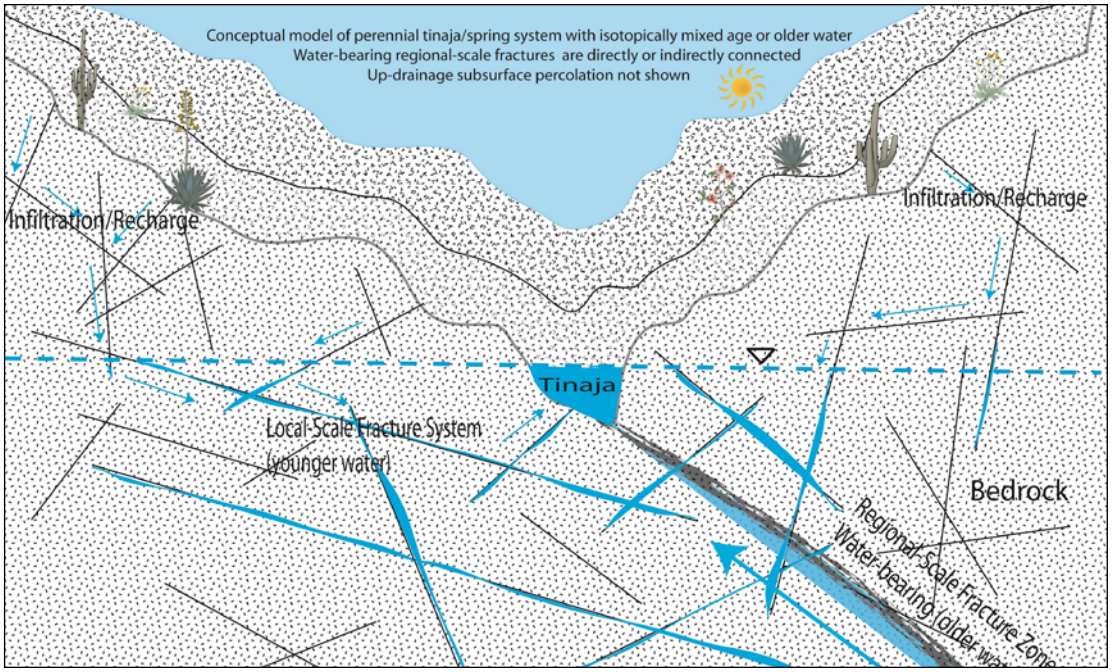


Figure 4.9.2-5. Conceptual model for groundwater flow to perennial or intermittent tinajas supplied by both regional and local sources.

water and sulfur isotopes collected at RMD wells, perennial springs and tinajas. Some of the discussion also refers to water collected outside the park. Data from sources inside the park were developed in collaboration with Chris Eastoe, retired co-director of the University of Arizona Environmental Isotope Laboratory (Eastoe, 2012). Data from sources outside the park boundaries were developed by students and staff of the University of Arizona (C. Eastoe, personal communication).

Stable isotopes of the elements that make up water, hydrogen and oxygen, as well as isotopes of dissolved species, including carbon and sulfate (sulfur, oxygen), provide information useful to the understanding of groundwater age and origin at RMD. Saguaro National Park has been pursuing the collection of stable water, sulfate, and tritium isotope data as funds allow at RMD since 2007. Eastoe (2012) combines NPS data with data collected independently in the area surrounding the park and provides an interpretation of the isotope data currently

available. While details of these data and the analysis are beyond the scope of this document, the following overall conclusions have resulted from the isotope interpretation. These conclusions and the accompanying graphs of data are adapted from Eastoe (2012) by combining data reported there with results collected at RMD since 2012.

Stable Water Isotopes ^{2}H and ^{18}O

Figure 4.9.2-6 illustrates results of stable water isotope measurments in surface water and groundwater at and in the immediate vicinity of RMD, where data are reported as delta-values, where

$\delta\delta = \{(Rsample/Rstandard) - 1\} \times 1000$, in ‰

and R = D/H for δD and $^{18}O/^{16}O$ for $\delta^{18}O$. The International standard in VSMOW (C. Eastoe, personal communication).

The orange triangle symbols shown in Figure 4.9.2-6 illustrate the departure from the global meteoric water line (GMWL; Craig 1961) that results from partial evaporation of water prior to sampling. Figure 4.9.2-7 illustrates ranges of values for stable water isotopes measured throughout the year in precipitation at high elevations in the Santa Catalina Mountains and at lower elevations in the Tucson Basin (values from Kalin 1994). Key points in the interpretation of Figures 4.9.2-6 and 7 include the following:

1. Groundwater discharging from five high elevation springs sampled in the Rincon Mountains derives from both summer and winter precipitation events; these samples did not show evidence of evaporation prior to infiltration into the rock-fracture system (Mud Hole, Deer Head, Italian, Spud Rock and Manning). Samples collected at high elevation springs show the unique signature of a mixture of high-elevation summer and winter water and rapid infiltration (blue diamond symbols on Figures 4.9.2-6 and -7).

2. Stable water isotopes measured in a sample from the Rincon Water Company well, RWC-1, in the Rincon Valley are nearly identical to the high elevation springs discussed above (red circle symbol on Figures 4.9.2-6 and -7). These data are key to linking the source of detachment-related water with high-elevation infiltration.

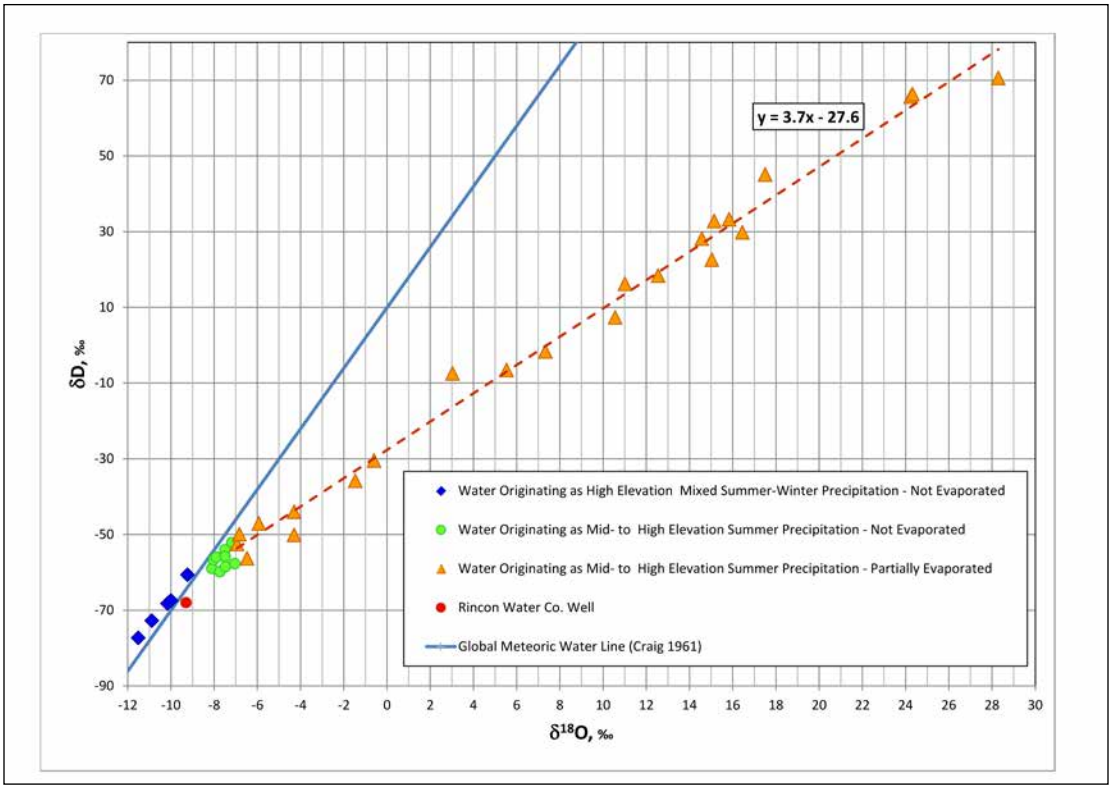


Figure 4.9.2-6. Plot of stable water isotopes measured in samples collected at RMD (after C. Eastoe 2012).

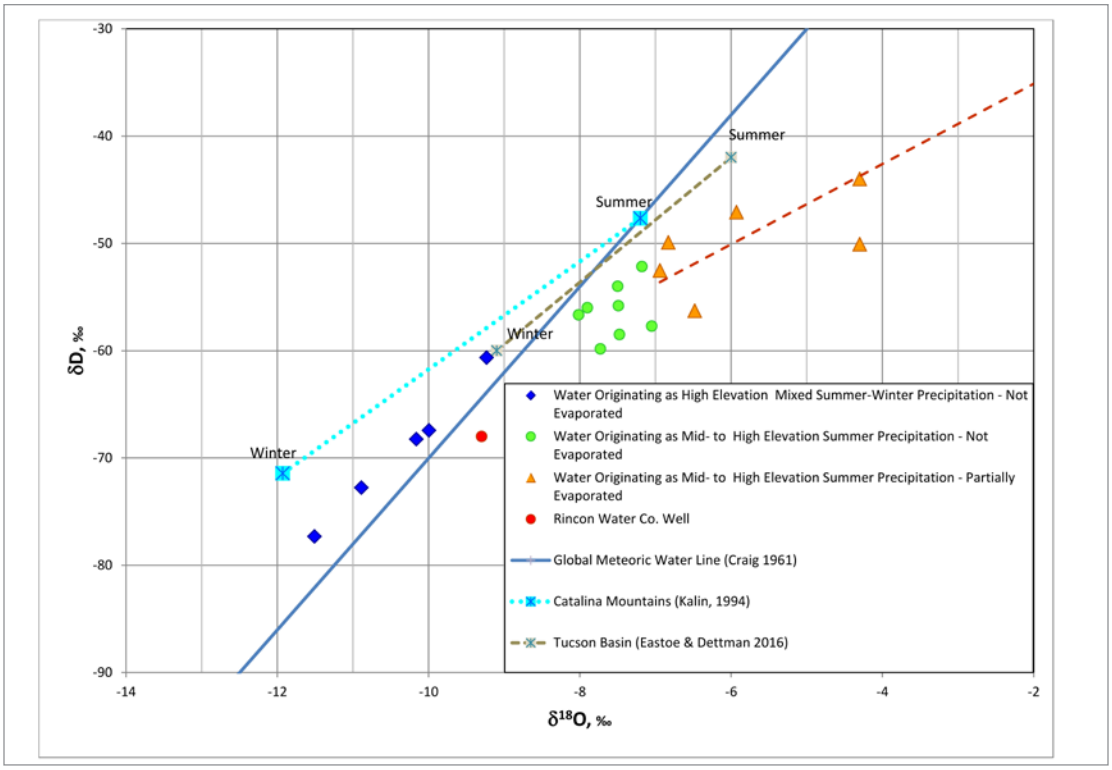


Figure 4.9.2-7. Plot of stable water isotopes with seasonal precipitation ranges for the Catalina Mountains and Tucson Basin (after Eastoe 2012).

3. Samples collected pre-monsoon from (mostly) mid- to lower-elevation springs, tinajas, an in-stream pool and a shallow well plotting in a cluster near the GMWL have experienced little to no evaporation and originate as summer precipitation (green circles on Figures 4.9.2-6 and -7). A data cluster just below the GMWL at $\delta^{18}O$ = -7.5 ± 0.5‰ includes samples from elevations ranging from 7,921 feet (Manning Camp) to 3,153 feet (Rincon Creek well RC-5). The significance of this is that this range of $\delta^{18}O$ values is most closely associated with summer precipitation in the mountains at elevations between about 5,000 ft and 7,000 ft. Since this cluster plots just below the GMWL, the samples may or may not be slightly evaporated, and some portion of the water source may originate at elevations above 7,000 feet. (Devil's Bathtub, Rincon Creek Pool A, Douglas Camp, Well RC-5, Upper Box Canyon Pool 23, Loma Verde Pool 3, Manning, and the Grotto Rincon Pool 1).

4. The remaining mid- to lower-elevation springs, tinajas and other surface waters sampled within RMD plot below the GMWL on a line with a slope of 3.7. These water samples reflect the effect of partial evaporation from an initial state near the cluster of green circles discussed above (orange triangles on Figure 4.9.2-6).

Tritium ^{3}H

Tritium (^{3}H) is produced naturally in the earth's atmosphere as a result of cosmic ray bombardment. Additional tritium was introduced to the atmosphere between 1954 and the 1970s, resulting in a two order of magnitude spike in tritium levels in precipitation by the mid-1960s (Eastoe et al. 2011). This "bomb pulse" increase in tritium in precipitation ended around 1992, and since that time precipitation in Tucson averages around 5 tritium units (TU; Eastoe et al. 2004). An additional source of tritium in the Tucson area came from the American Atomics plant in central Tucson. Releases from that plant increased tritium levels up to ~1,000 TU into the late 1970s. Tritium decays with a half-life of about 12.43 years (Lucas and Unterweger 2000), and water originating with a tritium concentration around 5 TU will decay to below 0.6 TU (the detection limit of the Tucson laboratory) after three half-lives (Eastoe et al. 2011). Pre-bomb water that originated with tritium concentrations similar to those seen today are now decayed to below the detection limit. After about 2030, bomb-pulse tritium will be indistinguishable

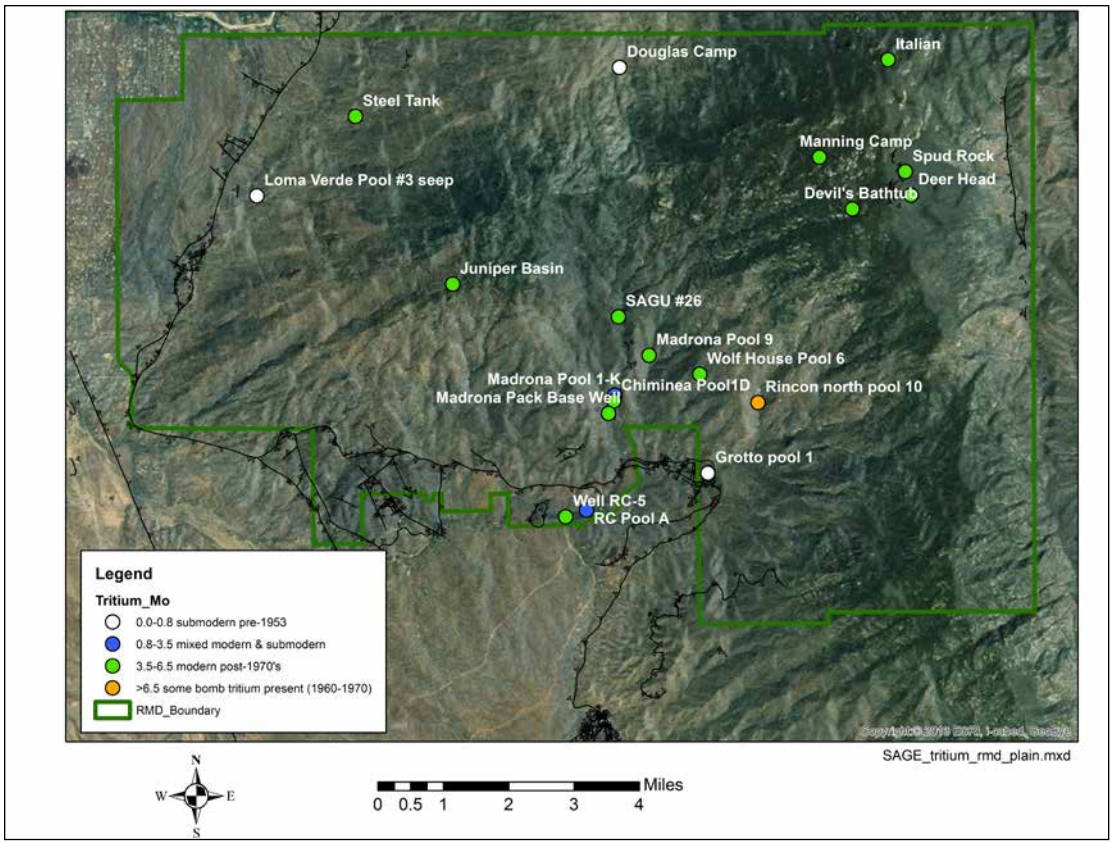


Figure 4.9.2-8. Map showing location of tritium analyses and age classes of RMD water samples (data from Eastoe 2012).

from post-1992 precipitation, and tritium will continue to be useful for identifying groundwater infiltrated in the last few decades (Eastoe et al. 2011).

Since 2007, tritium levels in springs, pools and wells at RMD have been sampled by NPS staff as resources allowed. All of these samples have been analyzed by the University of Arizona Environmental Isotope Laboratory in Tucson, Arizona. Figure 4.9.2-8 illustrates the location and age categories of tritium samples collected within RMD.

Key points from a review of the NPS RMD tritium data:

- Of 19 tritium samples collected at RMD, 13 derive from precipitation in the last few decades, since 1970 (3.5-6.5 TU=Modern; Eastoe 2011, 2012). All of the high elevation springs (>7000 ft) discharge modern-age water with $\delta^{18}O$ levels that indicate mixed summer-winter precipitation and no evaporation (blue diamonds on Figures 4.9.2-6 and -7), as do some of the mid-elevation samples (green circles on Figure 4.9.2-8).
- One of the samples, Rincon North Pool 10, contains modern water plus some bomb pulse tritium (9.2 TU), indicating water that has been resident since the 1960-1970 bomb spike (>6.5 TU=Modern plus some bomb pulse; Eastoe 2012). Stable water isotopes from Rincon North Pool 10 were highly evaporated.
- Two of the samples, the Grotto Pool 1 and Douglas Camp, are springs discharging water in which tritium levels are undetectable, consistent with pre-1953 recharge. Both of these samples show $\delta^{18}O$ signatures for mid- to high-elevation, summer water sources with no evaporation.
- Three samples are characterized by tritium levels that indicate a mixing of pre-bomb and modern water (0.8-3.5 TU=mixed Modern plus Submodern). These sites are all present at lower elevations in the park (below 3,550 ft), including Loma Verde Pool #3, Madrona Pool 1-K in the Chimenea

Creek drainage and Rincon Creek Pool A. However, tritium in seepage to Loma Verde Pool #3, taken in June 2016 after emptying the pool, was measured at <1 (apparent 0.6) TU, indicating pre-1953 tritium levels.

The preponderance of springs, pools and the two wells sampled for tritium at RMD show water containing between 3.9 to 6.5 TU, indicating origins as precipitation in the past few decades and relatively short residence times. The range of values suggests the presence of many short flow paths (Eastoe 2012). Samples from the remaining sites show tritium levels that indicate longer residence times for all (submodern) or some fraction (submodern plus modern, modern plus bomb pulse) of the water sampled. All of the samples with longer residence times occur at lower elevations, while the samples included in the modern age grouping occur at both high and low elevations.

In addition to the samples discussed above, a number of tritium measurements have been made in the Tucson Basin, including the area around RMD, by University of Arizona staff and students as part of ongoing research (Eastoe et al. 2004). Figure 4.9.2-9 shows locations of these samples in combination with samples collected at RMD, with age classifications indicted by color. Of a total of 48 samples, 28 were collected from wells, 19 from springs, tinaja or surface pools, and one from a cave. Of these, nine were found to be pre-1950s water (submodern; <0.8 TU)), ten were found to be a mix of modern and submodern (>0.8-3.5 TU); 24 were found to be modern (post-1970; 3.5-6.5 TU); and five samples were characterized by tritium levels between 7.3 and 17 TU, indicative of modern water mixed with bomb pulse increasingly likely at higher tritium levels.

Combining the RMD samples with samples collected outside the park, Figure 4.9.2-9 shows that away from major washes where surface flows from mountain runoff infiltrate, residence times of groundwater at lower elevations is greater than for water found at springs, pools or shallow wells on the slopes of the Rincon Mountains.

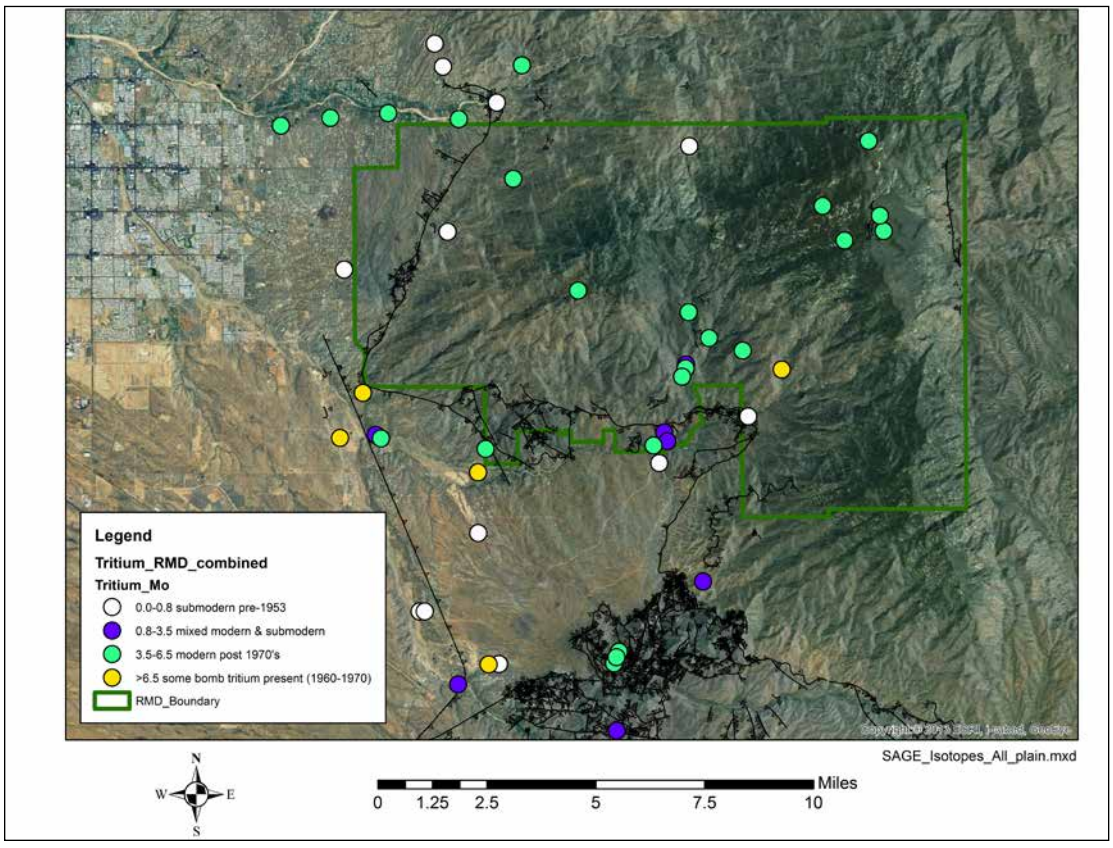


Figure 4.9.2-9. Map showing location of tritium analyses and resulting age classes of water samples from RMD and the surrounding area (data from Eastoe 2012).

Isotopes of Sulfate: Sulfur ^{34}S and Oxygen $^{18}O(SO_4)$

Stable isotopes of sulfur and oxygen in dissolved sulfate have application to the determination of sulfate sources, delineation of groundwater flow paths, and recharge mechanisms (Gu 2005). Two distinct classes of water were identified by Gu (2005) in the Rincon Creek drainage, one associated with Rincon Creek floodplain water ($\delta^{34}S$: 4-6‰; $\delta^{18}O(SO_4)$:4-8‰). The other water type (fracture hosted) is generally high in SO4 (>100 mg/L) and contains $\delta^{34}S$ around 8‰ but lower $\delta^{18}O(SO_4)$ (<3‰) than found in other groundwater in the Tucson Basin. This water type is associated with water originating as high-elevation precipitation in the Rincon Mountains that has migrated downgradient through fractures in the granitic bedrock, gaining sulfate through oxidation of sulfides, mainly pyrite (Gu 2005). These findings are similar to those of Olson (1982) who found that along the eastern Catalina mountains and Tanque Verde mountain front, water associated with groundwater recharge along stream channels and floodplains was chemically, physically and isotopically distinct from water recharging the Tucson basin via mountain-block fracture flow.

Within the park boundaries, a lack of $\delta^{18}O(SO_4)$ data for most of the limited number of samples that had been analyzed for $\delta^{34}S$ precluded further analysis using this criteria. However, in the areas just outside of park boundaries, several of the wells located near the Catalina-Rincon fault with submodern age water (Figure 4.9.2-9) fell into this category, including the Rincon Water Company well (RWC-1; 55-607532; 280 ft; aka Manera well #1; Manera, 1968), well 55-564266 (at X9 Ranch), well 55-544884 (at Tanque Verde Guest Ranch) and Agua Caliente spring. These results indicate that high elevation mountain recharge, seeping through deep fracture networks, flows basin-ward until blocked by a low-permeability zone in the plane of the Catalina-Rincon detachment fault zone. Investigators have suggested that water ponded behind the fault flows through breaches in discrete zones (Love et al. 2014; Gu 2005). This is the mechanism investigators believe is active where water flows to the surface under artesian conditions at Agua Caliente spring

In the Rincon Valley, the deep-fracture water is confined under pressure in discrete zones in granitic rocks under pressure between about 230 and 260 feet depth at the location of well RWC-1. When the fractured water-bearing zone was connected to the surface by this well (screened from 68 feet to 262 feet depth), water levels rose to within 70-80 feet below ground surface (Manera 1968). This level is approximately the level of the interface between upper plate rocks (Pantano Formation) with the underlying granite of the lower plate at the location of this well (Manera 1968). The discrete or irregular nature of the water-bearing zone was revealed when six of seven wells drilled in the surrounding area were declared to be "dry for all practical purposes" (Manera 1971), although most or all of these wells do not appear to have penetrated through the fault zone. A nearby seventh well, RWC-8 (ADWR 55-607531, aka Manera Well #8; Manera 1971), although 55 feet deeper, did not encounter the hard granite above and below the water-bearing zone of RWC-1. RWC-8 produced about half the discharge of RWC-1, and showed similar static water level. However, as is shown in the following section, water quality for these two wells is very different. Drilling records for both RWC-1 and RWC-8 indicate that at depth (280 feet for RWC-1 and between 300 and 350 feet for RWC-8), the drill bit fell freely for a distance of nearly 4 feet, at which time a lower aquifer was encountered and drilling stopped (Manera 1968, A.A. McDaniel 1962)

The interpretation of stable water, tritium and sulfate isotopes provide a significant basis for the development and verification of groundwater conceptual models at RMD. Previous researchers have identified key isotopic signals that have application to understanding water sources, ages and travel pathways at RMD (Eastoe 2012, Kalin 1994, Gu 2005). Although the data are limited in number, there are sufficient measurements of stable water and tritium isotopes to allow preliminary groupings of springs and to tentatively identify outliers that result from different conditions than the rest. The

application of tritium and sulfate isotope analysis to selected sites has provided key insight to processes active in the groundwater systems at the park.

Water Quality

Springs and perennial tinajas are supplied by groundwater. When combined with isotope data, chemical analyses provide insight to likely recharge areas and flow pathways. The discussion here follows the conceptual model presented in Drever (1988), that solutes in natural waters are derived from the atmosphere, weathering of primary minerals in bedrock and bedrock-derived materials in the watershed, changes related to interaction with the organic environment including organic materials in soils and living plants, and changes in storage of cations on clays, oxides and organic matter in soils. Where organic matter is negligible, the relationship can be simplified to "rock + atmospheric input = altered rock + solutes" (Drever 1988). Water chemistry evolves as it moves through the environment, influenced by transient conditions including temperature, rock-water interaction, atmospheric interaction, and chemical processes in soils.

All groundwater in the RMD originates as precipitation, which is characterized by dilute chemistry. Sorooshian et al. (2013) provide an overview of spatiotemporal trends of precipitation chemistry in the southwestern U.S., including southeastern Arizona. Water quality profiles of precipitation at the Chiricahua National Monument National Atmospheric Deposition Program (NADP) National Trends Network (NTN) monitoring site between 1999 and 2015 show that average monthly chemistry of rainwater in southeast Arizona is characterized by pH of 5.41 (range 4.59-7.56) sulfate 0.81 mg/L (range 0.13-4.37 mg/L), chloride 0.24 mg/L (range 0.01-6.90 mg/L), calcium 0.39 mg/L (range 0.03-7.77 mg/L), magnesium 0.04 mg/L (range 0.00-0.57 mg/L), and sodium plus potassium 0.17 mg/L (range 0.00-4.72 mg/L). These values provide a starting point in the interpretation of RMD water quality data.

In the Rincon Mountains, minerals composing primary bedrock and alluvium are derived from two granitic protoliths that have been subjected to a wide continuum of metamorphic processes (Davis 2013). Primary components of these include quartz, orthoclase and plagioclase feldspars, chlorite, hornblende, and biotite. Secondary amounts of muscovite, garnet, zircon, sphene and pyrite are present (Davis 2013). Minerals that weather more easily will contribute disproportionately to the solutes in natural waters in a weathering-limited regime (weathered materials are transported downslope more rapidly than new material is produced; Drever 1988) such as is present in the Rincon Mountains. In the case of crystalline silicate rocks, concentrations are also tend to be a function of flowpath length, contact time, and exposed rock surface area per unit volume of circulating water (Hem 1985 p. 192).

Water quality analyses from 23 unique sites, including springs, tinajas and wells in the Upper and Middle Rincon Creek, Upper and Middle Tanque Verde Creek, and Paige Creek watersheds were reviewed (Table 4.9.2-1). As indicated in Table 4.9.2-1, seven of the sample locations were outside of the administrative park boundary. Forty-five unique water quality samples collected at RMD and in the surrounding area were compared (Table 4.9.2-2). The samples were collected between 8,031 feet and 2,756 feet elevation by various investigators between 1964 and 2016. Anion-cation charge balances and water type were computed for each sample using the software package AquaChem 5.1, a Schlumberger Water Services software product. Eight of the water samples were found to have unacceptably high anion-cation charge balances ($|>8|$) and were omitted from further consideration (Table 4.9.2-2). An additional three samples were omitted because they had no measurement reported for bicarbonate, carbonate, alkalinity, or hardness, precluding a charge balance calculation. The remaining samples were characterized as calcium-sodium/ sodium-calcium bicarbonates and sodium sulfate bicarbonate waters (Table 4.9.2-2).

Sample analyses were grouped into high elevation (springs >7,000 ft), low elevation

Table 4.9.2-1. List of sample locations (J. Conver, elevations from park LiDAR data except #22, 23).

Station #	Station ID	Elevation (ft)	Watershed	Location (Source)
1	Manning	7,939	Upper Rincon	Manning Camp (1981 sample)
2	ManningSpr.Pool_01	7,918	Upper Rincon	Manning Camp Spr Pool 1 USGS 321227110331201
3	SpudRock	7,354	Paige Spring	Spud Rock Spring USGS 321215110315201
4	ItalianSpr	8,031	Upper Tanque Verde	Italian Spring USGS 321344110320601
5	Grotto	3,288	Upper Rincon	Grotto (NPS SODN)
6	MadronaCr	3,380	Upper Rincon	Madrona Creek ~100 m upstream of Madrona-04 USGS 320914110360400
7	Madrona Pack Base Well	3,365	Upper Rincon	Madrona Pack Base Well USGS 320902110363201
8	ChimeneaCr	3,434	Upper Rincon	Chimenea Creek ~50 m downstream from Pool 1a USGS 320913110362800
9	Chimenea.Pool_1D	3,431	Upper Rincon	Chimenea Pool 1D USGS 321157110362901
10	Chimenea.Pool_1D	3,431	Upper Rincon	Chimenea Pool 1D (NPS SODN)
11	LomaVerde.Pool_5	3,013	Middle Tanque Verde	Loma Verde Pool 5 USGS 321156110420001
12	LomaVerde.Pool3a	3,005	Middle Tanque Verde	Loma Verde plots nearest to Loma Pool 3a USGS 321156110415900
13	Steel Tank	3,339	Middle Tanque Verde	Steel Tank (University of Arizona, Olson 1982)
14	RinconCr.StreamGage	3,140	Middle Rincon	Rincon Creek stream gage USGS 0948500
15	RinconPoolA	3,156	Middle Rincon	Rincon Pool A (H&A)
16	RinconPoolB	3,145	Middle Rincon	Rincon Pool B (NPS SODN)
17*	RC-1	3,159	Middle Rincon	Well RC-1 (H&A)
18*	RC-2	3,162	Middle Rincon	Well RC-2 (H&A)
19*	RC-3	3,168	Middle Rincon	Well RC-3 (H&A)
20*	RWC-8	3,190	Middle Rincon	Rincon Water Co. #8 607531 (Manera 12/3/1968)
21*	RWC-1	3,186	Middle Rincon	Rincon Water Co. #1 607532 (Manera 12/3/1968)
22*	Agua Caliente Spr	2,756	Agua Caliente Wash	Agua Caliente Spr (AZ Geological Survey, Love et al., 2014)
23*	Well 564266	3,181	Middle Rincon	Well 564266/ D(15-17)16BDA (H&A)

*Denotes sample location outside of park boundaries

(springs, tinajas, streams and wells <3,500 ft) and detachment-fault related groups (Table 4.9.2-2). Detachment-fault related water was described by Olson (1982) and Gu (2005). This water possesses unique chemical characteristics found only in deep wells that intersect the footwall of the Catalina-Rincon detachment fault, and in two warm springs in the immediate vicinity of the fault (Agua Caliente, La Cebadilla; Gu 2005). Detachment-fault water is high in dissolved solids, fluoride, sulfate, and sodium relative to water from other sources in the area, and is believed to be the product of extended periods of circulation deep within the gneissic mountain block. Stable water isotope data indicate that detachment-fault related water is isotopically lighter than other

Table 4.9.2-2. List of samples reviewed with anion-cation balance and water type.

Station #	Station ID[1]	Sample Date	Anion-Cation Balance %	Water Type	Group[2]
1	ManningSpr.5.21.1981	5/21/1981	0.56	Ca-Mg-Na-HCO3	HE
2	ManningSpr.L1.5.14.2003	5/14/2003	2.71	Ca-Na-HCO3-SO4	HE
2	ManningSpr.L1.7.23.2003	7/23/2003	4.97	Ca-Na-HCO3	HE
2	ManningSpr.L1.9.24.2003	9/24/2003	7.26	Ca-Na-Mg-HCO3	HE
3	SpudRock.L1.5.15.2003[1]	5/15/2003	-56.68[1]	Suspect balance	HE
4	ItalianSpr.L1.5.15.2003	5/15/2003	-1.81	Ca-Na-HCO3	HE
4	ItalianSpr.L1.7.23.2003	7/23/2003	3.13	Ca-Na-Mg-HCO3	HE
4	ItalianSpr.L1.9.24.2003	9/24/2003	3.62	Ca-Na-HCO3	HE
5	Grotto.6.30.2010	6/30/2010	0.2	Na-Ca-Mg-HCO3	LE
6	Madrona.L1.11.8.2002	11/8/2002	1.99	Na-Ca-Mg-HCO3	LE
6	Madrona.L1.4.22.2003[1]	4/22/2003	na[1]	Lacking parameters	LE
6	Madrona.L1.10.31.2003	10/31/2003	5.44	Na-Ca-HCO3	LE
7	Madrona Pack Base	Feb-Mar 1964	-1.13	Ca-Na-HCO3-SO4	LE
8	Chimenea.Pool-1D. L1.11.8.2002	11/8/2002	4.55	Na-Ca-HCO3	LE
8	Chimenea.Pool-1D. L1.4.22.2003[1]	4/22/2003	na[1]	Lacking parameters	LE
8	Chimenea.Pool-1D. L1.10.31.2003	10/31/2003	0.4	Na-Ca-Mg-HCO3	LE
9	ChimeneaCr.5.14.2002	5/14/2002	1.89	Na-Ca-Mg-HCO3	LE
9	ChimeneaCr.6.30.2005	6/30/2005	6.57	Na-Ca-HCO3	LE
9	ChimeneaCr.6.5.2008	6/5/2008	2.65	Na-Ca-HCO3-CO3	LE
10	ChimeneaCr.9.23.2009	9/23/2009	-1.38	Na-Ca-CO3-HCO3	LE
11	LomaVerde.5.14.2002	5/14/2002	6.3	Na-Ca-Mg-HCO3	LE
11	LomaVerde.6.30.2005	6/30/2005	7.79	Na-Ca-Mg-HCO3	LE
11	LomaVerde.6.5.2008	6/5/2008	7.03	Na-Ca-HCO3-Cl	LE
12	LomaV.L1.12.12.2002[1]	12/12/2002	-17.78[1]	Suspect balance	LE
12	LomaV.L1.5.22.2003[1]	5/22/2003	na[1]	Lacking parameters	LE
12	LomaV.L1.10.15.2003	10/15/2003	6.03	Ca-Na-Mg-HCO3	LE
12	LomaV.3A.6.2.2016	6/2/2016	8.0	Na-Ca-HCO3	LE
13	Steel Tank	10/23/1981	-0.66	Ca-Na-HCO3	LE
14	RinconCr.L1.3.4.2003	3/4/2003	-4.65	Ca-Na-HCO3-SO4	LE
15	RinconPoolA.5.10.2005	5/10/2005	0.29	Ca-Na-HCO3	LE
16	RinconPoolB.9.23.2009	9/23/2009	6.05	Ca-HCO3-SO4	LE
17	RC-1 4/28/2005[1]	4/28/2005	63.52[1]	Suspect balance	LE
18	RC-2 4/26/2005[1]	4/26/2005	59.15[1]	Suspect balance	LE
19	RC-3 4/27/2005[1]	4/27/2005	62.6[1]	Suspect balance	LE
20	RWC-8/607531/<1968[1]	<1968	33.59[1]	Suspect balance	LE
20	RWC-8/607531 (top).9.23.1968	9/23/1968	-0.45	Ca-Na-HCO3	LE
20	RWC-8/607531 (bottom).9.23.1968	9/23/1968	-0.31	Ca-Na-HCO3	LE
21	RWC-1/607532/ Manera[1]	1968 or earlier	21.23[1]	Suspect balance	DR
21	RWC-1.5.4.1970	5/4/1970	-2.14	Na-Ca-HCO3	DR

Table 4.9.2-2. List of samples reviewed with anion-cation balance and water type continued.

Station #	Station ID[1]	Sample Date	Anion-Cation Balance %	Water Type	Group[2]
21	RWC-1.2.24.1971	2/24/1971	-0.83	Na-SO4-HCO3	DR
21	RWC-1.5.26.1971	5/26/1971	-1.66	Na-Ca-SO4-HCO3-Cl	DR
21	RWC-1.6.22.1971	6/22/1971	-1.19	Na-Ca-SO4-HCO3	DR
21	RWC-1.2.22.1980	2/22/1980	-1.73	Na-Ca-SO4-HCO3	DR
22	Agua Caliente Spr	10/25/2012	-2.67	Na-SO4-HCO3	DR
23	Well 564266[1]	4/27/2005	17.53[1]	Suspect balance	DR

[1] Sample analysis shows poor anion-cation balance (absolute values of charge balance between 17 and 63 percent) or lacking parameters needed to categorize water type. All of the other samples show absolute value of charge balance at or below 8 percent.

[2] HE=high elevation; LE=low elevation; DR=detachment-fault related

waters occurring at similar low elevation, originates as precipitation high in the Rincon Mountains, and falls on or just above the meteoric water line (is not evaporated). This water appears to be ponded or dammed by low-permeability features in the plane of detachment fault except where breaches occur at springs locations (Gu 2005; Love et al. 2014). The shared characteristics occurring in detachment-fault related water imply common flow paths or commonality in features along flow paths (Gu 2005). Carbon-14 dating has shown the age of detachment-related water from a well in the Rincon Valley to be on the order of 3,000-3,300 years, and the age of water at Agua Caliente to be 4,800-4,900 years old (Eastoe 2012).

No sample analyses were available for water between 3,430 ft (Madrona Pool 1D in the Chimenea drainage) and 7,355 ft (Spud Rock). The Spud Rock sample was omitted from the analysis in the quality assurance phase due to an unacceptably high anion-cation balance, as were samples collected in 2005 in the Rincon Creek drainage Table 4.9.2-2).

Figure 4.9.2-10 illustrates the measured total dissolved solids and pH (hydrogen ion activity) for each of the samples. The bar chart shows that the highest elevation sample sites, Manning and Italian Springs, were characterized by the lowest overall measured total dissolved solids, which averaged 50 mg/L for the seven samples. Average pH for the

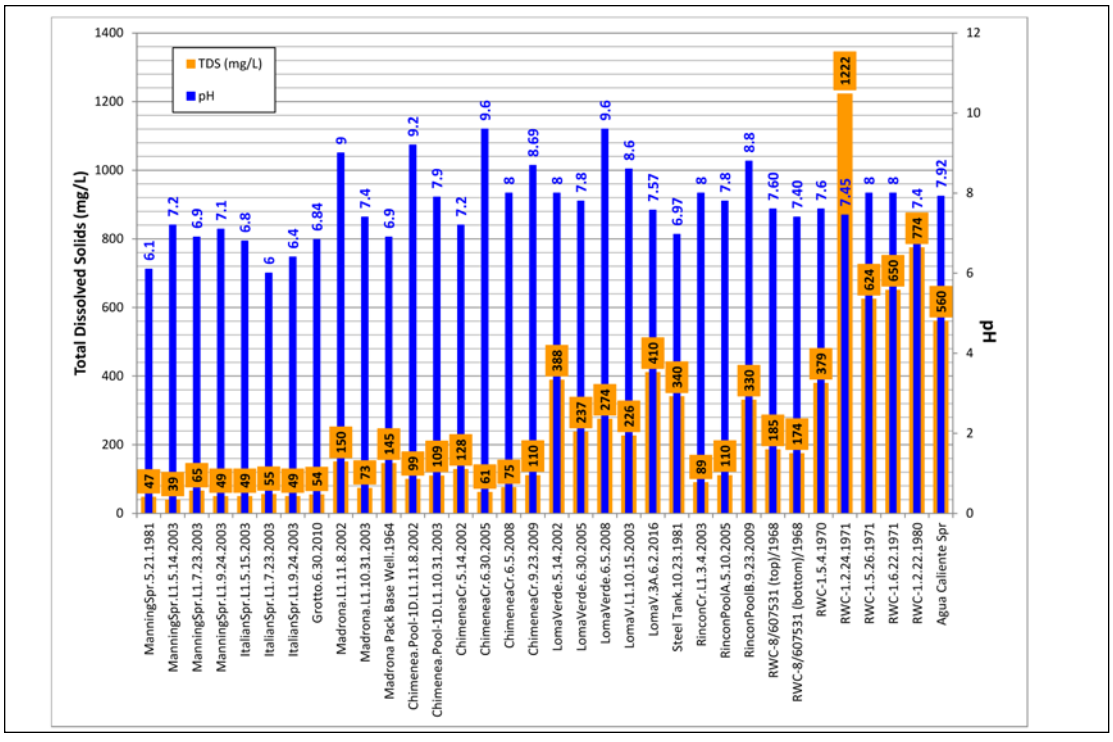


Figure 4.9.2-10. Total dissolved solids and pH for Rincon Mountain District water quality samples.

Table 4.9.2-3. Average values of primary ions in precipitation at the National Atmospheric Deposition Program Chiricahua National Monument AZ98 station and for RMD high elevation, low elevation and detachment-related water samples.

	pH	Total Dissolved Solids (mg/L)	Specific Cond. (mS/cm °C)	Mg (mg/L)	Na + K (mg/L)	Ca (mg/L)	SO_4 (mg/L)	Cl (mg/L)	HCO_3 (mg/L)
Average-AZ98 Monthly Precipitation*	5.4	na	9.27	0.04	0.17	0.39	0.8	0.24	na
Average RMD-High Elevation (7 samples)	6.6	50.4	61.4	1.63	2.39	5.4	3.8	1.96	25.1
Average-RMD Low Elevation (21 samples)	8.0	179.4	265.6 (19 samples)	6.06	14.21	24.1	20.7	10.61	105.1
Average Detachment-Fault Related (6 samples)	7.7	701.5	554 (4 samples)	5.2	99.49	47.3	254.0	44.52	210.8

*National Atmospheric Deposition Program Chiricahua National Monument AZ98 site; February 1999-October 2015; data downloaded from http://nadp.sws.uiuc.edu/data/sites/list/?net=NTN June 21, 2016.

seven high elevation samples was 6.6 slightly higher than average precipitation (Table 4.9.2-3). These results are consistent with the isotope data discussed above and with a conceptual model of infiltrated rainfall or snowmelt traveling relatively short distances and/or having short travel times in a fractured and weathered crystalline rock terrain.

Measured pH of waters collected at elevations below 3,500 feet was higher and more variable than for high-elevation springs, reflecting the numerous biotic and abiotic factors that influence pH in varying aquatic environments. Average total dissolved solids for 21 low-elevation, non-detachment samples is 179 mg/L, and average pH for this group is 8.0. The higher dissolved solids values are consistent with a longer travel path having greater rock- and/or alluvium-water interaction than that of the high-elevation springs discussed above. Evaporation likely also contributes to the concentration of ions in waters at lower elevations. Figure 4.9.2-10 also shows that dissolved solids in water samples from the Loma Verde Pools 3A and 5 and Steel Tank are two to three times greater than those found in samples from non-detachment low-elevation water bodies located in the upper Rincon Creek drainage. Although collected at a low-elevation site, on the basis of total dissolved solids and pH, the Grotto sample is shown to be very similar to those from the high elevation springs in Figure 4.9.2-10.

The highest overall measured dissolved solids were observed in samples from a well in the Rincon Valley, RWC-1 (Manera 1968), and from Agua Caliente spring (Love et al. 2014), located north of the park. Average total dissolved solids for the six samples from the RWC-1 well and Agua Caliente spring was 702 mg/L, while average pH for that group was 7.7. Both of these sites have been identified as detachment-fault related on the basis of isotopes and other water quality indicators discussed above (Eastoe 2012). Taken together with the Carbon-14 age data, these results are consistent with long travel times, likely moving slowly along lengthy pathways within deeply penetrating mountain block fault and fracture zones (Gu 2005).

Figure 4.9.2-11 shows fluoride levels in the samples. Fluoride measured below the method detection limits for all of the high elevation samples as well as the Grotto and three of the Chimenea Creek samples. Average fluoride levels were 0.44 mg/L in

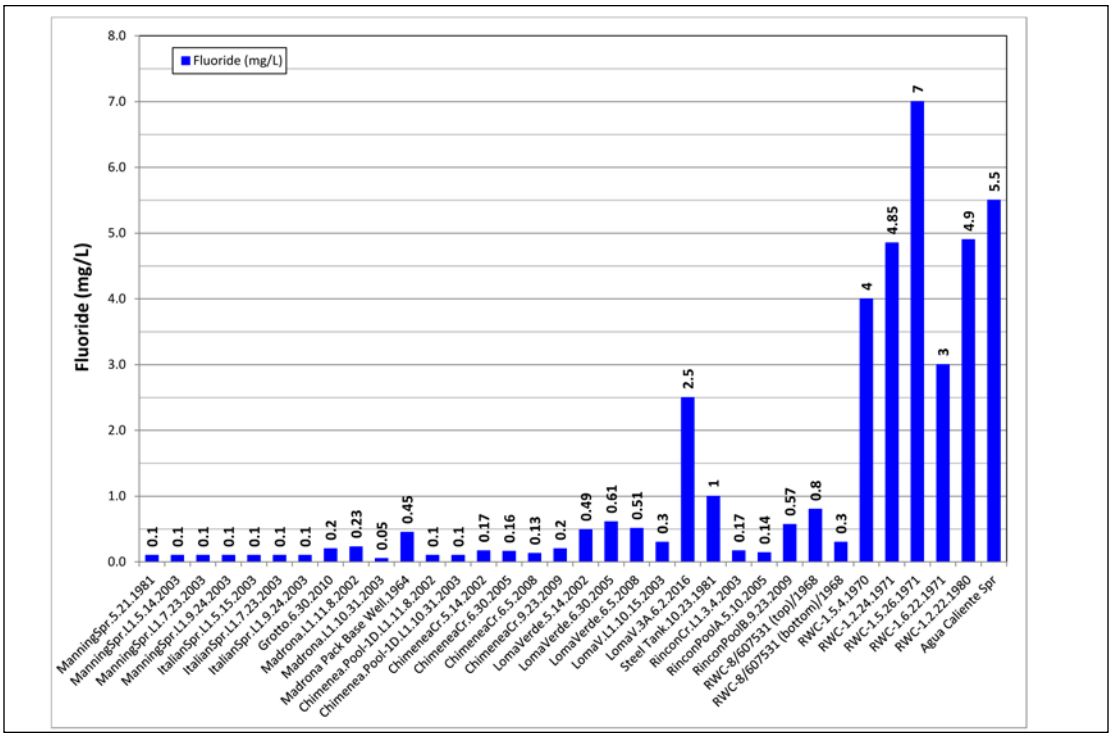


Figure 4.9.2-11. Fluoride concentrations at sample sites.

the low elevation samples. Average fluoride concentration in the detachment-fault related samples was 4.9 mg/L (Figure 4.9.2-11). Fluoride levels in inflowing seepage obtained from Loma Verde Pool 3a following complete draining of the pool was 2.5 mg/L, significantly higher than for other low elevation waters sampled and approximately five times greater than was measured in other samples collected previously at the same pool. Sources of fluoride in waters above the detachment fault include apatite-group minerals in igneous silicates, as well as fluorite, an accessory mineral in pegmatites and granites. Biotite and muscovite may also contain fluoride but at lower levels. The sedimentary Pantano Formation is another possible source of fluoride for waters coming in contact with it

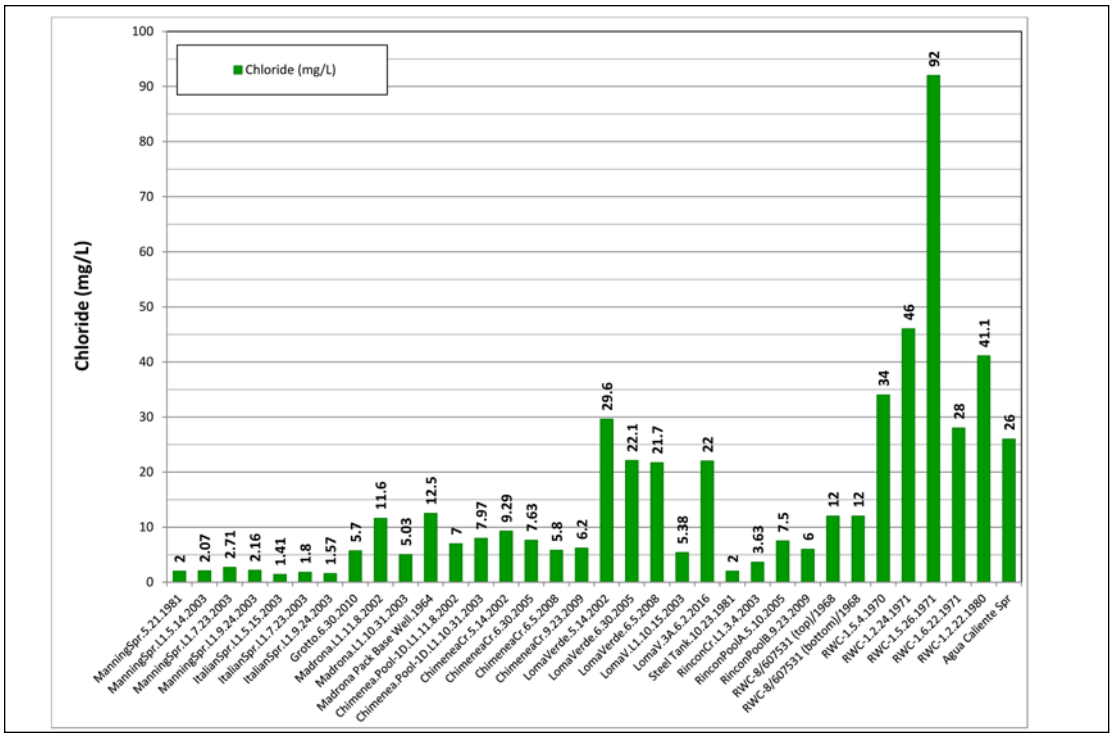


Figure 4.9.2-12. Chloride concentrations at sample sites.

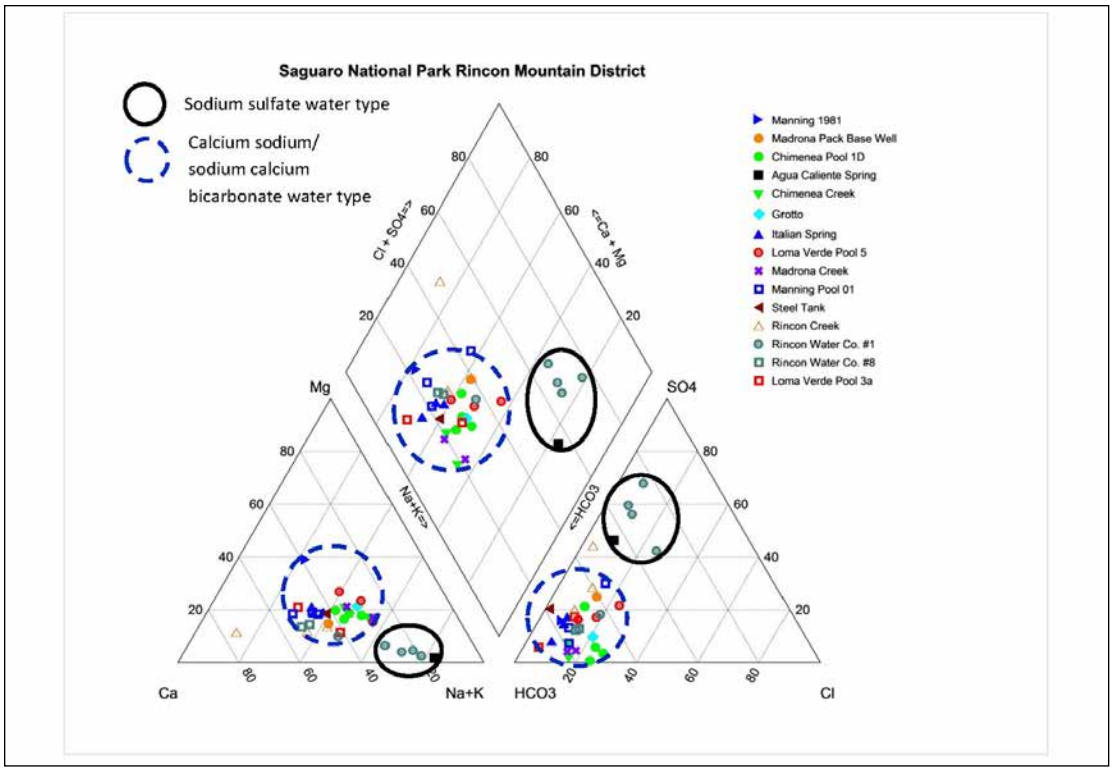


Figure 4.9.2-13. Piper plot of Rincon Mountain District water analyses illustrating primary water groupings of sodium-sulfate water type (black outline) and calcium-sodium bicarbonate water type (blue dashed outline).

at low elevations on the hanging wall side of the detachment fault. The source of elevated fluoride levels in detachment-fault related water adjacent to the Rincon and Santa Catalina Mountains has not been identified to date.

Figure 4.9.2-12 illustrates concentrations of chloride in the samples. While chloride is a minor anion component relative to sulfate and bicarbonate, the relative concentrations of chloride mirror those of fluoride for many of the samples and have similar possible sources as those discussed above for fluoride.

Figure 4.9.2-13 shows a piper plot including data from the 34 samples reviewed. The piper plot shows all but one of the samples falling generally into two groups, a sodium sulfate bicarbonate water type found at RWC-1 and Agua Caliente spring, and a calcium-sodium/ sodium-calcium bicarbonate water type found at all of the other sample locations. One of the RWC-1 samples is similar to the others except that it is lower in sulfate and therefore falls into the bicarbonate-dominant group. Since the samples were collected at different times in the 1970s and are not well documented, it is not possible to assess why this sample is lower in sulfate than all of the others.

Figures 4.9.2-14, -15, -16, and -17 are Schoeller plots of primary ion concentrations on a logarithmic scale. Figure 4.9.2-14 shows all of the samples plotted on the same graph. It should be noted on Figure 4.9.2-14 that all of the samples possess similar chemical species in generally similar relative proportions, the primary difference between the sulfate-dominant and the bicarbonate-dominant groups is that the sulfate-dominant group has more sulfate than the others, not a lack of bicarbonate. Figures 4.9.2-15, -16, and -17 illustrate sample groups including low-total dissolved solids (TDS) low-fluoride high-elevation springs (Figure 4.9.2-15), moderate-TDS low-fluoride low-elevation non-detachment fault related calcium-sodium/ sodium-calcium bicarbonate waters (Figure 4.9.2-16), and high-TDS high-fluoride detachment-fault-related sodium sulfate bicarbonate waters (Figure 4.9.2-17), The one RWC-1 sample categorized as a sodium bicarbonate water type is included with Figure 4.9.2-17 on the basis of its high TDS and high fluoride. As the figure shows, other than the lower sulfate concentration, this sample was

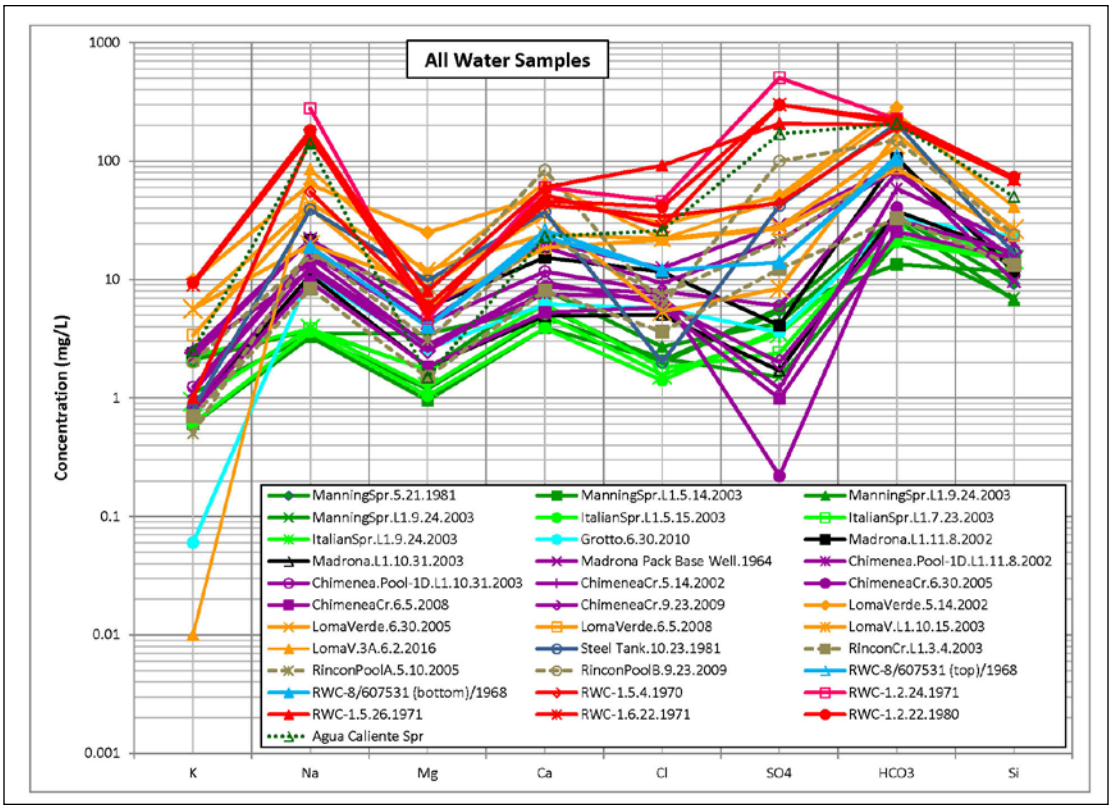


Figure 4.9.2-14. Schoeller plot of basic ions for all samples.

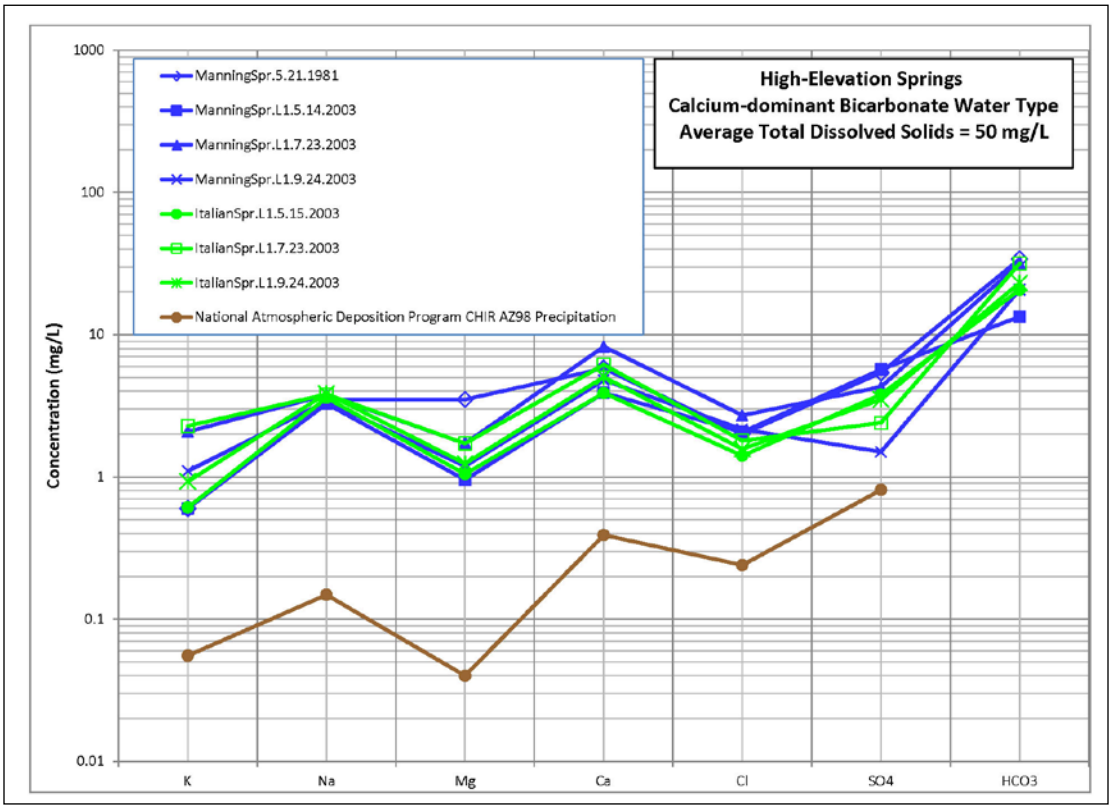


Figure 4.9.2-15. Schoeller plot for high elevation springs with precipitation chemistry from National Atmospheric Deposition Program Chiricahua AZ98 site.

very consistent with values observed in the other four RWC-1 samples.

Figures 4.9.2-10 - 17 provide important clues to some of the processes governing groundwater flow at RMD. The lowest TDS samples come from high elevation springs, with TDS increasing at low-elevation sampling locations and highest in the detachment-fault

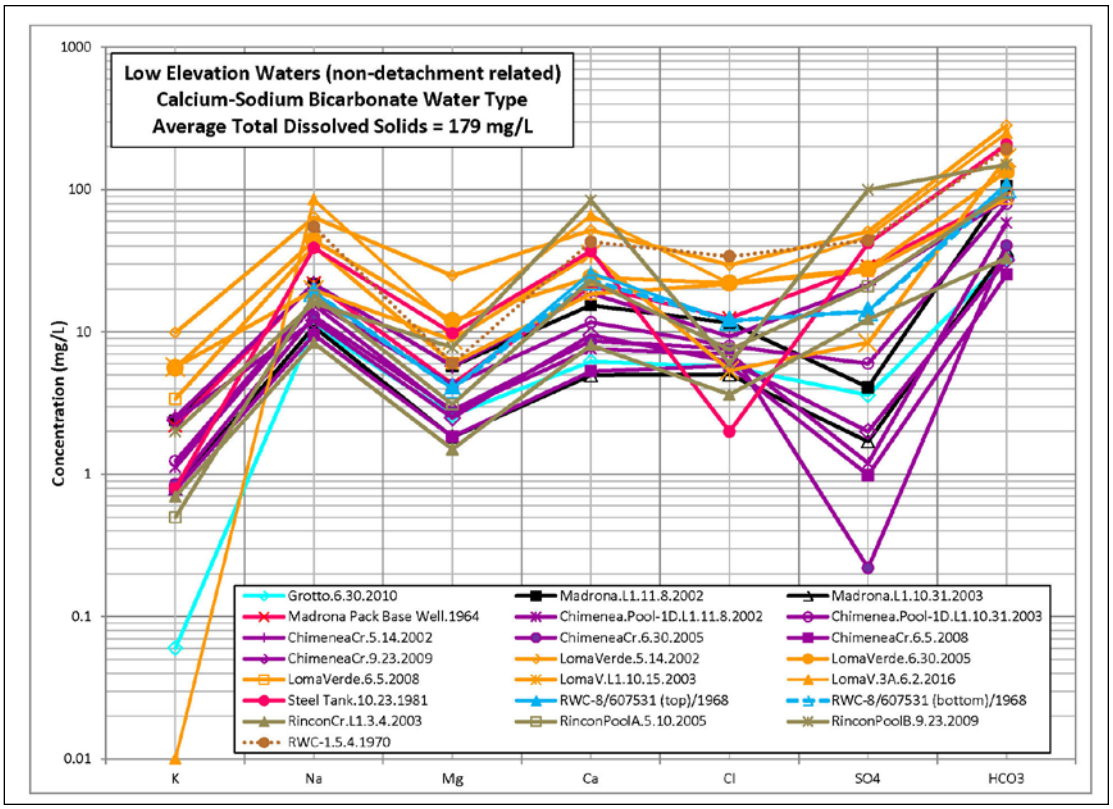


Figure 4.9.2-16. Schoeller plot for low elevation, non-detachment related samples.

related waters from RWC-1 and Agua Caliente spring.

High elevation springs show pH and concentrations of primary anions and cations nearest to regional precipitation averages of all of the groups (Figures 4.9.2-10 - 14, Table 4.9.2-3). All of the high elevation springs contain calcium-dominant bicarbonate water. The bicarbonate component originates when carbon dioxide dissolves in water to form carbonic acid, which then interacts with rocks to form bicarbonate and associated cations such as calcium or sodium. In combination with stable water and tritium isotope data, these results support the conceptual model of high elevation springs sourced by water that infiltrates in both winter and summer with minimal evaporation and moves via short flow paths before re-emerging at the surface. These springs are likely to be susceptible to interruption under scenarios of reduced overall precipitation and especially reduced snowpack, in combination with increased temperatures. How soils and vegetation at high elevations may respond to these projected changes in climate, and how soils and vegetation changes may affect runoff, infiltration and spring flow are unknown.

The low elevation springs, tinajas and well analyses (Figures 4.9.2-10 - 14 and 4.9.2-16) are much more variable than the high elevation springs. Distinct differences are present between water from the Middle Tanque Verde watershed (including Loma Verde and Steel Tank sites) and the other low elevation sites, all located within the Upper and Middle Rincon Creek watersheds. The Middle Tanque Verde sites are characterized by higher TDS (Figure 4.9.2-10), higher fluoride (Figure 4.9.2-11) and higher chloride (except for Steel Tank; Figure 4.9.2-12), than those from the Rincon Creek watersheds. The Middle Tanque Verde sites are also higher in sulfate than was found in the surface water samples from the Chimenea and Madrona Creek drainages (Figures 4.9.2-14 and 4.9.2-16). Sulfate was higher in low-elevation well samples in the Rincon Creek watershed including Madrona Pack Base well and RWC-8 than it was for the samples higher in the same watershed. Water sampled from Rincon Creek itself was also higher in sulfate than water sampled higher in the Chimenea and Madrona Creek drainages. The groundwater samples from RWC-8 and the surface water samples from Rincon Creek are likely gaining dissolved solids, including sulfate and fluoride, from the upper-plate

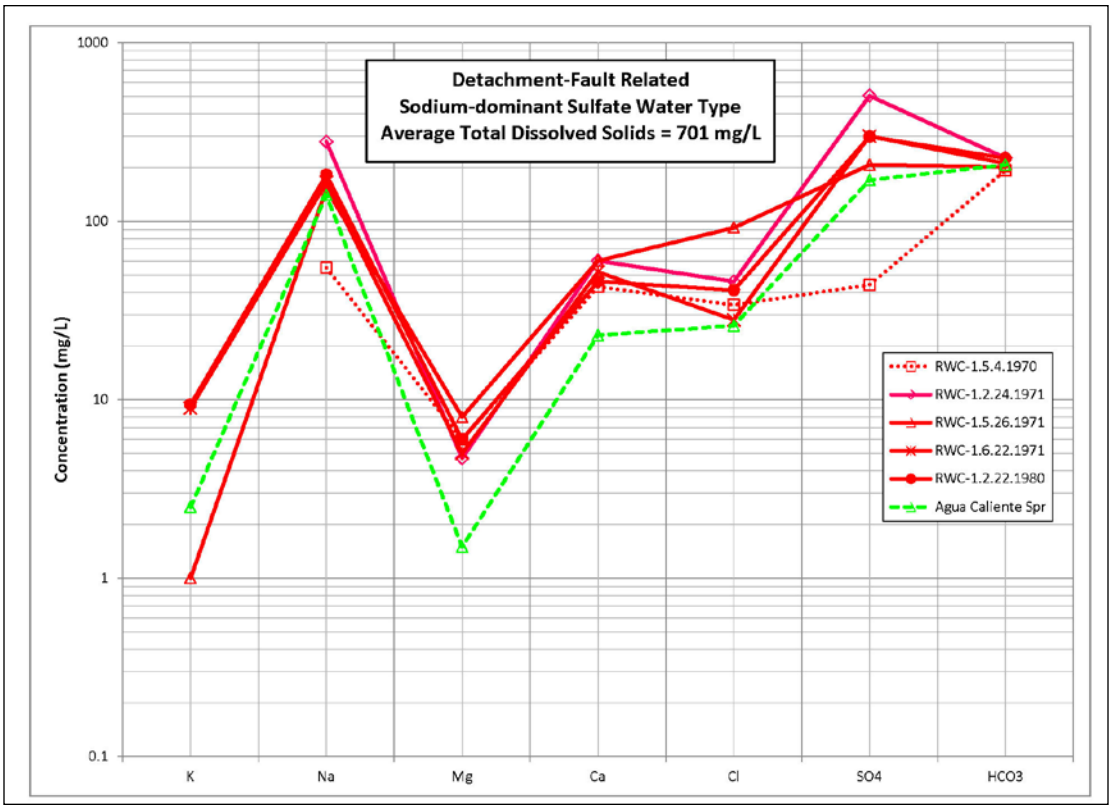


Figure 4.9.2-17. Schoeller plot for Catalina-Rincon detachment-fault related water selected analyses.

Pantano formation, exposed on the surface in this area. High similarity was observed between the analyses from Madrona Pack Base, RWC-8, and the Chimenea Creek sample collected on 5/14/2002.

The samples from Middle Tanque Verde watershed show evidence of mixing of the deep-circulation sodium sulfate water type with bicarbonate waters that appear to develop along local-scale flow pathways on-and near the surface. The sample from the Madrona Pack Base well may also include a mix of water types. Olson (1982) identified the presence of seven water samples characterized by chemistry belonging generically to the bicarbonate group that had been mixed to different degrees with the sodium sulfate group in the samples he reviewed, most of which were from the Middle Tanque Verde watershed. While the samples reviewed by Olson (1982) were lower in the drainage and had a higher sulfate:bicarbonate ratio than those reviewed here, it is possible that concentrations in the Loma Verde, Steel Tank and Madrona Pack Base samples may reflect a smaller contribution from the deep-circulation sodium sulfate water type than was present in Olson's samples, most of which came from much lower elevations. The high fluoride concentration found in the water sample from Loma Verde Pool 3a in June 2016 (Figure 4.9.2-11) supports this conceptual model, since that pool was emptied completely and the sample was taken the next day from water that had seeped in overnight, following a period of two months of warming temperatures without any precipitation or surface flow.

Water samples collected in the Chimenea and Madrona drainages and at the Grotto are all low in sulfate and fluoride and have lower TDS than samples from the Middle Tanque Verde watershed. Aside from having a higher proportion of sodium relative to calcium and higher TDS and pH, chemistry of these samples is most similar to that of the high elevation springs. Olson (1982) concluded that water samples with these characteristics originated as surface runoff. This is consistent with the conceptual model shown in Figures 4.9.2-4, in which local-scale water travels along pathways that can include both surface flow and subsurface routes in shallow fractures and in alluvium. Temporal differences in concentrations at the same location are likely associated with seasonal

factors, such as whether or not there has been recent surface flow, which would tend to be more dilute, or a long-term dry period with significant evaporation, which would increase concentrations.

Within the water groups, Figures 4.9.2-10 - 17 illustrate both similarity and temporal and spatial variability in relative proportions of calcium and sodium, as well as relative proportions of sulfate and bicarbonate. Potassium, magnesium and chlorine were minor components of most of the water samples with only a couple of minor exceptions. A sample from Rincon Creek Pool B is the only sample that does not fall into either of the primary groups delineated on the piper plot of Figure 4.9.2-13. Table 4.9.2-2 lists the water type for each of the samples, with the dominant cation first, followed by secondary cations, then the dominant anion, followed by any secondary anion components. Of the bicarbonate water type group, calcium was the dominant cation in all of the high elevation spring samples, Madrona Pack Base well, Steel Tank, Rincon Creek, Loma Verde Pool 3a and RWC-8 well samples. Sodium was the dominant cation for the Grotto, all of the Madrona Creek, Chimenea Creek, and the three Loma Verde samples from Pool 5. Sodium was also the dominant cation for all of the sulfate water type samples (including five samples from RWC-1 and the Agua Caliente spring sample). Explanation of these differences is not known.

The samples circled in black on Figure 4.9.2-13 and plotted in Figure 4.9.2-17 are designated as detachment-related waters (Eastoe 2012). One of these samples came from a 280 foot deep private well in the Rincon Valley and the other is from Agua Caliente spring, located north of the park along the trace of the Catalina-Rincon detachment fault. None of the samples collected inside the park proper had the characteristics of this water type but it is relevant to the regional-scale conceptual model of groundwater at the park. Olson (1982) characterized detachment-fault related waters as chemically and isotopically distinct from waters occurring on either side away from the fault. Gu (2005) determined that sulfates in precipitation originate from anthropogenic sources (mining activities and coal-fired power plants), but that the sulfates in detachment-fault related waters originated from the oxidation of sulfides (primarily pyrite) in the gneissic/granitic mountain block. Detachment-fault related water was also characterized by high sodium concentrations, attributed to alteration of plagioclase in the granitic bedrock present with high fluoride levels, and were identified as a unique water type on the basis of analysis of isotopes of sulfur and oxygen in sulfates of those waters (Olson 1982 p 83, Gu 2005). Additional isotopic analysis of detachment-fault related water shows that the water infiltrated in winter at high elevation and was not affected by evaporation before infiltration (rapid, high elevation, winter/ snowmelt recharge). These waters were all of pre-bomb age based on tritium data, and Gu (2005) concludes that they likely result from circulation through deep faults and fractures in the mountain block, and that the Catalina-Rincon detachment fault acts as a barrier, ponding the deep-circulation water around and within the mountain block except where the fault is breached, such as at Agua Caliente. This interpretation is consistent with that of Love et al. (2014) in the area of Agua Caliente.

The discussion above confirms the presence of at least two distinct water types present at the park, with mixing of these two present at some locations. These results are consistent with the findings of Olson (1982) and with isotope analyses conducted in and around the park (Eastoe 2012).

Rincon Valley Groundwater

At RMD groundwater monitoring is focused on the shallow alluvial aquifer of Rincon Creek, in the central section of the Upper and Lower Rincon Creek watersheds (Figure 4.9.1-4). The reach of greatest interest is designated the middle reach of Rincon Creek (NPS 2008). This reach of Rincon Creek harbors the “finest and most extensive riparian habitat remaining” (Baird et al. 2001) at Saguaro NP, and has been the focus of an instream water right application to the State of Arizona, submitted in 2002, followed by an assessment report in 2008 (NPS 2008). The

three primary hydrologic components of the middle reach include streamflow in Rincon Creek, persistent pools in Rincon Creek after streamflow has ceased, and the shallow alluvial aquifer. Water in the shallow alluvial aquifer is hydraulically connected to Rincon Creek and pools in the creek (NPS 2008). The shallow alluvial aquifer is recharged by streamflow, floods and by long-duration rainfall events. Outflow from the aquifer takes place through seepage to the creek and its pools, evapotranspiration, subflow within the shallow alluvium, and leakage to the deep bedrock aquifer (NPS 2008).

Tributaries to Rincon Creek also host rare perennial bedrock pools and springs, supplied by groundwater, and surface flow when present, that are vital to wildlife during the dry and hot seasons of the year. Intermittent pools and springs are sustained by seeping groundwater after surface flows are finished. The rarest and most critical pools are perennial and contain water through the driest seasons, when rain and surface flows have long ceased and temperatures linger above 100°F for weeks. Groundwater monitoring in this watershed complements surface flow data collected by NPS at Pool A (2003-present) and by the USGS at stream gage 09485000 (1952-1974; 1988-present), wet-dry mapping in the middle reach of Rincon Creek (2003-present), and pool stage at Madrona Pools 1D and 1K in the Chimenea Creek drainage. These water sources are carefully monitored by park staff and volunteers. Taken together, these data sets provide a holistic view of near-surface water dynamics and status in the watershed.

In the middle Rincon Creek watershed, both deep and shallow groundwater resources are present. Due to a lack of access to wells completed in the deep water-bearing zone, only shallow groundwater is monitored by NPS. While well 55-633106 is deep at 455 feet, it does not penetrate the fractured zone that is the primary host for what is known in reports as the "deep aquifer" (Manera, Inc. 1982). At lower elevations in the drainages, surface bedrock is covered by sediments, water is stored in the pore spaces of alluvium and pools are not present or are present only intermittently or ephemerally. Wildfire-related sedimentation has also been known to bury pools, eliminating surface water sources for wildlife, sometimes permanently. Within the lower drainages, water occurs seasonally

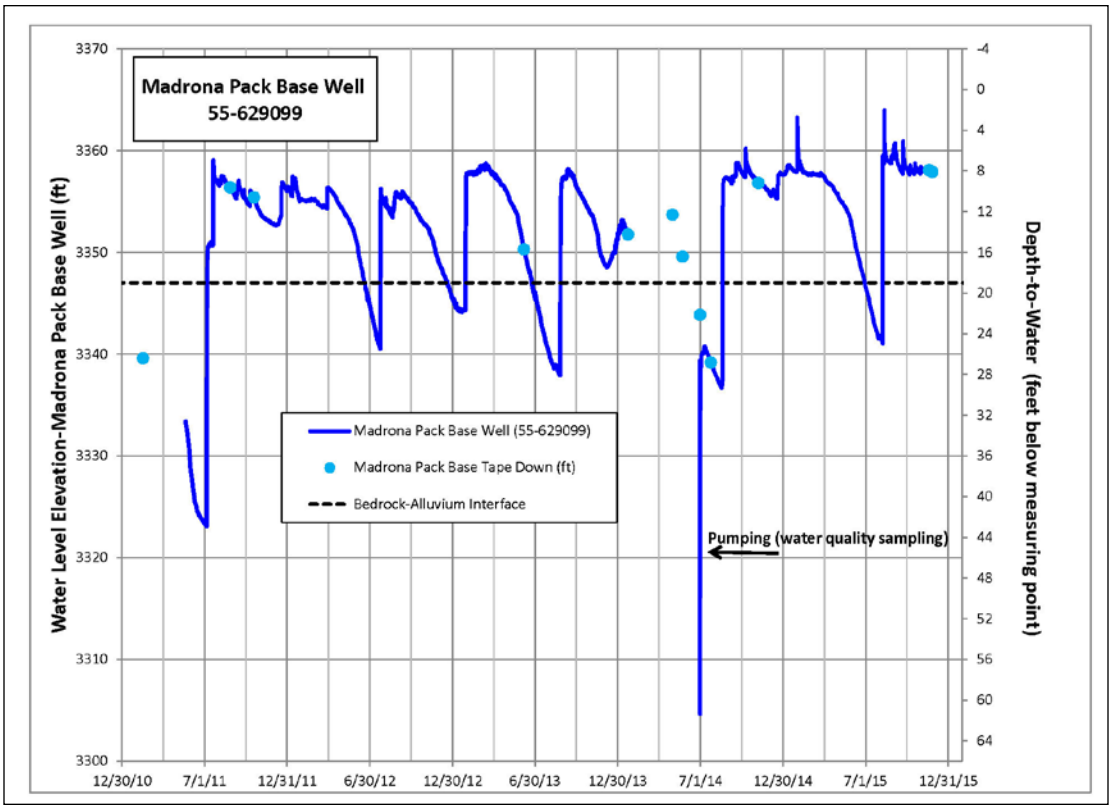


Figure 4.9.2-18. Water level elevation and depth to water at Madrona Pack Base well, 2010-2015.

flowing on the surface and within alluvium when the surface is dry. Shallow subsurface water is essential to the existence of the riparian corridor along Rincon Creek (Briggs 2008) but is not readily available to wildlife.

Figure 4.9.2-18 shows water level elevations and depth-to-water measured at the Madrona Pack Base well (Figure 4.9.1-5), between 2010 and 2015. This is the only NPS groundwater monitoring location on the footwall side of the Catalina-Rincon detachment fault. The well is constructed in coarse alluvium and bedrock in the flood prone area adjacent to Chimenea Creek near the former Madrona Ranger Station. Water levels at this well provide insight to the flow regime in the subsurface beneath Chimenea Creek. Depth to water at Madrona Pack Base well varied from a high water level of 2 feet below the top of casing in August 2015 (this water level is essentially at the ground surface), to the lowest natural (unpumped) water level during this time period of almost 43 feet below the measuring point in early July 2011. Figure 4.9.2-18 indicates the estimated location of the bedrock-alluvium interface based on driller's records. Bedrock was noted to be brecciated granitic gneiss by the well driller. Water levels do not show a change in slope on either the rising or falling limbs of the hydrograph as they cross this interface, indicating that the well intercepts bedrock that is sufficiently fractured to drain freely and flow is not occurring solely in the alluvium. There is a consistent change in slope during drainage cycles at around 3,352 feet (10 feet below ground surface), indicating a likely change in hydraulic properties of the alluvium at that level. The deepest water level shown on Figure 4.9.2-18 occurred in June 2014 when the well was purged prior to collecting a water sample. This is the water sample reported in the water quality section above.

Figure 4.9.2-19 illustrates water levels at Madrona Pack Base well plotted with the daily precipitation recorded at the Rincon Creek and Manning Camp ALERT weather stations through 2015 (A. Wigg 2016). The record shows how water storage in the subsurface declines during periods of little or no precipitation, only rising again when water is added to the system either by direct precipitation, subflow, or by flow in Chimenea Creek as indicated by estimated discharge from Madrona Pool 1-D in Chimenea Creek. Figure 4.9.2-20 illustrates

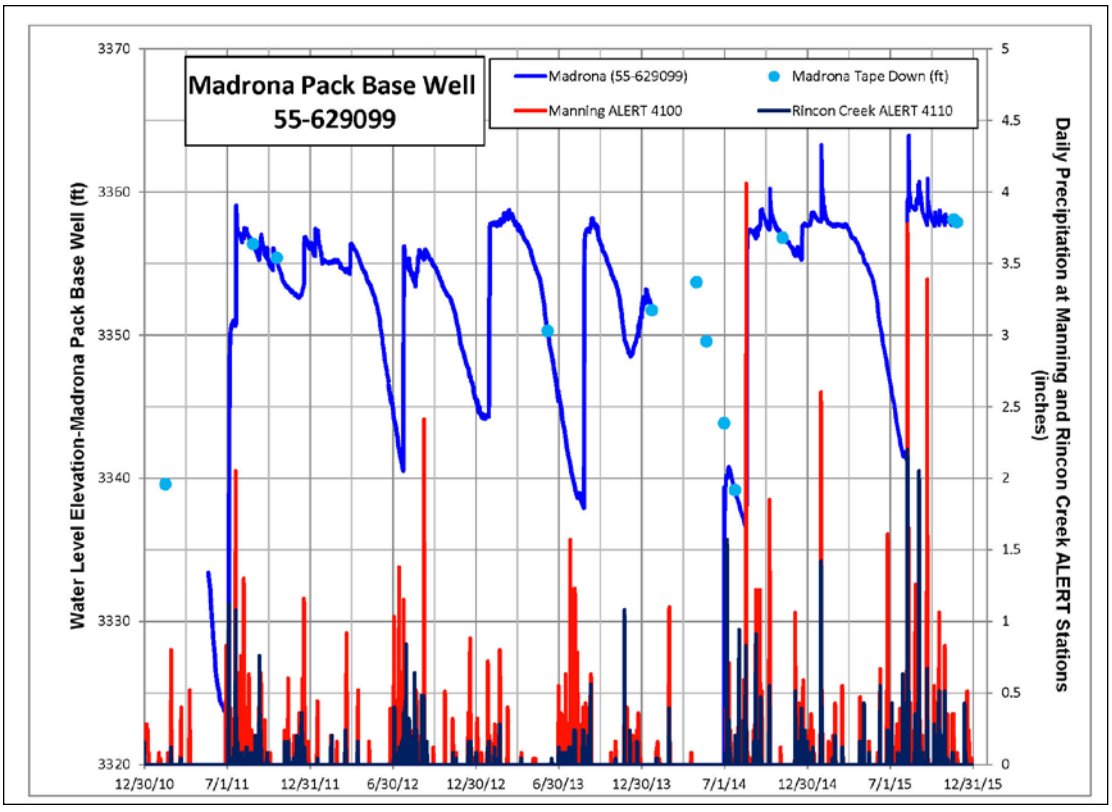


Figure 4.9.2-19. Water level elevations at Madrona Pack Base well with daily precipitation for the Rincon Creek (ALERT 4110) and Manning Camp (ALERT 4100) rain gages operated by Pima County.

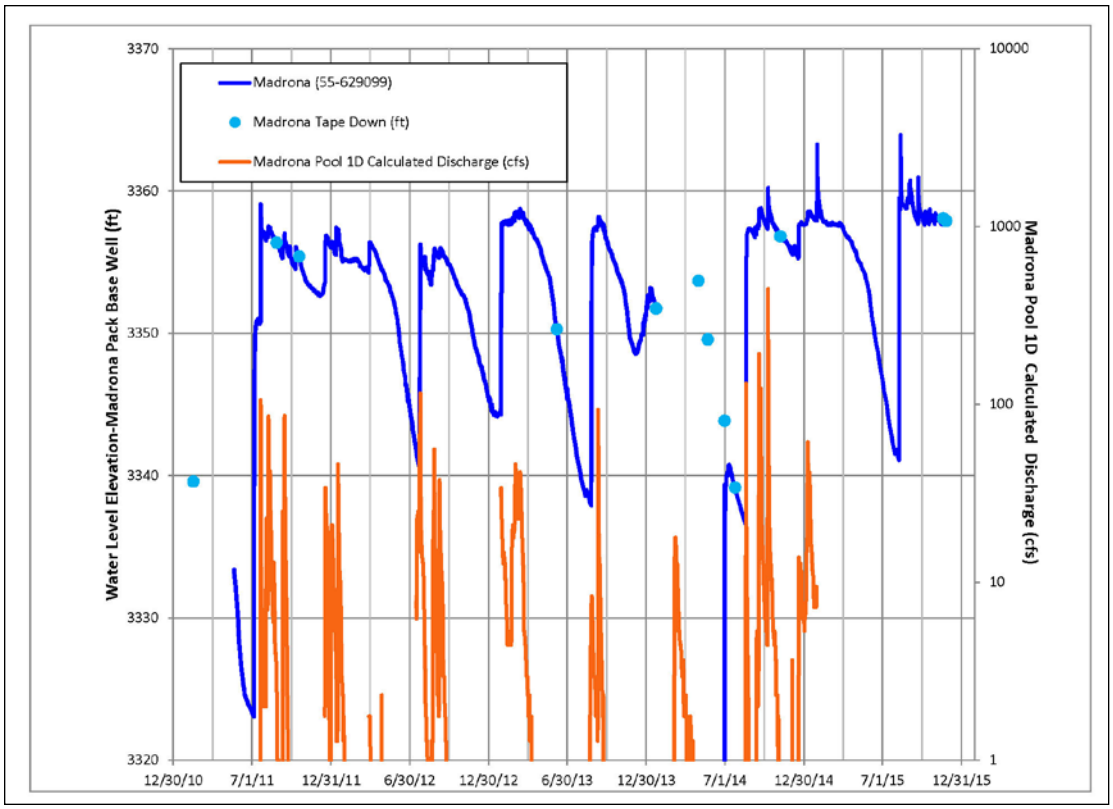


Figure 4.9.2-20. Water level elevation at Madrona Pack Base well and calculated discharge through 2014 in Chimenea Creek at the outlet of Pool 1D (discharge from C. Perger 2015b).

water levels at Madrona Pack Base well with calculated flow in Chimenea Creek based on measured water levels at Madrona Pool 1D, located about 1,100 feet upstream of the well in the Chimenea drainage (Perger 2015b). Water levels in the well rise in response to flow in the creek, but at times they rise ahead of flow in the creek, presumably a response to local precipitation and runoff or subsurface flow moving downgradient in alluvium or fractures.

Storage in the alluvium and the bedrock of the Chimenea Creek drainage is transient, i.e., voids in the bedrock and alluvium fill with water when inflows occur, the voids drain as the inflows decline and eventually stop, draining until the next influx of water occurs. The lowest water levels at this well occur during the months of June to August following the normally dry months of April through June. Once the monsoon rains begin in late June or early July, time to water level rise at Madrona Pack Base well varies from almost instantaneous to two months or longer. The relationship between inflow to the system via precipitation or snowmelt and water level rise is complex, including event-specific factors not easily characterized, including location, duration and intensity of precipitation, runoff rates, presence or absence of surface flow in Chimenea Creek, and volume of drained storage above and below the surface in the watershed. Surface temperatures will also influence how water is removed from the watershed via losses to evaporation. In the Chimenea Creek subsurface, drainage of stored groundwater occurs slowly. Following flow in the creek, two to three months pass before water levels at Madrona Pack Base well fall below the alluvium-bedrock interface, and drainage continues beyond that point in the fractured bedrock. The data do show subsurface flow occurring outside of the periods of surface flows in the drainage.

Figure 4.9.2-21 shows the location of Pool A, the USGS gage and the RC and 55-633106 wells in the middle reach of Rincon Creek. In this reach, Rincon Creek is the park boundary and all of the groundwater monitoring sites south of Rincon Creek are located on private lands. Seven shallow piezometers, RC-1 to RC-7, were installed in 2005 (Table 4.9.2-4; NPS 2008). The RC wells were constructed to bedrock, and the deepest of the RC wells is 17 feet deep (Table 4.9.2-4). An additional deeper well on adjacent private property,

Table 4.9.2-4. Groundwater wells at Saguaro National Park Rincon Mountain District.

Common Name(s)/ PLSS Location	Description (total depth)	Depth to Water (ft; Date)	State Registration Number
Baker #2/ D(14-16) 31BBC1	Former water supply 1931-?? (312 ft)	274.4 ft (3/1/1977)	55-629105
Baker #3/ D(14-16) 31BBC2	Former water supply 1964-?? (500 ft)	251.9 ft (12/2/1987)	55-629106
C.C.C. Well/ D(14-16) 32ABD	(108 ft)	74 ft (1930s)	55-629100
Freeman Drilled Well D(15-16) 5ABC	(78)	na	55-629101
Freeman Dug Well/ D(15-16) 5ABC	unknown	Dry (1982)	55-629102
Genemata Well/ D(14-16) 15ACB	(19.5 ft[1])	17.5 ft (1982)	55-629103
Greene #1/ D(14-16) 9AAB	Water supply for Greene property (68 ft)	12.3 ft (8/10/2016)	55-629107
Well 55-633106 [3]/ D(15-17) 17ADC	Monitoring well (455 ft)	8.5-10.8 ft (Jan-Sept 2015)	55-633106
RC-1[3]/ D(15-17) 16ACB	Monitoring well (8.5 ft)	5.0-8.1 ft (Jan-Sept 2015)	55-206881
RC-2[3]/ D(15-17) 16ACB	Monitoring well (13 ft)	6.4-10.2 ft (Jan-Sept 2015)	55-206882
RC-3[3]/ D(15-17) 16ACB	Monitoring well (17 ft)	10.5-1 4.9 ft (Jan-Sept 2015)	55-206883
RC-4[3]/ D(15-17) 17ADB	Monitoring well (8.5 ft)	7.0-9.2 ft (Jan-Sept 2015)	55-206880
RC-5[3]/ D(15-17) 17ADB	Monitoring well (9 ft)	9.2-12.0 ft (Jan-Sept 2015)	55-206879
RC-6[3]/ D(15-17) 17ADB	Monitoring well (11.5 ft)	10.0-13.9 ft (Jan-Sept 2015)	55-206878
RC-7[3]/ D(15-17) 17ACA	Monitoring well (13 ft)	9.4-11.5 ft (Jan-Sept 2015)	55-206877
Madrona Pack Base Well/ D(15-17) 4DCB	Monitoring well (117 ft)	9.2-26.8 ft (Jan-Nov 2014)	55-629099
Hope Camp/ D(15-17) 7CCA	Monitoring well (51 ft)	Dry (2015)	none
Box Canyon/ D(15-16) 4CC	Former wildlife watering well (76 ft)	unknown	none
Kennedy-Creosote Well/ D(14-16)10ACC	unknown	76.5 ft (March 2016)	none

[1] Well registration indicates that timbers at the base of the well may have prevented a true depth measurement.

[2] Well may have been abandoned; records are vague.

[3] Located on inholdings within the legislated park boundary.

known as well 55-633106; Table 4.9.2-4, Figure 4.9.2-21), is also monitored.

Water levels have been monitored manually on a biweekly schedule by C. Perger at the Rincon Creek RC-1 through RC-7 piezometers and well 55-633106 since 2005 (Figure 4.9.2-22). Some manual data are missing for RC-1, RC-2 and RC-3 due to inability to access those sites during changes in land ownership. In addition to the manual measurements, water level sensors have recorded data in Pool A, RC-1, RC-2, RC-3 and well 55-633106 during the better portion of that time period. All water level elevations at the Rincon Creek wells are based on the

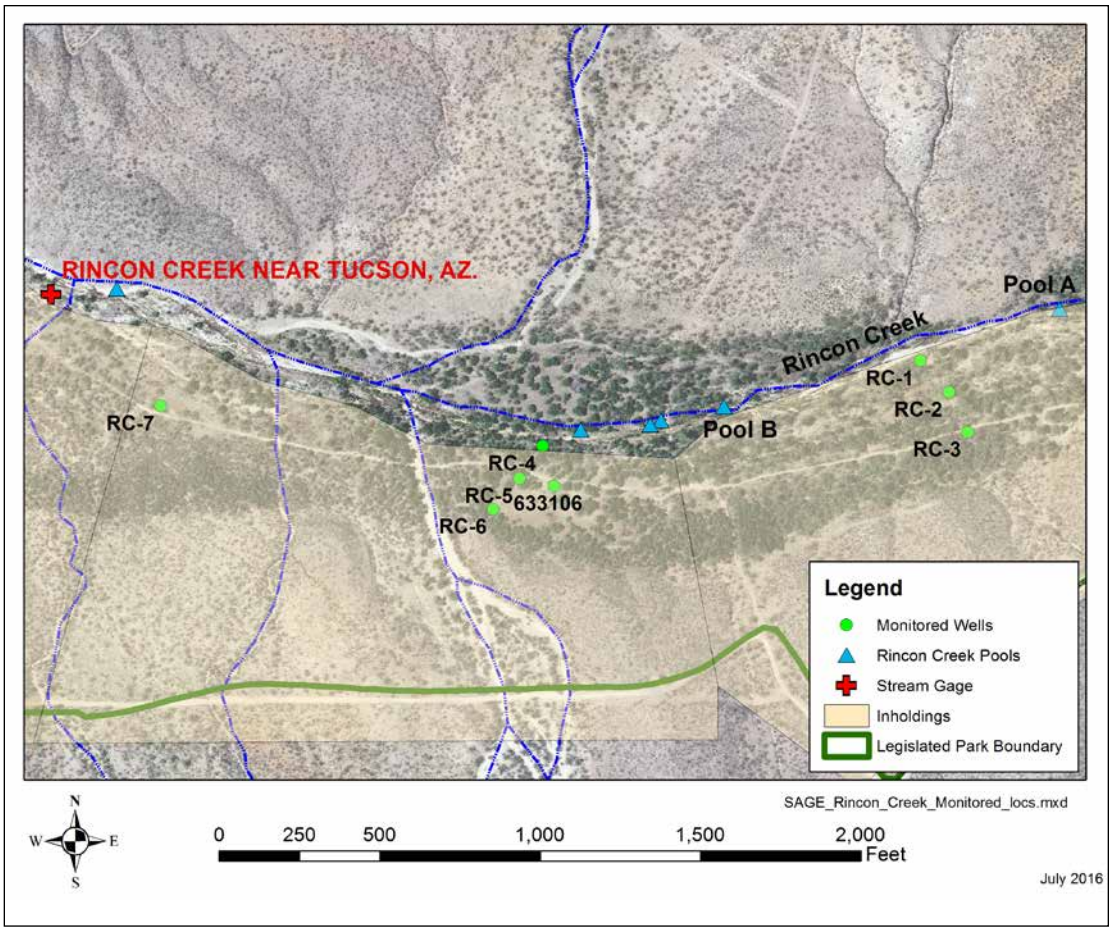


Figure 4.9.2-21. Location of Rincon Creek Pool A, the Rincon Creek USGS stream gage, and the RC and 55-633106 wells in the middle reach of Rincon Creek.

2010 survey of elevations conducted by the NPS Water Resources Division Water Rights Branch (NPS WRD 2010).

Figure 4.9.2-23 shows depth to water below ground surface for the eight groundwater monitoring wells south of Rincon Creek. Note that all of these wells, except for 55-633106, are shallow (Table 4.9.2-4) and where the data "flat line", water level has fallen below the bottom of the well which is located at the alluvium-bedrock interface for each of the RC wells. Water levels at well 55-633106 track closely with water levels at well RC-5, which is the nearest and about the same distance from the creek (Figure 4.9.2-21). Figure 4.9.2-22 shows that all of the RC wells went dry for at least some part of the period shown. Water levels measured at well 55-633106 declined to a minimum of 18 feet below ground surface in February 2014, although a lower minimum may have occurred during a seven month gap in the data following that low measurement.

Figure 4.9.2-24 plots water level elevations at the monitored sites south of Rincon Creek. Surface water level monitored by NPS at Pool A, located 450 feet upstream of the RC-1 well group, is also shown on this graph. As pointed out earlier, it should be noted for all

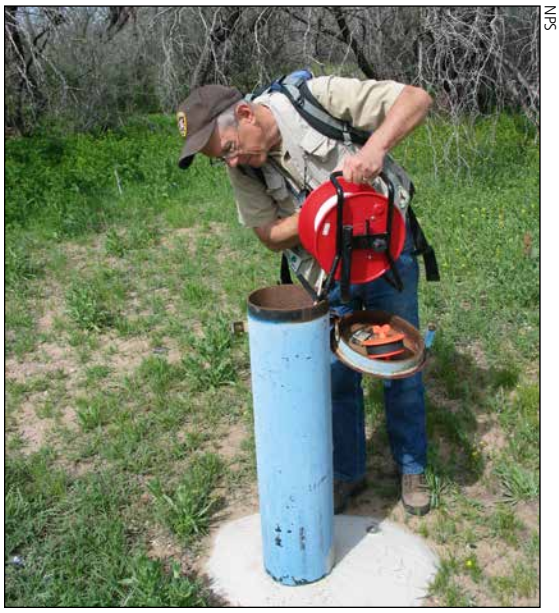


Figure 4.9.2-22. C. Perger manually monitoring groundwater levels.

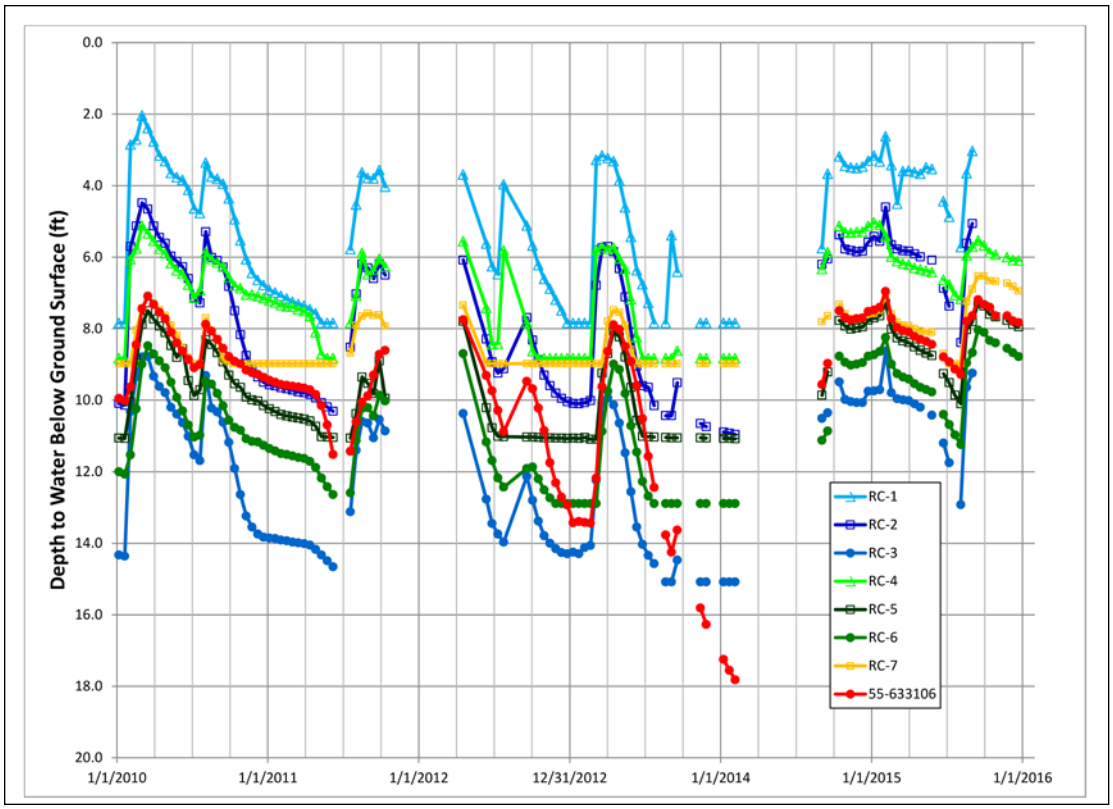


Figure 4.9.2-23. Depth to water at Rincon Creek monitor wells 2010-2015.

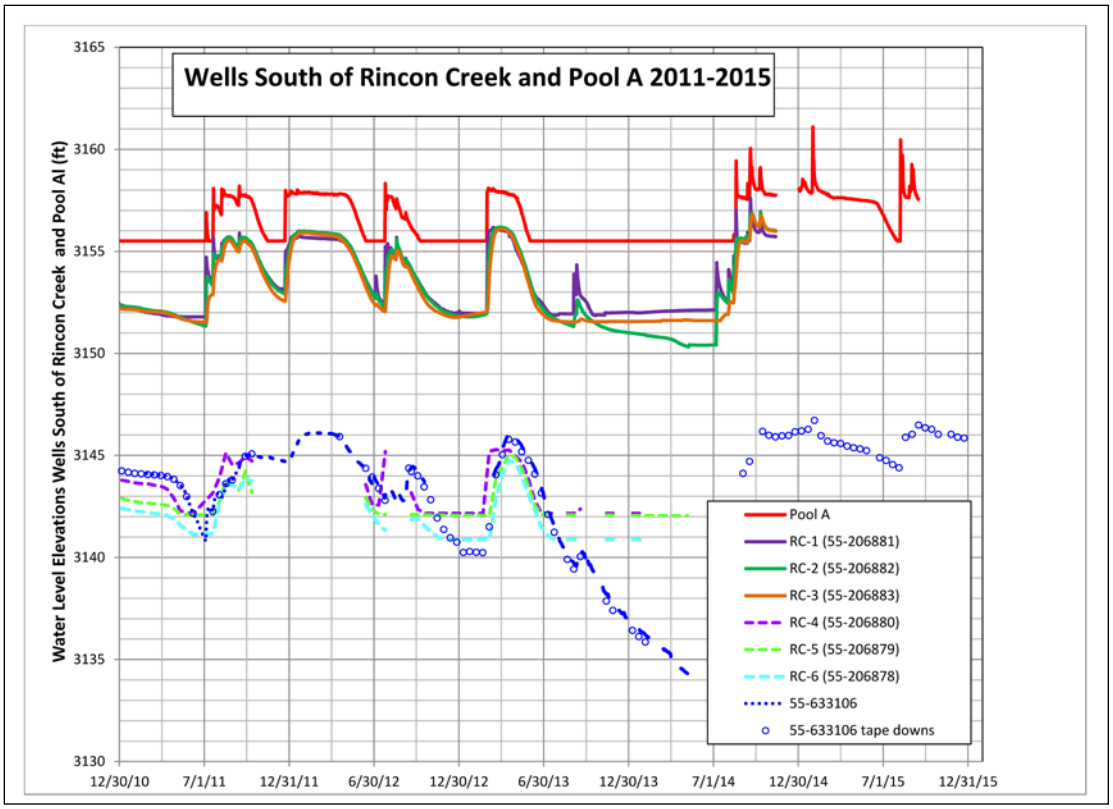


Figure 4.9.2-24. Water level elevations for Rincon Creek Pool A and monitored wells south of Rincon Creek, 2011-2015.

of these wells and for Pool A, when the graph "flat lines" at low points, that is an indication of a dry condition. Water levels are collected automatically at Pool A and well RC-1, RC-2 and RC-3.

Figure 4.9.2-24 clearly shows the movement of seasonal inflows to the system as they propagate from Rincon Creek at Pool A, down-gradient and laterally to the RC-1 to RC-3 piezometers, followed by the RC-4

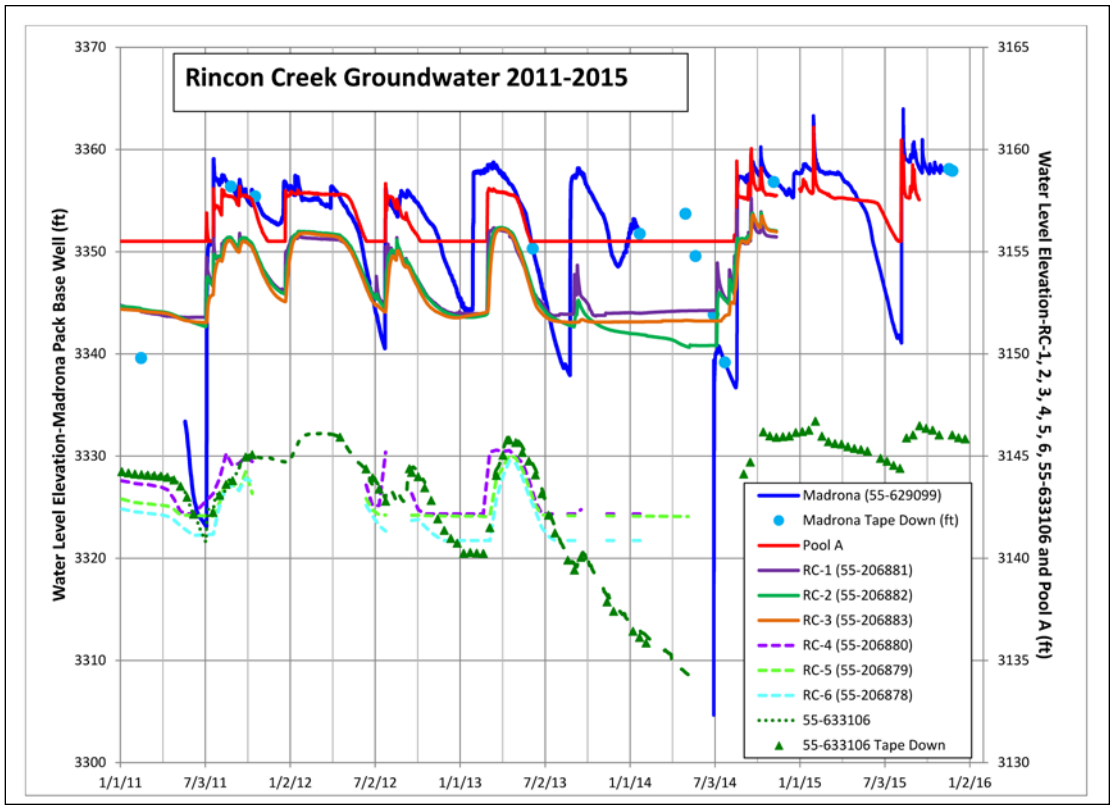


Figure 4.9.2-25. Water level elevations for the Madrona Pack Base well, Rincon Creek Pool A, and monitored wells south of Rincon Creek.

to RC-6 piezometers and well 55-633106. Since measurements at RC-4, RC-5 and RC-6 are obtained on a less frequent basis, information about water movement is less well characterized at the downstream end of the middle reach. However, propagation of groundwater pulses laterally from the creek accompanied by dampening and diminishment of peaks related to the lateral spreading of water in the subsurface is clear.

Water level elevations for the Madrona Pack Base well, along Chimenea Creek, Pool A and the wells south of Rincon Creek are plotted together on Figure 4.9.2-25. Note the different scales on the right (south wells and Pool A) and left (Madrona Pack Base well) axes on this graph. Figure 4.9.2-25 clearly illustrates the normal sensitivity of the groundwater system along Rincon Creek to inflows to the system via Chimenea Creek as represented by the well at Madrona Pack Base (former ranger station). A water level decline of about 10 feet observed at well 55-633106 between spring of 2013 and spring of 2014 is believed to be occurring throughout the middle watershed but is not observed elsewhere as water levels fall below the bottom of the shallow RC wells. How much water availability there may be to riparian plants once water levels fall below the alluvium-bedrock interface is uncertain. This indicates that more water was removed by transpiration, evaporation, outflow and possibly a slow draining of residual groundwater in the system to the deeper aquifer, than was replenished. Atypically, during this period subsurface flow at Madrona Pack Base Well had no impact at Pool A and minimal impact at the RC wells.

Insofar as this reach is also influenced by inflows from other tributaries in the upper watershed including Madrona Creek and upper Rincon Creeks, it should be kept in mind that Pool A and the Rincon Creek wells respond to inflows from all of these sources, while Madrona Pack Base well responds to precipitation and surface and subsurface water in the Chimenea Creek drainage alone.

Figure 4.9.2-26. shows groundwater levels for the July 2011 to June 2012 period, and Figure 4.9.2-27. shows groundwater levels for December 2011. These data show in more detail the nature of the hydrologic response to surface and subsurface water flowing in the Chimenea and Rincon Creek watersheds at points lower in the watershed.

Rincon Mountains Groundwater

The following paragraphs summarize key points of each of the unique Saguaro National Park Rincon Mountain District groundwater systems identified here as they pertain to indicators and determination of status:

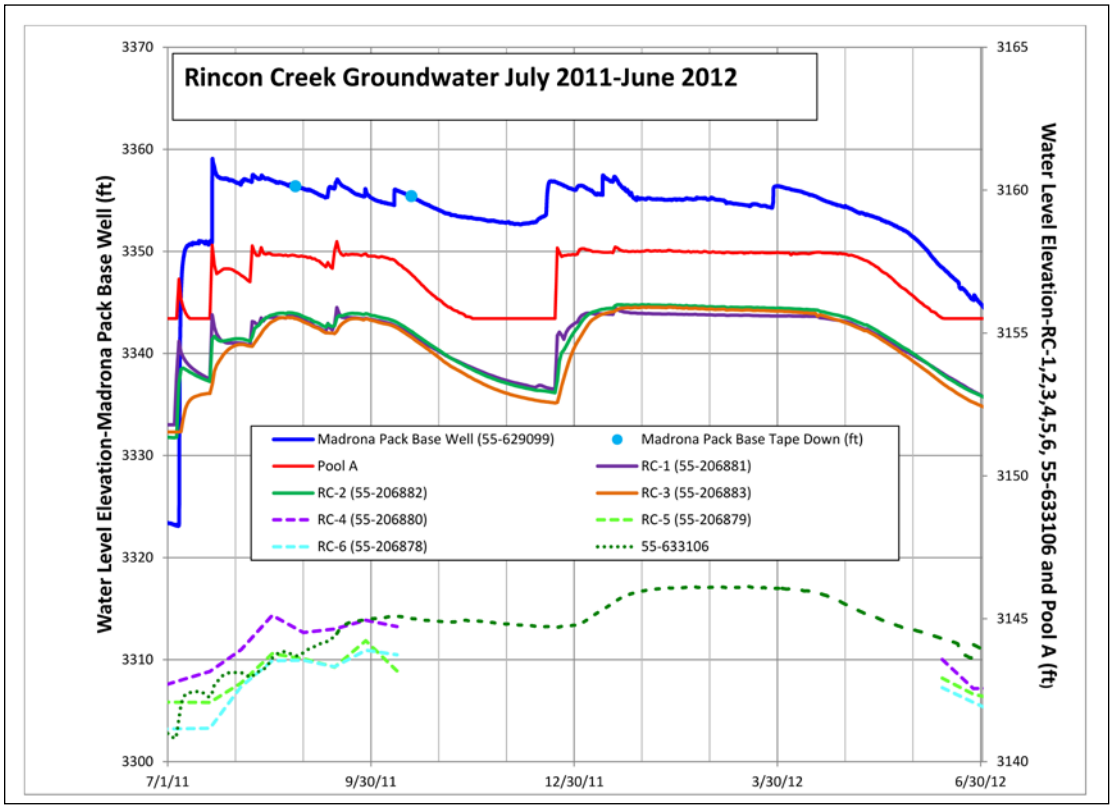


Figure 4.9.2-26. Water level elevations for the Madrona Pack Base well, Rincon Creek Pool A, and monitored wells south of Rincon Creek, 2011-2012.

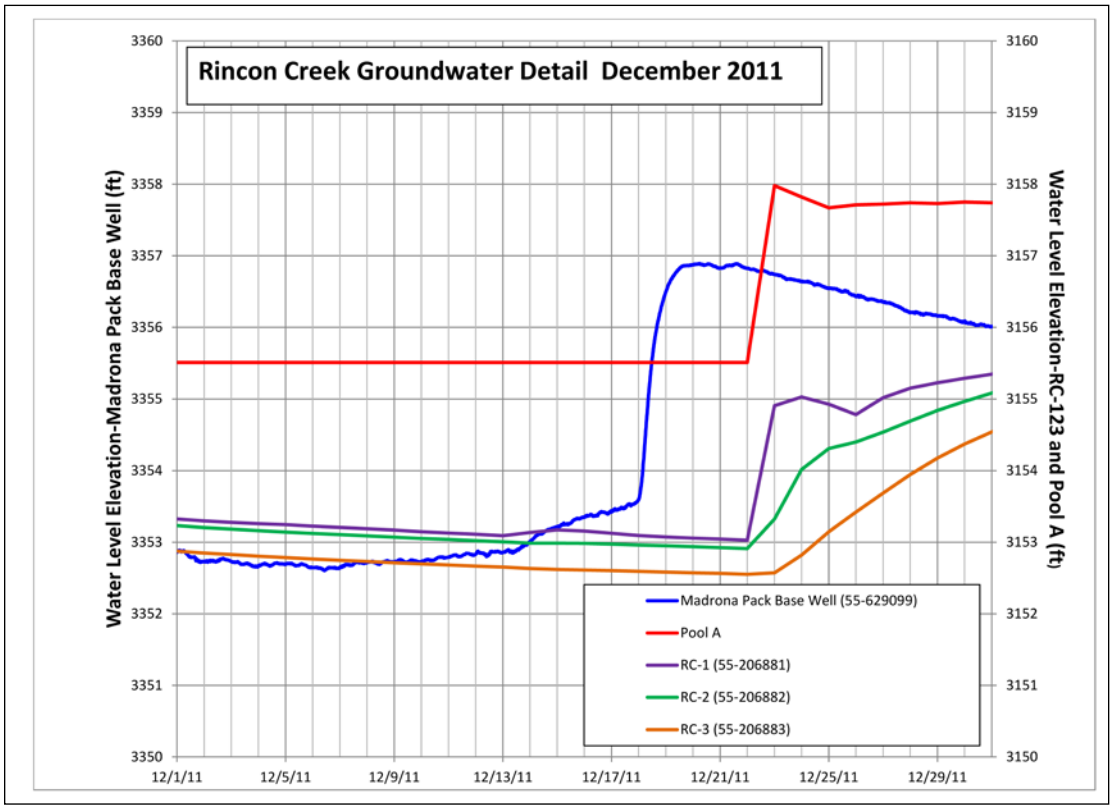


Figure 4.9.2-27. Water levels in Madrona Pack Base well, wells RC-1,2,3, and Pool A, December 2011.

Mountain-block groundwater hosted in regional-scale fractures

Groundwater in deep fractures is difficult to monitor directly. Conditions at private well 585628 (Figure 4.9.4-2, Table 4.9.4-2), located above the detachment fault, may be a useful observation site if that well was available for monitoring. This is the only indicator deemed potentially meaningful for this system at this time. The piezometric surface in this well was at 3,100 feet when it was constructed in 2001. Mountain-block regional-scale fractures are believed to be the primary source of detachment-fault related groundwater, and barring a new monitoring opportunity, detachment-fault groundwater is likely the most meaningful potentially available surrogate for water within the mountain-block regional-scale. Response time for fracture-hosted groundwater under climate change and/or landscape modification may (possibly centuries) or may not be very long.

Mountain-block groundwater hosted in local-scale fractured rocks, weathered-in-place rock and derived surficial sediments –source for high elevation springs

Rincon Mountain groundwater supplying high elevation springs is best monitored by observing the springs themselves. Very few measurements of rate of discharge from high-elevation springs exist in park records, but isotope data indicate a relatively short travel time (months to decades) between precipitation (as rain or snow) and emergence in springs. Storage in these systems is believed to be relatively small, and relatively rapid response to changes in the water balance is expected, on the order of months to a few years in most cases. In addition to the variability that may occur as a result of annual and seasonal weather patterns and differences in measurement methods, some of the spring sites were maintained in the past, imparting an additional uncertainty in how much water was present relative to current unmaintained conditions. Watershed-scale changes in vegetation and land surface cover as a result of fire or other processes will also play a part in these systems. A compilation of historical reports relating to springs in the Rincon Mountains is not available. Due to these issues, perennial presence of water sufficient to supply backcountry visitors and to sustain wildlife and aquatic vegetation is identified as the most useful indicator available for assessing historically perennial high elevation groundwater systems at this time.

Mountain-block groundwater hosted in drainage-scale shallow fractured rock, weathered-in-place rock and derived surficial sediments – source for low elevation springs, pools, tinajas, and intermittent streamflow in Rincon Creek

Groundwater in these systems originates at high and mid-elevations, moves through relatively quickly (days to decades), and response to changes in inflows or outflows is expected to be rapid, on the order of a few weeks to a couple of years. Loss of sediments and weathered rock materials in the drainages following scouring floods would significantly reduce storage, while gains in drainable sediments would increase storage capacity, providing additional buffer through dry periods. Indicators for drainage-scale groundwater systems are water presence, based on a 20-year history of water presence-absence at pools and tinajas across the park, with focus on those pools found to be perennial between 95 and 100 percent of the times visited for monitoring. Months per year of depth to water under 12 feet at Madrona Pack Base well is also identified as an indicator of this type of system in the Chimenea Creek drainage.

Detachment-fault related groundwater

Isotopes have shown that groundwater associated with the Catalina-Rincon detachment fault is thousands of years old. It is feasible but not proven that a continuous and unique groundwater system, separate from the basin aquifer and groundwater in upper plate rocks, is present along the trace of the detachment fault, with water flowing beneath the confining zone toward and discharging from Agua Caliente spring. Water quality results indicate that the detachment fault zone receives water from both the regional-scale fracture system in the mountain core and probably, at least locally, from mountain-front recharge. Threats to this system include climate change,

landscape-scale alteration, and groundwater pumping. Response to the first two of these would likely be delayed and gradual, but response to pumping could be rapid. At present, no opportunities for monitoring of this system other than private wells that are not readily accessible have been identified, although if the system is continuous along the fault zone, flow at Agua Caliente spring is a potential surrogate indicator. Publically available data from the 1960s through 2006 show a relatively consistent piezometric level in the Rincon Valley around 3,110 feet. The indicator selected is a piezometric level in Rincon Valley not less than 3,100 feet that is stable over the preceding 5 years, and continued flow at Agua Caliente spring.

Rincon Valley shallow groundwater including alluvial aquifer and Pantano formation

Water level measurements in monitoring wells constructed in the shallow aquifer of Rincon Valley show seasonal variability directly related to subflow in Chimenea Creek as monitored at Madrona Pack Base well. Well 55-633106 was chosen as the reference location due to its accessibility and depth, i.e., when water levels have declined below the bottom of the RC wells. Well 55-633106 appears to continue to reflect water level in the area. Data collected since 2005 show that well 55-633106 tracks closely with the RC wells when they contain water, and can be used as a surrogate for water levels around the middle reach of Rincon Creek. Due to the needs of riparian vegetation for access to subsurface water, and based on the observed relationships between water levels at well 55-633106 and the other RC wells, the indicator measures identified in Table 4.9.4-1 were chosen.

Shallow groundwater outside of Rincon Valley and inside the park boundary

Figure 4.9.1-5 shows and Table 4.9.2-4 lists wells at RMD. Except for well 55-633106 and the former water supply wells known as Baker #2 and Baker #3, the RMD wells are all relatively shallow. None of the wells listed in Table 4.9.2-4 are believed to intercept the detachment-fault groundwater system. Of these wells, the Unknown and Genemata wells have not been located, and it is uncertain if a feature located recently in Box Canyon is the 76-foot deep well identified in park records. Except for those located in Rincon Valley, the Greene #1 well and the newly found Kennedy-Creosote well, the other wells shown and listed have not been monitored for many years. Groundwater in these areas is generally not used by visitors, riparian vegetation or wildlife and has been a lower priority. Status of water resources in these areas is relatively unknown and there is no indicator condition.

4.9.3. Reference Conditions

As discussed in the preceding sections, systematic hydrologic monitoring combined with interpretation of geological conditions and isotope and water quality analyses provide a foundation for beginning to understand processes governing groundwater flow in the Rincon Mountains. The conceptual models proposed are consistent with currently available data. Although work remains, the conceptual models of local, regional and mixed groundwater flow pathways, deep and shallow mountain-block, valley and detachment-fault related groundwater systems are based on the evidence available to date and provide the basis for continuing discussion, planning additional investigations, and development of alternatives or refinements as additional information becomes available. Apart from wells in the Rincon Valley, groundwater in wells shown in Figure 4.9.1-5 has not been adequately investigated to allow assessment of condition at those locations at this time.

The conceptual models discussed above are key to assessing the susceptibility of groundwater resources to threats including changing climate, groundwater pumping, and wildfire. Water in storage within a groundwater system can provide a buffer that may temporarily mitigate the effect of depletion due to below-normal recharge or above-normal outflows. In systems such as springs and groundwater-fed tinajas, this would mean that surface flows may be sustained through periods of drought. The storage may then be replenished during wetter periods. The amount of dynamic storage and the rate of depletion of that storage will determine how long flow is able

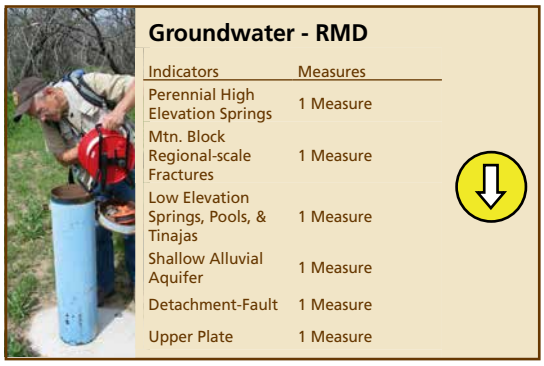
Table 4.9.3-1. Reference classes for assessing groundwater condition at Saguaro NP.

Condition Class	Description
Good	In the Sonoran Desert, a good reference condition consists of a water balance that sustains visitor uses and ecosystem integrity in keeping with established uses without threat of interruption or long-term declining trends in groundwater levels. Water level variability reflects a system in dynamic equilibrium, characterized by natural short-term variation in environmental inflows and outflows, but with sufficient reserves remaining in storage to sustain flow to springs, perennial pools and riparian aquifers through low water level cycles of normal magnitude and duration.
Moderate Concern	A moderate groundwater condition exists when natural groundwater levels are capable of meeting established visitor use and/or ecosystem needs but evidence of imbalance is present. For example: • Long-term declining trends in groundwater level are present. • Fluctuating water levels are regularly reaching lower levels than were previously observed, and/or flow to springs is decreasing over time. • Periods of low water levels or minimal to no spring flow are longer in duration than were previously observed. • Average groundwater levels or flows to springs are significantly lower than previously observed and are approaching a condition that is marginally sufficient to maintain established uses. In this scenario, prolonged drought or increased runoff, lack of snow, excessive or new groundwater withdrawals, or physical alteration of the surface environment such as loss of water-bearing soils and sediments by erosion, diversion of runoff by road entrenchment, or streambed channelization, interrupt the hydrologic processes supporting established uses. A moderate condition is indicated before marginal levels are reached when long-term (multi-year) declines in water levels occur regardless of the origin of the negative water balance.
Significant Concern	A condition of significant concern exists when groundwater supplies are marginally adequate, are intermittently inadequate, or are consistently inadequate to sustain established uses.

to be sustained during an extended period of negative water balance. When a given system has limited storage, decreased inflows will be reflected in decreased outflows more rapidly than for a system with a greater volume of water in storage.

Establishing reference conditions for the diverse groundwater systems present at RMD is complicated by the vastly different available information about and the varied effort required to monitor each. High elevation springs may be formally monitored once every few years, while shallow groundwater levels along Rincon Creek are recorded every 15 minutes. Groundwater percolating into the crystalline mountain core along regional-scale fractures is not monitored, and changes in this system may take decades to hundreds of years to be detected. In the case of the regionally extensive detachment-fault related groundwater system, Saguaro NP does not currently have access to monitor that resource, creating even more of a challenge.

General reference condition classes used for assessing groundwater condition at Saguaro NP's Rincon Mountain District are listed in Table 4.9.3-1.



4.9.4. Condition and Trend

Overall Condition and Trend

Table 4.9.4-1 summarizes a current assessment of indicators, measures, conditions and rationales for the various groundwater systems at RMD.

As discussed above, multiple unique groundwater systems are present within the

Table 4.9.4-1. Summary of the groundwater indicators, measures, and condition rationale.

Indicator of Condition	Measure	Condition	Rationale for Condition
Groundwater Supplying Perennial High Elevation Springs	Presence of perennial water sufficient to supply visitors, wildlife and aquatic plants	Moderate Concern	Climate change is resulting in increased temperatures and reduced snowpack and overall precipitation; Storage appears to be marginal; drying and low flow conditions are reported in 2016; Long-term monitoring is lacking. Trend is deteriorating and confidence level in the assessment is medium.
Mountain Block Fracture Groundwater	Piezometric level at well 585628 >3,100 feet	Moderate Concern	Threatened by climate change and reduced infiltration in case of wildfire; difficult to obtain data due to lack of access. Trend is unknown and confidence level in the assessment is low.
Groundwater Supplying Low Elevation Springs, Pools and Tinajas	All 29 of the perennial tinaja pools on the park's "best pools" list contain water every time they are monitored in June; Over a five-year period, the remaining 18 pools on the "best pools" list contain water at least 95% of the time when monitored in June; Depth to water at Madrona Pack Base well is <12 feet at least 8 months per year.	Moderate Concern	Climate change and potential for wildfire-related watershed effects are a concern; Storage appears to be marginal; long-term presence-absence monitoring provides strong basis for assessment; Madrona Pack Base well provides indicator in one drainage. Trend is stable and confidence level in the assessment is high.
Shallow Groundwater in Rincon Valley and Pantano Formation	Depth to water at well 55-633106 <8 feet >3 months/year and depth to water at well 55-633106 <10 feet >6 months/year	Moderate Concern	Climate change, private groundwater pumping and potential for additional pumping from shallow aquifer are concerns; Water presence is intermittent; storage is negligible; Well 55-633106 is accessible and tracks with other shallow wells. Trend is deteriorating and confidence level in the assessment is medium.
Detachment-Fault Related Groundwater	Water level elevation in Rincon Valley >3,100 ft	Significant Concern	Recent drying of Agua Caliente spring, threatened by climate change and pumping; declining trend 2002-2006; storage unknown; inability to monitor status since 2006. Trend is stable and confidence level in the assessment is low.
Upper-plate Groundwater	Depth to water similar to documented past conditions	Unknown	Except for Rincon Valley, most wells in the upper plate units have not been monitored recently, some are not located in the field, and status remains to be determined. Trend is unknown and confidence level in the assessment is low.

boundaries of Rincon Mountain District. Several of the systems extend well beyond the park boundaries. Condition of most of these was assessed as moderate, primarily on the basis of climate changes affecting all systems that have already begun to be manifested and are predicted to increase in severity in future decades. Monitoring of surface pools and tinajas across the park, initiated in 1996, combined with focused data collection in the riparian corridor of the Rincon Valley beginning in 2005, has proven to be essential to the understanding and assessment of the groundwater systems

related to those resources. Data relating to groundwater supplying high elevation springs are less robust and would benefit from more systematic data collection where possible, but reports of decreasing flow and dry conditions show that impacts of long-term drought are already occurring. In the cases where it is not practical to monitor, such as the deep fracture flow groundwater systems of the mountain block and the detachment fault aquifer, little can be done at this point to increase monitoring and improve understanding without the cooperation of landowners adjacent to the park. Trend and confidence levels for each of the groundwater systems at RMD are assessed to be:

- Groundwater supplying high elevation springs - trend = decreasing; confidence = medium
- Mountain block fracture groundwater – trend = unknown; confidence = low
- Groundwater supplying low elevation springs, pools, and tinajas – trend = stable; confidence = high
- Shallow groundwater in Rincon Valley – trend = decreasing; confidence = medium
- Detachment-fault related groundwater – trend = stable; confidence = low.
- Upper plate groundwater – trend = unknown; confidence = low.

Key Uncertainties/Threats

Key uncertainties associated with groundwater status at RMD are related to how future climate conditions will vary from those of the past and how these changes will affect overall hydrologic function of the park, including all of the interdependent elements of the water balance. The same is true for the threat of groundwater pumping, as it is uncertain if this will increase in future years, or how much. Uncertainties in the present are associated with lack of data about some of the systems as identified in previous sections, as well as uncertainty in the interactions between the systems and how changes in one will propagate through the other systems.

An important uncertainty related to the detachment-fault related groundwater system is whether or not water flows along the fault zone from recharge areas including the Rincon Valley toward discharge sites at Agua Caliente to the north. If this is occurring, pumping along the fault zone has the potential to affect the level of the piezometric surface in the Rincon Valley and into the groundwater fracture system of the Rincon Mountains along its length. Piezometric levels of groundwater within the penetrative fractures of the mountain block are unknown, and have been estimated to be near 3,100 ft on the basis of levels observed adjacent to park boundaries in the Rincon Valley. However, if water moves along the fault toward Agua Caliente, piezometric levels on the north side of the park are more likely to be lower, between 3,000 and 2,800 feet. This is important because it is more likely that pools occurring below these levels may be affected if water levels along the detachment fault decline as a result of pumping or reductions in recharge.

Three primary threats to groundwater resources at Saguaro NP RMD were identified, including climate change, groundwater pumping, and landscape-scale surface modification, especially by wildfire. The following paragraphs discuss each of these as it has potential to impact groundwater resources at the park.

Climate Change

Many publications have focused on the impacts of climate change on groundwater conditions (Brekke et al. 2009, Kumar 2012, Ajami et al. 2012, Meixner et al. 2016). The largest climate-change related declines in groundwater storage are anticipated for the southwestern United States (Meixner et al. 2016). Decreases in groundwater resources are projected as a direct result of long-term drought, reduced summer precipitation, increased evapotranspiration due to rising temperatures, and reductions in the duration of seasonal infiltration due to reduced snowpack and storms of greater intensity (Brekke et al. 2009, Kumar 2012). Indirect effects of drier conditions include landscape-level impacts such as altered wildfire conditions and changes in vegetation cover and soils (Dennison 2014). Isotope studies at RMD have shown that groundwater

recharge to high-elevation springs was linked to both summer and winter precipitation (Eastoe 2012). Recharge to the shallow alluvial aquifer in the Rincon Valley was associated with winter precipitation), and recharge to lower elevation springs and tinajas was associated with summer precipitation (Eastoe 2012). With the exception of Douglas Camp, the Grotto and Loma Verde Pools 3 and 3a seep, isotopes show that each of these systems is recharged by and contains water of recent age with a high probability of originating as precipitation within a time period of one tritium half-life of 12.43 years. Reduced water availability at pools and springs recharged at least in part by older water may be less noticeable in the near term, but all groundwater systems will eventually be impacted under projected changes in climate for Arizona. Figure 4.9.4-1 illustrates the primary mechanisms that are expected to increasingly impact recharge and storage in groundwater resources into the future (from Meixner et al. 2016). Measurable changes in water resources associated with changing climate are ongoing and will continue to evolve (it's likely that precipitation in the form of snow will decrease; see photos in Figure 4.9.4-2).

Groundwater pumping

A key concept to assessing potential impact of groundwater pumping on surface water is that of hydraulic connectivity. When a water

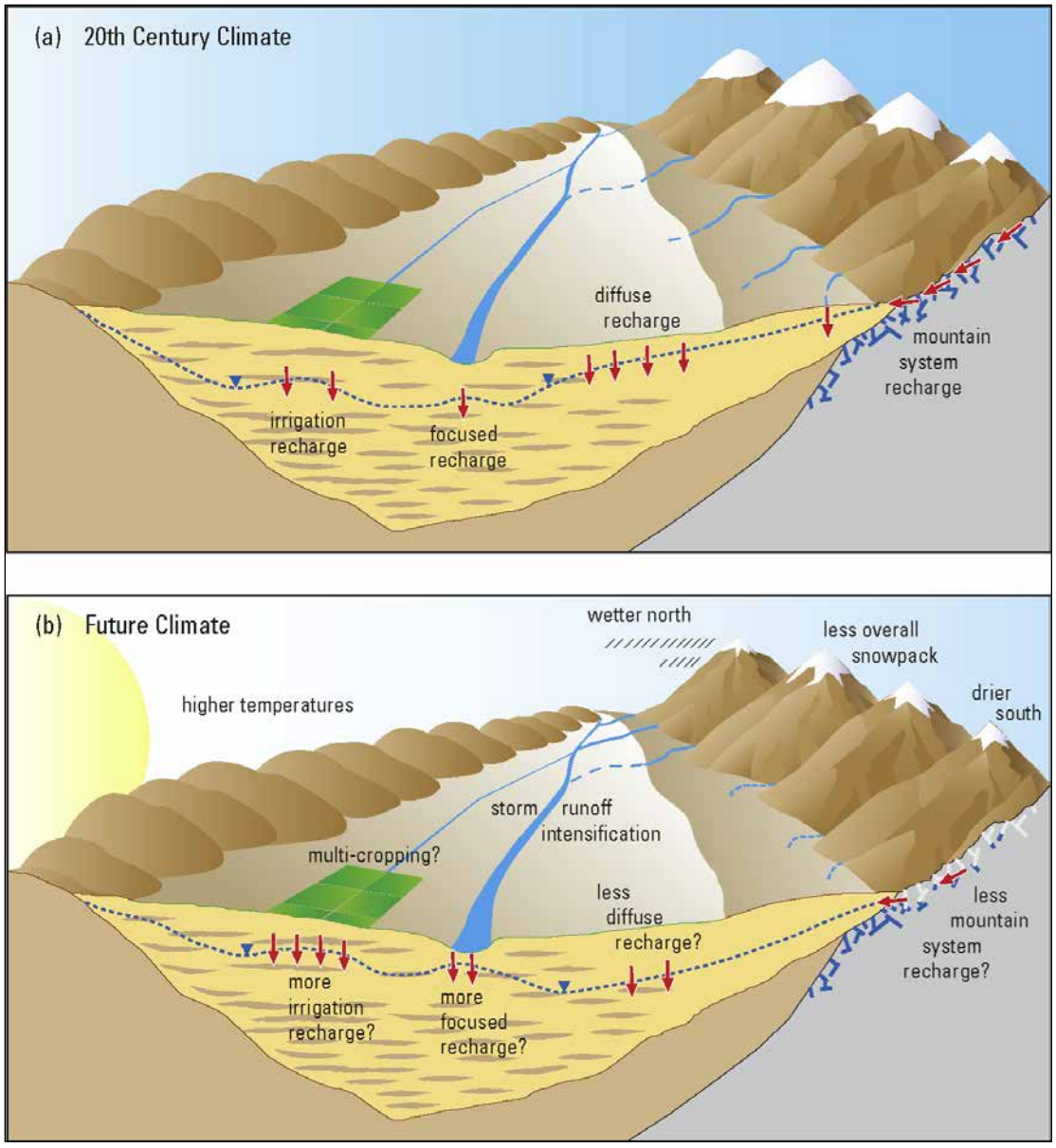


Figure 4.9.4-1. Conceptual illustration of four different recharge mechanisms under 20th Century climate (top) and future climate (bottom) (from Meixner et al. 2016).

Figure 4.9.4-2. Snow in the Rincon Mountain District.

body on the surface is in direct contact with the water table, the two are hydraulically connected, and changes in groundwater level will affect the rate of water exchange between them. In cases where a surface water body is not in direct contact with the groundwater system, the rate of seepage is independent of groundwater levels and depends only on the depth of water in the surface water body and the permeability of the substrate (Bear 1979). Another key concept is that of an aquifer. An aquifer is defined as a saturated geologic formation or group of contiguous formations that contain water and can transmit significant amounts of water under ordinary field conditions (Bear 1979, Freeze and Cherry 1979). It is not established if the groundwater associated with regional-scale fractures within the Rincon Mountains, believed to be subsequently impounded by the Catalina-Rincon detachment fault, comprise a connected groundwater system. It is unknown how contiguous the detachment-fault groundwater may be along the miles of fault trace, and it is possible, but unproven if, the detachment-fault related groundwater may flow from zones of recharge along the fault to low-discharge point at Agua Caliente spring. It is established that a number of wells in the vicinity of the fault pump significant amounts of detachment-fault related groundwater. The terms aquifer, groundwater system and water-bearing zone are used interchangeably here with recognition that there is uncertainty in which is the most applicable terminology.

All groundwater pumping in the RMD area occurs on private lands surrounding the park. Possible impacts of groundwater pumping in the Rincon Valley to flow in Rincon Creek, the shallow alluvial aquifer, or to pools and springs above the detachment fault are a concern of park staff (D. Swann, personal communication). High-elevation springs show no evidence of hydraulic connection to groundwater resources around the base of the Rincon Mountains and are not threatened by pumping. Potential threats to riparian ecosystem-supporting groundwater resources at RMD are associated with pumping from the shallow aquifer system consisting of alluvial sediments and Pantano Formation bedrock, located in the Rincon Valley. Possible impacts of detachment-fault related groundwater pumping to low elevation springs and perennial pools are less well characterized, but as discussed below, if any exist, are believed to be limited to water bodies at elevations below 3,110 feet.

Rincon Valley Shallow Groundwater

In 2007, investigators reported that no groundwater withdrawals from the shallow alluvial aquifer in the Rincon Valley had been identified. At that time, outflows from the shallow alluvial aquifer were identified as 1) seepage to the creek and its pools; 2) evapotranspiration; 3) subflow; and 4) downward leakage to the deep bedrock aquifer (NPS 2008). However, the Rincon Water Company (RWC) holds an assured water supply certificate authorizing the company to pump over 600 acre-feet of water per year from wells in the Rincon Valley. Documents developed by RWC hydrogeology consultants and concurred with by the State of Arizona make the case for 135 acre-feet of water per year available for consumption

from the deep aquifer in Rincon Valley. The consultants subsequently petitioned for, and were awarded, authority to pump up to 60 4.98 acre-feet per year on the basis of 470 acre-feet per year of "renewable" water deemed available in the upper aquifer, including the shallow alluvium and the top 75 feet of the "permeable" conglomerate (Manera 1983). Any significant rate of pumping from the upper aquifer by RWC has the potential to dry Rincon Creek year-round along with the shallow alluvial aquifer that supports the riparian habitat along the creek. This is a significant threat to valued park resources.

Detachment-Fault Groundwater

The Catalina-Rincon detachment fault is believed to act as a barrier to flow around the western base of the Rincon Mountains except where it is breached at the Agua Caliente and La Cebadilla springs (Olson 1982, Gu 2005, Love et al. 2014). Low-permeability features along the fault prevent the loss of groundwater on the footwall (park) side due to dewatering occurring in the greater Tucson basin aquifer. Piezometric levels below the fault, which is inclined 15-30° southwest from the Rincon and Catalina Mountains, were around 3,110 feet in the Rincon Valley in 2006 and appear to decrease in elevation to the north, toward Agua Caliente spring, which discharges at an elevation of about 2,760 feet. It is possible but not established whether flow occurs along the fault zone from areas of high piezometric level (Rincon Valley) toward areas of low piezometric level (Agua Caliente spring), although a limited number of water levels in the system suggest that this is a possibility.

Pumping from detachment-fault related groundwater can lower groundwater levels (where unconfined) or the piezometric surface (where confined) on the footwall (mountain) side of the detachment fault, as was observed at Agua Caliente spring in recent years. Surface flow of warm artesian detachment-fault related groundwater at Agua Caliente spring ceased, reportedly as a result of nearby groundwater pumping and long-term drought (Kreutz 2016). Flow at the spring has since returned, but this event serves to underscore the relationship between drought and pumping from detachment-fault related groundwater, and spring flow in the area, and to disavow any impression of an unlimited water supply from that source. Piezometric levels in the Rincon Valley deep groundwater system appear to be near those measured in the 1960s (Table 4.9.4-2), but measurements at both wells 537373 and 564266 between 2002 and 2006 show a steady decline of about 1.7 feet per year (NPS). If the groundwater system along the fault is contiguous, pumping from distant areas has the potential to lower piezometric levels upgradient, although this could take decades or longer to be observed. At the present time, there are no known established monitoring wells anywhere along the detachment-fault.

Only a very limited sampling of water quality or isotopes is available for wells in the Rincon Valley adjacent to the park. Water-quality analyses for RWC-8 (607531; Figure 4.9.4-3; Manera 1982), shown in Figures 4.9.2-10 - 14 and Figure 4.9.2-16, show that water samples from this well, located in the Rincon Creek floodplain between the confluence of the main creek with Madrona Creek and Chimenea Creek, possessed water quality characteristics more similar to those of water sampled at Madrona Pack Base well and some of the samples from Chimenea Creek and Rincon Creek than those of the detachment-fault related water reported for RWC-1 (Figures 4.9.2-10 - 14 and Figure 4.9.2-17). These similarities suggest that recharge to the water bearing zone encountered at a depth of 340 feet at RWC-8 likely occurs primarily along the mountain front, in contrast to RWC-1, which appears to be primarily recharged by high-elevation infiltration to fractures penetrating the crystalline mountain core. Driller's records clearly indicate that when RWC-8 and RWC-1 were drilled, water levels rose to within 64 and 75-feet of ground surface respectively (Table 4.9.4-2). In each case drilling was ended when a 4-foot free-fall of the drill stem occurred and the water-bearing zone was encountered, i.e., the water source to both wells is at least partially confined in an open cavity or zone. It is easily conceivable that some portion of the water flowing in the subsurface of Chimenea Creek (and likely Madrona and other drainages) flows into the deeper water-bearing zone. If this is the case,

Table 4.9.4-2. Construction data and piezometric levels for selected privately owned wells along Chimenea and Rincon Creeks, from ADWR well registration records and Manera (1982).

Well ID ADWR Wells 55 # TRS location	Elevation* (ft)	Month Completed	Total Depth (ft bgs)	Static Depth to Water when constructed (ft)	Piezometric Level/Water Table (ft)	Inferred Water Source
585628 D(15-17)09ABB	3,321	May 2001	605	211	3,110	Detachment-fault related
540626 D(15-17)09ADB	3,282	November 1993	595	350 (first water 540)	2,932	inconclusive
585559 D(15-17)09DAC	3,254	May 2001	520	47 (drawdown 338 ft @7 gpm)	3,207	Pantano Formation
537373 D(15-17)16ACA	3,185	September 1993	255	65 (first water at 230)	3,120 (~3,104 April 2006)	Detachment-fault related
564266 D(15-17)16BAD	3,181	February 1998	440	67 (first water at 200; 10x increase at 439)	3,114 (~3,104 April 2006)	Detachment-fault related
633106 D(15-17)17ADC	3,155	July 1964	455	14 (produces 3 gpm)	3,141 (unconfined)	Pantano Formation
607532 D(15-17)16ACD	3,186	March 1962	286	75 (deep water zone encountered at 265 ft)	3,111 (3,120 in 1971)	Detachment-fault related
607531 D(15-17)16ADC	3,190	Summer 1968	335+	64 (deep water zone encountered at 340 ft)	3,126	Detachment-fault related
607533 D(15-17)10CAA	3,240	May 1982	120	33.5	3,206	Abrigo Limestone

* Elevations are based on estimated well location, actual location is uncertain.

a key question is whether or not declines in piezometric levels in the deep aquifer will result in increased capture of surface or subsurface water flowing in those drainages.

A limited sampling of tritium isotopes in wells around the park identified submodern, detachment-fault related water in the Rincon Valley, north of the park boundary (Figure 4.9.2-9; Eastoe 2012). The sampled well in Rincon Valley and the sampled well to the north are located within the Tucson Active Management Area and are registered as non-exempt, allowing pumping of substantially larger water volumes than exempt domestic wells. RMD and most of the area west of the park are served by the City of Tucson water department, Tucson Water (City of Tucson 2015). The Rincon Valley and areas west of there are served by small independent water systems, including Rincon Water Company, Rincon Creek Water Company, Spanish Trail Water Company and Saguaro Water Company. These service areas and the area around Tanque Verde Guest Ranch to the north are not served by the City of Tucson. Other wells around the park boundary not sampled for the isotope study may be pumping detachment-fault related water, but locations and rates/volumes of pumping are

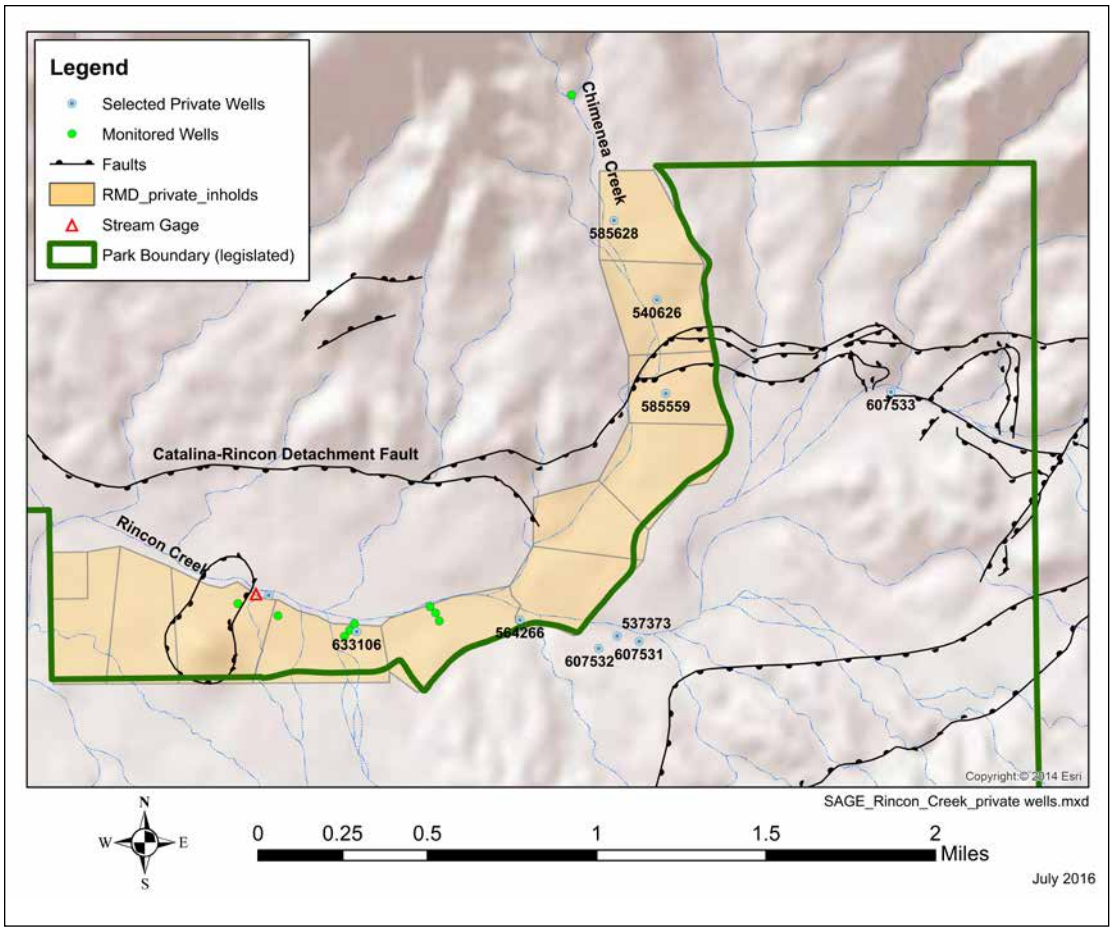


Figure 4.9.4-3. Map of the Rincon Valley showing faults, wells monitored by NPS, private inholdings and selected private well locations.

unknown. Declines in the elevation of the piezometric surface of the detachment-fault related water bearing zone have the potential to affect hydraulically connected springs and tinajas, which may include one or more pools in the Loma Verde drainage, the Grotto and possibly Douglas Camp, all of which were shown to contain some portion of submodern (pre-1953) age water. Further testing of fresh groundwater inflow after emptying tinajas, as was done for the Loma Verde 3 seep in 2016, could reveal that additional lower elevation water springs and tinajas are connected with fracture-hosted/detachment-fault related water. In 2017-2018, the park is planning to test additional tinajas, including in Wildhorse Canyon, where no data are currently available. No established monitor wells tracking the piezometric surface in the detachment-fault groundwater near the park were located.

On the basis of water quality and isotope results discussed in the preceding sections, the tinajas for which data are available in Chimenea and Madrona drainages do not appear to receive any substantial contribution from water with detachment-fault related characteristics. Taken as a group, water from these drainages was of recent age, originated in mid-to high-elevation range, was low in sulfate, fluoride and TDS. Only pool Madrona-1K had a tritium isotope result that suggested a possible mixing of recent waters with pre-bomb water, and there are no water quality data from Pool-1K at this point to examine this possibility further. Water from the Grotto was of pre-1953 age, similar to detachment-fault related water and was recharged in the mid- to high-elevation range, but was very similar in all water quality parameters to high-elevation springs otherwise. Water from Rincon North Pool 10 was shown by isotopes to include a significant component of water dating to 1960 to 1970 time frame (Eastoe 2012). The sulfur and oxygen isotope analysis of Rincon North Pool 10 indicates that the origin of sulfate in the Rincon North Pool 10 water was most likely the Pantano formation, not from pyrite oxidation as is the case for detachment-fault related

waters ($\delta^{34}S(SO_4)$ = 12.1%; $\delta^{18}O(SO_4)$ = 10.3%; Eastoe 2012; Gu 2005). On the basis of these limited results, the probability of recharge of mountain-block fracture groundwater to those springs and pools is believed to be low. However there is uncertainty, since data from the pools in these drainages is limited, no single pool has a complete suite of isotope and water quality analyses, and the characteristics of a deep water table or piezometric surface, if any exists within the Rincon Mountains, is unknown.

Groundwater pumping at wells completed in deep water-bearing (detachment-related) fractures or fracture system will affect the piezometric level (hydraulic head) in hydraulically connected features in the central Rincon Valley. The magnitude of decline in the hydraulic head around the well(s) depends on the rate and duration of pumping and physical and hydraulic characteristics of the surrounding formations. Testing at RWC-1 in the 1960s showed declines on the order of only 9 feet when pumping over 1,000 gallons per minute for 29 days (Manera 1968). No hydrologic boundary effects were observed during that test, indicating a large reservoir extent (Manera 1984). Annual reported groundwater pumping from RWC-1 is listed in Table 4.9.4-3. The table shows that average annual pumping at that well was 23.3 acre-feet per year from 2000 to 2010, and 29.1 acre-feet per year from 2012 to 2014, an increase of about 20%. How this volume of pumping compares to annual groundwater recharge is unknown, and the absence of monitoring wells in the deep water bearing zone(s) precludes further understanding of the effect this pumping, in combination with that of private wells in the valley, may be having on the capture of hydraulically connected waters within the mountain block.

Studies in the middle reach of Rincon Creek have shown that between 2002 and 2006, piezometric head in wells completed in detachment-related groundwater of the middle reach (537373 and 564266) declined from around 3,110 to near 3,104 feet above mean sea level (amsl). Rincon Creek itself is between 3,140 and 3,170 feet amsl in the middle reach (NPS 2010), and Madrona

Table 4.9.4-3. Annual reported pumping volumes at RWC-1; ADWR 55-607532 (Arizona Corporation Commission Utilities Division Annual Reports).

Year	Annual Total Pumped (acre-feet)
1984	1253.11
1985	9.13
1986	14.52
1987	17.34
1988	21.03
1989	24.66
1990	27.06
1991	32.28
1992	29.73
1993	22.09
1994	31.60
1995	28.15
1996	33.84
1997	23.48
1998	25.92
1999	
2000	18.96
2001	33.42
2002	20.86
2003	14.58
2004	16.55
2005	2 4.97
2006	23.08
2007	24.20
2008	25.11
2009	25.14
2010	29.57
2011	
2012	29.24
2013	27.05
2014	31.01

Pack Base well and the Chimenea Pools are all above 3,400 feet amsl. Chimenea Creek crosses the detachment fault at elevations between 3,251 feet and 3,236 feet (J. Conver Sagauro NP, pers. comm., Richard et al. 2005). Three private wells constructed

along the Chimenea drainage provide insight to groundwater conditions in this reach. Table 4.9.4-2 summarizes key data about these wells and a selection of other privately owned wells in the Rincon Creek watershed. The private well nearest to the south boundary of the park along Chimenea Creek is well 585628 (Figure 4.9.4-3). As (Figure 4.9.4-3) shows, this well is located on the footwall side of the Catalina-Rincon detachment fault. Piezometric level at well 585628 when constructed in 2001 was 3,110 feet (Table 4.9.4-2). Well 540626 is located a short distance to the south, also in the footwall, as shown in (Figure 4.9.4-3). Piezometric level at this well was 2,932 feet when the well was constructed in 1993. The next well south along Chimenea Creek, well 585559, had a water level of 3,207 feet when constructed the same month as well 585628. Records indicate that well 585559 has a low specific capacity, with a drawdown of 338 feet when pumping at 7 gallons per minute, suggesting that this well did not penetrate deep water-bearing features and is completed in the upper-plate rocks of the Pantano formation. This is most similar to conditions encountered at well 633106 (Manera Well #2; 55-633106; (Figure 4.9.4-3)) by the McDaniel Drilling Company in 1964 (Manera 1982). Pumping-drawdown data for the other two private wells along Chimenea Creek are not available. During construction of well 540626, water was encountered at a depth of 540 feet and subsequently rose to a depth of 350 feet, indicating confined conditions and a piezometric level about 180 feet lower than the 3,110 foot level observed in RWC-1, RWC-8 and well 585628. The little available information from these three wells when combined with data from the drilling of wells in the central Rincon Valley discussed earlier indicates the presence of fracture-controlled confined conditions with a piezometric level around 3,110 feet within the mountain block proper. The mountain-block groundwater (at ~3,110 feet) appears to be contained by an impermeable or extremely low permeability fault-gouge zone present in the plane of the Catalina-Rincon detachment fault. The fact that the piezometric surface in Rincon Valley in 2006 is substantially similar to that observed in the 1960s reflects a balance between inflows to and outflows from deep Rincon Valley groundwater features. Inflows consist of mountain front recharge and any seepage that may be occurring from the surface to the deeper aquifer, although this is believed to be negligible due to the presence of confined conditions in the deep zone. Outflows consist of groundwater pumping by private wells, some of which is reflected in Table 4.9.4-3, and any outflow occurring through along/beneath the fault zone itself. Outflow along the fault zone toward Agua Caliente is deemed possible on the basis of a limited number of piezometric water levels at wells completed in detachment-fault related groundwater along the perimeter of RMD. These levels show a monotonic decrease in piezometric level between a high in the Rincon Valley to a low at Agua Caliente. However, this conceptual model must be considered to be only speculative at this point.

The evidence suggests that water flowing in Chimenea Creek and other drainages along the mountain-front contributes to recharge of detachment-related groundwater in the central part of Rincon Valley. However, water quality analyses indicate that infiltration to the crystalline mountain core regional groundwater system is the primary source of inflow to the detachment-related groundwater system in this area. Elevation of the piezometric surface just south of the park along Chimenea Creek was about 3,110 feet in 2001, very similar to that observed in the central Rincon Valley in the 1960s and as recently as 2006. These data and the elevations of drainages within the park point to a conceptual model in which mountain-front recharge increases storage in the deep water-bearing zone, but the void space of the flow path is not filled to the surface at the inflow zone, i.e. there is no hydraulic connection. Under these conditions, changes in the level of the piezometric surface in the central Rincon Valley will not affect the rate of inflow. While recharge implies continuous pathways between these points, these conditions do not constitute connectivity in a hydraulic sense between the recharge areas at the surface and the confined, detachment-fault related water-bearing zone in the central Rincon Valley. Under those conditions, declines in

piezometric level in the deep water-bearing zone would not result in changes in the rate of downward seepage. This same conceptual model applies to any springs, pools or tinajas occurring at elevations above the piezometric level of about 3,110 feet in the Rincon Valley, and possibly lower for water bodies on the west side of the park including Loma Verde and Wildhorse canyons.

Landscape-scale modification-wildfire/ erosion/sedimentation/vegetation changes

Researchers have documented increasing trends for large fires or total fire area per year particularly in southern and mountain ecoregions of the western U.S. (Dennison 2014). The effects of fire, including both prescribed and wildfire, on ecosystems, soils, and hydrologic processes have been widely studied (Robichaud et al. 2000, Shakesby and Doer 2005, Parker 2006, Neary et al. 2008; Moody et al. 2013). The common observation of these studies has been that aside from the obvious effects on vegetation, fire effects on watershed properties that govern hydrologic processes, including infiltration to groundwater, are highly significant. It is also widely accepted that the degree of burn severity exerts a high level of control over the magnitude of change that occurs in hydrologic properties and subsequent watershed response to precipitation as a result of a fire (Moody et al. 2016).

Fire is a very central component of ecosystem function and evolution. Under natural conditions, low frequency, moderate frequency and high frequency fire regimes develop interdependently with vegetation and climatic variables, and ecosystem resiliency evolves. In southeastern Arizona, including at RMD, the rapid spread of invasive buffelgrass has increased the frequency and ecosystem mortality of wildfire in desert landscapes not adapted to wildfire. Buffelgrass-fueled low-elevation wildfires have been identified as a severe threat to the long-term survival of the Sonoran desert ecosystem, including the saguaro cactus. In mid- and high-elevation ecosystems, increased fuel loads during the era of suppression (1900-1970; Hunter et al. 2014) have been reduced in places since the 1970s by prescribed and/or managed fires particularly in the area around Mica Mountain (Figure 4.9.4-4). As Figure 4.9.4-4 also shows, based on a fire-return interval of 10 years, mid- and high-elevation vegetation on the slopes of Rincon Peak have not burned in more than three fire-return intervals. Hunter et al. (2014) indicate that the Rincon Peak slopes have not burned in over a century, and prescribed fire has not been utilized there due to the complexities of managing fire in wilderness on steep slopes with high fuel loads and limited access, adjacent to private property and overlooking habitat for sensitive resources including spotted owl and lowland leopard frog. These conditions are the basis for significant concern for all natural resources in the affected watersheds, including groundwater. Without intervention, wildfire in the dark orange or red areas shown on Figure 4.9.4-4 will eventually occur. When this happens, runoff from burned areas will increase by orders of magnitude for some period of time and infiltration will be decreased in proportion to loss of vegetation and erosion of degraded soils. How this will ultimately impact groundwater flow to high elevation springs, low elevation springs, pools and tinajas, and deeper groundwater resources is unknown, but the water balance dictates that increased runoff translates directly into decreased infiltration and reduced groundwater resources.

4.9.5. Sources of Expertise

The groundwater assessment for Saguaro National Park was developed by Colleen Filippone, NPS Intermountain Region hydrologist and groundwater protocol lead for the Sonoran Desert Inventory and Monitoring Network. The assessment would not be possible without major contributions by Don Swann, park biologist, and Chuck Perger, dedicated volunteer scientist, NPS Water Resources Division Water Rights Branch staff, University of Arizona researchers, USGS researchers and numerous NPS volunteers and interns through the years. The information contained in the report is derived from personal experience at the park, discussions with park staff, and from supporting information in the cited literature. Special thanks to Josh Conver, Saguaro National Park GIS/Biological Research

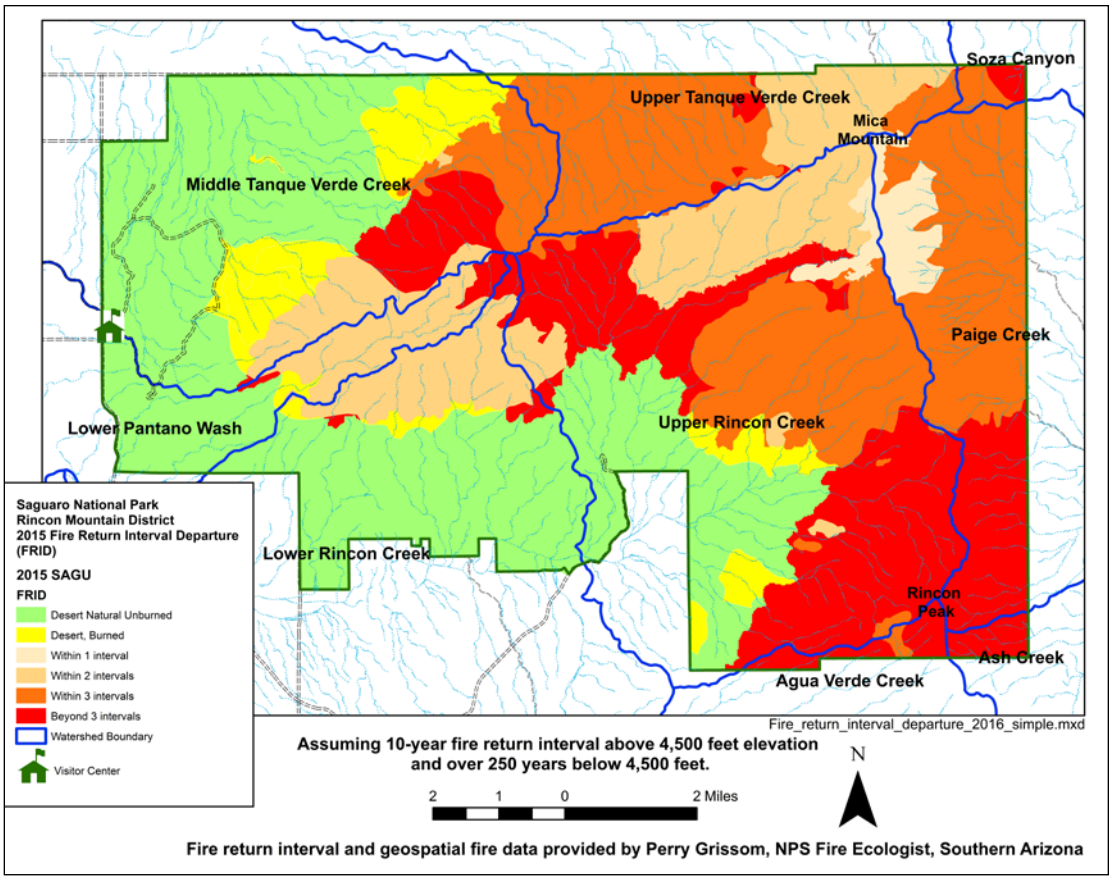


Figure 4.9.4-4. Map of Saguaro National Park with 2015 fire return interval departures for 10-year fire return interval above 4,500 feet and 250-year fire return interval departure below 4,500 feet (all data from P. Grissom, NPS Fire Ecologist, Southern Arizona).

Technician for his support with geospatial mapping data collection, and to Perry Grissom for his generous sharing of geospatial data relating to fire return intervals at RMD, and to Chuck Perger, Chris Eastoe, Steven Rice and Jennifer Back for their thoughtful reviews of the groundwater chapters.

Ms. Filippone holds a Masters of Science degree in Hydrology and Water Resources from the University of Arizona in Tucson. Her areas of expertise include groundwater hydrology, water quality and unsaturated zone hydrology.

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4.10. Biodiversity

Indicators/Measures

- Species Richness (3 Measures)
- Non-native Species (4 Measures)
- Extirpated Species (4 Measures)
- Threatened and Endangered Species (3 Measures)

Condition – Trend – Confidence

Good - Deteriorating - Low

4.10.1. Background and Importance

Arizona is one of the most biologically diverse areas in North America. According to The Nature Conservancy's States of the Union Report, Arizona ranks as the third most biodiverse state in the U.S., with more than 4,700 species of plant, bird, mammal, fish, reptile, and amphibian (Stein 2002). Of these, 135 species are endemic – plants and animals found nowhere else in the world (Stein 2002). Only California and Texas rank higher in terms of species richness. However Arizona, which is 43% the size of Texas, is 71% as diverse, and is equally as diverse as California when considering its smaller size (source of statistics: Stein 2002). High levels of overall biodiversity are attributed to the great variation in topography, climate zones, geology, and soil types found throughout the state.

Saguaro National Park (NP), located in southeastern Arizona, lies at the boundary of two distinct and diverse ecoregions: the Sonoran Desert ecoregion and the Madrean Sky Islands ecoregion (also known as the Madrean Archipelago). The boundary between these two areas has given rise to ecosystems that occur nowhere else in America and as a result, Saguaro NP ranks as one of the most biologically diverse parks in the U.S. (NPS 2014a) (Figure 4.10-1-2). Saguaro NP is divided into two districts separated by the city of Tucson, AZ: the Tucson Mountain District (TMD), west of Tucson, and the larger Rincon Mountain District (RMD), east of Tucson. The RMD lies within the Madrean Sky Islands region at the northern end of a biodiversity hotspot known as the Madrean Pine-Oak Woodlands (CEPF 2016). The pine-oak woodland habitat type for which

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Figure 4.10.1-1. Saguaro NP supports a variety of vegetation communities as shown clockwise from upper left: pine forest, Sonoran Desert, pinyon-juniper woodland, and riparian.

the hotspot is named is the key component of the Madrean Archipelago, consisting of about 40 mountain ranges stretching from the Sierra Madre Occidental in Sonora, Mexico to the Mogollon Rim in Central Arizona, with vast areas of desert and grasslands between them (Figure 4.10.1-2). Hotspots are regions that capture a disproportionate amount of biodiversity for their area, and the Madrean Archipelago supports remarkable species richness with 5,300 plant species, more than 300 mammal species, more than 500 species of bird, and nearly 600 species of reptile and amphibian (CEPF 2016).

In addition to the Madrean Sky Islands region, Saguaro NP protects a prime example of the Sonoran Desert ecosystem with exceptional stands of saguaro cactus (*Carnegiea gigantea*) and uniquely Sonoran Desert species, including Bailey's pocket mouse (*Chaetodipus baileyi*) and Gila Woodpecker (*Melanerpes uropygialis*). The Sonoran Desert is home to more than 2,000 species of plants, at least 60 species of mammals, more than 350 bird species, 20 amphibians, some 100 reptiles, and about 30 species of native fish (NPS-SODN 2014). Because of this high diversity, the Sonoran Desert is thought to have the greatest species richness of any desert in North America (NPS-SODN 2014).

The National Park Service (NPS) Organic Act (1916) states that the purpose of the NPS is to conserve the "natural and historic objects and the wild life" in national parks and "to provide for the enjoyment of the same in such manner and by such means as will leave them unimpaired for the enjoyment of future generations" (NPS 2016). Although biodiversity did not exist as an ecological concept in 1916, implicit in the Act is that all natural resources and wildlife are protected in parks. The NPS has recognized this concept in recent years through several high profile initiatives to quantify biodiversity in the nation's parks. These include All Taxa Biological Inventories in Great Smoky Mountains NP (Steury 2014), the NPS Inventory and Monitoring Program (Monahan and Gallo 2014), and ten BioBlitz events organized by the National

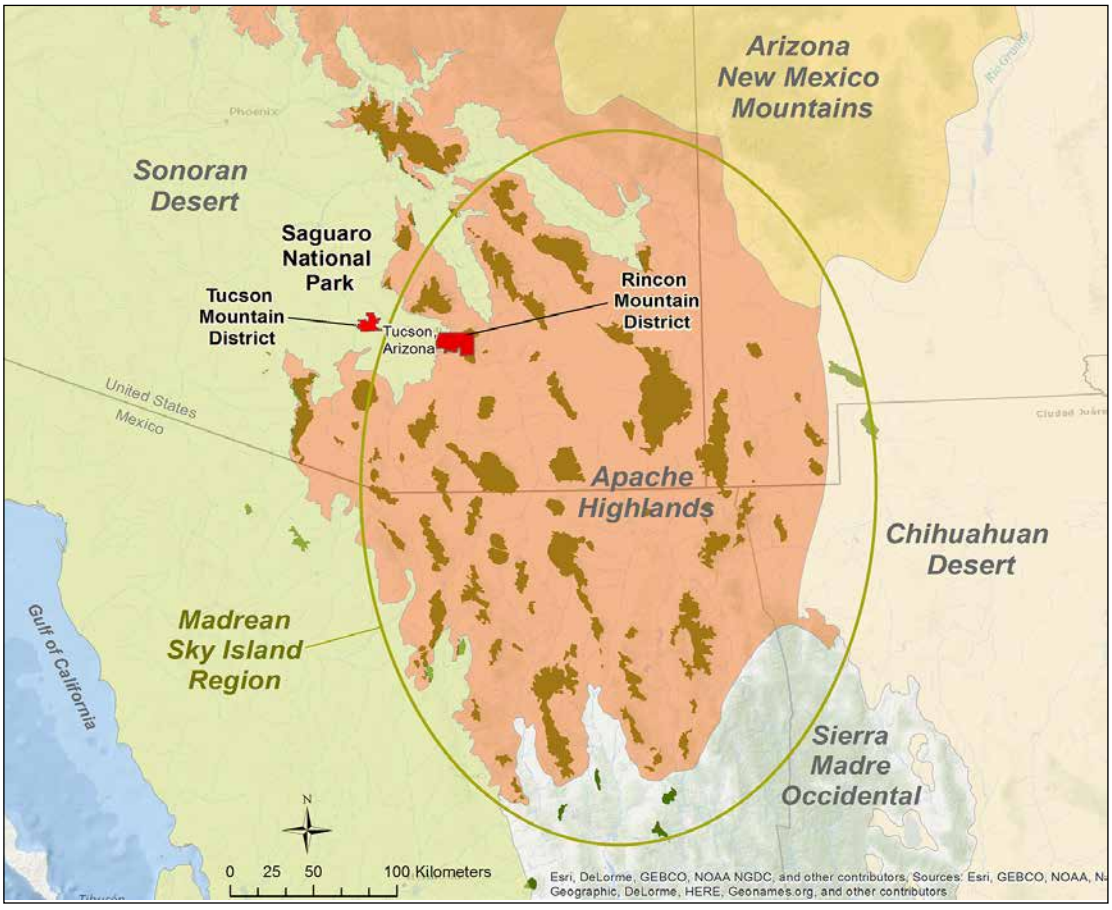

Figure 4.10.1-2. The Madrean Archipelago consists of about 40 isolated mountain ranges with vast stretches of desert and grasslands between them. Sky islands data were provided by Saguaro NP.

Geographic Society in cooperation with the NPS in celebration of the 2016 centennial anniversary of the park service (Budde and Kingston 2014).

In 2011, Saguaro NP hosted a BioBlitz event on October 21-22, which was the largest public event in the history of the park, with thousands of citizen scientists joining more than 200 scientists and naturalists to survey life forms throughout the park (Kline and Swann 2014). During the 24-hour event, scientists documented species not known to occur in Saguaro NP, several of which were new to science (Kline and Swann 2014). To date more than 1,100 species have been documented during Saguaro's BioBlitz, and the list continues to grow as scientists work to identify specimens collected.

The functioning of Saguaro NP's ecosystems depends on maintaining species that perform unique services such as decomposition, photosynthesis, nitrogen cycling, herbivory, and predation (Margules and Sarkar 2007). It also depends on natural processes, such as fire in fire-adapted communities (Swetnam et al. 2001). However, an ecosystem may become disrupted when a critical amount of biodiversity has been lost (Chapin et al. 2000), and with Saguaro NP being one of the most imperiled national parks due to urban sprawl (Hansen et al. 2014) and climate change (Saunders et al. 2009), it faces the potential of a tremendous loss of biodiversity even before baseline inventories have been conducted throughout the park.

The biodiversity that Saguaro NP preserves through its legislated wilderness and management actions benefits humans with ecosystem services, such as clean water and air, in addition to its intrinsic worth, which serves as an essential part of humanity's natural and spiritual surroundings. In addition, studies have shown that people who are exposed to natural settings experience an improvement in mood and a reduction in stress and anxiety (Dallimer et al. 2012).

The growing metropolis of Tucson, Arizona creates a significant threat to Saguaro NP's resources. However, the park's proximity to a large urban community provides a very unique opportunity for easy access and exposure to the globally unique biodiversity and natural setting that the protected status of the park offers. The districts are surrounded by a local community of almost 1 million people, as well as visited by people that travel greater distances to experience the park. Saguaro NP staff actively promotes regional community engagement through a variety of outreach efforts and partnerships to foster a conservation ethic that will continue to safeguard the biodiversity that makes this national park and region so incredibly unique.

4.10.2. Data and Methods

This assessment is based on four indicators, with between three and four measures each. The indicators are species richness, extirpated species, non-native species, and the population status of federally listed threatened and endangered species. The three measures of richness are: 1) overall species richness of Saguaro NP compared to Arizona, using eight taxonomic groups (plants, birds, mammals, herpetofauna, invertebrates, fungi, byrophytes, and lichen); 2) species richness in the TMD compared to the Sonoran Desert Network (SODN) for five taxonomic groups (plants, birds, mammals, herpetofauna, and lichen); and 3) species richness in the RMD compared to the Madrean Sky Islands for four taxonomic groups (plants, birds, mammals, and herpetofauna). The four measures of extirpated species are number of extirpated plants, birds, mammals, and herpetofauna at the park level. The four measures of non-native species are the number of non-native plants, birds, mammals, and herpetofauna at the park level. Finally, the four measures of threatened and endangered species are population status for the endangered lesser long-nosed bat (*Leptonycteris curasoae yerbabuenae*), endangered Southwestern Willow Flycatcher (*Empidonax trailii extimus*), threatened Yellow-billed Cuckoo (*Coccyzus americanus*), and threatened Mexican Spotted Owl (*Strix occidentalis lucida*).

Indicator/Measures

Species Richness (3 measures)

Species richness refers to the number of species occurring in a given area and is a basic indicator of biodiversity. Despite its simplicity, richness remains one of the most commonly used biodiversity metrics because it is usually readily available and can be easily compared between different areas (Davies and Codette 2011). A key question with respect to biodiversity is how diverse is Saguaro NP relative to regional biodiversity? Saguaro NP lies within the biologically diverse state of Arizona, while each district lies within a distinct and diverse ecoregion. The TMD is located within the Sonoran Desert while the RMD is located primarily within the Madrean Sky Islands region. Therefore, we compare park-wide richness to that of Arizona and richness within each district to that of their respective ecoregions to put Saguaro's biodiversity in context with the surrounding landscape.

Measure

Proportion of Arizona plants, birds, mammals, herpetofauna, invertebrates, fungi, bryophytes, and lichen represented in Saguaro NP

We measured species richness park-wide for eight taxonomic groups: vascular plants, birds, mammals, herpetofauna, invertebrates, bryophytes, fungi, and lichens. To determine species richness at the park level we relied primarily on Powell et al. 2006 and Powell et al. 2007, NPspecies, (NPS 2015) data collected during the 2011 BioBlitz held October 21-22 (NPS 2013), one report on lichens (Wetmore 1987) and one report on bryophytes (Spence 2013). Powell et al. 2006 and Powell et al. 2007 summarize the results of the first comprehensive inventory of vascular plants and vertebrates (mammals, birds, herpetofauna) within the RMD and the TMD, respectively. Because these surveys do not necessarily capture all species that may occur in the park we used Appendices A-D at the end of each report. The appendices included all species observed during the inventory as well as species observed or collected during previous monitoring efforts. We combined the two appendices for each taxonomic group and removed duplicate species. We refined these lists by excluding extirpated species (except for vascular plants), nonnative species, hybrids, varieties (for plants) and subspecies. The extirpated plant species list is under development; therefore, we did not exclude extirpated plant species (D. Swann, NP, pers. comm.).

To determine the number of species for each taxonomic group within the state of Arizona we relied on Stein (2002) for vascular plants, the Arizona Checklist of Birds (ABC 2016), the Arizona Game and Fish Department for mammals and hepetofuana (AZG&F 2016), data extracted from the NatureServe website for invertebrates and bryophytes (NatureServe 2016), and the Checklist of Arizona Macrofungi, Lichens, and Slime Molds (2016). For each list we only included native and extant species.

Measure

Proportion of plants, birds, mammals, herpetofauna, invertebrates, and lichen found in the Sonoran Desert Network represented in the TMD

To assess species richness within the SODN we downloaded NPSpecies data for the 11 SODN parks (NPSpecies 2015). The SODN includes 11 national park units: 10 in central and southern Arizona and 1 unit in southwestern New Mexico (Figure 4.10.2-1). These parks are characteristic of two ecoregions: the upper Sonoran subdivision of the Sonoran Desert Ecoregion and the Apache Highlands Ecoregion. SODN parks range in size from 147 to 133,882 hectares (half a square mile to 517 square mi) (Mau-Crimmins et al. 2005). We excluded nonnative species, records not accepted by the park, and records not approved by park staff as indicated in the attributes column of the table extracted from NPSpecies (2015). We then combined all 11 lists and removed duplicate species, varieties (for plants), hybrids and subspecies to arrive at the final list of species known to occur in the Sonoran Desert Network. We relied primarily on the appendices in Powell et al. 2007 to develop a species list for the TMD. We

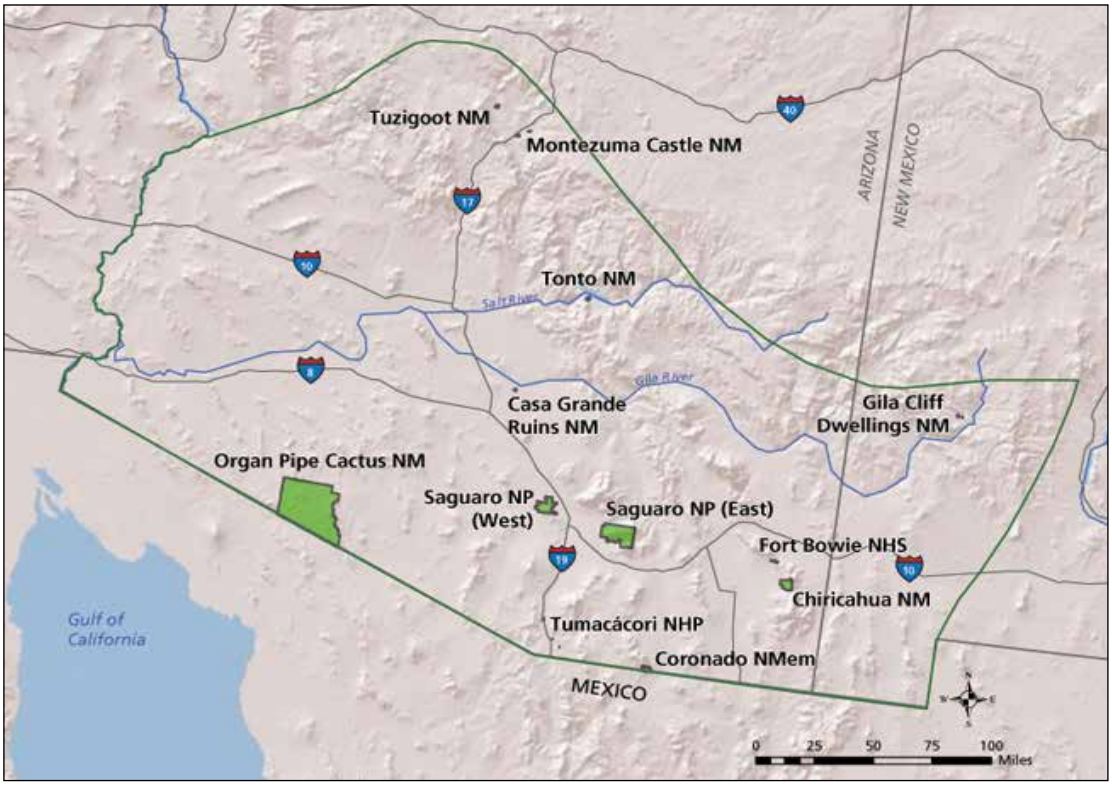

Figure 4.10.2-1. The Sonoran Desert Inventory and Monitoring Network includes 11 national parks, including Saguaro National Park in Tucson, Arizona (map excerpted from NPS SODN 2014).

excluded non-native and known extirpated species. We then calculated the proportion of species in the SODN that are represented in the TMD.

Measure

Proportion of plants, birds, mammals, and herpetofauna found in the Madrean Archipelago represented in the RMD

For species richness in the Sky Islands region we used data derived from the Madrean Archipelago Biodiversity Assessment database (www.madrean.org). We downloaded species lists for individual sky islands within the Madrean Archipelago for mammals, birds, and herpetofauna then combined the lists to arrive at total species richness for the region. We acknowledge that these lists are incomplete, but are the best available data for which to compare biodiversity in the RMD. We relied primarily on the appendices in Powell et al. 2007 to develop a species list for the RMD. We excluded non-native and known extirpated species. We then calculated the proportion of species in the Madrean Archipelago that are represented in the RMD.

Indicator/Measures

Extirpated Species (# of extirpated plants, birds, mammals, and herpetofauna)

We relied on Powell et al. 2006 and Powell et al. 2007 and personal communication with Saguaro NP biologists to determine the number of plants, bird, mammal, reptile, and amphibian species that are known to be extirpated in Saguaro NP. In addition to those reports, we also used a list of extirpated plants for the TMD published in Rondeau et al. (1991) and a list of potentially extirpated species in the RMD in the process of being developed by Saguaro NP staff. We then compared these lists to Powell et al. 2006 and Powell et al. (2007) to determine if any of these species were observed in the most recent surveys (1998-2004) and with each other to determine if these species were extirpated in one district, but occurred in the other district.

Indicator/Measures

Non-native Species (# of non-native plants, birds, mammals, and herpetofauna)

We relied on Powell et al. 2006 and Powell et al. 2007, NPSpecies, and personal communication with Saguaro NP biologists to

determine the number of non-native plants, birds, mammals, reptiles, and amphibians known to occur in Saguaro NP.

Indicator/Measures

Status of Federally Listed Threatened and Endangered Species (status of the lesser long-nosed bat, Southwestern Willow Flycatcher, Yellow-billed Cuckoo, and Mexican Spotted Owl)

We accessed the U.S. Fish and Wildlife Service's Endangered Species database for Arizona on December 14, 2015 and cross-referenced the list with the park-wide lists derived from Powell et al. 2006 and Powell et al. 2007 to determine which species are listed by the U.S. Fish and Wildlife Service under the Endangered Species Act (1973). Since this has already been done for these species in the mammal and the bird assessments, we extracted information from those reports and added them here. For details on data sources please refer to those assessments.

4.10.3. Reference Conditions

Reference conditions for this assessment are shown in Table 4.10.3-1. Reference conditions are described for resources in good condition, moderate condition, and significant concern for the measures of biodiversity in Saguaro NP.

4.10.4. Condition and Trend

Species Richness: Proportion of Arizona Species in Saguaro NP

The number of native species observed in Saguaro NP is presented in Table 4.10.4-1. More than 200 bird species, more than 65 mammal species, nearly 60 species of reptile and amphibian, and about 1200 vascular plant species occur in Saguaro NP. Species lists for vascular plants, mammals, birds, and herpetofauna are thought to be complete or near complete (Powell et al 2006, Powell et al. 2007). The remaining groups are not well studied, but preliminary data from the 2011 BioBlitz event indicate high diversity for invertebrates (Figure 4.10.4-1), fungi, and lichens as well. Species lists of birds, mammals and herpetofauna are presented in the corresponding assessments. In the interest of space, species lists for the remaining taxonomic groups are not presented here, but are available from the park. Half of all mammal species and approximately two thirds of all plants, birds, herpetofauna, and invertebrates found in Arizona are represented in Saguaro NP. Overall, diversity is relatively high, especially when considering the small area of Saguaro NP relative to Arizona. The remaining groups are less well known within the park and because species lists are incomplete it is difficult to compare richness of these groups to that of Arizona. Despite these data gaps, overall biodiversity is high in Saguaro NP and the condition for this measure is considered good for plants, birds, mammals and herpetofauna, but it is unknown for the remaining taxonomic groups. As additional data become available from the 2011 BioBlitz, species lists for the lesser known groups will likely increase.

Overall, RMD has greater diversity than TMD (Table 4.10.4-1). The larger size and greater diversity of habitat types found within the RMD account for the greater richness as opposed to the smaller TMD. The RMD is also bordered by National Forest land to the north, east and south, which tends to promote movement of wildlife, whereas TMD is bordered mostly by private and state land, which likely decreases dispersal and migration. A large number of species found in the RMD have not been documented in the TMD. Most of these are unlikely to occur in the TMD because they are outside of their

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Figure 4.10.4-1. Moth collage from Saguaro National Park.

Table 4.10.3-1. Reference conditions used to assess biodiversity in Saguaro National Park.

Indicator	Measure	Good	Moderate	Significant Concern
Richness	Proportion of Arizona plants, birds, mammals, herpetofauna, invertebrates, fungi, bryophytes and lichens present in the park.	We consider the condition to be good if a large proportion of the eight taxonomic groups found in Arizona are represented in the park.	We consider the condition to be moderate if a modest proportion of the eight taxonomic groups found in Arizona are represented in the park.	We consider the condition to be of significant concern if a small proportion of the eight taxonomic groups found in Arizona are represented in the park.
	Proportion of Sonoran Desert Network plants, birds, mammals, herpetofauna, and lichens present in the Tucson Mountain District.			
	Proportion of Madrean Sky Islands plants, birds, mammals, and herpetofauna present in the Rincon Mountain District.			
Extirpated Species	# of vascular plants	We consider the condition to be good if none, or only a few, native species have been extirpated in the park.	We consider the condition to be moderate if a few native species have been extirpated in the park.	We consider the condition to be of significant concern if many native species have been extirpated in the park.
	# of birds			
	# of mammals			
	# of herpetofauna			
Non-native Species	# of vascular plants	We consider the condition to be good if one or only a few non-native species occur in the park and their presence does not disrupt ecosystem function.	We consider the condition to be moderate if only a few non-native species occur in the park and their presence causes some disruption to ecosystem function.	We consider the condition to be of significant concern if many non-native species occur in the park and their presence causes significant disruption to ecosystem function.
	# of birds			
	# of mammals			
	# of herpetofauna			
Threatened and Endangered Species	Status of the lesser long-nosed bat	We consider the condition to be good if the estimated numbers of the subject species are approximately the same or increasing based on the information available.	We consider condition to be of moderate concern if estimated numbers of the species have decreased or may be decreasing somewhat.	We consider the condition to be of significant concern if the estimated numbers of species have decreased substantially and/or may continue to do so.
	Status of the Southwestern Willow Flycatcher			
	Status of the Yellow-billed Cuckoo			
	Status of the Mexican Spotted Owl			

Table 4.10.4-1. An assessment of species richness in Saguaro National Park compared to species richness within the Sonoran Desert Network, Madrean Archipelago, and State of Arizona.

Taxonomic Group	Arizona	Park-wide (% AZ total)	TMD Richness	RMD Richness	Species Unique to Each District	SODN Richness (% TMD in SODN)	Sky Island Richness (% RMD in Sky Islands)
Vascular Plants[1,2,3,4,5,6]	3,512	1123 (32)	467	1085	RMD = 682 TMD = 64	1821 (26)	2005 (54)
Birds[1,2,3,5,6,7]	543	205 (38)	131	203	RMD = 73 TMD = 2	350 (59)	287 (71)
Mammals[1,2,3,5,6,8]	134	66 (49)	38	62	RMD = 28 TMD = 4	109 (61)	48 (129)
Herpetofauna[1,2,3,5,6,8]	152	59 (39)	34	55	RMD = 25 TMD = 4	111 (53)	107 (51)
Invertebrates[9,10]	1206[8]	324 (27)	---	---	----	---	---
Bryophytes[10,11]	91[8]	11 (1)	---	---	---	---	---
Fungi[9,12]	1437[9]	197 (14)	---	---	---	---	---
Lichen[12,13]	969[9]	249 (26)	64	223	RMD = 185 TMD = 26	---	---

[1] Powell, B.F, Halvorson, W.L., and Schmidt, C.A., eds., 2007, Vascular plant and vertebrate inventory of Saguaro National Park, Tucson Mountain District: U.S. Geological Survey Open-File Report 2007-1296, 92 p. [http://pubs.usgs.gov/of/2007/1296/]. (excluded nonnative species whenever it was explicit in text; also used the number reported in text that gave the maximum number of species including those found in other surveys).

[2] Powell, B. F, W. L. Halvorson, and C. A. Schmidt. Vascular Plant and Vertebrate Inventory of Saguaro National Park, Rincon Mountain District. OFR 2006-1075. U.S. Geological Survey, Southwest Biological Science Center, Sonoran Desert Research Station, University of Arizona, Tucson, AZ.

[3] National Park Service (NPS). 2015. NPSpecies List for Saguaro National Park. All species list with details. Obtained December 2015 from https://irma.nps.gov/npsecies.

[4] Stein, B.A. 2002. States of the Union: Ranking America's Biodiversity. Arlington, Virginia: NatureServe.

[5] National Park Service (NPS). 2015. NPSpecies List for Sonoran Desert Network Parks. All species list with details. Obtained December 2015 from https://irma.nps.gov/npsecies.

[6] Madrean Archipelago Biodiversity Assessment (MABA). 2015. MABA Web-interface. Available at http://madrean.org (accessed December 15, 2015).

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[8] Arizona Game and Fish (AZG&F). 2016. Available at http://www.azgfd.gov (accessed February 22, 2016).

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[13] Wetmore, C.M. 1987. Lichens and air quality in Saguaro National Monument with chemical analysis of Chiricahua lichens final report. University of Minnesota, Botany Department, St. Paul, MN.

geographical or elevational range limits or because suitable habitat does not occur within the TMD. The TMD accounts for two species of bird, four species of mammal, four species of herpetofauna, 64 species of plant and 26 species of lichen that are not represented within the RMD. In contrast, the RMD supports 74 bird species, 28 mammals, 682 plants, 25 species of reptile and amphibian and 185 species of lichen that are not known to occur within the TMD. Despite the greater diversity of plants and animals found in the RMD, the TMD protects an important example of the Sonoran Desert Ecosystem and is one of the more diverse parks located within the SODN network.

Species Richness: Proportion of SODN species in the TMD

Table 4.10.4-1 shows that between 26% and 61% of native Sonoran Desert species are represented in the TMD. Mammals show

the greatest representation in TMD while vascular plants show the least. The greater mobility of birds, mammals, and to a lesser extent, herpetofauna, account for the high number of SODN species represented within TMD. The relatively low diversity of SODN plants represented within the TMD may be a function of the low dispersal ability of many plants, incomplete surveys, or simply because of the high diversity of plants in the region. Overall, TMD contains exceptionally high diversity given that the district represents only about 5% of the land area within the SODN. Furthermore, the park's protected status provides refuge for species. Given the relatively high proportion of SODN network species represented within the TMD, the condition for this measure is considered good.

Species Richness: Proportion of Madrean Sky Islands Region in the RMD

Between 51% and 129% of diversity within the Sky Islands Region is represented within the RMD. The Sky Islands inventories are incomplete and some of the species lists contained only one specimen, which accounts for the greater than 100% value obtained for mammals. The rugged terrain characteristic of the Sky Islands region has limited the number and extent of surveys in the region. Still, richness within the RMD is high compared with known species occurrence throughout the Sky Islands Region considering the district represents less than 1% of the total land area of the Madrean Archipelago. The RMD provides refuge for plants and wildlife in region that has lost 80% of its original extent (CEPF 2016). Given the relatively high proportion of Madrean Sky Islands network species represented within the TMD, the condition for this measure is considered good.

Extirpated Species: Plants

The total number of extirpated plant species in Saguaro NP is unknown. The high diversity of plants, limited distribution of rare species, and incomplete surveys have hampered establishing a final list although park staff are in the process of developing one (D. Swann, Saguaro NP, pers. comm.) Bowers and McLaughlin (1987) cited 41 species that they believed were extirpated from the RMD because of habitat modification. None of these species were located during surveys conducted from 2001-2003, but during their review of other studies Powell et al. 2006 determined that six of these species occurred in the RMD, including two species of rush (*Juncus sp.*) and the alderleaf mountain mahogany (*Cercocarpus montanus*). The current park potential list of extirpated species consists of 34 species and 6 subspecies, a number of which occurred in the high elevation areas of the RMD (D. Swann, Saguaro NP, pers. comm.). Species most likely to be extirpated are moisture-loving, high elevation plants as a result of habitat disturbance and climate change (Bowers and McLaughlin 1987). Rondeau (1991) listed 27 plant species as extirpated from the TMD, most of which were obligate spring annuals. When compared to the plant species listed in Appendix A in Powell et al. 2006 and Powell et al. 2007, only one of the 27 species was listed as observed in both the TMD and RMD sometime during 1998-2004 as part of Saguaro NP's long-term monitoring program. There was no overlap in Table 2 from Rondeau (1991) and the list of potentially extirpated species provided by NPS staff, therefore there are likely at least 26 species of extirpated plant species in the TMD and 34 extirpated species in the RMD for a total of 60 potentially extirpated plant species park-wide (Table 4.10.4-2). We acknowledge that this list is incomplete and represents a list of potentially extirpated species. As Saguaro NP continues its long-term plant monitoring program plant species may be added or removed from this list, therefore, we consider the condition for this measure unknown.

Table 4.10.4-2. Extirpated species in Saguaro NP.

Taxonomic Group	Extirpated Species
Vascular Plants	60
Birds	0
Mammals	6
Herpetofauna	0

Extirpated Species: Birds

Three species may have been historically present in the park including Aplomado Falcon (*Falco femoralis*), California Condor (*Gymnogyps californianus*) and Thick-billed Parrot (*Rhynchopsitta pachyrhyncha*), but this is unconfirmed (Powell et al. 2006). Since there are no confirmed extirpated bird species in Saguaro NP, the condition for this measure is considered good. The likelihood that no bird species have been extirpated in the park is due to the high mobility of birds and the presence of unique habitat types and generally high quality of those habitat types compared with regions outside of the park. For example, deciduous woody vegetation along Rincon Creek provides exceptional habitat to a variety of riparian-dependent bird species such as the Yellow Warbler (*Setophaga petechia*) and Song Sparrow (*Melospiza melodii*), and mature stands of saguaro cactus are important habitat refuges for Gila Woodpecker and Cactus Wren (*Campylorhynchus brunneicapillus*) (Powell et al. 2006, Powell et al. 2007).

Extirpated Species: Mammals

For the entire park, there are six species believed to be extirpated (Swann and Perkins 2013; Table 4.10.4-2). They are the grizzly bear (*Ursus arctos*), Mexican gray wolf (*Canis lupus baileyi*), bighorn sheep (*Ovis canadensis*), jaguar (*Panthera onca*), North American porcupine (*Erethizon dorsatum*), and banner-tailed kangaroo rat (*Dipodomys spectabilis*). All six were once documented in the RMD, and three were documented in the TMD (Swann and Perkins 2013). In the RMD: grizzly bears were last recorded in the early 1920s; Mexican gray wolves in 1948; bighorn sheep in the 1950s; jaguars in the 1930s; and porcupines in the early 1990s (Swann and Perkins 2013). In the TMD: the bighorn sheep was last recorded in the 1950s; the Mexican gray wolf in the 1930s or 1940s; and the porcupine in the 1960s. Porcupines may be experiencing a regional decline, possibly due to increased mountain lion predation (Brown and Babb 2008, as cited by Swann and Perkins 2013); however, there was an unconfirmed road killed porcupine in the TMD during the mid-1990s (N. Kline, Saguaro NP, pers. comm.). Kit foxes (*Vulpes macrotis*) may be extirpated from the TMD, although this has not been confirmed (N. Kline, Saguaro NP, pers. comm.). As recently as 2015, a bighorn sheep, one translocated into the nearby Santa Catalina mountains, was observed and photographed in the park (D. Swann, Saguaro NP, pers. comm.). Banner-tailed kangaroo rats have not been trapped in decades and no sign of this species has been observed by park biologists (D. Swann, pers. comm.). This measure warrants significant concern because of the loss of these six mammals and increasing loss of habitat connectivity, especially for the TMD.

Extirpated Species: Herpetofauna

No species of reptile or amphibian has been extirpated in the park. Two additional species, the desert horned lizard (*Phrynosoma platyrhinos*), which occupied flats and lower bajada, and the western shovel-nosed snake (*Chionactis occipitalis*), which occupied the valley-center desert scrub flats, may be also be extirpated from the TMD (Powell et al. 2007); however, there is no evidence to indicate they historically occurred there. Since none of the 59 extant reptiles and amphibians in Saguaro NP is considered extirpated, the condition for this measure is good.

Non-native Species: Plants

According to Saguaro NP's restoration ecologist, Dana Backer, there are 125 non-native plants species that have been listed for the park from various sources, including NPSpecies (2015), which includes plants without vouchers and ones that may now be removed; the park's Restoration Management Plan Environmental Assessment (NPS 2014b); and the park's Exotic Plant Management Plan Environmental Assessment (NPS 2004) (Table 4.10.4-3). Eighty-seven of these plants are known to be present in the park, and at least 26 of theses species are considered invasive (NPS 2014b).

Invasive species are those that cause considerable disruption to native ecosystem structure and function (NPS 2014b). Their presence may lead to the loss of plant diversity and abundance and ultimately cause permanent changes in community composition. Invasive species in Saguaro

NP include buffelgrass (*Pennisetum ciliare*), Lehmann lovegrass (*Eragrostis lehmanniana*), African lovegrass (*Eragrostis echinochloidea*), soft feather pappusgrass (*Enneapogon cenchroides*), and red brome (*Bromus rubens*). According to previous studies, invasive species are increasing in both quantity and diversity (Holden 2005, Funicelli et al. 2001). Long-term monitoring transects indicate that the percentage of non-native species in the TMD increased from 2.5% in 2001 to 10.5% in 2005, however, this increase could be due to sampling design (Holden 2005, Powell et al. 2007). Non-native species may remain at low abundance for years then increase rapidly in response to favorable conditions. The spread of buffelgrass in the Sonoran Desert Ecosystem is of considerable concern because it competes with native plants, creates dense stands which inhibits the growth of native species and increases the risk of high intensity fires which threatens species not adapted to this disturbance including saguaro cactus and desert tortoise (*Gopherus agassizii*) (NPS 2014a). Buffelgrass was first recorded in the park in 1989. By 2002, buffelgrass covered approximately 71 ha (175 acre) in the park. A decade later, aerial mapping efforts estimated approximately 809 ha (2,000 acre) of buffelgrass, primarily large patches in rugged terrain and remote wilderness (NPS 2014b). The park has a non-native plant control program targeted at 12 of the 26 invasive plant species and efforts have been successful in limiting the spread of these species (NPS 2014b). However, because of the high number of non-native plants, many of which are invasive, and the ability of non-native plants to spread rapidly and change ecosystem structure and function, the condition for non-native plant species is of significant concern.

Non-native Species: Birds

There are four non-native bird species found in Saguaro NP (Table 4.10.4-3). They are the European Starling (*Sturnus vulgaris*), European House Sparrow (*Passer domesticus*), Rock Pigeon(*Columba livia*), and Eurasian Collared Dove (*Streptopelia decaocto)* (Powell et al. 2006 and N. Kline, Saguaro NP, pers. comm.). The species with the greatest potential impact on native species is the starling (and possibly house sparrow) since they compete with native birds for nesting cavities, particularly cavities in saguaro cacti, but a study on the effects of non-native cavity nesting species on native cavity nesters found little cause for concern (Mannan and Bibles 1989); however, an increase in housing density surrounding the park is likely to increase their distribution in the park. Although all four species of non-native birds occur in both districts, their distribution is limited and their effects on native birds is minor, therefore, the condition for this measure is considered good.

Non-native Species: Mammals

Four non-native mammal species are found in Saguaro National Park (Table 4.10.4-3). They are the domestic cow (*Bos taurus*), domestic dog (*Canis lupus familiaris*), feral cat (*Felis catus*), and Abert's squirrel (*Sciurus aberti*). The feral cat and domestic dog have both been recorded in the TMD, but all four non-native mammals have been recorded in the RMD; however, park staff does not believe that domestic mammals have established feral populations (Powell et al. 2006). Domestic cattle no longer occur in the TMD and only occasionally in the RMD because of improved land management practices which included the cessation of grazing during the 1950s and 1960s (Powell et al. 2007). The park maintains a boundary fences to limit cattle wandering into the park (N. Kline, Saguaro NP, pers. comm.) The non-native Abert's squirrel is present in RMD with potentially negative consequences for the native Arizona gray squirrel (Koprowski 2008). Because of

Table 4.10.4-3. Non-native species in Saguaro NP.

Taxonomic Group	Non-native Species
Vascular Plants	125
Birds	4
Mammals	4
Herpetofauna	4

improved land management practices which have eliminated cattle grazing in Saguaro NP, and the limited distribution of feral cats and dogs in both districts, the condition for non-native mammals is considered good.

Non-native Species: Herpetofauana

Four species of non-native reptile and amphibian have been recorded in Saguaro NP, all of which are found in the RMD (Table 4.10.4-3). No non-native reptiles and amphibians have been documented in the TMD. Although the spiny-tailed iguana (*Ctenosaura hemilopha*) and the Mediterranean gecko (*Hemidactylus turcicus*) have not been recorded in the TMD, their presence seems likely given that they have escaped from the grounds of the Arizona-Desert Sonora Museum just outside the district, and some individuals may move into the district at King's Canyon (Powell et al. 2007). A population of non-native American bullfrogs (*Rana catesbeiana*) became established in the park at Wildhorse Canyon during the 1970s but has since been eliminated by park staff (Powell et al. 2006); however, bullfrogs occur in many areas surrounding the park and their establishment would be cause for concern (N. Kline, Saguaro NP, pers. comm.) In 2001, a tiger salamander (*Ambystoma tirinum*) was observed near Rincon Creek, but because the species spends most of its time underground, its breeding status is unknown. The Mediterranean house gecko is established near the administration building, but is likely restricted to this area (Powell et al. 2006). Because there are few non-native reptiles and amphibians in the RMD and none in the TMD, and those that do occur are limited in distribution, the condition for non-native herpetofauna is considered good.

Threatened and Endangered Species

There are two endangered species (lesser long-nosed bat and Southwestern Willow Flycatcher) and two threatened species (Yellow-billed Cuckoo and Mexican Spotted Owl) listed by the USFWS under the Endangered Species Act (1974) that occurs in Saguaro NP (USFWS 2015). Four threatened and endangered species historically present in Saguaro NP are now extirpated. They are the Mexican gray wolf, grizzly bear, jaguar, and Aplomado Falcon. Additional threatened and endangered species that may have been historically present in the park include California Condor (*Gymnogyps californianus*), Thick-billed Parrot (*Rhynchopsitta pachyrhyncha*), and Gila topminnow (*Poeciliopsis occiddentalis occidentalis*) (Powell et al. 2006, topminnow reference). The park is being considered as a possible re-introduction site for the topminnow (N. Kline, Saguaro NP, pers. comm.).

Lesser Long-nosed Bat

The lesser long-nosed bat was listed as endangered in 1988, and roost counts have been conducted in the park since 1991 (Sidner 1991) as funding allows, but not in every year (Natasha Kline, Saguaro NP, pers. comm.). Numbers of bats counted in roosts may vary from year to year due to annual variation in when the bats arrive, when their abundance peaks, and when they depart (Wolf 2013). Wolf (2013) further suggests that the abundance of bats at the RMD roost "may be connected to the abundance and phenology of agaves in southeastern Arizona, which also vary from year to year." There are not enough data of the same type (e.g., from external surveys) to determine a trend in condition for the lesser long-nosed bat, but the number of bats using the roost generally appears stable over the past several years resulting in a good condition rating. For more details, please refer to the mammals assessment 4.22.

Southwestern Willow Flycatcher

The following information on the Southwestern Willow Flycatcher is from NPS (2014b; Restoration Management Plan Environmental Assessment):

> *This endangered songbird is a riparian (cottonwood/willow, mixed broadleaf and tamarisk) obligate, and has become very rare with the loss of this habitat in the southwest over the last century (Pima County 2001). It is a neotropical migrant, present in Arizona from April through September (Pima County 2001).*

> *Southwestern willow flycatchers are transient visitors in the spring to Saguaro NP in the riparian areas along Rincon and Chimenea creeks (Powell et al. 2006). This species has not been documented breeding in the park, and it appears SNP does not contain sufficient quality riparian habitat to support breeding.*

It is uncertain whether the endangered subspecies has been recorded during the SODN annual monitoring surveys (for 2007-2013 and 2015). The Willow Flycatcher has been recorded during the surveys, and while it is probable that the observation was of the Southwestern Willow Flycatcher, this is uncertain (Moez Ali, pers. comm.). Because of limited information on the occurrence and status of this species, the condition for this measure is unknown.

Yellow-billed Cuckoo

The Yellow-billed Cuckoo has been recorded during the annual SODN landbird surveys. Also, Powell et al. (2006) reported breeding by one to two pairs along Rincon Creek in the park (NPS 2014b). NPS (2014b) includes the following information on the species:

> *The Yellow-billed Cuckoo is a neotropical migratory bird, designated by the USFWS as a candidate species for listing...*[note that the cuckoo has been listed as threatened since the publication of this report] *due to loss of habitat (USFWS 2013). Yellow-billed Cuckoos are found throughout Arizona below 5,000 feet, generally in large blocks of riparian woodlands (cottonwood, willow, or tamarisk galleries) where they breed (USFWS 2013).*

This species is considered rare in the park and only found in some years along Rincon Creek where it occasionally breeds (N. Kline, Saguaro NP, pers. comm.). Because of limited information on the status of this species, the condition for this measure is unknown.

Mexican Spotted Owl

NPS (2014b) contains the following information on the Mexican Spotted Owl (Figure 4.10.4-2):

> The threatened Mexican Spotted Owl (MSO) is one of three spotted owl subspecies. They occupy a variety of habitat types ranging from dense mixed conifer forests to steep-walled, rocky canyons, favoring sites with complex structure (USFWS 1995). Nest sites are generally located in closed canopy forests or on ledges in steep-walled canyons. These owls are threatened by habitat loss from logging and wildfire and by displacement by the con-generic barred owl (USFWS 2011).
>
> In 1995, telemetry studies of MSO documented five territories within the Rincon MD (Willey 1997). Since then, each has been designated a Protected Activity Center (PAC) per the MSO Recovery Plan (USFWS 1995), and is managed as such, including regular monitoring and strict regulation of permitted activities. All five sites appear to be consistently occupied, though sometimes by only one bird or a non-breeding pair (Kline 2012). In February 2001, the USFWS designated virtually all of the Rincon MD above 6,000 feet as critical habitat for the MSO. In the park, wildfire is

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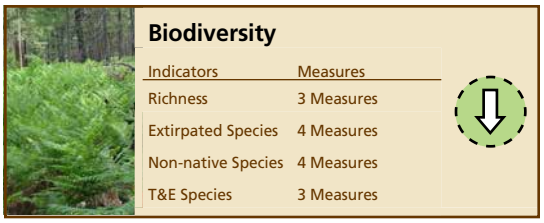
Figure 4.10.4-2. Mexican Spotted Owl (*Strix occidentalis lucida*) in Saguaro National Park.

the biggest threat to MSO and their habitat. The Helens 2 Wildfire in Summer 2003 affected a large portion of MSO habitat on the north slope of the Rincons.

The Helens 2 Wildfire appears to be affecting resident owl habitat and distribution (N. Kline, Saguaro NP, pers. comm); however, SNP (2013) reported that the Mexican Spotted Owl population in the park appears to be stable. Therefore, the condition for this measure is good.



Overall Condition and Trend

For assessing biodiversity in Saguaro NP, we used four indicators with between three and four measures each (Table 4.10.4-4). The overall condition of biodiversity in Saguaro NP is considered good. Species richness for

Table 4.10.4-4. Summary of the biodiversity indicators, measures, and condition rationale.

Indicator	Measure	Condition / Confidence Level	Condition Rationale
Proportion of Arizona Species Present in the Park			
Richness	Plants	Good / Medium	Nearly half of all species of bird, mammal, and herpetofauna found in Arizona are represented in Saguaro NP. Although fewer plant species in Arizona are represented in the park (32%) than for other groups, the diversity is still relatively high, especially when considering the small area of Saguaro NP relative to Arizona.
	Birds	Good / High	
	Mammals		
	Herpetofauna		
	Invertebrates	Unknown / Low	The lack of information prevents us from assigning a condition for this measure. The confidence is low because inventories are incomplete.
	Fungi		
	Bryophytes		
	Lichens		
Proportion of Sonoran Desert Network Species Present in TMD			
Richness	Plants	Good / Medium	Between 26% and 61% of native Sonoran Desert species are represented in the TMD. Overall, TMD contains exceptionally high diversity given that the district represents only about 5% of the land area within SODN.
	Birds	Good / High	
	Mammals		
	Herpetofauna		
	Lichens	Unknown / Low	The lack of information prevents us from assigning a condition for this measure. The confidence is low because inventories are incomplete.
Proportion of Madrean Sky Islands Present in RMD			
Richness	Plants	Unknown / Low	Between 51% and 129% of diversity within the Sky Islands Region is represented within the RMD. Richness within the RMD is high compared with known species occurrence throughout the Sky Islands Region considering the district represents less than 1% of the total land area of the Madrean Archipelago, although there the species lists for the Madrean Archipelago are incomplete, therefore, richness is unknown.
	Birds		
	Mammals		
	Herpetofauna		

Table 4.10.4-4. Summary of the biodiversity indicators, measures, and condition rationale continued.

Indicator	Measure	Condition / Confidence Level	Condition Rationale
Park-wide			
Extirpated Species	# of vascular plants	Unknown / Low	There are 60 potentially extirpated plant species in Saguaro NP; however, the list has not been finalized. As Saguaro NP continues its long-term plant monitoring program plant species may be added or removed from this list, therefore, we consider the condition for this measure unknown.
	# of birds	Good / High	Since there are no confirmed extirpated bird species in Saguaro NP, the condition for this measure is considered good.
	# of mammals	Significant Concern / High	This measure warrants moderate concern because of the loss of six mammals and increasing loss of habitat connectivity, especially for the TMD.
	# of herpetofauna	Good / High	None of the 59 extant reptiles and amphibians in Saguaro NP is considered extirpated.
Non-native Species	# of vascular plants	Significant Concern / Medium	There are 125 non-native plants listed in the park's management plant; 87 have been confirmed; 26 are invasive. Coupled with the ability of non-native plants to spread rapidly and change ecosystem structure and function (e.g. altered fire patterns), the condition for non-native plant species is of significant concern.
	# of birds	Good / High	Although four species of non-native bird occur in both districts, their distribution is limited and their effects on native birds is minor.
	# of mammals		Improved land management practices have eliminated cattle grazing in Saguaro NP and although cows are occasionally found in the RMD, they are not established. Feral cats and dogs in both districts have not established populations and their distribution is limited. Abert's squirrel may have effects on the native Arizona gray squirrel.
	# of herpetofauna		There are only four non-native reptiles and amphibians in the RMD and none in the TMD, and those that do occur are limited in distribution.

major taxonomic groups is high and many native Arizona species are found within the park. With the exception of plants, few non-native species are adversely affecting native species in the park and their distribution is generally limited. No birds, reptiles or amphibians have been extirpated although six mammal species are no longer found in the park. The park provides refuge for three threatened and endangered species. Although the status of other taxonomic groups is less well-known, the loss of plants and mammals suggests concerns for other groups. The number of non-native vascular plants and the five extirpated large mammals warrants significant concern. This assessment also highlights data gaps in microbiota such as lichens, bryophytes, fungi, and invertebrates

Table 4.10.4-4. Summary of the biodiversity indicators, measures, and condition rationale continued.

Indicator	Measure	Condition / Confidence Level	Condition Rationale
Park-wide			
Threatened and Endangered Species	Status of the lesser long-nosed bat	Good / Medium to High	The lesser long-nosed bat was listed as endangered in 1988, and roost counts have been conducted in the park since 1991. There are not enough data to determine a trend in condition for the lesser long-nosed bat, but the number of bats using the known roost generally appears stable over the past several years resulting in a good condition rating.
	Status of the Southwestern Willow Flycatcher	Unknown / Low	There is not enough information to assign a condition.
	Status of the Yellow-billed Cuckoo		
	Status of the Mexican Spotted Owl	Good / Medium to High	There are five breeding territories in the RMD and all appear to be occupied in most years and SNP (2013) reported that the Mexican Spotted Owl population in the park appears to be stable.

and unknown status for two threatened and endangered species. Although relatively little is known about these groups in Saguaro NP, events like the 2011 BioBlitz and other inventory and monitoring projects have narrowed this data gap.

Level of Confidence/Key Uncertainties

The lack of comprehensive taxa inventories greatly impacts the park's ability to manage its resources. Given that there has not been a comprehensive review of biodiversity within Saguaro NP prior to this assessment, we treat this report largely as the baseline reference condition for the park, with the understanding that many data gaps exist due to the lack of baseline information.

Instead, the data presented throughout this section provide a coarse assessment of relative biodiversity in Saguaro NP. Species inventories are ongoing and will undoubtedly change the known number of species observed within the park. For example, the middle elevation areas of the RMD have not been as thoroughly surveyed for plants as other regions within the district, and this area may support species not previously documented in the park (Powell et al. 2006). Furthermore, inventories for the Sonoran Desert Network and especially the Madrean Archipelago are incomplete. As biologists learn more about these two ecoregions, the relative diversity of Saguaro NP is likely to change, especially for taxonomic groups that are less well known such as invertebrates, bryophytes, lichens, and fungi, but which make up the bulk of biodiversity. The confidence level for most measures for which we assigned a condition is high with the exception of the number of extirpated plant species.

Threats to Biodiversity

The greater Tucson metropolitan area is one of the fastest growing population centers in the U.S. According to the 2010 census, Pima County's population is 980,263 and is projected to reach 1.45 million by 2041 (PAG 2016). In 2000, 55% of the private land surrounding Saguaro NP was undeveloped, but exurban development is expected to increase 38% by 2030 and 105% by 2060 (Hansen et al. 2014). Much of that development will occur along the periphery of the park. Concomitant with the increase in population and development is a variety of human-related issues including an increase abundance of existing non-native species,

introduction of new non-native species, increased predation of native species by non-native species (e.g. feral cats), air pollution from vehicle emissions, increased water demands, disease, a reduction in connectivity, and roadkill, among others (Briggs et al. 1996).

Connectivity is important for maintaining biodiversity. Corridors facilitate migration and dispersal, namely for animals although plants that are dispersed primarily by animals also benefit from maintaining connectivity. Relative to the RMD, the TMD is surrounded by more development. In the assessments for mammals (4.22) and herpetofauna (4.23), connectivity with the surrounding landscape for the RMD is considered good to moderate concern, while that for the TMD is of significant concern. However, connectivity for both districts is expected to decline in the future as development surrounding the park increases.

Several human-adapted non-native species occur in Saguaro (i.e. house sparrow, rock pigeon, European starling, feral cat, domestic dog, and domestic cow). Although the three non-native mammals have not established populations within the park, their presence may influence local biodiversity through overgrazing native vegetation and erosion of riparian areas, spreading invasive species such as buffelgrass, and through direct mortality of native species (e.g. feral cats killing native birds). Of particular concern are the non-native invasive plant species found in the park (NPS 2014b). Some of these species may cause irreversible changes to the ecosystem in which they invade. The spread of invasive species in difficult to reach wilderness areas is particularly alarming. The NPS has established a management plan to control and limit the spread of invasive species into wilderness areas through aerial application of herbicides and physical removal of individual plants. While the latter method is only minimally successful for small, localized populations, aerial spraying affects a much larger area and has proven effective in controlling buffelgrass near the city of Tuscon, AZ and may soon be implemented in Saguaro NP (NPS 2014b).

Disease may also threaten biodiversity. A widespread upper respiratory tract disease (URTD) caused by the bacterium *Mycoplasma agassizii*, as well as *M. testudineum*, (Jacobson et al. 2014) is of concern for the Sonoran desert tortoise (*Gopherus morafkai*). In the Sonoran Desert, URTD has not been implicated in any die-offs of desert tortoises (Jones 2008), but the disease has been documented in the Tucson area, and tortoises within the park carry Mycoplasma antibodies indicating that the population has been infected. Tortoises can remain carriers for life (Jacobson 1992), and outbreaks of the disease can potentially occur with added environmental stresses, human impacts, and the escape or release of captive ill tortoises (Jacobson et al. 2014). Amphibian chytrid fungus *Batrachochytrium dendrobatidis*, and the disease it causes, can result in mass mortality events in amphibian populations. Chytrid fungus has been found in at least two species in the park: the lowland leopard frog (*Rana* [or *Lithobates*] *yavapaiensis*) and the canyon tree frog (*Hyla arenicolor*) (Ratzlaff 2012). Prevalence was relatively high for lowland leopard frogs in at least two locations sampled in and around the RMD compared to prevalence in the canyon tree frog (Ratzlaff 2012).

The condition of air quality at Saguaro NP is of moderate to significant concern. While there is no overarching assessment of the impact of air quality on overall biodiversity, the vegetation health risk from ground-level ozone warrants significant concern at Saguaro NP (see the Air Quality assessment for more details). Of all the stressors on biodiversity, however, climate change has the most potential to influence community composition and richness. The climate in the southwestern U.S. has shifted into a drier and warmer pattern (Prein et al. 2016). Since 1974 there has been a 25% decrease in precipitation, a trend that is partially counteracted by increasing precipitation intensity (Prein et al. 2016). However, shifts in the timing and magnitude of precipitation may influence biodiversity. Plants and animals may not be able to take advantage of short duration, intense precipitation events followed by long intervals of drought. Many species in Saguaro NP depend on the limited

water sources in the park's already arid environment including amphibians, riparian plants, and many species of bird. The riparian area around Rincon Creek contains the most well-developed vegetation in the park; however, mature trees and other vegetation growing along the creek show signs of water stress and there is a general lack of seedling recruitment (Baird et al. 2001). Temperature has also increased in the southwest (Hansen et al. 2014, Prein et al. 2016). Increased temperature has the potential to shift biomes northward and higher in elevation which may increase the potential for Saguaro NP to lose species adapted to higher elevation areas. Climate change, as well as invasive plant-species, has shifted the fire regime from low-intensity frequent fires that occur on a roughly decadal basis to infrequent, but high intensity fires (Powell et al. 2006, 2007). These factors are all stressors on biodiversity in Saguaro NP.

4.10.5. Sources of Expertise

No outside experts were consulted for this resource topic. This section was authored by writer, Lisa Baril, with contributions from Donna Shorrock, NPS IMR NRCA Coordinator and writer, Patty Valentine-Darby. Park staff Don Swann, Natasha Kline and Dana Backer contributed to this assessment.

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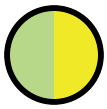
4.11. Saguaro Cactus (*Carnegiea gigantea*)

Indicators/Measures

- Population Status / Health (2 Measures)
- Historic Integrity & Appearance on Landscape (1 Measure)
- Habitat Availability & Quality (2 Measures)

Condition – Trend – Confidence



Good to Moderate Concern – Varied – High

4.11.1. Background and Importance

The saguaro cactus (*Carnegiea gigantea*), often reaching a height of 12 m (39.4 ft) or more, is the largest cactus in the United States (Figure 4.11.1-1). This slow-growing, columnar cactus is found only in the Sonoran Desert of the U.S. and Mexico. Within the U.S., it occurs in southern Arizona and extreme southeastern California. Freezing temperatures and altitude limit its range. The plant's average life-span is 100-175 years (Pierson et al. 2013). Ecologically, the saguaro is a highly important species. Large and small bird species build nests on its arms or within excavated cavities (Figure 4.11.1-2). A variety of animals, including species of birds, bats and other mammals, reptiles, and insects, benefit from its flower, fruit, and flesh for nectar, food, and moisture. In addition to providing food and shelter for numerous desert animals, the saguaro plays a vital role in the culture of the Tohono O'odham people. Their traditional harvest of saguaro fruit continues in the park today (Toupal et al. 2006).

The saguaro cactus is the signature species of Saguaro National Park (NP) (Ahnmark and Swann 2009). The park was established in 1933 (originally as a national monument) to preserve the "Cactus Forest," the dense stand of large saguaros at the base of the Rincon Mountains east of Tucson. The Tucson Mountain District (TMD) was added to the park in 1961, also to protect the saguaro and associated vegetation in the area.

Concerns over an observed decline of saguaros in the Cactus Forest led to research on saguaros in the park as early as 1939, and research and monitoring continue today. For

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Figure 4.11.1-1. Saguaro cacti at Saguaro National Park.

NPS

Figure 4.11.1-2. Gila Woodpecker nesting in a saguaro cactus.

example, a Saguaro Census is now conducted every 10 years in both the Rincon Mountain District (RMD) and TMD. This long history of research on saguaro ecology and disease has been described in reports such as McAuliffe (1993) and Ahnmark and Swann (2009), and is itself a very unique and valuable resource.

This assessment makes use of the more than 70 years of research on the saguaro cactus within the park. Note that we focus on research and monitoring information that is most useful in our task of assessing current condition. There is a wealth of interesting and important information, such as on the saguaro's life history and reproduction, that is not included here.

4.11.2. Data and Methods

Three indicators were used to assess saguaro cactus condition at the park. The first indicator, population status/health, has two measures: 1) saguaro cactus density and/or population level, and 2) age class (and/or size class) distribution. The second indicator, historic integrity and appearance of saguaro cacti on the landscape, has one measure, and the third indicator, habitat availability and quality, has two measures (occurrence/extent of buffelgrass and percent cover of nurse plants).

Each indicator and measure is discussed below, followed by a description of the studies and datasets that were used in the corresponding analyses.

Indicator/Measures

Population Status / Health (Density/ Population Size and Age Class)

This indicator of saguaro cactus condition has two measures, that of saguaro cactus density and/or population size, and age class (or size class) distribution. Many of the same reports were used for both measures, so the reports are described under one section below.

Saguaro Cactus Density or Population Size

This measure was assessed using data from several studies or surveys that have been conducted at the park-- some by researchers associated with universities, and some by park personnel. We did little of our own data analysis, as the reports provided most of the analysis needed. Information, and in many cases, graphics, were used on saguaro cactus density and/or population size from the following surveys/datasets, which are described briefly two sections below:

- The Saguaro Census from 1990, 2000, and 2010 (O'Brien et al. 2011).
- For RMD only, the Section 17 Saguaro Survey, in which saguaros within a one-square-mile section in the Cactus Forest were surveyed in 1941 and 2011-2012 (Conver et al. 2013).
- For RMD only, the long-term study on six 10-acre plots in Section 17 (surveyed every year since 1941; Orum et al. 1999, Orum et al. 2016).
- The "Historic Plots," five-acre plots in both park districts, surveyed in 1941, 1975, and later (Swann et al. 2011 and Swann et al. 2015).

Saguaro Cactus Age (or Size) Class Distribution

For this measure, we examined the structure of the population with regards to age or size class distribution. Within a population, information on the number or proportion of individuals in each age group can be used along with other factors to estimate future changes in age structure and total population size. Examining the age or size class distribution can also reveal problems, such as a lack of recruitment of young into the

population, or a loss of mature individuals. Again, for this measure, various monitoring and research reports from the park were used (and are described below).

Data Sources

2010 Saguaro Census (O'Brien et al. 2011)

The 2010 Saguaro Census focused on the demographics of the saguaro cactus in the national park. Under the Census, park staff and volunteers collect data on saguaro cacti in 45 plots of 4 ha (9.9 acres) each that were established in both park districts in 1989-1990 by Duriscoe and Graban (1991, 1992). The plots (at least some of them) were surveyed again in 2000 by Turner and Funicelli (2000). The plots in TMD were randomly located, and those within RMD were randomly located in "prime" saguaro habitat (areas that were previously identified as high quality saguaro habitat).

Duriscoe and Graban (1991) measured the heights of all saguaros less than 2 m (6.6 ft) tall on each of the 45 plots (O'Brien et al. 2011). They also estimated the heights of 30 saguaros that were more than 2 m tall, and they used these data to make estimates of the heights of all larger saguaros. Due to differences in resources and goals in 1990, 2000, and 2010, there have been some differences in the types of data collected in the three censuses (O'Brien et al. 2011). For example, in 2010 under the census, park staff and volunteers mapped the distribution of buffelgrass (*Pennisetum ciliare;* a non-native invasive plant) on all 45 plots; this non-native plant will be discussed under a separate indicator/ measure. It is also important to note that in the 2000 Census, saguaros were counted and measured on only 18 of the original 45 study plots (due to limited resources), and the 2010 Census was conducted on 37 plots, with subsamples taken from the remaining eight plots (O'Brien et al. 2011).

Of the 45 plots placed in the park, 25 are in RMD and 20 are in TMD (Figures 4.11.2-1 and 4.11.2-2). In 2010, census-takers followed the methods that had been used in 1990 and 2000. Within each plot, field crews systematically searched for and then counted and measured each saguaro cactus. They measured (for saguaros < 4 m [13.12 ft] tall) or estimated the height (for taller saguaros [using clinometers and metric tape measures]) of all saguaros on each plot.They also counted the number of bird holes and branches on each cactus. Saguaro habitat was classified as "bajada" (the lower slopes of each district, with fine

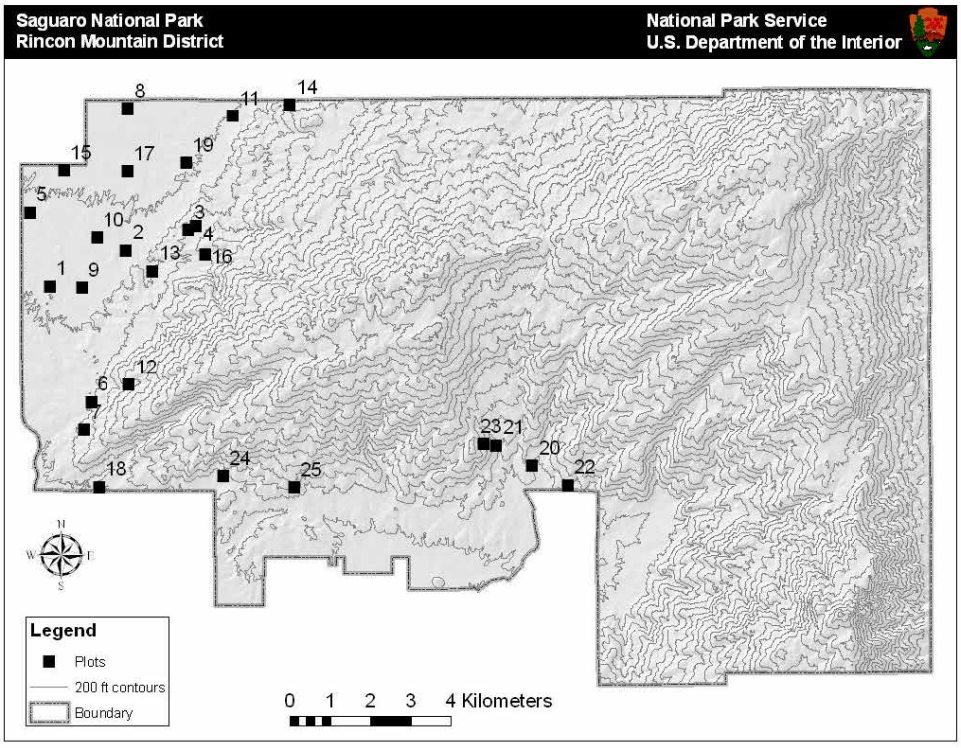

Figure 4.11.2-1. Map showing the 25 sampling plots in RMD used in the Saguaro Census, conducted in 1990, 2000, and 2010. Figure Credit: O'Brien et al. (2011).

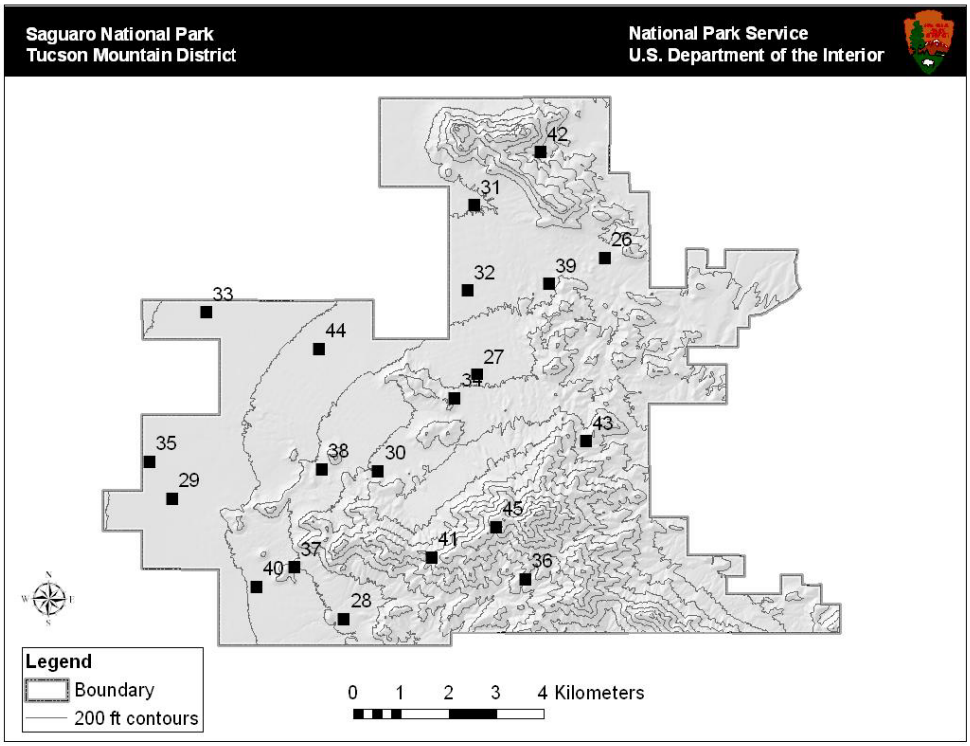

Figure 4.11.2-2. Map showing the 20 sampling plots in TMD used in the Saguaro Census, conducted in 1990, 2000, and 2010. Figure Credit: O'Brien et al. (2011).

soils present); "slopes" (bedrock-dominated steep hills); or "foothills" (intermediate areas with mixed bedrock, boulders, and generally coarse soils).

One-Square-Mile-Section Survey of Saguaros in Section 17 in 1941 and 2011-2012 (Conver et al. 2013)

Conver et al. (2013) surveyed all saguaro cacti in a 1-square-mile section (Section 17) in RMD that had been surveyed originally in 1941. Conver et al. (2013) searched 64 4-ha (9.9-acre) subplots in a systematic fashion to measure each saguaro observed, as well as its location and number of bird holes and branches (Figure 4.11.2-3).

Six 10-acre Plots in Section 17: Surveyed Annually from 1941-Present

Researchers Lake Gill and Paul Lightle (1942) established six 10-acre plots in 1941 in Section 17 (Figure 4.11.2-4). These plots were also later sampled by S.M. Alcorn, and Tom Orum and Nancy Ferguson. For a complete description of the chronology and history of these researchers' efforts, see Ahnmark and Swann (2009). These same six plots have been surveyed annually (except for 1955) since 1942 (Orum et al. 1999, Orum et al. 2016).

During the survey, individual saguaro condition is noted, and searches are conducted for young, previously undetected saguaros (Orum et al. 2016, Ahnmark and Swann 2009). The locations of young saguaros are recorded and their heights are measured. Each year, the heights of all saguaros less than 1.8 m (6 ft) tall are measured, and for those taller, heights are estimated in 1.8 m height classes (with some estimated using a clinometer). At this time, this group of surveys is the longest ongoing effort in the park to monitor saguaro cacti (Ahnmark and Swann 2009). It should be noted that the topography of the study area (Section 17) is relatively flat and very different from rocky slopes east of the loop drive (Orum et al. 1999).

Five-Acre (2-Ha) Plots in both Park Districts: 1941 and 1975 and Later ["Historic" Plots]

Finally, we mention a fourth saguaro monitoring effort here, largely because the data address both RMD and TMD, and because the plots were last sampled recently, in 2014. We describe the history of the plots only briefly here, and refer the reader to Ahnmark and Swann (2009) for a more detailed description.

In the fall of 1941, L. Gill and P. Lightle established six plots in and near the Cactus Forest in RMD. The plots were originally established to study bacterial necrosis (Ahnmark and Swann 2009). They were intended to be studied regularly but were not studied again until 1975 (by W.F. Steenbergh and C.H. Lowe). Steenbergh and Lowe also established one 2-ha (5-acre) plot in TMD in 1971, and they tagged and recorded all saguaros and surveyed the plot annually through 1975. At that time, they established four additional 2-ha (5-acre) plots in TMD. In 2002, C.S. Funicelli and D.S. Turner surveyed all 11 plots again. The 11 plots in both districts of the park were surveyed again by park personnel in 2010 (during the Census) and 2014. Although no reports are available to date on the 2014 re-surveys, some results that were provided by Don Swann (i.e., Swann et al. 2015) are presented in the Condition and Trend section. Additionally, Swann et al. (2011) provides some results from 2010 and earlier. Also note that a report is currently in preparation on the 2014 re-surveys (i.e., Conver et al.; Don Swann, Saguaro NP, pers. comm., February 2016).

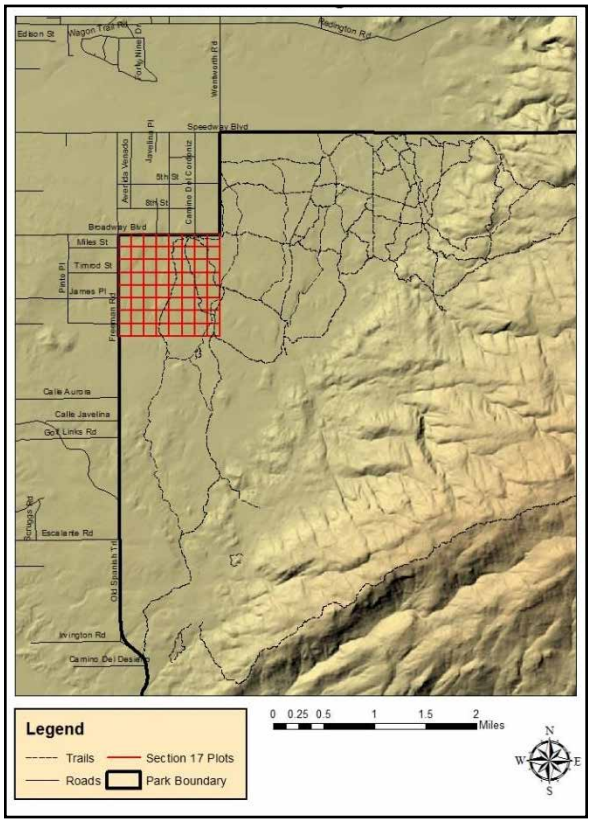

Figure 4.11.2-3. Map showing the location of the 64 4-ha (10-acre) plots in Section 17 surveyed in 1941 and 2011-2012. Figure from Swann et al. (2015).

Other Data and Information Sources

There are a large number of reports on the saguaro cactus in Saguaro NP. We use these various reports as appropriate for this and other indicators in the condtion assessment. Those other reports or studies are described where and as appropriate.

Indicator/Measure

Historic Integrity and Appearance of Saguaro Cacti (Change Over Time)

Historic Integrity and Appearance of Saguaro Cacti on the Landscape

This indicator has one measure, change over time. The idea behind this indicator/measure is to examine whether changes that have occurred in the saguaro cactus population over time (addressed in the first indicator) have led to changes in the appearance and perception (e.g., by park visitors) of saguaro cacti on the park landscape. The park (national monument at the time) was established in 1933 by President Herbert Hoover. The presidential proclamation stated that the park's purpose is to protect for "the public interest" its "outstanding scientific interest because of the exceptional growth thereon of various species of cacti, including the so-called giant [saguaro] cactus." Homer L. Shantz, one-time President of the University of Arizona, stated that "nowhere in the world is there so fine a stand of the giant saguaro (*Carnegiea gigantia*)…" (see McAuliffe 1993, page 7; Figure 4.11.2-5). This indicator/measure focuses on the present-day RMD, particularly the Cactus Forest. The assessment is based on photos taken from the approximate same location in 1935 and 2010. An additional photo (using the 2010 photo as a template) was edited to portray the projected appearance in 2050.

Data Sources

Data/information sources used to assess this indicator/measure are the following photos taken from the same location: a 1935 photo (part of the U.S. Geological Survey [USGS] Desert Laboratory Repeat Photography

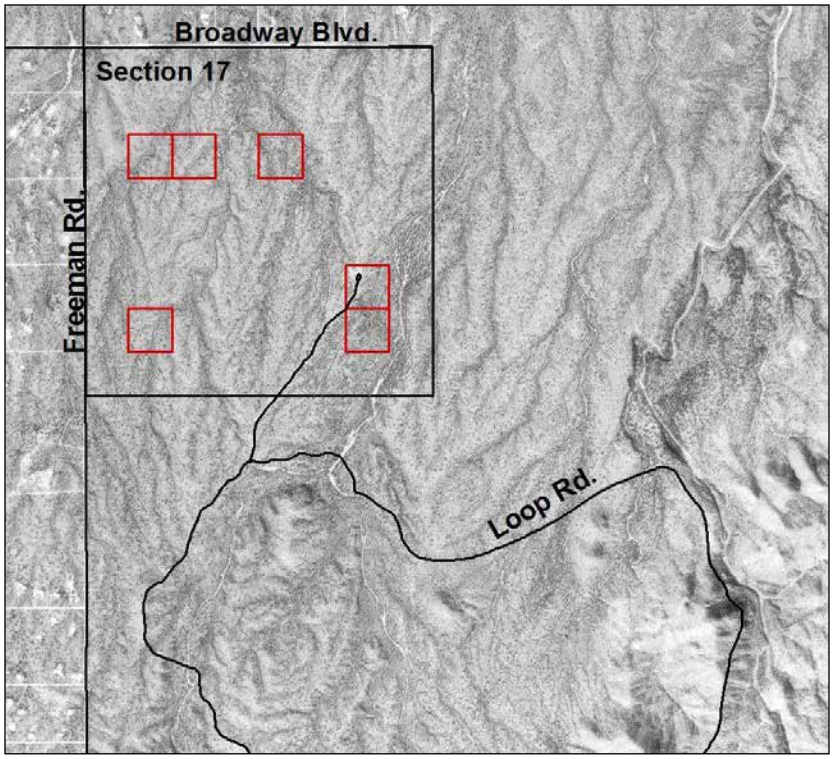

Figure 4.11.2-4. The six 10-acre (4-ha) plots in Section 17 of RMD surveyed annually since 1942. Figure Credit: Swann et al. (2015).

Collection), a 2010 photo (taken by park personnel; Conver and Swann 2013), and a projected photo for 2050 (created by park personnel; Conver and Swann 2013). In addition to the reports used for the previous indicator (which is very much related to this indicator), we primarily used Conver and Swann (2013) for sources of information and assistance in interpretation of the photos.

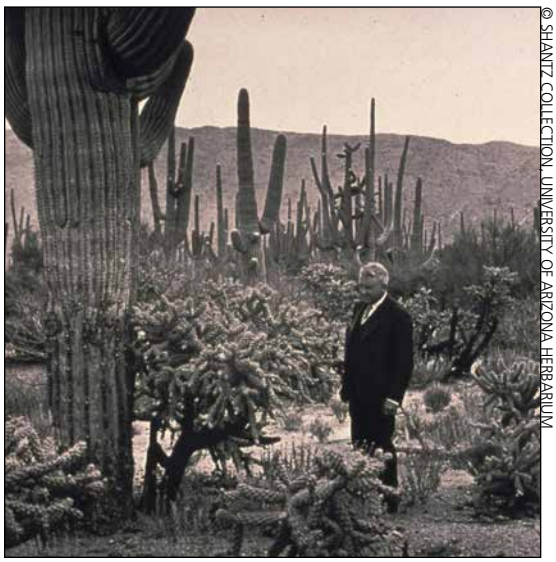

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Figure 4.11.2-5. Photo from 1930 of University of Arizona President Homer R. Shantz in the Cactus Forest in the future RMD of Saguaro NP.

Conver and Swann (2013) compared photos of saguaro cacti in RMD from 1935 and 2010. The authors also produced an image that projects the view of the cactus forest in 2050. To accomplish this, they used observations in the field, saguaro growth models, remote sensing techniques, and Adobe® Photoshop.® For example, they used the 2010 photo as the background, and projected the age and height of saguaros in 2050 using Photoshop. They made four main assumptions (e.g., they did not include placement of any saguaros that might germinate between 2012 and 2050), which are described in Conver and Swann (2013).

Indicator/Measures

Habitat Availability & Quality (Cover of Nurse Plants and Occurrence of Buffelgrass)

Availability (Percent Cover) of Nurse Plants

The saguaro cactus is a very slow-growing plant. For example, a 36-year-old saguaro may only be approximately 1.8 m (6 ft) tall. The survival of saguaro seedlings and small plants is enhanced by nurse plants (e.g., McAuliffe 1993; Figure 4.11.2-6), including shrubs and trees such as yellow palo verde (*Parkinsonia microphylla*), velvet mesquite (*Prosopis velutina*), and creosote bush (*Larrea tridentata*). McAuliffe (1993) described the importance of nurse plants and some of the early studies in the park and elsewhere that revealed the importance of these plants (e.g., Turner et al. 1966, Steenbergh and Lowe 1976, Nobel 1980). Nurse plants ameliorate both low and high temperature extremes (McAuliffe 1993). For example, in RMD, Turner et al. (1966) found that the cover of nurse plants was required for the survival of young saguaros (McAuliffe 1993). Turner et al. (1966) found that even when water was not limited all saguaro seedlings in exposed microhabitats died during the summer months, while seedlings provided with partial shade survived. In some areas (e.g., the rocky slopes at the base of the Rincon Mountains), rocks provide young saguaros with adequate cover (McAuliffe 1993).

Data Sources

This measure of habitat availability and quality was assessed using terrestrial vegetation and soils monitoring data collected and analyzed by the Sonoran Desert Inventory and Monitoring Network (SODN) within both districts of the park (Hubbard et al. 2011a and 2011b, Hubbard et al. 2015). Monitoring data are available for RMD for 2008-2012 and for TMD for 2009-2013. The only component of the data that we used for this measure is that on nurse plants (trees and shrubs), for which cover data are collected in the canopy and subcanopy.

The SODN sampling program at Saguaro NP uses a multi-year sampling strategy in which one-fifth of the monitoring sites (within each district) are sampled in a given year, with all of the plots completed after five field seasons (Hubbard et al. 2011a and 2011b). Within each district, vegetation and soils plots (permanent, 20 x 50-m sampling plots) were established within strata based on elevation and soil type (Figures 4.11.2-7 and 4.11.2-8). Although the overall data collection is much more widespread, data are collected on saguaro cacti and nurse plants only in the rocky bajada (shrubland/wooded shrubland) and non-rocky bajada (shrubland/wooded shrubland) strata in RMD and the rocky bajada (wooded shrubland) and valley-bottom (shrubland/wooded shrubland) strata in TMD. Each bajada stratum ranges in elevation from 2,501 to 3,700 ft, and the valley-bottom stratum is below 2,501 ft in elevation.

NPS

Figure 4.11.2-6. Young saguaro cacti under nurse tree at Saguaro NP.

Vegetation sampling is conducted along six transects within each plot. The vegetation cover of plants is measured using line-point intercept techniques. Along each of the six transects, using the line-point intercept method, vegetation is recorded within three height categories- field (<0.5 m), subcanopy (0.5-2.0 m), and canopy (>2.0 m). For nurse plant cover in the bajada strata, the program uses a reference value, or management assessment point, of 15% cover; if percent

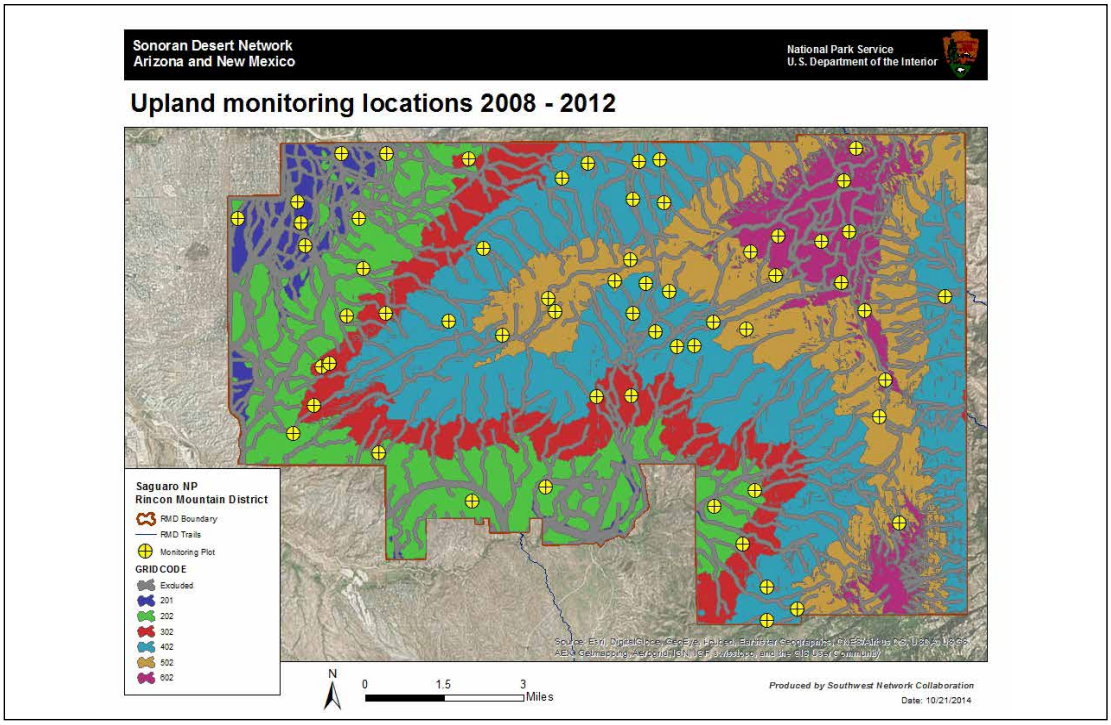


Figure 4.11.2-7. Map showing the upland monitoring locations in RMD. Rocky bajada and non-rocky bajada strata are shown in green and dark blue, respectively. Figure Credit: SODN (2014).

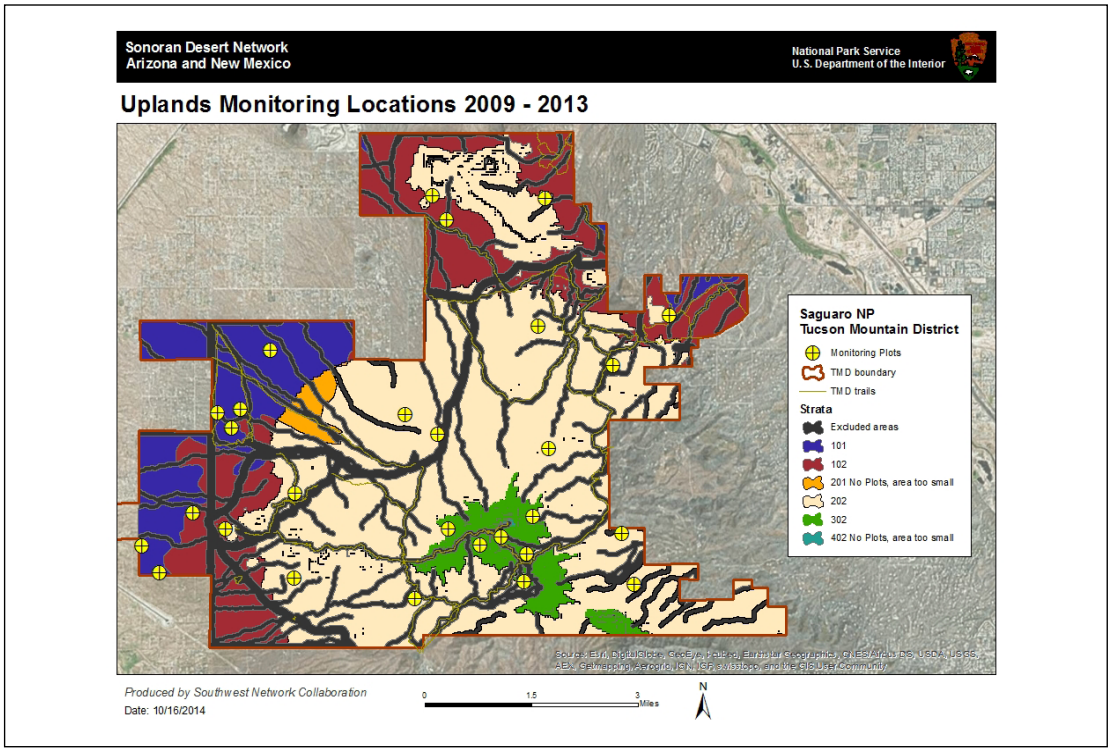


Figure 4.11.2-8. Map showing the upland monitoring locations in TMD. Valley-bottom stratum is shown in blue and red, and rocky bajada stratum is shown in tan. Figure Credit: SODN (2014).

cover is found to be below 15%, park and network scientists and managers will further assess the results and consider options (Hubbard et al. 2015). For the valley-bottom stratum, the reference value or management assessment point used by SODN is 10% cover.

Although not used to assess condition, some interesting information on nurse plants is also available from Orum et al. (2010) from Section 17 of RMD. These researchers found that 21 species of plants served as nurse plants in their study plots. They separated the plants into four categories: trees and large shrubs that provide good cover; trees and shrubs that provide sparse cover; shrubs and cacti that provide minimal cover; and grasses or no nurse plant providing poor cover. Orum et al. (2010) found that more saguaros were found under less protective nurse plants for saguaros germinating between 1979 and 1991 compared to those germinating between 1960 and 1978. A catastrophic freeze separated these two periods, and Orum et al. (2010) suggested that many of the saguaros that germinated under poor cover in the handful of years prior to 1978 may have been killed during the 1978 freeze, while those under good cover (e.g., palo verde and mesquite) survived. Because no freezes occurred between 1978 and 1991, saguaros germinating under cover in the poorer classes survived.

Occurrence of Buffelgrass in Saguaro Habitat

Non-native invasive plants are threats to the ecosystems in which they occur. Buffelgrass (*Pennisetum ciliare*; Figure 4.11.2-9), a perennial grass native to Africa, is a particularly concerning non-native invasive plant with regards to the Sonoran Desert and the saguaro cactus. Where it invades, it alters natural ecological processes, competes with and excludes native plants, alters wildlife habitat, and increases the frequency of wildfires (Saguaro NP 2011). This plant is of significant concern to Saguaro NP managers and other land management agencies in the Southwest. The saguaro cactus is not adapted to fire, and plants do not fare well during fires that burn their habitat. Historically, fire is an infrequent occurrence in the Sonoran Desert, burning about once every 250 years (Saguaro NP 2011). The presence of buffelgrass can potentially lead to more frequent and intense fires in this desert ecosystem. An experimental study in 2008 revealed that buffelgrass fires may burn hotter, have higher flame lengths, and spread faster than previous or more typical desert fires (Saguaro NP 2011).

Buffelgrass was first recorded in the park in 1989, and after recognizing it as a threat, park staff began removing it in 1993 (Saguaro NP 2011). Methods now used to control the plant include hand removal and herbicide applications. As of 2012, there was an estimated 2,000 acres of buffelgrass in the park (Saguaro NP 2011). A recent study looked at the spread of buffelgrass in 11 sites on the south-facing, lower slopes of the Santa Catalina Mountains since 1980. The researchers found that infestations of buffelgrass doubled in size every 2.3 to 7.0 years since 1988 (Olsson et al. 2012).

Because of the substantial threat from this plant to saguaro cacti, we included it as a measure and assessed it using Saguaro NP's GIS data on the known extent of buffelgrass in the park in each district. To examine buffelgrass in relation to saguaros, we used coverages of buffelgrass below 5,000 ft., which included the cumulative extent of buffelgrass across years, in which buffelgrass may be treated or untreated (Dana Backer, Restoration Ecologist, Saguaro NP, pers. comm.). We then overlayed the occurrence of buffelgrass with known saguaro cactus habitat. For TMD, this was the entire district, and for RMD, we used a 1937 map of saguaro cactus occurrence within the district (i.e., from Roseberry and Dole 1939). This 1937 map was also used to select the area within which to conduct the original Saguaro Census in RMD in 1990.

4.11.3. Reference Conditions

Reference conditions for this assessment are shown in Table 4.11.3-1. Reference conditions are described for resources in good, moderate concern, and significant concern conditions for each of the three indicators' five measures.

In addition to the reference conditions described in the table, this section addresses three topics that help provide context for the assessment and aid in its interpretation. These topics are the biology of the saguaro cactus, particularly its life span and maturation time frame, the episodic nature of recruitment, and human activities that occurred in the park prior to and after its establishment that affected the saguaro and its habitat.

Figure 4.11.2-9. Invasion of buffelgrass in saguaro cactus habitat.

Saguaro Cactus Growth and Age

One of the main points to keep in mind for this assessment is that saguaro cacti are long-lived and slow-growing. A 12.2-m- (40-ft-) tall individual is estimated to be about 150 years old, and some individuals live 200 years or more (Steenbergh and Lowe 1983, as cited in Turner et al. 1995 [regarding last statement]). The amount a plant grows in height each year depends upon the plant's size (Turner et al. 1995), site, situation (Steenbergh and Lowe 1977), and genetics. Seedlings may grow as little as 1-2 mm (0.04-0.08 in) per year during their first few years of life. The growth rate then increases dramatically until the saguaro attains sexual maturity at 30-35 years of age (Steenbergh and Lowe 1977). Once plants reach reproductive age, energy is placed into flowering and fruiting, and vegetative growth decreases. The plant produces more fruit as it ages, with up to 100 fruits per year produced by age 50-70. A saguaro may produce its first branches by the same age, and within a few years the new branches may also produce flowers and fruits (Steenbergh and Lowe 1977). Growth rates level off after the saguaro branches. Causes of mortality, once a plant is established, include wind, lightning, fire, catastrophic freezes, and disease.

It also is important to keep in mind that there may be saguaro cacti on the landscape that are not obvious to the casual observer due to the small size of young saguaros and/or the presence of other, taller vegetation.

Nature of Recruitment

For the saguaro cactus, recruitment is described as episodic. It is episodic because

Table 4.11.3-1. Reference conditions used to assess current condition of the saguaro cactus at Saguaro NP.

Indicators	Measures	Good	Moderate Concern	Significant Concern
Saguaro Cactus Population Status / Health	Saguaro Density and/ or Population Count	We consider condition to be good if the density or population level of saguaros has remained approximately the same or increased over time (since the start of monitoring).	We consider condition to be of moderate concern if saguaro density or population level has decreased somewhat over time.	We consider condition to be of significant concern if saguaro density or population level has decreased substantially over time.
	Age (or Size) Class Distribution	We consider condition to be good if age (or size) class distributions are as expected (fairly even-aged), and recruitment into the population is occurring at a rate adequate to maintain the population/stand.	We consider condition to be of moderate concern if saguaro age (or size) class distributions are somewhat off (i.e., not even-aged), and/or recruitment into the population has somewhat decreased.	We consider condition to be of significant concern if age (or size) class distributions are undesirable and/or recruitment into the population/stand is not occurring at a rate high enough to maintain saguaro numbers.
Historic Integrity and Appearance of Saguaro Cacti on the Landscape	Change over Time	We consider condition to be good if changes in saguaro stands in the park maintain the historic (and cultural) integrity and appearance to park visitors.	We consider condition to be of moderate concern if saguaro stand changes at the park deviate somewhat from historic conditions, creating some loss of historic integrity and appearance.	We consider condition to be of significant concern if saguaro stand changes at the park deviate dramatically from historic conditions, creating a substantial loss of historic integrity and appearance.
Habitat Availability and Quality	Cover of Nurse Plants	An adequate supply of nurse plants is available to support young saguaros (and allow for population growth). Condition is good if the percent cover of nurse plants (trees and shrubs in the canopy and subcanopy) is 15% or greater in the bajada strata and 10% or greater in the valley-bottom stratum.	We consider condition to be of moderate concern if percent cover (based on SODN monitoring) is found to be somewhat below 15% for the bajada strata and 10% for the valley-bottom stratum.	We consider condition to be of significant concern if percent cover (based on SODN monitoring) is substantially below 15% for the bajada strata and 10% for the valley-bottom stratum.
	Occurrence of Buffelgrass in Saguaro Habitat	We consider condition to be good if there is no occurrence of the non-native, invasive plant buffelgrass in saguaro habitat in the park.	We consider condition to be of moderate concern if a low level of buffelgrass occurs in saguaro habitat (i.e., a small proportion of saguaro habitat has been invaded), and it is relatively under control.*	We consider condition to be of significant concern if buffelgrass occurs in saguaro habitat in higher numbers/in a greater proportion of saguaro habitat, and/or it is not under control.*

* Control means that the infestation is in a state of maintenance or the invasive plant population is less than five percent cover Dana Backer (Restoration Ecologist,Saguaro NP).

recruitment is influenced by climatic (and other) conditions, such as sufficient moisture, mild winters, and the presence of nurse plants, that vary over time (see summary in Pierson et al. 2013). This episodic recruitment leads to large fluctuations in age structure and population size on relatively long time scales (e.g., decades or longer; Pierson et al. 2013). The time period between significant recruitment events may even be as long as the human lifespan (Pierson and Turner 1998, Pierson et al. 2013).

Human Activities in the Vicinity of the Park

McAuliffe (1993) summarized land use in the vicinity of Saguaro NP prior to it being established as a national monument, and he addressed the importance of understanding how the use of the land affected the saguaro. McAuliffe (1993) wrote:

> "The forest of giant, many-branched saguaros that was present at the base of the Rincon Mountains in the 1930s represented reproduction that had occurred long in the past. In addition, the rarity of younger saguaros within

> the University Cactus Forest at the time the monument was founded suggest environmental changes in the half-century preceding 1933 that greatly affected the establishment of young saguaros. A comprehensive understanding of the saguaro population decline that began about 1940 requires a knowledge of the types of impacts that had been occurring for at least a half century prior to 1933."

McAuliffe (1993) provided a history of ranching activities in the area, which started in the late 1800s and continued through the middle of the 1900s. While settlement and ranching activities occurred along Tanque Verde and Rincon Creeks below the west and southwest slopes of the Rincon Mountains, the same land use did not occur in the vicinity of the future TMD (McAuliffe 1993). Because this area lacked perennial surface water, it escaped the impacts of heavy grazing that occurred in RMD.

The history of cattle grazing in RMD was also addressed in Pinto (2013). This document addressed cattle grazing through the mid-1980s and provided an overview of the factors "that affected range and park management and some of the efforts to document the long-term consequences of cattle grazing" in the park (Pinto 2013).

Another land use impact on the future RMD was several decades of heavy woodcutting. Trees, such as mesquite, were cut for domestic use and for fuelwood for local lime manufacturing. McAuliffe (1993) also wrote:

> "The more than 50 years of heavy use of the saguaro forest area and the maturity of the saguaros set the trajectory of decline in the saguaro population that was to follow for more than a half century after the establishment of the monument."

4.11.4. Condition and Trend

Saguaro Cactus Population Status / Health

Saguaro Cactus Density and/or Population Size

As discussed in the Data and Methods section, this measure was assessed using the several main data sources for saguaro cactus densities/populations at the national park, as well as updates (e.g., personal communications) since the last reports from the primary data sources.

Results from the Saguaro Census, 1990, 2000, and 2010: O'Brien et al. (2011) presented results from the 2010 Saguaro Census and summarized trends based on the 1990, 2000, and 2010 censuses. The authors presented information on several important aspects of the saguaro cactus monitoring, but we focus here on results of cactus counts and densities.

O'Brien et al. (2011) observed more saguaros on the study plots, especially young saguaros (described more in the second measure), in 2010 than were observed in 1990 and 2000. In RMD, the number of saguaros observed on the plots in 2010 increased by 60.0% since 1990 and 40.7% since 2000. In TMD, the number of saguaros in 2010 increased 67.4% since 1990 and 10.3% since 2000. Table 4.11.4-1 shows the Saguaro Census results, as well as the estimated number of saguaros (i.e., population estimates) in the park and in each district. O'Brien et al. (2011) used the same method as Turner and Funicelli (2000) to estimate the number of saguaros park-wide and district-wide. Based on these estimates, the number of saguaros in the park in 2010 was 1,896,030 (228,163 SE), up from an estimated 1,145,784 (125,024 SE) in 1990; this represents an increase of 65.5% over the 20-year period. This increase in the number of saguaros has occurred across all habitat types (i.e., bajada, foothills, and slopes [Figure 4.11.4-1]; O'Brien et al. 2011). As described in more detail under the next measure, the increase is primarily due to an increase in the number of saguaros in the height classes between 0.1-1.99 m (0.33-6.53 ft); the authors point out that this was the first time that large numbers of small cacti were recorded. In summary, from this study,

Table 4.11.4-1. The numbers of saguaros observed, densities, and population estimates from the Saguaro Census in 1990, 2000, and 2010.

Year	District	# Saguaros Observed	# Plots Surveyed	Total Hectares Surveyed	Density (SE): # Saguaros/ha	Estimated # of Saguaros (Standard Error)
1990 (45 plots)	RMD	5,706	25	100	57.1 (10.7)	299,736 (56,139)
	TMD	6,716	20	80	84.0 (12.0)	846,048 (121,307)
	Total	**12,422**	**45**	**180**	**70.5 (8.2)**	**1,145,784 (125,024)**
2000 (18 plots)	RMD	2,335	9	36	64.9 (12.9)	340,715 (67,729)
	TMD	4,587	9	36	127.4 (25.1)	1,284,105 (252,456)
	Total	**6,922**	**18**	**72**	**96.1 (15.6)**	**1,624,821 (239,631)**
2010 (45 plots)	RMD	9,127	25	100	91.3 (19.2)	479,441 (100,753)
	TMD	11,245	20	80	140.6 (22.4)	1,416,589 (225,546)
	Total	**20,372**	**45**	**180**	**112.7 (14.9)**	**1,896,030 (228,163)**

Table from O'Brien et al. (2011, Table 2, with minor modifications).

saguaro numbers were at their relative highest in 2010 (compared to 1990 or 2000).

Results from 1941 and 2011-2012 Surveys within 1-Square Mile in Section 17: The surveys in 1941 and 2011-2012 only occurred in Section 17, which is within the northwest corner of RMD (just north of Cactus Forest Loop Road). The number of individual saguaro cacti counted in the 1941 survey was 13,304, while that counted in the 2011-2012 survey was 9,023 (Conver et al. 2013). This represents a 31.4% decrease in the number of saguaros over the 70-year period. On a per plot basis, the range of saguaros was similar for the two time periods, but the average number of saguaros was lower in 2011-2012: 144.1 saguaros in 2011-2012, compared to 205.4 in 1941. Changes in the age/height composition over the 70-year period are discussed under the second measure for this indicator.

Results from Six 10-acre (4-ha) Plots in Section 17 Surveyed Annually from 1941-Present: One of the outcomes of this monitoring is evidence that saguaro mortality is strongly height/age dependent (Orum et al. 1999, Orum et al. 2016). In 1999, these authors reported that 58% of the original (1942) Class 1 population (those cacti 0-6 ft tall) were still alive in 1998, compared with 26% of the original Class 2 (6-12 ft)

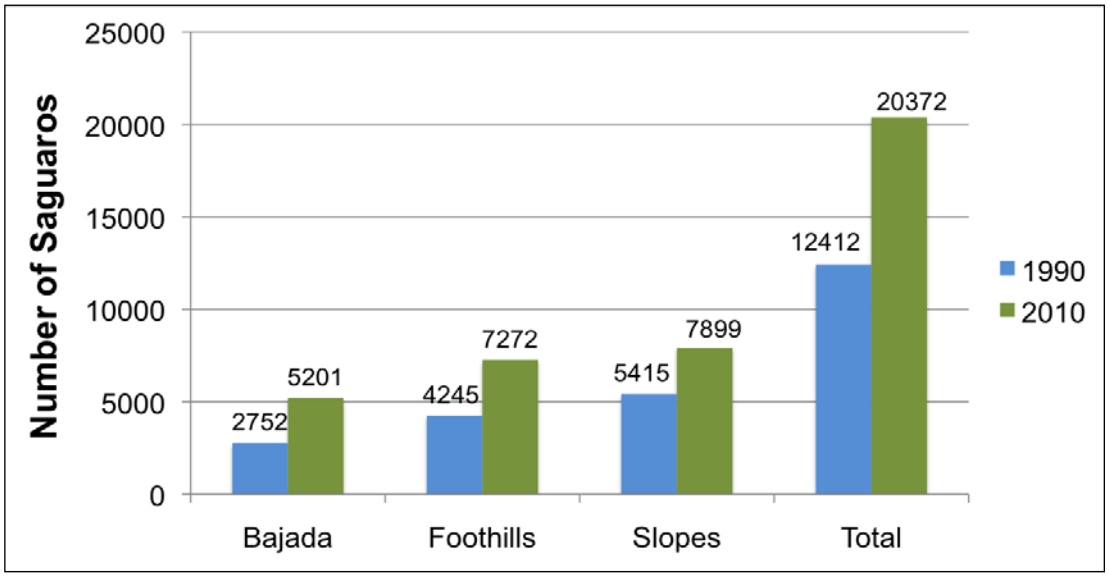


Figure 4.11.4-1. The number of saguaros counted on 45 plots, showing distribution across major habitat classifications. Figure Credit: Adapted from O'Brien et al. (2011).

population, 11% of the original Class 3 (12-18 ft) population, and 2% of the original Class 4 (18-24 ft) population. None of the Class 5 saguaros were still alive in 1998. This study is also valuable for its data on recruitment and age structure of the saguaro population, which are discussed under the next measure for this indicator.

Eleven Five-Acre (2-Ha) Plots in both Park Districts, 1941 and 1975 and Later: As previously noted, these "historic plots" were surveyed in 1941, 1975, 2002, 2010, and 2014. The saguaro population in RMD declined between 1941 and 1975, but increased substantially since 1975 (Swann et al. 2011). The population in TMD also increased since 1975. In 2010, a total of 2,612 saguaros were observed on the 11 plots (Swann et al. 2011). Data from these plots for 1975 and 2014 are shown in Figure 4.11.4-2.

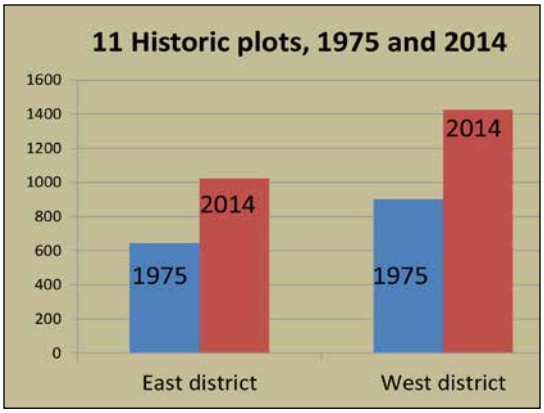


Figure 4.11.4-2. Increase in population size from 1975 to 2014, as observed in 11 "historic plots" in RMD (left) and TMD (right). Figure Credit: Swann et al. (2015).

Age (or Size) Class Distributions

We used the same data and information sources for this measure as we used for the last measure.

Results from the Saguaro Census, 1990, 2000, and 2010: As noted previously, the 2010 Saguaro Census revealed that young saguaros (in the 0.1-1.99-m height classes) were largely responsible for the overall increase in the number of saguaros recorded in 2010 (O'Brien et al. 2011). In both districts of the park, the number of saguaros in the smallest size class measured (0.1-0.99 m) was much greater than in the other size classes (e.g., Figure 4.11.4-3 for RMD). Of the saguaros measured in the park plots in 2010, about 62% were < 2 m (6.6 ft) in height. Also, while the number of saguaros in the two smallest size classes measured increased from 1990-2010, the number of those in the taller size classes (greater than or equal to 3 m [9.8 ft] in height) generally changed little over the 20-year period (see Figure 4.11.4-3).

O'Brien et al. (2011) also presented a graphic of the age structure of the saguaro population at the national park for saguaros >10 cm (3.9 in) in height based on a growth model developed by Steenbergh-Lowe). The analysis indicates that the population is skewed toward younger individuals, with the most numerous being 17 to 24-year-old saguaros (Figure 4.11.4-4). These 17 to 24-year-olds would have germinated in the late 1980s and early 1990s (O'Brien et al. 2011).

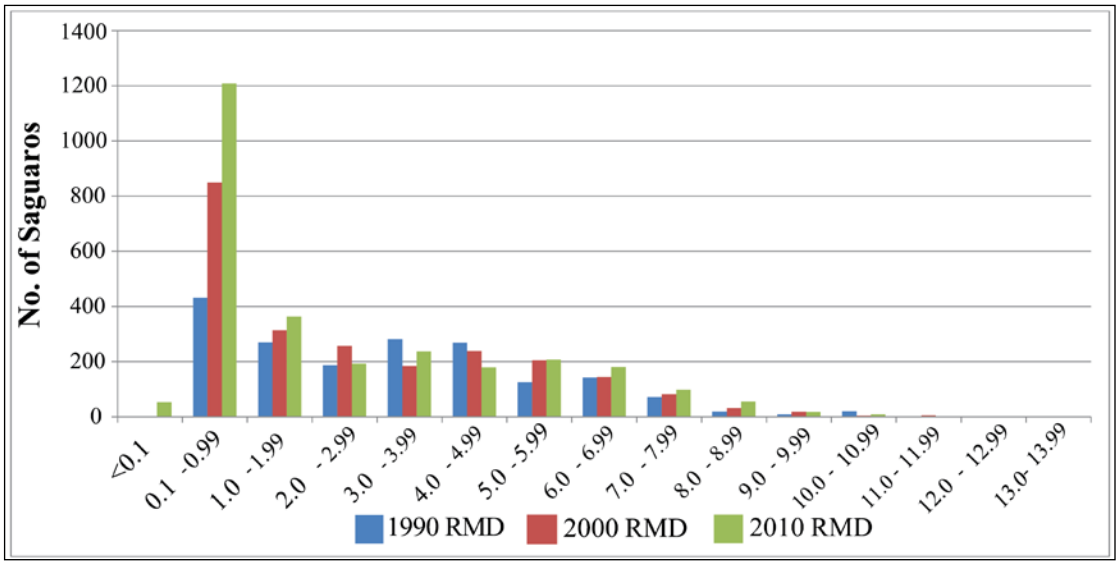


Figure 4.11.4-3. Saguaro cactus size distribution in RMD for all 18 plots surveyed in 1990, 2000, and 2010. Figure Credit: O'Brien et al. (2011).

Based on the Census data and using models for growth rates (Steenbergh and Lowe 1983) and detection probability (Orum et al. 2016), the researchers made inferences about recruitment during the past few decades (O'Brien et al. 2011). Their analysis suggestsed that there was a "surge" in the survival of germinating saguaros that started in the 1960s, peaked in the early 1990s, and slowed in more recent years (especially from the mid-1990s to the mid-2000s; O'Brien et al. 2011). This increase in recruitment, and its likely causes, are discussed in the indicator summary section below.

O'Brien et al. (2011) wrote "If survival of these young saguaros continues to be high, the number of mature plants visible to park visitors should explode in the coming decades as they increase in height, push through the shrub and tree canopy, and grow branches."

Results from 1941 and 2011-2012 Surveys within 1-Square Mile in Section 17: The age/height composition of the population within Section 17 changed from 1941 to 2011-2012 (Conver et al. 2013). The population in 1941 was dominated by older, taller individuals (Gill and Lightle 1942, Steenbergh and Lowe 1983, Conver et al. 2013; Figure 4.11.4-5). In 1941, 80% of the saguaros were taller than 3.66 m (12 ft), which, based on estimates, would have made them more than 50 years old (Table 4.11.4-2). In 2012, the shortest height class (<1.8 m [~6 ft]) accounted for 57.1% of the total population (and 80% of the population was less than 3.66 m (12 ft) tall. This means that the majority of the current population is younger than 36 years old (Conver et al. 2013, Table 4.11.4-2). These saguaros (36 years old and younger) were established in the park in 1976 or later (Figure 4.11.4-6). As also observed by O'Brien et al. (2011), trends in saguaro establishment over the past 30 years indicate a decrease in recruitment starting in the 1990s (see Figure 4.11.4-6, and Figure 4.11.4-7 for saguaros parkwide). From this Section 17 study, the authors reported a peak in saguaro recruitment in the mid-1980s, when approximately 400 saguaro cacti germinated in one year alone.

Results from Six 10-acre Plots in Section 17 Surveyed Annually from 1941-Present: Very few new, young saguaros were detected in the study plots during the first 25 annual surveys, but this started to change in the mid-1960s (around the end of cattle grazing in the cactus forest; Orum et al. 2016). Orum et al. (2010) also discussed the shift in the age structure of the saguaro population within the study plots in RMD since 1942. A graphic from Orum et al. (2010) shows this change (Figure 4.11.4-8).

Other Results: O'Brien et al. (2011) reported that a hard freeze occurred on February 2-4 in 2011 in the Tucson area (the first one since 1978), and that there was evidence that some mortality of saguaros had occurred. According to a National Oceanic and Atmospheric Administration (NOAA) website (http://www.wrh.noaa.gov/twc/climate/monthly/feb11.php), the temperatures were some of the coldest ever recorded in Tucson: "the lows...of 18°F (-7.8°C) on the 3rd and 4th were not only their coldest February temperatures on record but only 2°F (1.1°C) away from their all time low." Researcher Tom Orum later reported to the park that on the plots he monitors in Section 17, saguaros that were more than 80 years old experienced a 36% mortality rate. In contrast, only 2% of saguaros younger than 80 years old died (Don Swann, Biologist, Saguaro NP, pers. comm.).

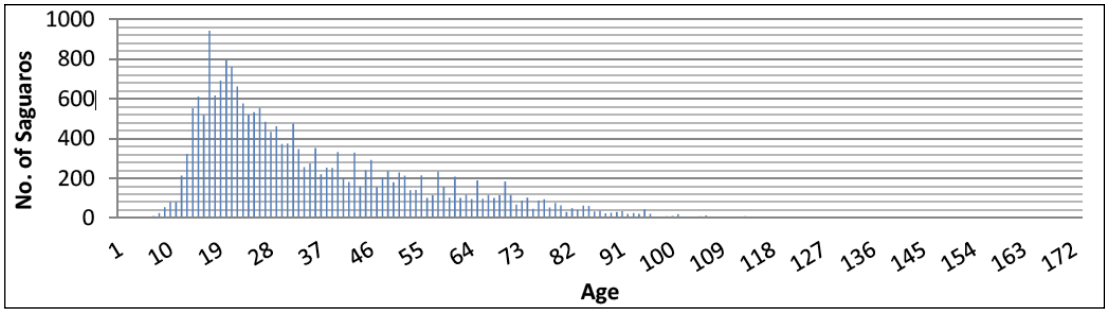


Figure 4.11.4-4. Age structure for all saguaros observed on 45 plots during the 2010 Saguaro Census. Figure Credit: O'Brien et al. (2011).

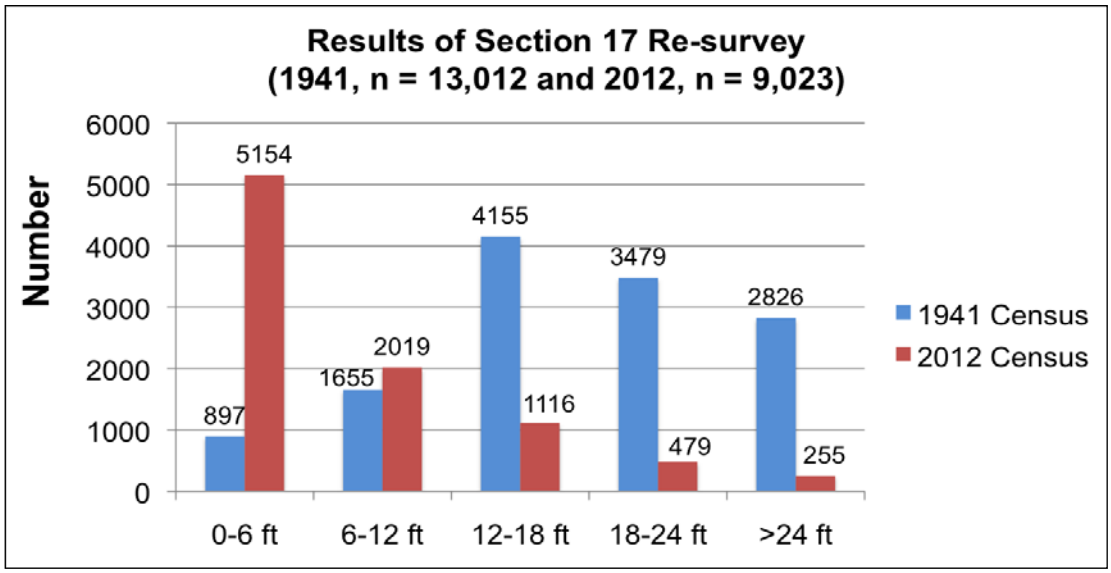


Figure 4.11.4-5. Results from Conver et al. (2013) showing the number of saguaros in each height class in the Section 17 survey in 1941 and 2011-2012. Figure Credit: Adapted from Conver et al. (2013).

Summary and Condition for Saguaro Cactus Population Status / Health

The reasons for the population decrease (since 1941) and later increase of saguaros in RMD are not clear (Swann et al. 2011). However, the decrease is thought to have been caused by wood-cutting and cattle grazing, along with cold temperatures and drought in the mid-1900s (McAuliffe 1993, as cited by Swann et al. 2011; O'Brien et al. 2011). The subsequent increase in young saguaros may be related to an end of wood-cutting and cattle grazing, along with warmer winter temperatures and wetter conditions since the 1970s (Swann et al. 2011, O'Brien et al. 2011). Results of saguaro cactus monitoring in the park point to high recruitment during the 1970s and into the early 1990s throughout the park (Swann et al. 2011, O'Brien et al. 2011).

However, as previously discussed, recruitment has declined over the past few decades during a period of drier conditions (Swann et al. 2011). Conditions were particularly dry, for example, during 2005-2006, and many plants showed evidence of having been chewed on by rodents seeking moisture (O'Brien et al. 2011); lower recruitment in this period was observed in the data from the 2010 Census. The next Census in 2020 will provide information on more recent recruitment. Given that saguaro recruitment is episodic by nature (e.g., Pierson et al. 2013), and recruitment had been relatively high for a number of years in the 1970s-early 1990s, we have no particular concern over recruitment at this time, although park staff continue to monitor the situation until a longer period of recruitment can be observed.

With regards to current condition under the saguaro cactus density/population level measure, we consider condition to be good. Based on population estimates from the three Censuses, the number of saguaros in the park in 2010 was 1,896,030 (228,163 SE), up from an estimated 1,145,784 (125,024 SE) in 1990- an increase of 65.5% over the 20-year period.

Table 4.11.4-2. Height class definitions used in 1941 and 2011-2012, and corresponding ages based on a model from Steenbergh and Lowe (1983).

Height Class	Height in Feet	Height in Meters	Age
1	0-6	0-1.8	0-36
2	6-12	1.8-3.66	37-52
3	12-18	3.66-5.49	53-68
4	18-24	5.49-7.32	68-85
5	24+	7.33+	85+

Table from Conver et al. (2013, Table 1).

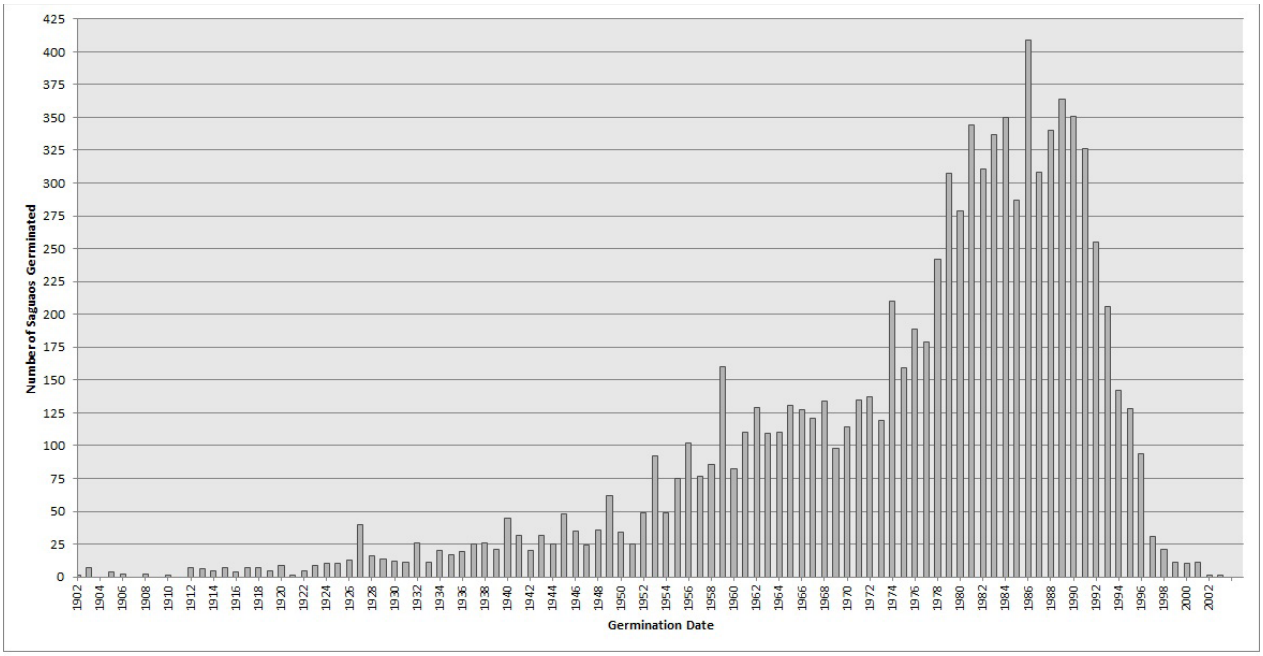


Figure 4.11.4-6. The estimated date of germination for every saguaro in Section 17 measured during the 2012 census. Figure Credit: Conver et al. (2013).

Monitoring over the longer term within Section 17 of RMD indicated that the number of individual saguaro cacti counted was lower in the 2011-2012 survey compared to the 1941 survey (a 31.4% decrease in the number of saguaros over the 70-year period). Data from the eleven "historic" plots indicated that the saguaro population in RMD declined between 1941 and 1975, but increased substantially since 1975 (and through 2014). The population at TMD also increased from 1975 to 2014 (the plots in this district were not sampled in 1941). Although the saguaro population was in decline around the time that surveys started in RMD in the early 1940s, the population has increased in more recent years, and based on our reference conditions for this measure, we consider condition to be

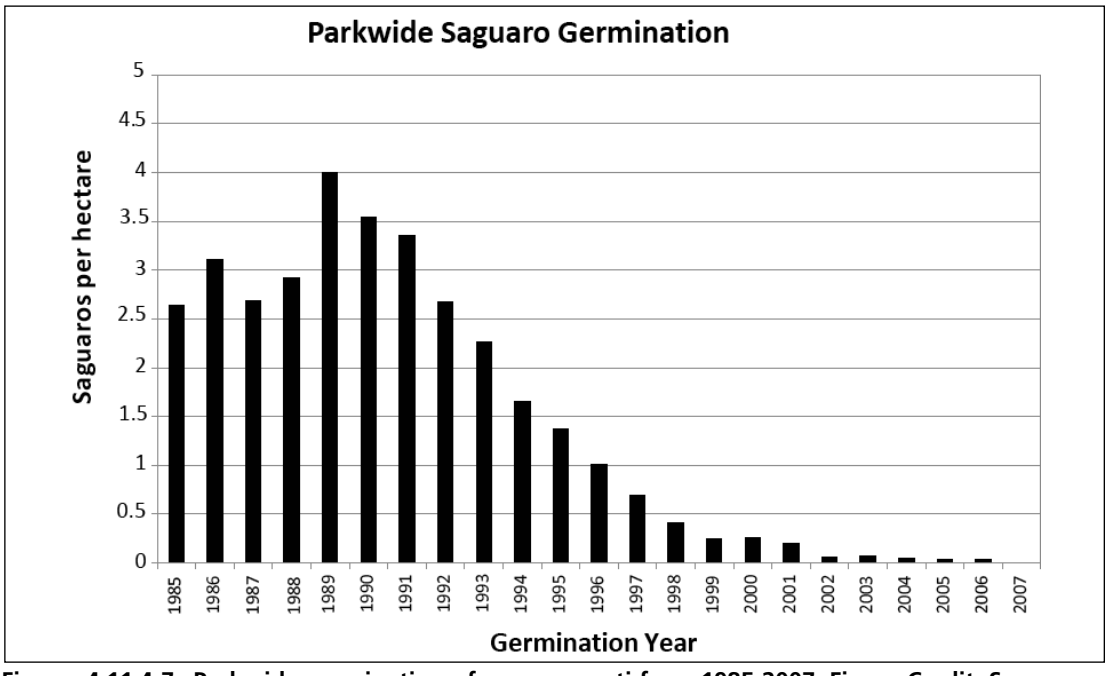


Figure 4.11.4-7. Parkwide germination of saguaro cacti from 1985-2007. Figure Credit: Saguaro NP.

good. Although the population apparently decreased since monitoring first started in the early 1940s, the population in both districts has experienced substantial increases since the 1970s (e.g., historic plots) and 1990s (Censuses).

Due to the surge in recruitment from the 1970s to the early 1990s, both districts of the park now have a large number of young saguaro cacti. Even with a decrease in recruitment over the past several years, it is unclear at this time how long that decrease in recruitment will last. Over the more recent history of the park, we consider the trend for this measure to be increasing.

With regards to the age class/height class distribution measure, we consider current condition to be of moderate concern. For the first many years (at least 25 years) of the annual monitoring in Section 17 of RMD, there was almost no recruitment of young saguaros. Due to the surge in recruitment from the 1970s to the early 1990s, however, in both districts of the park, there are now a large number of young saguaro cacti. As discussed in the above sections, the structure of the population has changed substantially, at least within the Cactus Forest, with the population in the 1940s being dominated by tall, mature saguaros, and that at the present time are being dominated by shorter, younger saguaro cacti. For example, based on the estimates of O'Brien et al. (2011) for saguaros > 10 cm (3.9 inches) tall, the age group with the most individuals was the 17-24-yr-old group. Based on the work of Conver et al. (2013) and their predecessors in the 64 plots in Section 17, 80% of the population in that area in 1941 consisted of saguaros taller than 3.66 m (12 ft), which based on the estimates, would make them more than 50 years old. By 2012, however, 80% of the population was shorter than this height and younger than 50 years old, with 57.1% being shorter than 1.8 m (6 ft), therefore, younger than 36 years old. Results of the annual monitoring also showed this substantial change in the structure of the population in RMD from 1942 to 2010.

Given the low recruitment for the approximate first half of the 20th century, it is not surprising that there are not a greater proportion of taller, mature saguaros at the present time. It is also not surprising that the population is dominated by shorter, younger saguaros given the high levels of recruitment in the 1970s-early 1990s. Although it is positive that there are so many young saguaros that established during the years conducive for germination, and that the population has recovered from the likely effects of land management activities (i.e., wood-cutting and cattle grazing), the current age/height structure of the park's population is skewed towards younger and smaller saguaro cacti. In general, a more even-aged population structure would be desirable.

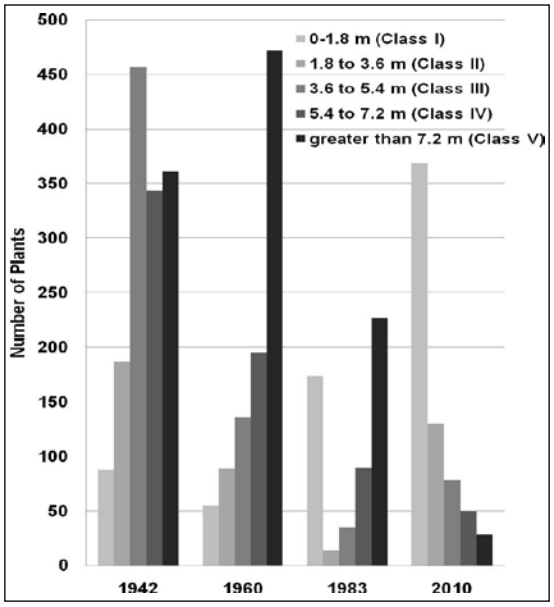


Figure 4.11.4-8. Demographic change in the Cactus Forest since 1942 from the annual monitoring of six 10-acre plots in Section 17 of RMD. Figure Credit: Orum et al. (2010).

It will also be of great interest to park biologists to see how long the recent down-turn in recruitment will last. The coming years of saguaro monitoring, such as the Census in 2020 and the annual monitoring in Section 17, will provide more information on present-day recruitment. Based on the available information at this time, we consider the trend under this measure to be increasing, as the age/size class distribution becomes somewhat more even-aged.

Historic Integrity and Appearance of Saguaro Cacti on the Landscape

Although the basis for the measure is one set of photographs taken at the same location, the location is an historically significant one, the

Cactus Forest in RMD. This area is significant from an historic and scientific perspective, as well as from the visitors' perspective since the view along Cactus Forest Loop Road has been popular for many years.

The view of the saguaros in this area in 2010 had changed considerably from the view in 1935 (Figure 4.11.4-9). As shown in the top, black and white photo, in 1935 there was a large number of mature saguaro cacti in the area. There was also a very sparse coverage of shrubs (Conver and Swann 2013). In 2010, there were many fewer saguaros visible in the Cactus Forest, and the coverage of shrubs and trees had increased. The changes observed in the density/population level of saguaros and in recruitment were discussed previously. We know, based on the information presented under the previous indicator, that the population is recovering (with many young saguaros present). Given the saguaro's long lifespan and slow growth, it will take a considerable amount of time for the area to reach a comparable appearance to that in 1935. The 2050 projection photo shows that, compared to the 2010 photo, a higher number of saguaros will be visible above the shrubs in an additional 40 years (Conver and Swann 2013).

We consider condition under this indicator/measure to be good to moderate concern, with an improving trend. The decline in the number of larger, mature saguaros was documented as early as the 1940s, and more recent estimates of recruitment for the 1900s showed low recruitment during the first half of the 20th century. Although the current appearance of the Cactus Forest may not reveal the recovery, there has been an increase in the saguaro population park-wide since the dramatic increase in recruitment starting around the 1970s. With time, the views will more closely approach the appearance seen in the days of the park's establishment, but the view may never again be as dramatic as it was in 1935 in the near-absence of trees. With the continued protection and management of the saguaro cactus and its habitat, the historic value and history of research are maintained. Visitor education of the saguaro cactus lifespan, growth, and recovery should help visitors understand more fully the changes that have occurred and are occurring within the national park.

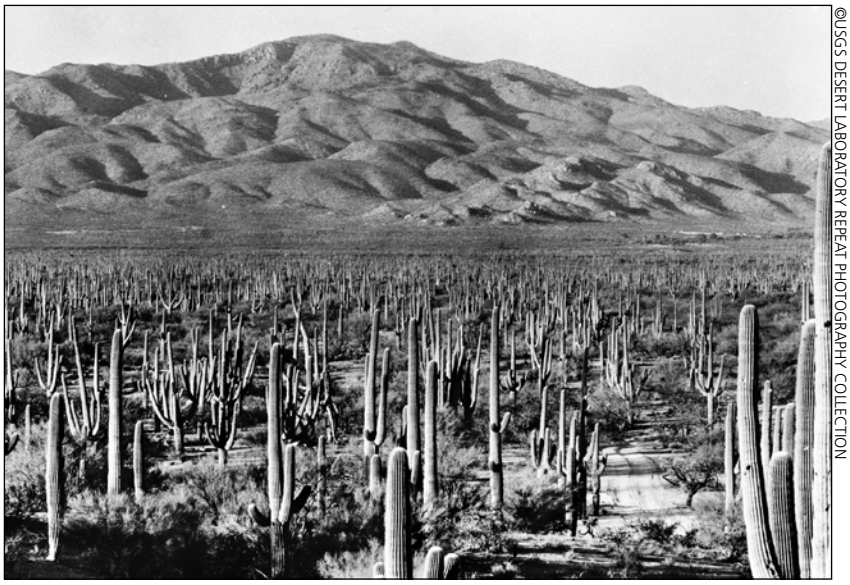
Habitat Availability & Quality

Availability (Percent Cover) of Nurse Plants

The data from 2008-2012 for RMD and 2009-2013 for TMD for nurse plants in the bajada strata (2,501-3,700 ft) indicate that the cover of nurse plants is currently good (Table 4.11.4-3). For the three areas monitored (one in TMD and two in RMD), the percent cover values were above the reference level of 15%. When percent cover is below 15%, SODN suggests that park and network managers should further assess the results. Based on the levels recorded, which ranged from 19.2% in RMD rocky bajada to 24.2% in RMD non-rocky bajada), we consider condition to be good. For the valley-bottom stratum, the cover of nurse plants was closer to the reference value of 10% (i.e., 11.7% ± 3.4%); the percent cover of nurse plants in the valley-bottom stratum may warrant discussion by SODN and park managers. Overall, however, we judge this measure to be in good condition, but no information is available at this time to report trends. However, as SODN continues the annual monitoring at the park, such information should be available in the future.

Occurrence of Buffelgrass in Saguaro Habitat

Overlaying the known occurrence of buffelgrass with the area mapped as saguaro cactus habitat for RMD (based on the 1937 map from Roseberry and Dole [1939]) and the entire TMD, we created Figures 4.11.4-10 and 4.11.4-11. In RMD, buffelgrass is known to occur in approximately 1,221 acres of the 9,973 acres of the area mapped as saguaro habitat, or 12% of saguaro habitat in the district. In TMD, buffelgrass is known to occur in 507 acres, or 2% of the district (virtually all of which is potential saguaro cactus habitat). If we were determining a condition separately for each district, we would assess condition of buffelgrass occurrence in saguaro habitat to be of moderate concern in TMD based on our reference conditions, even though 2% is a relatively small proportion. This is because buffelgrass is very difficult to control and poses substantial ecological threats to saguaros and their habitat. Also, the estimate of 507 acres



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NPS

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Figure 4.11.4-9. Photos showing the Cactus Forest in RMD: 1935 (top) and 2010 (middle), and a projection of appearance in 2050.

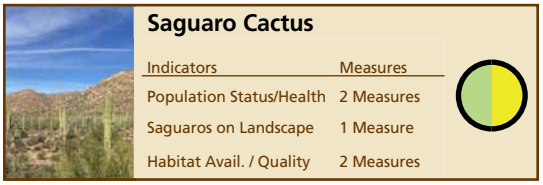
Table 4.11.4-3. SODN terrestrial vegetation and soils monitoring data for percent cover of saguaro cactus nurse plants.

District	Stratum Name	Proportion of Stratum Relative to District	Nurse Plant Cover (%) (and Standard Error)
RMD	Rocky Bajada	14%	19.2% (± 3.3%)
RMD	Non-rocky Bajada	2%	24.2% (± 5.6%)
TMD	Rocky Bajada	45%	19.5% (± 2.0%)
TMD	Valley-bottom	23%	11.7% (± 3.4%)

Data are for both districts for the bajada stratum (2,501-3,700 ft) and the valley-bottom stratum (<2,501 ft; Hubbard et al. 2015).

is a minimum value, as not all of the park has been surveyed for the plant. The occurrence of buffelgrass in RMD is higher, and based on our reference conditions, we consider condition to be of moderate to significant concern. Again, because of the threat that this non-native invasive plant poses, we consider the overall condition under this measure to be of moderate to significant concern.

Park staff are maximizing the resources to monitor and treat buffelgrass. They have been successful at minimizing the infestation to maintenance levels in some areas of the park. In these areas, buffelgrass is <1% cover, and no longer poses a direct threat to competition or an indirect threat to carrying fire. At the same time, untreated areas continue to grow and new patches of buffelgrass are becoming established (Dana Backer, Restoration Ecologist, Saguaro NP, pers. comm.). Therefore, we consider trend to be variable across space (i.e., improving in some areas and decreasing in other areas).



Overall Condition

To assess the condition of the saguaro cactus at Saguaro NP, we used a variety of indicators/measures that were not mutually exclusive but were intended to be different ways of capturing the essence of what we thought represented the condition of this iconic plant in the park. A summary of how the indicators and measures contributed to the overall saguaro condition is summarized in Table 4.11.4-4.

Based on the measures, and the information and data available, we consider the overall condition of the saguaro cactus at the park to be in good to moderate condition. Of the five measures, two were assessed to be in good condition- saguaro cactus population level, and cover of nurse plants. One was assessed to be of moderate concern (age [or size] class distribution; but with an improving trend). For the other two measures, one, change over time in historic integrity and appearance on the landscape, was considered to be in good to moderate condition, (with an improving trend), and one, the occurrence of buffelgrass in saguaro habitat, was considered to be of moderate to significant concern (with a trend that varies spatially). Although the estimated occurrence of buffelgrass in saguaro habitat is not particularly high overall (12% in RMD and 2% in TMD), this non-native invasive species represents a substantial threat to the saguaro cactus and its habitat.

Level of Confidence/Key Uncertainties

Overall, our confidence in this assessment is high. However, as is often the case, there are some uncertainties. One of the main uncertainties for the assessment is the actual extent of buffelgrass occurrence in saguaro cactus habitat. The figures used in this report represent the park's best estimate based on areas surveyed or monitored in the park for treatment purposes, but not all areas have been surveyed for the plant. Another area of uncertainty is the relatively recent down-turn in saguaro cactus recruitment observed starting in the 1990s. Park biologist Don Swann (pers. comm.) and the author of this assessment believe it is too soon to determine the significance of the decrease, and saguaro

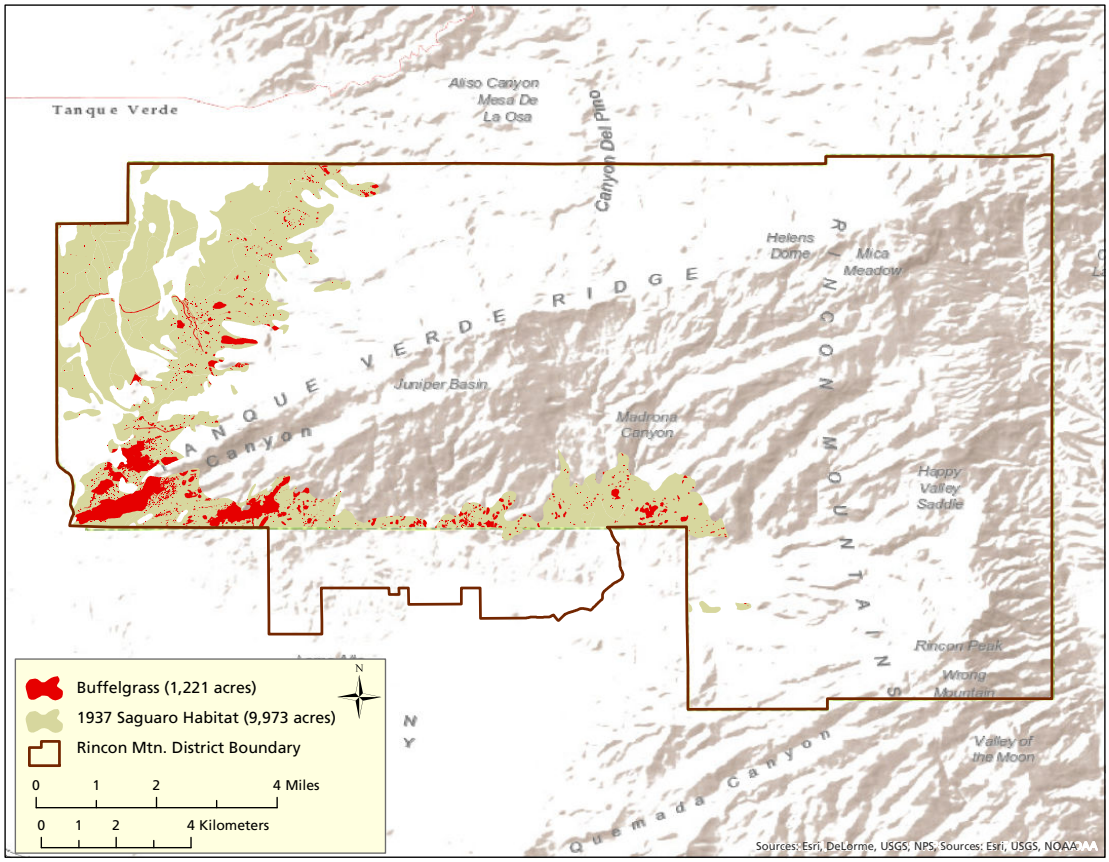


Figure 4.10.4-10. The extent of buffelgrass in saguaro cactus habitat in RMD through 2015. Data Source: Saguaro NP.

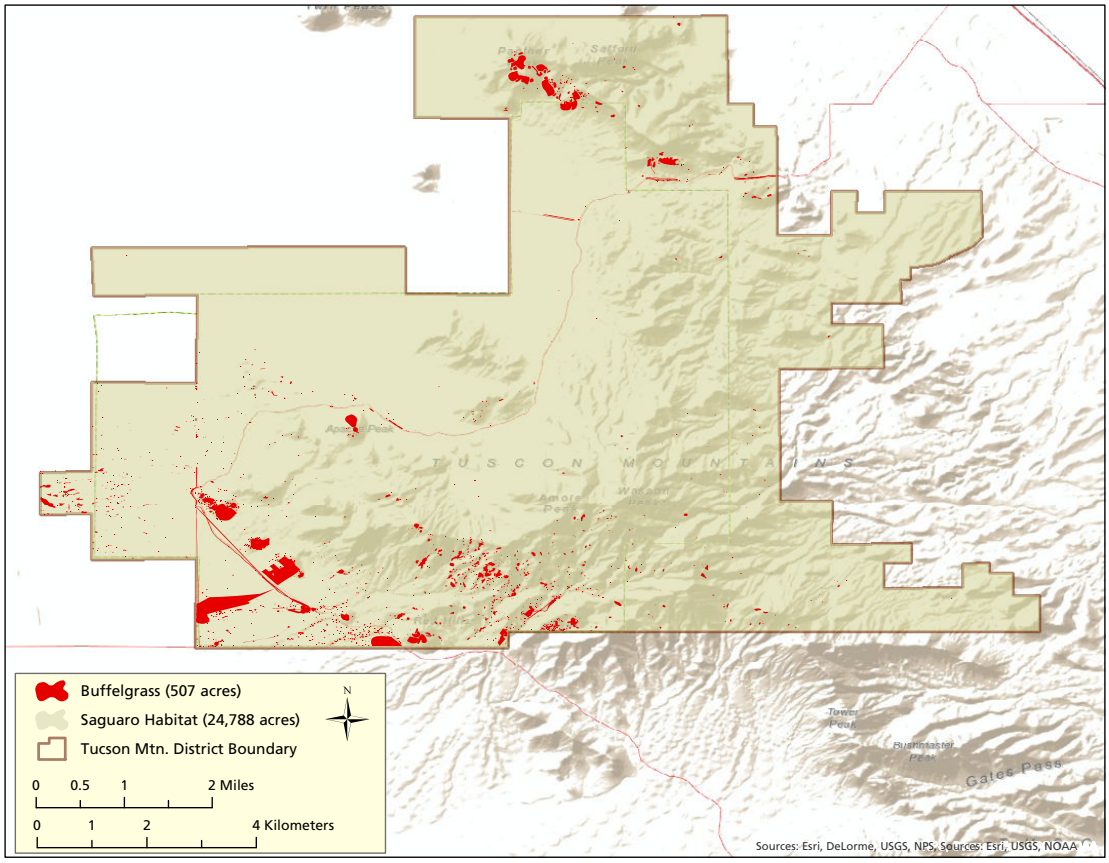


Figure 4.10.4-11. The extent of buffelgrass in saguaro cactus habitat in TMD through 2015. Data Source: Saguaro NP.

Table 4.11.4-4. Summary of the saguaro cactus indicators, measures, and condition rationale.

Indicator	Measure	Condition	Condition Rationale
Population Status / Health	Density and/ or Population Size	Good, with an improving trend	We consider current condition to be good. Data on the saguaro population are available from a number of studies. Based on population estimates from the three Censuses, the number of saguaros in the park in 2010 had increased by about 65.5% from 1990 numbers. Data from the eleven "historic" plots indicated that the saguaro population in RMD declined between 1941 and 1975, but increased substantially since 1975 (and through 2014). The population at TMD also increased from 1975 to 2014. Sampling within Section 17 of RMD, including the Cactus Forest, indicated that the number of individual saguaro cacti counted was lower in the 2011-2012 survey compared to the 1941 survey. Although the saguaro population was in decline around the time that surveys started in RMD in the early 1940s, the population has increased in more recent years. Based on our reference conditions, we consider condition to be good, with an improving trend.
	Age (or Size) Class Distribution	Moderate Concern, with an improving trend	We consider current condition to be of moderate concern. There was little to no recruitment in Section 17 of RMD in the 1940s-1960s. However, due to the surge in recruitment in the 1970s to the early 1990s, in both districts of the park, there are now a large number of young saguaro cacti in both districts. At least within the Cactus Forest, the age/size structure of the population has changed substantially, with the population in the 1940s being dominated by tall, mature saguaros, and that at the present time being dominated by shorter, younger saguaro cacti. Given the low recruitment for the approximate first half of the 20th century (at least within the Cactus Forest), it is not surprising that there are not a greater proportion of taller, mature saguaros; nor is it surprising that the current population is dominated by shorter, younger saguaros given the high levels of recruitment in the 1970s-early 1990s. Although there are now a large number of saguaros that will support the population for many years to come, the population is dominated by young, short saguaros. Based on our reference conditions, condition is of moderate concern. The coming years of saguaro monitoring, such as the Census in 2020 and the annual monitoring in Section 17, will provide more information on present-day recruitment. Based on the available information, we consider the overall trend to be increasing, as the age/size class distribution becomes somewhat more even-aged.

Table 4.11.4-4. Summary of the saguaro cactus indicators, measures, and condition rationale continued.

Indicator	Measure	Condition	Condition Rationale
Historic Integrity and Appearance of Saguaro Cacti on the Landscape	Change over Time	Good to moderate concern, with an improving trend	The Cactus Forest has a different appearance today than it did in the 1930s. However, the decline in the number of larger, mature saguaros was documented as early as the 1940s, and recent estimates of recruitment for the 1900s showed low recruitment during the first half of the century. Although the appearance of the Cactus Forest may not yet reveal the recovery, there has been an increase in the saguaro population park-wide since the dramatic increase in recruitment starting around the 1970s. Eventually, the appearance of the Cactus Forest will likely more closely approach the appearance seen in the days of the park's establishment. Also, one component of recovery- the increase in the tree and shrub layer (including nurse plants)- contributes to the younger saguaros being more difficult to see. With the continued protection and management of the saguaro cactus and its habitat, the historic value and history of research are maintained. Visitor education of the saguaro cactus lifespan, growth, and recovery should help visitors understand the changes that have occurred and are occurring within the park.
Habitat Availability and Quality	Cover of Nurse Plants	Good, with an unknown trend	SODN uplands monitoring data from ~2008-2013 for both park districts for nurse plants in the bajada strata (2,501-3,700 ft) indicate that the cover of nurse plants is currently good. For each of the three areas monitored (one in TMD and two in RMD), the percent cover values were above the reference level of 15% (ranging from 19.2% to 24.2%). For the valley-bottom stratum, the cover of nurse plants was closer to the reference value of 10% (i.e., 11.7% ± 3.4%); the percent cover of nurse plants in this stratum may warrant discussion by SODN and park managers. Overall, we assess this measure to be in good condition. Data are not available to report trends at this time.
	Occurrence of Buffelgrass in Saguaro Habitat	Moderate to Significant Concern, with a trend that is improving in some areas and decreasing in other areas	Based on park monitoring, buffelgrass is known to occur in approximately 12% of the saguaro habitat in RMD and 2% of saguaro habitat in TMD. Buffelgrass is very difficult to control and poses a substantial threat to saguaros and their habitat. Because not all of the park has been surveyed for buffelgrass to date, these estimates are probably somewhat underestimated. The overall condition (i.e., both districts combined) is of moderate to significant concern. Park managers are monitoring and treating buffelgrass within the park. Despite the lack of systematic, complete surveys of this plant on an annual basis, the park has been effective in eliminating buffelgrass in some areas of saguaro habitat and controlling the infestation in other places. However, untreated areas remain. Therefore, the trend is variable across space.

recruitment is episodic by nature (e.g., Pierson et al. 2013).

4.11.5. Sources of Expertise

No outside experts were consulted for this resource topic. However, the assessment was based on studies and monitoring conducted for the national park, and most of the graphics were supplied by Don Swann, Biologist, Saguaro NP. This section was authored by biologist Patty Valentine-Darby.

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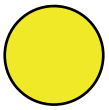
4.12. Desert and Riparian Vegetation and Soils

Indicators/Measures

- Plant Community Resilience (2 Measures)
- Erosion Hazard (2 Measures)
- Fire Hazard (3 Measures)
- Non-native and Invasive Plants
- (10 Measures)
- Threatened, Endangered, or Rare Plants (1 Measure)
- Conservation Potential of Rincon Creek (1 Measure)
- Prevalence of Native Vegetation Along Rincon Creek (4 Measures)
- Prevalence of Non-native Plants Along Rincon Creek (1 Measure)

Condition – Trend - Confidence



Moderate Concern– Unknown - Medium

4.12.1. Background and Importance

Saguaro National Park (NP) lies within the Sonoran Desert, a vast area occupying approximately 260,000 km^2 (100,387 mi^2) in the southwestern U.S. (including the southern half of Arizona and northwestern Mexico) (NPS 2016). Saguaro NP supports several biome types that occur within the Sonoran Desert Ecosystem, including desert, desert thornscrub, and semi-desert grasslands (Figure 4.12.1-1). All three of these desert biome types occur below 1,372 m (4,500 ft) and are supported by three distinct landform types. The landforms are: valley bottom, bajada, and foothills. These three landform types support desert, desert thornscrub, and semi-desert grassland vegetation, respectively. These biome types and supporting landforms are the focus of this assessment. We also included low elevation riparian vegetation of the Rincon Creek area located in the Rincon Mountain District (RMD). Vegetation above 1,372 m (4,500 ft) includes Madrean evergreen woodlands, interior chaparral, and temperate forests. These vegetation types are addressed in a separate assessment.

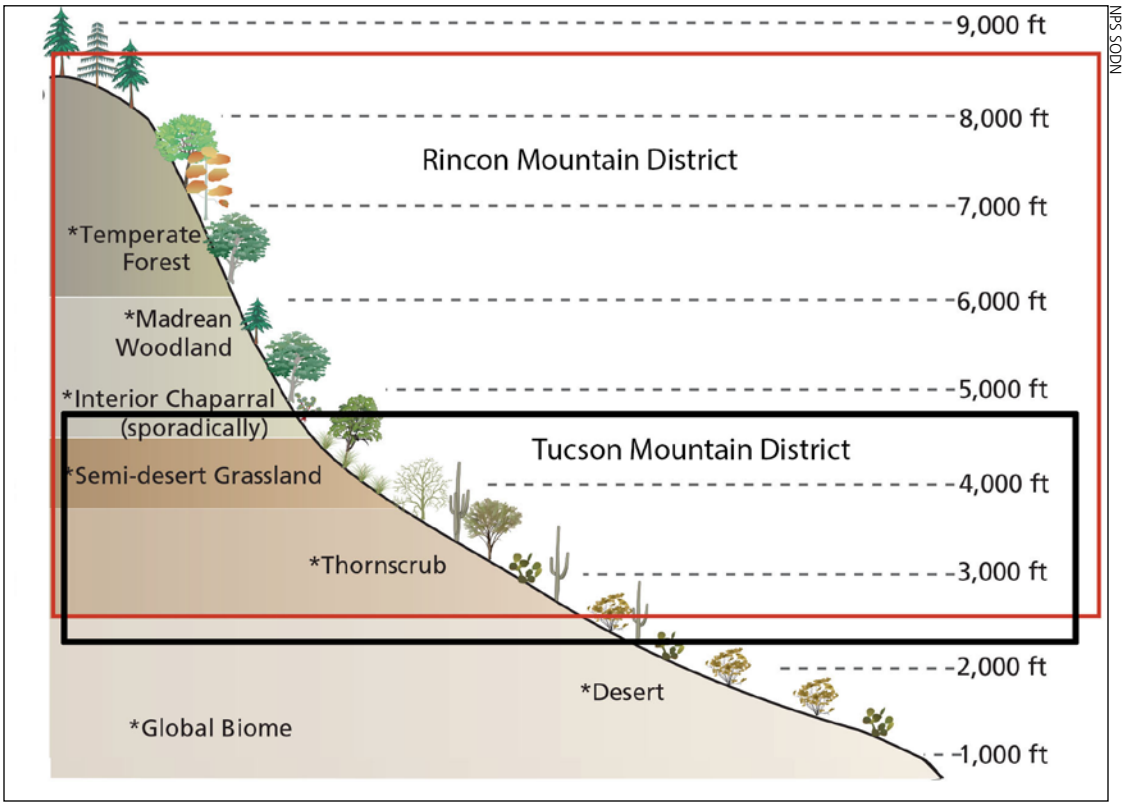


Figure 4.12.1-1. Vegetation biomes by elevation in Saguaro National Park.

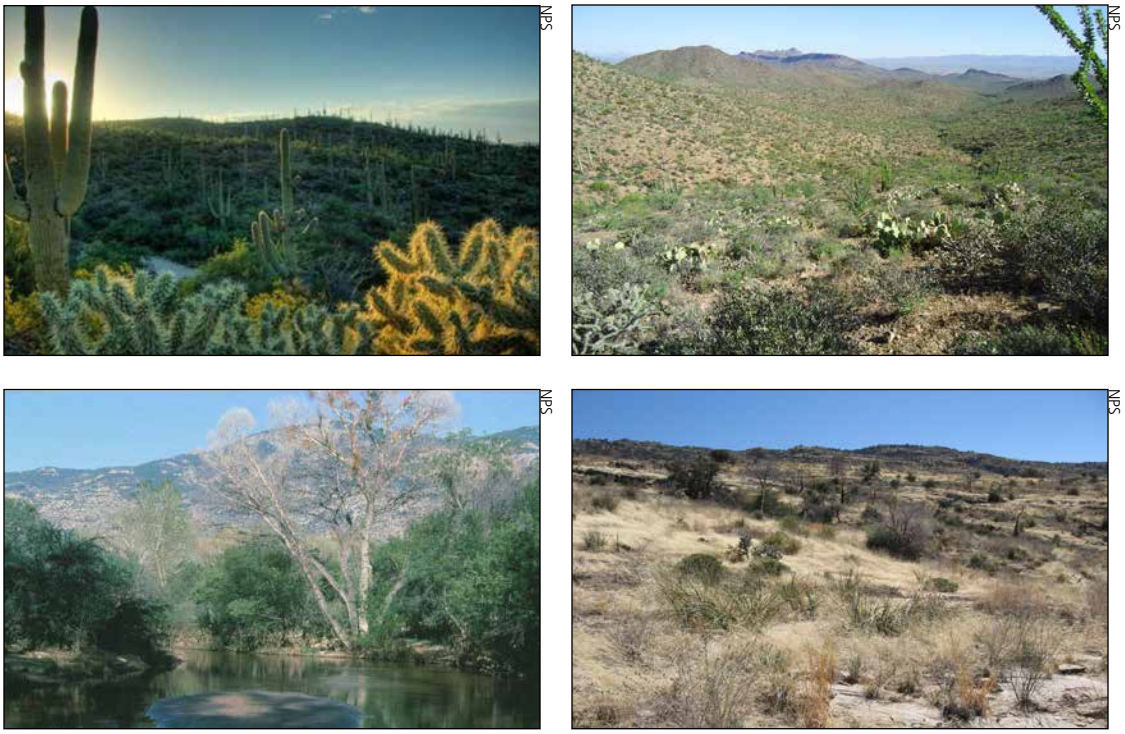


Figure 4.12.1-2. Saguaro National Park supports a diversity of low elevation plant community types. Clockwise from upper left: desert, desert thornscrub, semi-desert grasslands, and riparian vegetation.

Saguaro NP is best known for its lowest elevation desert biome, which occurs only within the Tucson Mountain District's (TMD's) valley bottom. Desert vegetation in the TMD is characterized by several species of succulent, including Saguaro cactus (*Canegiea gigantea*), agave (*Agave* spp.), yucca (*Yucca* spp.), barrel cactus (*Ferocactus* spp.), pincushion cactus (*Mammillaria* spp.), pricklypear (*Opuntia* spp.), and cholla (*Cylindropuntia* spp.) (Hubbard et al. 2012). Velvet mesquite (*Prosopis velutina*), acacias (*Acacia* spp.), paloverdes (*Parkinsonia* spp.), creosotebush (*Larrea tridentata*), and desert ironwood (*Olneya tesota*) are also common desert plants (Hubbard et al. 2012, NPS 2014a).

Ascending from the valley bottom to the bajada, vegetation transitions from desert to desert thornscrub. Desert thornscrub occurs in both districts and is composed of many of the same species found in the valley bottom, including Saguaro cacti. However, vegetation in the bajada is usually taller and denser with more woody subshrubs and perennial grasses and fewer succulents than found in the desert (Hubbard et al. 2012).

Above the bajada, vegetation grades into semi-desert grasslands in the foothills. The upper edge of semi-desert grasslands is bounded by Madrean evergreen woodlands in the RMD, but represents the highest elevation habitat type in the TMD (NPS 2014a). Semi-desert grasslands are typically composed of perennial short- and mid-grass species with occasional shrubs or trees (Hubbard et al. 2012).

Riparian woodland vegetation is a rare but critically important habitat type given the park's largely arid environment. Riparian woodlands occur along Rincon Creek and associated tributaries. Rincon Creek is an intermittent stream with Freemont cottonwood (*Populus fremontii*), Arizona sycamore (*Platanus wrightii*), velvet ash (*Fraxinus velutina*), willow (*Salix* spp.), and netleaf hackberry (*Celtis laevigata* var. *reticulata*) growing along its banks (Briggs et al. 2003). Riparian woodlands provide habitat for a wide variety of flora and fauna, many of which depend on the creek for water, food, breeding habitat, and refuge from predators (NPS 2008).

Vegetation is one of the most useful indicators of ecological integrity because it forms the foundation of terrestrial ecosystems, comprising nearly 99% of the earth's biomass (Hubbard et al. 2012). Monitoring

vegetation dynamics (e.g., productivity, community composition, and life form) can indicate whether ecosystem processes (e.g., nutrient and hydrologic cycles) are functioning properly and/or changing over time. Monitoring vegetation is also a useful indicator of ecosystem integrity since it is immobile and can therefore, be monitored relatively easily over the long-term (Hubbard et al. 2012).

4.12.2. Data and Methods

We used eight indicators with between one and ten measures each for a total of 25 measures to assess the condition of desert and riparian vegetation and soils in Saguaro NP. We relied on data provided by the Sonoran Desert Network's (SODN) Vegetation Monitoring Program, Saguaro NP's Restoration and Invasive Plant Management Program, data provided by Briggs et al. (2003), and geographic information system (GIS) data available from Pima County, Arizona (Pima County, 2016a).

Indicator / Measures

Plant Community Resilience (Tree and Shrub Cover and Perennial Grass Cover)

Vegetation was monitored by SODN in each of 51 permanent vegetation and soils sampling plots located via a random, spatially balanced process within each of the park's two districts (Hubbard et al. 2012). Plots were stratified on the basis of elevation and soil rock-fragment class (Table 4.12.2-1). Park-wide, nine plots were located in the valley bottom, 28 plots in the bajada, and 14 plots in the foothills. Soils were characterized as either rocky or non-rocky (loamy) soils. Rocky soils were comprised of 35-90% rock fragments and non-rocky soils were comprised of <35% rock fragments.

Plots were 20 × 50-m (66 x 164-ft) and contained six transects each (Figure 4.12.2-1). Vegetation was measured along each transect at 0.5-m (1.6-ft) intervals (240 points per plot) in one or more of the three following vegetation layers:

- Field: < 0.5 m (1.6 ft);
- Subcanopy: 0.5-2.0 m (1.6-6.6 ft); and
- Canopy: > 2.0 m (>6.6 ft).

Table 4.12.2-1. Summary of vegetation plots by district and elevation strata in Saguaro National Park.

Strata	Soil Rock-fragment Class	TMD	RMD
Valley Bottom (desert): < 762 m (2,500 ft)	Rocky	4	---
	Non-Rocky	5	---
Bajada (desert thornscrub): 762-1,128 m (2,500-3,700 ft)	Rocky	13	10
	Non-Rocky	---	5
Foothills (semi-desert grasslands): 1,128-1,372 m (3,700-4,500 ft)	Rocky	6	8

Each plot was visited once during 2008-2013. Repeat sampling is scheduled to occur every five years. The second round of sampling will be completed in 2018 for the RMD and 2019 for the TMD (A. Hubbard, pers. comm.).

The following two measures address plant community resilience, or the ability of plant communities to recover after a disturbance, maintain natural processes, and resist invasion by non-native plants.

Tree and Shrub Cover (%)

This measure was calculated as the absolute proportion of tree and shrub cover in the subcanopy layer within foothill plots in both districts.

Perennial Grass Cover (%)

This measure was calculated as the absolute proportion of all perennial grass cover in the field layer within foothill plots in the RMD only.

Indicator / Measures

Erosion Hazard (Bare Ground, Soil Stability Class Index)

Bare ground cover and the soil class stability index address erosion hazard by wind, water, or disturbance events. The data for these two measures were collected by SODN as part of their vegetation monitoring program within the plots described above.

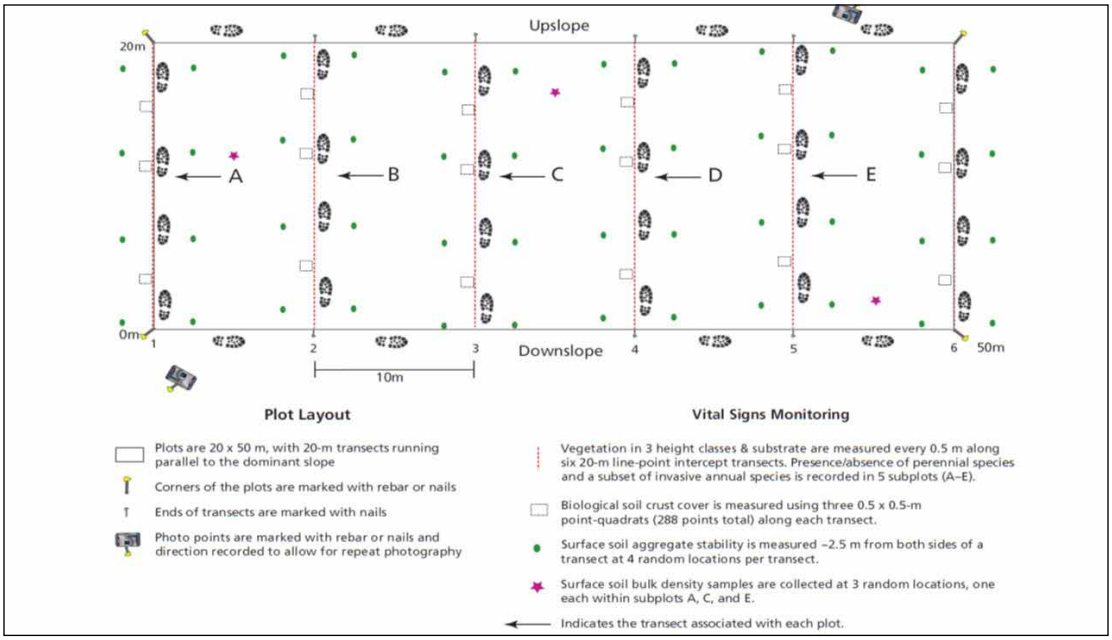


Figure 4.12.2-1. The design of lowland vegetation and soils monitoring plots, showing six transects per plot (Hubbard et al. 2011).

Bare Ground Cover (%)

The amount of bare ground is the inverse of soil cover, which was measured excluding overhead vegetation in all three elevation strata in both districts.

Soil Stability- No Canopy

Surface soil aggregate stability was measured at -2.5 m (-8.2 ft) from both sides of each transect at four random locations per transect for a total of 40 samples per plot (Figure 4.12.2-2). The average soil class stability index was calculated for each plot within bajada and foothill strata of both districts using only those samples with no overhead vegetation. The soil stability index ranges on a scale from 0 to 6, with 0 indicating very unstable soils and 6 indicating very stable soils (Table 4.12.2-2).

Indicator / Measures

Fire Hazard (Ratio of Non-native Plant Cover to Total Plant Cover, Extent of Red Brome, and Combined Grass and Forb Cover)

The following three measures address fire hazard as a result of the invasion of non-native plants. Data were provided by SODN as described above.

Table 4.12.2-2. Soil stability class index (adapted from Herrick et al. 2001).

Stability Class	Category	Criteria for assignment to stability class
0-1	Very Unstable	50% of structural integrity lost (melts) within 5 seconds of immersion in water AND <10% of soil remains on sieve after 5 dipping cycles, OR soil too unstable to sample (falls through sieve)
1-2	Unstable	50% of structural integrity lost (melts) within 5-30 seconds of immersion in water AND <10% of soil remains on sieve after 5 dipping cycles
2-3	Somewhat Unstable	50% of structural integrity lost (melts) within 30-300 seconds of immersion in water OR <10% of soil remains on sieve after 5 dipping cycles
3-4	Moderately Stable	10-25% of soil remains on sieve after 5 dipping cycles
4-5	Stable	25-75% of soil remains on sieve after 5 dipping cycles
5-6	Very Stable	75-100% of soil remains on sieve after 5 dipping cycles

Ratio of Non-native Plant Cover to Total Plant Cover

This measure is presented as both a ratio of non-native plant cover to total plant cover

and as the proportion of total plant cover represented by non-native plants for the field layer within each of the three strata for both districts. Both annual and perennial plants were included.

Extent of Red Brome

This measure was calculated as the percent of plots occupied by red brome (*Bromus rubens*) in each of the three strata in both districts.

Combined Grass and Forb Cover

This measure was calculated as the absolute proportion of grass and forb cover in the field layer within the bajada in both districts.

Indicator / Measures

Non-native and Invasive Plants (New Non-native Species Detected per Plot, Existing Non-native Perennial Species Detected in New Plot or Strata, Change in Buffelgrass Cover, Change in Extent of Buffelgrass, Total Cover of Non-native Plants, Ratio of Non-native Plant Cover to Total Plant Cover, New Non-native Species Detected (2004-2014), Occurrence of Buffelgrass, Occurrence of Non-native Plants)

According to Saguaro NP's Restoration Ecologist, Dana Backer, there are 125 non-native plants species that have been listed for the park from various sources, including NPSpecies (2015), which includes plants without vouchers and that have been removed from the park; the park's Restoration Management Plan Environmental Assessment (NPS 2014a); and the park's Exotic Plant Management Plan Environmental Assessment (NPS 2004). Eighty-seven of these plants are known to be present in the park, and at least 26 of these species are considered invasive, including buffelgrass (*Pennisetum ciliare*) (NPS 2014a). Buffelgrass is considered the largest and most significant threat to the natural resources at Saguaro NP(NPS 2014a).

Buffelgrass is a perennial grass native to Africa and is a particularly concerning non-native invasive plant with regards to the Sonoran Desert (Figure 4.12.2-2). Where buffelgrass invades, it alters natural ecological processes, competes with and excludes native plants, alters wildlife habitat, and increases the frequency of wildfires (NPS 2011). This plant is of significant concern to Saguaro NP managers and other land management agencies in the Southwest. The presence of buffelgrass can potentially lead to more frequent and intense fires. An experimental study in 2008 revealed that buffelgrass fires may burn hotter, have higher flame lengths, and spread faster than previous or more typical desert fires (NPS 2011). Data were not recorded by park staff, therefore is unknown (D. Backer, Restoration Ecologist, pers. comm.).

SODN Monitoring Data

Data for the first six measures described below were collected as part of SODN's Vegetation Monitoring Program. The first four of these measures are based on repeat sampling of plots established by SODN, which will be completed in autumn 2019 (A. Hubbard, pers. comm.). We reported data collected during the first round of SODN sampling to establish a baseline condition. We describe each measure below.

New Non-native Species Detected per Plot

This measure will be calculated as the number of non-native annual and perennial species never found in the park before that were found in any plot in any of the three strata. We reported the total number and provided a list of all non-native species detected within each stratum.

Existing Non-native Perennial Species Detected in New Plot or Strata

This measure will be calculated as the number of non-native, perennial species already known to occur within a stratum that are found in a new plot or stratum for all three strata. We reported all non-native species recorded in SODN plots as described for the previous measure.

Change in Buffelgrass Cover (%)

This measure will be calculated as the percent change in buffelgrass cover by plot in each of the three strata. In this assessment we report % cover of buffelgrass recorded during SODN's first round of sampling (2008-2013).

Change in Extent of Buffelgrass (%)
This measure will be calculated as the percent change in the number of plots occupied by buffelgrass in each of the three strata. In this assessment we reported initial extent of buffelgrass recorded during SODN's first round of sampling (2008-2013).

Total Cover of Non-native Plants (%)
This measure is based on the percent cover of all non-native plants found in the field layer in each of the three strata.

Ratio of Non-native Plant Cover to Total Plant Cover
This measure is presented as both a ratio of non-native plant cover to total plant cover and as the proportion of total plant cover represented by non-native plants in the field layer within each of the three strata. Both annual and perennial plants were included.

Saguaro NP Data
The following three measures are based on data gathered by Saguaro NP's Restoration and Invasive Plant Management Program.

New Non-native Species Detected (2004-2014)
We compared the list of non-native plants published in Saguaro NP's Exotic Plant Management Plan Environmental Assessment (NPS 2004) to the list of non-native plants published in the Restoration Management Plan Environmental Assessment (NPS 2014a) to determine the number of species reported in 2014 that were not reported in 2004. We then subset this list to the species known to occur in lower elevation areas in the RMD and TMD according to Dana Backer, Restoration Ecologist, Saguaro NP. This represents the minimum number of known new non-native species in low elevation areas over a 10-year period.

Occurrence of Buffelgrass
Park staff provided digital data on the known extent of buffelgrass in each district. We used GIS data layers including the cumulative extent of buffelgrass across years in which buffelgrass may be treated or untreated (Dana Backer, Restoration Ecologist, Saguaro NP, pers. comm.) and determined the proportion of area within each stratum that is infested with buffelgrass. This represents to total known extent of buffelgrass in Saguaro NP through 2012 as determined by aerial surveys.

Occurrence of Non-native Plants
As with the occurrence of buffelgrass, we determined the proportion of all non-native plants combined, excluding buffelgrass that have been mapped in each of the three strata using GIS data layers provided by Saguaro NP. This represents the total known extent of non-native invasive plants in Saguaro NP (excluding buffelgrass) through 2014.

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Figure 4.12.2.2. Ground-based herbicide control of invasive buffelgrass.

However, it should be noted that there is no survey for many non-native species. Only species under active management are mapped.

Buffelgrass Mapping and Control Effort
We used data provided by Saguaro NP's Restoration and Invasive Plant Management Program to determine ground control efforts to map and treat buffelgrass in the park. These data are separate from the aerial mapping efforts. Data on the number of hectares surveyed, hectares mapped, and number of hectares treated (mechanically and chemically) were reported from 2011-2015. We also summarized the results of a study that investigated the long-term effectiveness of different buffelgrass control treatments (i.e., manual pulling or herbicide application), timing of treatments, frequency of treatments, and site characteristics of the area being treated (see Hunter 2012 for more details on study design).

Non-native Plant Mapping and Control Effort
We used data provided by Saguaro NP's Restoration and Invasive Plant Management Program to determine ground control efforts to map and treat invasive plants (excluding buffelgrass) in the park as described above.

Indicator / Measures
Threatened, Endangered, or Rare Plant Species (Cover and Frequency)

This measure is based on change in cover and frequency of threatened, endangered, and rare plants occurring in each stratum. Frequency is the "number of times a plant species/ lifeform is encountered in a given number of plots or sample points" (Hubbard et al. 2012). While there are currently no federally listed threatened or endangered plant species in Saguaro NP (U.S. Fish and Wildlife Service 2016), there are seven sensitive plant species that will be evaluated after the second round of SODN monitoring occurs in 2019 (Table 4.12.2-3). The sensitive plant list was developed by the Resource Management Division of the park (email correspondence with D. Backer, 2016). Any plant species listed as threatened or endangered by the U.S. Fish and Wildlife Service in the future will also be evaluated for change in cover and frequency in each of the three strata. Although this measure is based on change over time, we reported initial percent cover and frequency data provided by SODN for each of these seven species.

Indicator / Measures
Conservation Potential of Rincon Creek (% Land Use Type)

The park is concerned about the middle reach of Rincon Creek and how land use in the region bordering the park may influence ecosystem function (see map on page 311). The primary concern is where Rincon Creek leaves the park then flows back into the park along the southern boundary then out of the park again in addition to privately held (inholdings) lands located within the park boundary.

We determined the proportion of riparian habitat with various land use types in and around Saguaro NP using GIS data layers available from Pima County, Arizona's GIS library (Pima County 2016a). We used the final regulatory riparian GIS layer (RIPUNIRA) used by Pima County, Arizona in their riparian habitat mitigation ordinance (Pima County 2011a).

Regulated riparian habitat as defined by Pima County "consists of important riparian areas, hydroriparian, mesoriparian, and xeroriparian habitats," (Pima County 2011a).

Table 4.12.2-3. Sensitive plant species occurring in Saguaro National Park.

Species	Common Name
Tumamoca macdougalii[1]	Tumamoc globeberry
Psilotum nudum[2]	Whiskbroom
Carnegiea gigantea[3]	Saguaro cactus
Stenocereus thurberi[3]	Organ pipe cactus
Agave palmeri[3]	Palmer's century plant
Echinomastus erectocentrus[3]	Needle spine pineapple cactus
Graptopetalum rusbyi[3]	Stone crop

[1] U.S. Fish and Wildlife de-listed species.

[2] Arizona state listed species

[3] Saguaro NP special status species.

We subset the RIPURNA layer to the Rincon Creek area from 2.3 km (1.4 mi.) east of the point where it first flows west out of the park and along its length until it intersects with the boundary of the upper and lower Rincon Creek watershed approximately 17 km (10.5 mi) east (see Condition and Trend for a map).

We then determined the proportion of regulatory riparian habitat within three land use categories: protected, unprotected, and planned for protection. The data layers we used were preserved areas (preserve), community open space (cosp2015), priority areas that are privately held (hppp2015), and priority areas that are state held (hpps2015) (Pima County 2016b). The first two layers include areas that are currently protected at the state, county, or federal level while the latter two layers include areas that are planned for protection.

Indicator / Measures

Prevalence of Native Vegetation Along Rincon Creek (Age Class Distribution, Species Richness, Species Wetland Status, and Percent Cover)

To assess riparian vegetation along the middle reach of Rincon Creek, we used data collected by Briggs et al. (2003). On July 13, 2001, the Arizona Department of Water Resources issued a Certificate of Assured Water Supply No. 27-400201 to Mountain Creek Ranch (a subdivision) near Rincon Creek (NPS 2008). The Certificate was for a three-fold increase in water withdrawal from the Rincon Creek watershed (NPS 2008). The park became concerned about the effects this increase would have on vegetation and wildlife along Rincon Creek. To determine the amount of water needed to support the riparian and aquatic ecosystems within the middle reach, the NPS conducted hydrologic, wildlife, and plant studies beginning in 2003 (NPS 2008). Data provided in Briggs et al. (2003) were collected during 2003 in support of the NPS water right application, which has not been resolved.

Although these data are 13 years old, they represent the most current and best available data for the Rincon Creek area. Data were collected in 2 m x 40 m (6.6 ft x 131 ft) plots located perpendicular to each of four transects that bisected the middle reach of Rincon Creek. The transects extended from the skirt of Rincon Peak to just downstream of the Rincon Creek-Chimenea Creek confluence (Briggs et al. 2003). Between four and six plots were established per transect and categorized as either terrace plots or floodplain plots.

Each plot was surveyed for the following measures using the line-intercept method (see Briggs et al. 2003 for more details on study design and data collection). Species evaluated included all woody and select herbaceous species.

Species Richness

Richness was determined by summing the number of key species (i.e., all woody and select herbaceous species) recorded during measurements of percent cover and density. Therefore, richness is not total richness, but richness of woody and key herbaceous species that were encountered in the vegetation plots (Briggs et al. 2003).

Species Wetland Status

We determined wetland status for each species recorded by Briggs et al. (2003) using the U.S. Department of Agriculture's (USDA) PLANTS Database (USDA 2016). Plants were divided into five categories based on wetland status. The categories are: obligate wetland (OBL = almost always occurs in wetlands), facultative wetlands (FACW = usually occurs in wetlands but may occur in non-wetlands), facultative (FAC = occurs in wetlands and non-wetlands), facultative upland (FACU = usually occurs in non-wetlands), and obligate upland (UPL = almost never occurs in wetlands).

Total Percent Cover (key species only)

Total percent cover was measured along a 40-m (131 ft) transect within each plot for all key species (i.e., all woody species and selected herbaceous species). Multiple canopy layers of different species were measured separately. Percent cover was calculated by dividing the total distance that each key species crossed the line by 40, then multiplying by 100 (Briggs et al. 2003).

Age-class Distribution

Trunk diameters were measured to determine age class distribution for key woody species. Trees with a diameter < 5 cm (< 2 in) were considered seedlings/saplings and trees with a diameter > 5cm (> 2 in) were considered adults (Briggs et al. 2003).

Indicator / Measures

Prevalence of Non-native Plants Along Rincon Creek (New Non-native Species Detected and Mapped Non-native Plants)

New Non-native Species Detected (2004-2014)

We assessed this measure as described above for new non-native species in the TMD and low elevation areas of the RMD, except we subset this list to the species known to occur in riparian areas in the RMD and TMD according to Saguaro NP's GIS database. This represents the minimum number of known new non-native species in riparian areas over a 10-year period.

Mapped Non-native Plants

Park staff provided GIS data on the known extent of non-native plants along Rincon Creek. The data included the cumulative extent of non-native plants across years, in which buffelgrass and other non-native plants may be treated or untreated (Dana Backer, Restoration Ecologist, Saguaro NP, pers. comm.). This represents the total known area of non-native plants along Rincon Creek through 2012 that is accessible. Only some private land owners allow access for invasive plant removal efforts, which are restricted to the creek bottom. We used the RIPURNA layer within the park to determine the proportion of riparian habitat represented by non-native species.

4.12.3. Reference Conditions

Reference conditions for this assessment are shown in Table 4.12.3-1 (valley bottom, bajada, and foothills) and Table 4.12.3-2 (Rincon Creek). Reference conditions are described for resources in good, moderate concern, and significant concern conditions for each of the eight indicators and 25 measures.

Condition thresholds for all data provided by SODN were developed as management assessment points (MAPs). MAPs are "pre-selected points along a continuum of resource-indicator values where scientists and managers have agreed to stop and assess the status or trend of a resource relative to program goals, natural variation, or potential concerns" (Bennetts et al. (2007) as cited in Hubbard et al. (2011)). MAPs serve as trigger points that alert scientists and managers to possible issues. MAPs were developed jointly by SODN and Saguaro NP staff as part of the Natural Resource Condition Assessment (NRCA) process (Hubbard et al. 2011).

Condition class thresholds for non-native plant species data provided by Saguaro NP and conservation potential of Rincon

Table 4.12.3-1. Reference conditions used to assess the current condition of vegetation and soils in the valley bottom, bajada, and foothills in Saguaro National Park.

Indicator	District	Strata	Measure	Good	Moderate Concern	Significant Concern
Plant Community Resilience	TMD/ RMD	Foothills	Tree and Shrub Cover (subcanopy)[1]	≤30% tree and shrub cover	>30% tree and shrub cover	
	RMD	Foothills	Perennial Grass Cover (field)[1]	≥20% perennial grass cover	< 20%perennial grass cover	
Erosion Hazard	TMD	Valley Bottom	Bare Ground Cover[1]	Bare ground is ≤20%	Bare ground >20%	
	TMD/ RMD	Bajada/ Foothills	Bare Ground[1]	Bare ground ≤10%	Bare ground >10%	

Table 4.12.3-1. Reference conditions used to assess the current condition of vegetation and soils in the valley bottom, bajada, and foothills in Saguaro National Park continued.

Indicator	District	Strata	Measure	Good	Moderate Concern	Significant Concern
Erosion Hazard	TMD/ RMD	Bajada/ Foothills	Soil Stability Class Index (no canopy)[1]	Class 3 or greater on any given plot within a stratum (moderately stable to very stable)	< Class 3 in any given plot in a stratum (unstable to very unstable)	
Fire Hazard	TMD/ RMD	Valley Bottom/ Bajada/ Foothills	Ratio of Non-native Plant Cover to Total Plant Cover (field)[1]	1:20 (< 5%)	1:20 (> 5%)	
			Extent of Red Brome[1]	No condition threshold set		
		Bajada	Grass and Forb Combined Cover (field)[1]	≤20% total cover	>20% total cover	
Non-native and Invasive Plants	TMD/ RMD	Valley Bottom/ Bajada/ Foothills	New Non-native Species Detected per Plot (annual and perennial)[1]	No new non-native species detected in any one plot compared to previous monitoring cycle.	New non-native species detected in any one plot compared to previous monitoring cycle.	
			Existing Non-native Perennial Species Detected in New Plot or Strata[1]	No extent increase from previous monitoring cycle	Any extent increase from previous monitoring cycle	
Non-native and Invasive Plants	TMD/ RMD	Valley Bottom/ Bajada/ Foothills	Change in Buffelgrass Cover[1]	No % change in cover within a plot.	Any % change increase in cover change within a plot.	
			Change in Extent of Buffelgrass[1]	No % change in plots occupied by stratum.	Any % change increase in plots occupied by stratum.	
			Total Cover of All Non-native Plants (field)[1]	≤5% total cover	>5% total cover	
		Low Elevation Areas	New Species Detected (2004-2014)[2]	No increase in non-native species, or an increase but none are considered invasive and none have become established.	An increase in non-native species, some of which are invasive and have become established.	
		Valley Bottom/ Bajada/ Foothills	Occurrence of Buffelgrass[2]	No occurrence of buffelgrass by elevation stratum in the park.	<1% buffelgrass infestation by elevation stratum, and it is relatively under control[3]	Buffelgrass occurs in >1% of each stratum, and/or it is not under control[3]
			Occurrence of Non-native Plants[2]	Same as above except measure refers to all other non-native plants combined, excluding buffelgrass.		

Table 4.12.3-1. Reference conditions used to assess the current condition of vegetation and soils in the valley bottom, bajada, and foothills in Saguaro National Park continued.

Indicator	District	Strata	Measure	Good	Moderate Concern	Significant Concern
Non-native and Invasive Plants	TMD/ RMD	Park-wide	Buffelgrass Control Effort[2,3]	A large proportion of infested/mapped area is controlled	A moderate proportion of infested/ mapped area is controlled.	Little or none of the infested/ mapped area is controlled.
			Non-native Plant Control Effort (excluding Buffelgrass)[2,3]	A large proportion of infested/mapped area is controlled	A moderate proportion of infested/ mapped area is controlled.	Little or none of the infested/ mapped area is controlled.
Threatened, Endangered or Rare Plant Species	TMD/ RMD	Valley Bottom/ Bajada/ Foothills	Cover/Frequency[1]	No decrease or increase in cover/ frequency	Any decrease in cover/ frequency	

Note: Cover of dead plants (field) and cover of dead plants (subcanopy) were included as management assessment points (MAPs), but the Sonoran Desert Network (SODN) did not report these data. Therefore, we excluded these measures.

[1] Condition class thresholds developed by SODN and Saguaro National Park (NP) as MAPs.

[2] Condition class thresholds developed jointly by Natural Resource Condition staff, Dana Backer (Restoration Ecologist,Saguaro NP), and Scott Stonum (Chief of Resources, Saguaro NP).

[3] Control means that the infestation is in a state of maintenance or the invasive plant population is less than five percent cover Dana Backer (Restoration Ecologist,Saguaro NP).

Table 4.12-3-2. Reference conditions used to assess the condition of Rincon Creek in Saguaro National Park.

Indicator	Measure	Good	Moderate Concern	Significant Concern
Conservation Potential of Rincon Creek[4]	Land Use Type (% area)[2]	Fully Protected	Partially protected with planned protection projects	Not Protected
Prevalence of Native Vegetation	Species Richness[1]	There is diverse composition (at least 2 functionally equivalent species) of riparian-wetland vegetation for maintenance/recovery and erosion control.	There is a lack of diverse composition of riparian-wetland vegetation for maintenance/recovery and erosion control.	
	Species Wetland Status[1]	Species present indicate maintenance of riparian-wetland soil moisture characteristics (i.e., species designated as either obligate wetland, facultative wetland and/or facultative).	Species present do not indicate maintenance of riparian-wetland soil moisture characteristics.	
	Total Percent Cover[1]	Adequate riparian-wetland vegetative cover is present to protect banks and dissipate energy during high flows (approximately 70% cover).	Adequate riparian-wetland vegetative cover is not present to protect banks and dissipate energy during high flows (< 70% cover).	

Table 4.12.3-2. Reference conditions used to assess the condition of Rincon Creek in Saguaro National Park continued.

Indicator	Measure	Good	Moderate Concern	Significant Concern
Prevalence of Native Vegetation	Age Class Distribution	At least two age class that includes young plants (recruitment) and middle-aged plants (replacement).	One or both of age classes that indicate recruitment and replacement are absent. Other age classes may be present, but they do not contribute to population growth.	
Prevalence of Non-native Plants[2]	New Non-native Species Detected (2004-2014)[2]	No increase in non-native species, or an increase but none are considered invasive and none have become established.	An increase in non-native species, some of which are invasive and have become established.	
	Occurrence of buffegrass and Other Non-native Plants[2]	No occurrence of buffelgrass by elevation stratum in the park.	<1% buffelgrass infestation by elevation stratum, and it is relatively under control [3]	Buffelgrass occurs in >1% of each stratum, and/or it is not under control [3]

[1] Measures and condition thresholds developed by Prichard et al. 1998.

[2] Condition class thresholds developed jointly by NRCA staff, Dana Backer (Restoration Ecologist,Saguaro NP), and Scott Stonum (Chief of Resources, Saguaro NP).

[3] Control means that the infestation is in a state of maintenance or the invasive plant population is less than five percent cover Dana Backer (Restoration Ecologist,Saguaro NP).

Creek, were developed by NRCA staff, Dana Backer (Restoration Ecologist, Saguaro NP), and Scott Stonum (Chief of Resources, Saguaro NP). To determine the condition of native vegetation along Rincon Creek, we adapted condition class thresholds described in Prichard et al. (1998).

4.12.4. Condition and Trend

Plant Community Resilience

Tree and Shrub Cover %

Subcanopy tree and shrub cover in both the TMD (Table 4.12.4-1) and RMD (Table 4.12.4-2) averaged well under 30%. Therefore, we consider the condition for this measure to be good.

Perennial Grass Cover %

Perennial grass cover in the RMD foothills averaged 19.64%, which is slightly below the threshold considered good, although the standard error of the mean overlaps the management assessment point of 20% (Table 4.12.4-2). Despite this, we consider this measure to warrant moderate to significant concern.

Erosion Hazard

Bare Ground Cover (%)

Bare ground cover with no overhead vegetation in the TMD's valley bottom, averaged 13%, which is well within the range considered good (Table 4.12.4-1). For the bajada and foothills, the threshold for good condition was slightly more stringent than for the valley bottom (<10% vs. <20%). In foothills of both districts the threshold for good condition was met; however, in RMD's bajada region the standard error of the mean overlaps the management assessment point for rocky sites and approaches the management assessment point in non-rocky sites (Table 4.12.4-2). Therefore, we consider the condition for this measure to be good in the valley bottom, foothills, and in TMD's bajada strata, but moderate to significant concern for the RMD's bajada stratum.

Soil Stability

At least one plot in all strata in both districts exhibited an average soil stability class less than two, which warrants moderate to significant concern for this measure (Table 4.12.4-1, Table 4.12.4-2). When considering the average of all plots within a stratum, soil stability would be considered good for the

Table 4.12.4-1. Data for valley bottom, bajada, and foothills vegetation and soils in the Tucson Mountain District.

Indicator	Measure*	Valley Bottom < 762 m (2,500 ft)		Bajada 762-1,128 m (2,500-3,700 ft)	Foothills 1,128-1,372 m (3,700-4,500 ft)
		Rocky Sites	Non-Rocky Sites	Rocky Sites	Rocky Sites
Plant Community Resilience	Tree and Shrub Cover (subcanopy)	---	---	---	8.12% ± 3.10% tree; 5.56% ± 1.25% shrub
Erosion Hazard	Bare Ground Cover (with no overhead vegetation)	13.0% ± 3.6%		4.3% ± 0.6%	1.4% ± 0.4%
	Soil Stability Class Index (no canopy)	---	---	2.93 (n = 13) 7 plots < class 3	2.31 (n = 6) 5 plots < class 3
Fire Hazard	Ratio of Non-native Plant Cover to Total Plant Cover (field)	NA (0%)		1:120 (0.85%)	1:200 (0.49%)
	Extent of Red Brome	0	0	0	0
	Grass and Forb Cover (field)	---	---	9.84%	---
Non-native and Invasive Plants	Buffelgrass Cover	0%		0.03% ± 0.03%	0%
	Extent of Buffelgrass (# of plots)	0 of 9 plots (0%)		1 of 13 plots (8%)	0 of 6 plots (0%)
	Total Cover of Non-native Plants (field)	0%		0.03% ± 0.03%	0.21% ± 0.21%

* Data provided by the Sonoran Desert Monitoring Network (2008-2012).

RMD's bajada and foothill strata, but would warrant moderate to significant concern for the TMD's bajada and foothill strata. However, since the management assessment point is based on any one plot in a stratum, we consider this measure to warrant moderate to significant concern for all strata within each district.

Fire Hazard

Ratio of Non-native Plant Cover to Total Plant Cover

The ratio of non-native plant cover to total plant cover for all strata and soil rock formation class was well within the range considered good (Table 4.12.4-1 and Table 4.12.4-2).

Extent of Red Brome

Red brome occurred in only two out of eight plots in the RMD foothill stratum. This invasive plant was not found in any other monitoring plot. There are no condition class thresholds established for this measure, therefore, we could not assess the current condition.

Combined Grass and Forb Cover

Grass and forb cover in the bajada averaged less than 20% for each district and soil rock fragment class, therefore, we consider the condition for this measure to be good.

Non-native and Invasive Plants

New Non-native Species Detected per Plot (annual and perennial)

Nine species of non-native plant, six of which are considered invasive and one of unknown status, were recorded in SODN monitoring plots across all three strata (Table 4.12.4-3). Marsh parsley (*Cyclospermum letpohyllum*) was identified by SODN as non-native, but this species is not listed in Saguaro NP's list of non-native and invasive plants. None of the nine species occurred in valley bottom plots and most occurred only within plots located in the RMD. Lehmann lovegrass (*Eragrostis lehmanniana*) occurred in the most plots, but buffelgrass was the most widespread species.

Table 4.12.4-2. Data for bajada and foothills vegetation and Soils in the Rincon Mountain District.

Indicator	Measure*	Bajada 762-1,128 m (2,500-3,700 ft)		Foothills 1,128-1,372 m (3,700-4,500 ft)
		Rocky Sites	Non-Rocky	Rocky Sites
Plant Community Resilience	Tree and Shrub Cover (subcanopy)	---	---	7.97% ± 2.79% tree; 3.13% ± 1.19% shrub
	Grass Cover (field)	---	---	19.64% ± 4.09%
Erosion Hazard	Bare Gound Cover (with no overhead vegetation)	9.6% ± 2.1%	8.7% + 0.9%	3.0% ± 0.8%
	Soil Stability Class Index (no canopy)	3.26 (n = 10) 6 plots < class 3	3.79 (n = 5) 1 plot < class 3	3.62 (n = 7) 1 plot < class 3
Fire Hazard	Ratio of Non-native Plant Cover to Total Plant Cover (field)	1:20.5 (4.9%)	1:190 (0.5%)	1:25.4 (3.93%)
	Extent of Red Brome	0 of 10 plots	0 of 5 plots	2 of 8 plots (25%)
	Grass and Forb Cover (field)	14.13%	15.92%	---
Non-native and Invasive Plants	Buffelgrass Cover	1.08% + 0.91%	0.17% ± 0.17%	0.05% ± 0.05%
	Extent of Buffelgrass (# of plots)	3 of 10 plots (30%)	1 of 5 plots (20%)	1 of 8 plots (13%)
	Total Cover of All Non-native Plants (field)	1.83% ± 0.94%	0.17% ± 0.17%	2.03% ± 1.00%

* Data provided by the Sonoran Desert Monitoring Network (2009-2013).

The remaining species occurred in relatively few plots. Because this measure is based on detection of new non-native species per plot, we cannot determine condition until the second round of sampling is completed in 2019.

Existing Non-native Perennial Species Detected in New Plot or Strata

Three of the nine non-native species found in SODN monitoring plots are perennial (Table 4.12.4-3). As with the previous measure, we could not assign a condition since this measure is based on change over time.

Change in Buffelgrass Cover %

Overall, buffelgrass cover was relatively low in each district and stratum. No buffelgrass was found in valley bottom or foothill plots in the TMD and only a small amount (0.03%) was found in the TMD's bajada stratum (Table 4.12.4-1). In the RMD, buffelgrass occurred in both strata, but exhibited relatively low cover where it was found (Table 4.12.4-2).We could not assign a condition for this measure since it is based on change over time.

Change in Buffelgrass Extent (%)

Buffelgrass occurred in few of SODN monitoring plots and occurred most often in the RMD. In the TMD, buffelgrass did not occur in any of the valley bottom or foothill plots and was found in only one of the eight bajada plots (Table 4.12.4-1). In the RMD, buffelgrass occurred in at least one plot in each of stratum and soil rock fragment type (Table 4.12.4-2). Since this measure is based on change, we could not assign a condition.

Total Cover of All Non-native Plants (%)

Total cover of non-native plants ranged from 0% in valley bottom plots to 2.03% in RMD's foothill plots (Table 4.12.4-1 and Table 4.12.4-2). Overall, non-native plant cover was low and well below the 5% threshold identified as

Table 4.12.4-3. Non-native and invasive plant species in vegetation monitoring plots in both districts of Saguaro National Park.

Species	Life Form	Stratum (# of plots)
Bromus rubens (red brome)*	graminoid (annual)	Foothills (2 of 8 plots RMD)
Bromus tectorum (cheatgrass)*	graminoid (annual)	Foothills (1 of 8 plots RMD)
Centaurea melitensis (Maltese star-thistle)*	forb/herb (annual)	Bajada (1 of 15 plots RMD)
Cyclospermum leptophyllum (marsh parsley)	forb/herb (annual)	Bajada (1 of 15 plots RMD)
Eragrostis cilianensis (stinkgrass)*	graminoid (annual)	Bajada (1 of 15 plots RMD) Foothills (1 of 8 plots RMD)
Eragrostis curvula (weeping lovegrass)*	graminoid (perennial)	Foothills (1 of 8 plots RMD)
Eragrostis lehmanniana (Lehmann lovegrass)*	graminoid (perennial)	Bajada (4 of 15 plots RMD) Foothills (3 of 8 plots RMD)
Erodium cicutarium (redstem stork's bill)	forb/herb (annual)	Bajada (1 of 13 plots TMD) Foothills (1 of 6 plots TMD)
Pennisetum ciliarus (buffelgrass)*	graminoid (perennial)	Bajada (1 of 13 plots TMD) Bajada (4 of 15 plots RMD) Foothills (1 of 8 plots RMD)

* Considered invasive by Saguaro National Park.

the trigger point between good and moderate to significant concern.

New Non-native Species Detected (2004-2014)
Parkwide, there were 68 species non-native species listed in the Exotic Plant Management Plan (2004) and 87 species listed in the Restoration Management Plan Environmental Assessment (2014). Of these, 26 non-native species were listed in 2014 that were not listed in 2004, 24 of which are known to occur in the TMD and low elevation areas in the RMD (Table 4.12.4-4). Nine of these species are considered invasive. Since at least 24 known

Table 4.12.4-4. List of new non-native species in the Tucson Mountain District and low elevation areas in the Rincon Mountain District from 2004 to 2014.

Species Name	Common Name
*Asphodelus fistulosus**	onionweed
Avena sativa	common oat
*Bothriochloa ischaemum**	yellow bluestem
Brassica nigra	black mustard
Bromus catharticus	rescuegrass
Cenchrus spinifex	coastal sandbur
Conyza bonariensis	flaxleaved fleabane
Cyperus esculentus	yellow nutsedge
Descurainia sophia	herb sophia
Dimorphotheca sinuata	African daisy
*Enneapogon cenchroides**	soft feathered pappus grass
Galinsoga parviflora	gallant soldier
Bassia scoparia	mock cypress
*Malva parviflora**	cheeseweed
Medicago sativa	alfalfa
*Melilotus officinalis**	yellow sweetclover
*Nicotiana glauca**	tree tobacco
*Opuntia engelmanii var. linguiformus**	cow's tongue prickly pear
*Parkinsonia aculeata**	Jerusalem thorn
Physalis peruviana	Peruvian ground cherry
Polygonum persicaria	spotted ladysthumb
Polypogon viridis	beardless rabbitsfoot grass
*Tamarix ramosissima**	saltcedar
Verbascum thapsus	common mullein

* Considered an invasive species by Saguaro NP.

new non-native species have invaded the TMD and low elevation areas in the RMD, this measure warrants moderate to significant concern. However, the apparent increase in non-native species may be partially due to increased awareness and interest in non-native and invasive plants. Some of these species likely existed in the park prior to 2004, but were undetected. Detection is likely to increase as non-native plants spread and become more visible. While this provides a rough estimate of the number of new non-native plants in Saguaro NP, the way non-native plants were classified between the two reports may have changed.

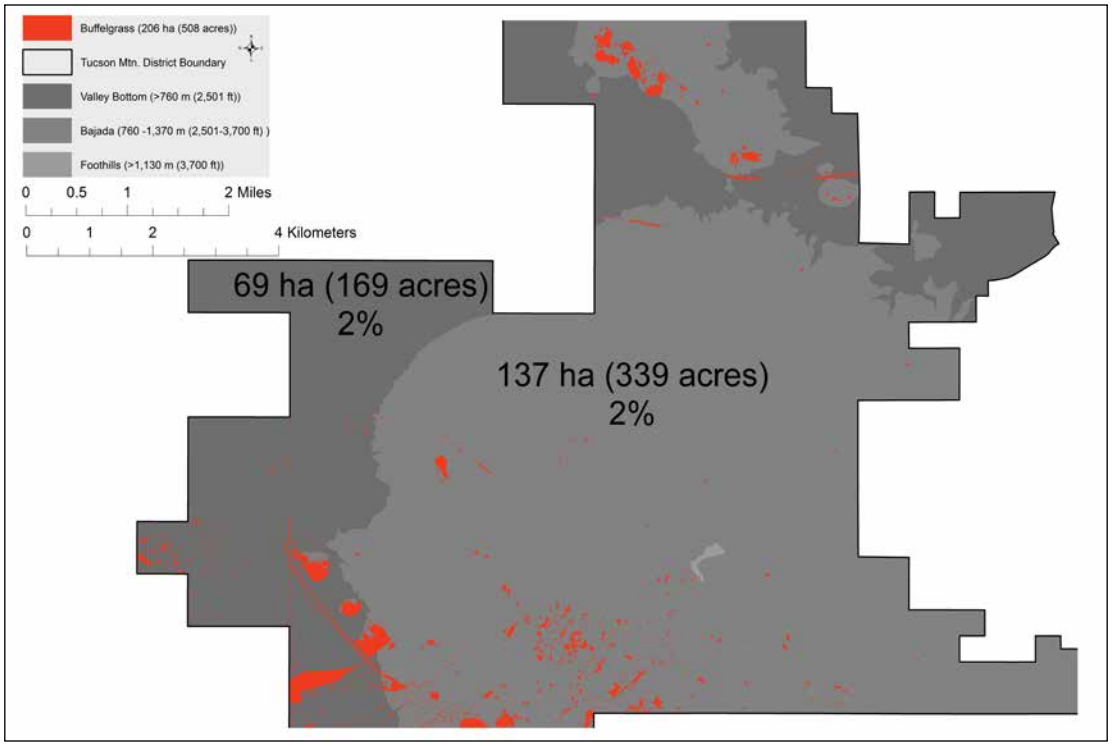

Figure 4.12.4-1. The occurrence of buffelgrass in the Tucson Mountain District (through 2012).

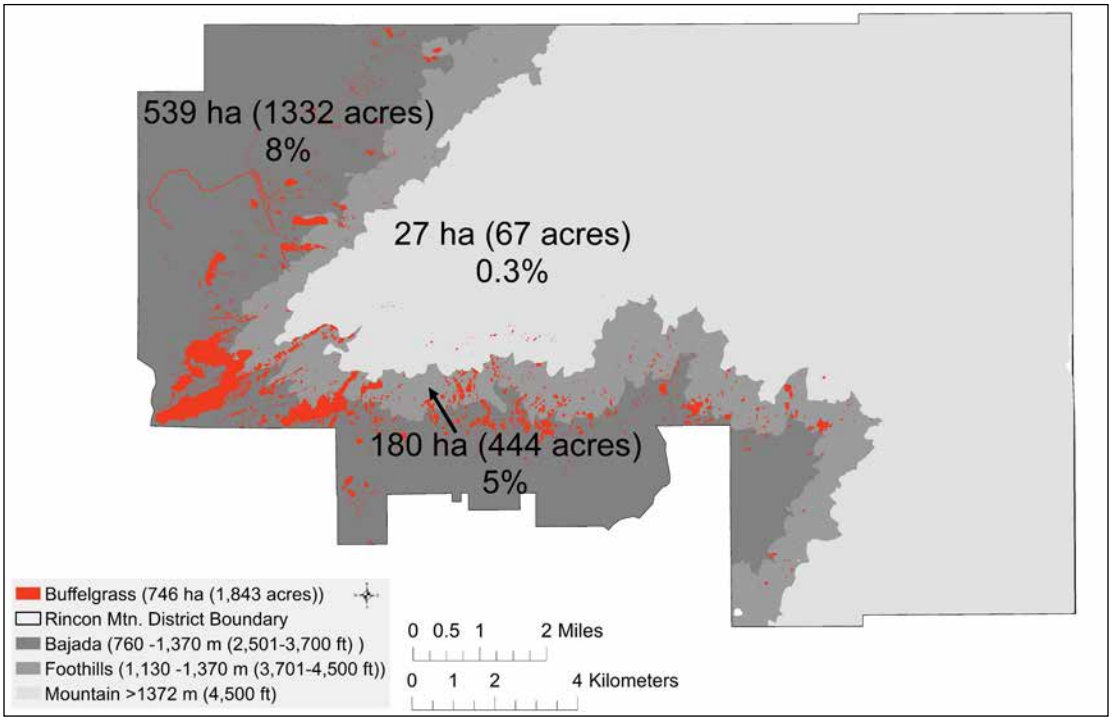

Figure 4.12.4-2. The occurrence of buffelgrass in the Rincon Mountain District (through 2012).

Occurrence of Buffelgrass

Figure 4.12.4-1 shows the occurrence of buffelgrass by strata in the TMD. Within the district, 206 ha (508 ac) of buffelgrass has been mapped, and the majority occurs within the bajada region. Proportionally however, buffelgrass is represented equally in the valley bottom and bajada strata (2% of each stratum). Since buffelgrass occurrence exceeds 1% in both strata, this measure warrants significant concern. No buffelgrass was mapped in the small foothill region of the TMD, which indicates good condition. However, it should

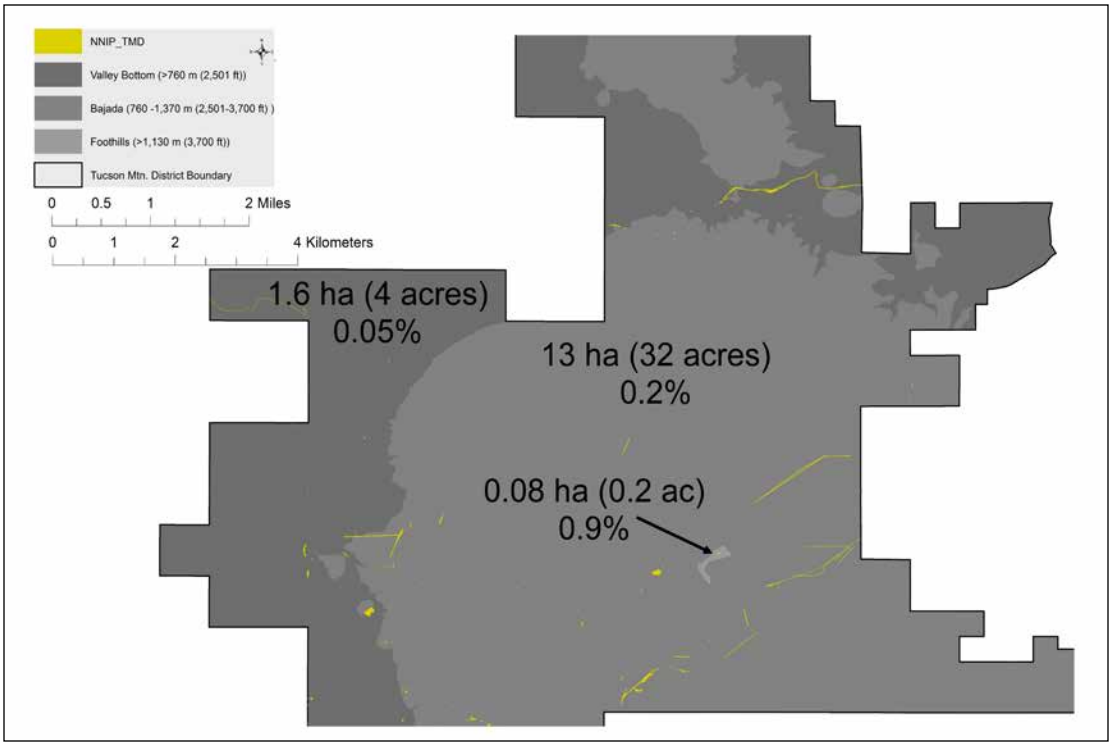

Figure 4.12.4-3. The occurrence of non-native plants (excluding buffelgrass) in the Tucson Mountain District (through 2012).

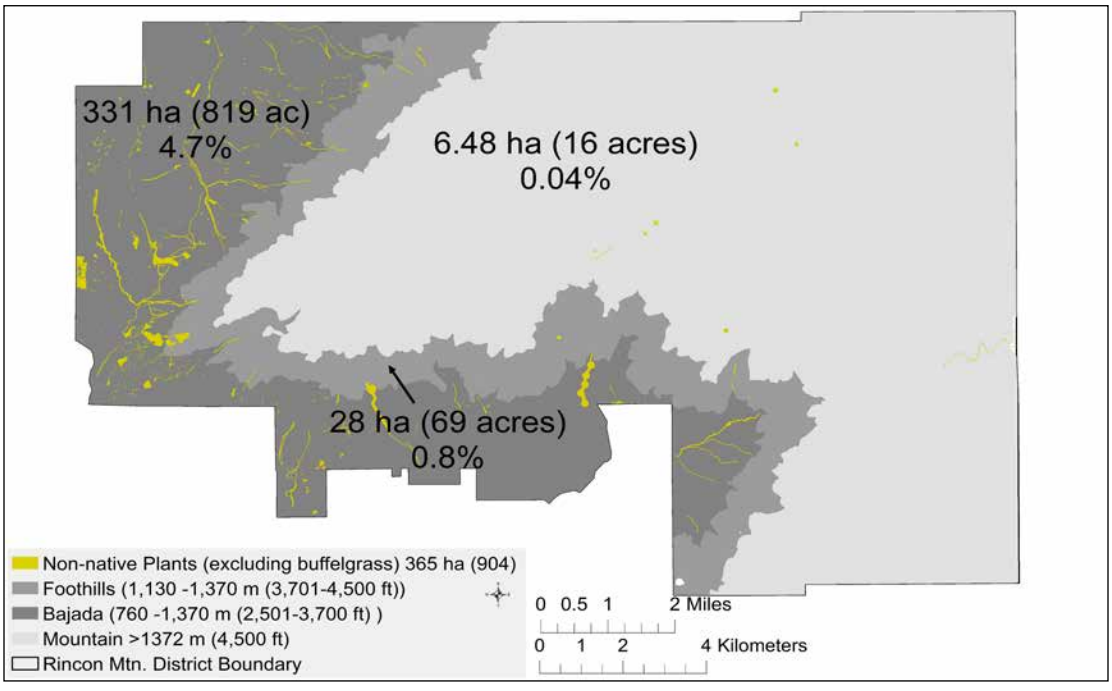

Figure 4.12.4-4. The occurrence of non-native plants (excluding buffelgrass) in the Rincon Mountain District (through 2012).

be noted that no comprehensive survey of buffelgrass has been conducted in the park.

Buffelgrass is much more prevalent within the RMD than within the TMD. Within the RMD, 746 ha (1,843 ac) of buffelgrass has been mapped, and the majority (96%) of buffelgrass occurs below 4,500 feet (Figure 4.12.4-2). Most buffelgrass was mapped in the bajada and accounted for 8% of this strata, which warrants significant concern. Buffelgrass accounted for 5% of the foothill strata, which warrants significant concern. According to Dana Backer, Saguaro NP Restoration Ecologist, some of these acres are under treatment and some are under

Table 4.12.4-5. Ground mapping and control treatments for non-native and invasive plants in Saguaro NP.

Year	Area Surveyed ha (ac)	Buffelgrass Mapped ha (ac)	Buffelgrass Treated ha (ac)	Buffelgrass Controlled ha (ac)	All other Non-native Species Mapped ha (ac)	All other Non-native Plants Treated ha (ac)
2011	1,173 (2,898)	51 (127)	45 (110)	37 (91)	15 (36)	13 (32)
2012	2,840 (7,017)	21 (52)	20 (49)	60 (149)	21 (51)	17 (42)
2013	3,035 (7,500)	119 (294)	37 (92)	81 (200)	10 (24)	4 (11)
2014	3,679 (9,091)	46 (113)	43 (107)	101 (250)	21 (53)	19 (46)
2015	3,785 (9,354)	27 (67)	23 (56)	146 (360)	26 (64)	18 (44)

Data were provided by D. Backer (Restoration Ecologist, Saguaro NP).

maintenance (i.e., finished being treated for now).

Occurrence of Non-native Plants

The number of mapped acres in the TMD was relatively low for each of the three strata (<1%) (Figure 4.12.4-3). The foothill stratum exhibited the highest proportion of mapped non-native species (0.9%, or 0.2 ac), which is approaching the 1% threshold between moderate concern and significant concern. This was also the case for the foothill region in the RMD, which exhibited 0.8% cover of non-native plants, which warrants moderate concern (Figure 4.12.4-4). The occurrence of non-native plants warrants moderate concern in all strata of the TMD. In the RMD's bajada stratum, non-native plants were mapped in 4.7% of the district, which warrants significant concern.

Buffelgrass & Other Non-native Plant Control Effort

During 2011-2015, Saguaro NP staff and volunteers have surveyed between 1,173 ha (2,898 ac) and 3,785 ha (9,354 ac) for non-native plants annually, and the area surveyed via these ground mapping and control efforts has increased over time (Table 4.12.4-5). Within the areas surveyed, the number of mapped hectares of buffelgrass has varied substantially between years with as few as 21 ha (52 ac) in 2012 to 119 ha (294 ac) in 2013. At least some of the buffelgrass that was treated was controlled, but this was variable among years. In 2011, approximately 83% of the treated area was controlled while in 2015 about 15% of the treated area was controlled since there were fewer areas of buffelgrass to treat since control has steadily increased (D Backer, Resoration Ecologist, pers. comm.).

The area of all other non-native plants mapped has remained relatively constant as has the area of non-native plants that were treated (excluding buffelgrass), but data on the effectiveness of these treatments is lacking. Therefore, the condition for this measure is unknown.

In some areas, treatments are having a positive effect on controlling buffelgrass and other non-native species while in other areas untreated patches continue to grow and new patches are constantly being established (D. Backer, pers. comm.). Repeat surveys of areas where buffelgrass was controlled indicated that the combined use of manual and chemical control treatments were more effective in reducing plant density and area than either treatment type alone (Hunter 2012). The majority (83%) of all plots (n = 106) showed a reduction in patch area greater than 90% (Hunter 2012). The study concluded that the most successful treatments were those which included both manual and chemical treatments over multiple, consecutive seasons. Overall, buffelgrass control efforts in Saguaro NP have been successful, but require constant effort to limit the spread of existing patches and to prevent new patches from forming (Hunter 2012). Therefore, we consider this measure to warrant moderate concern.

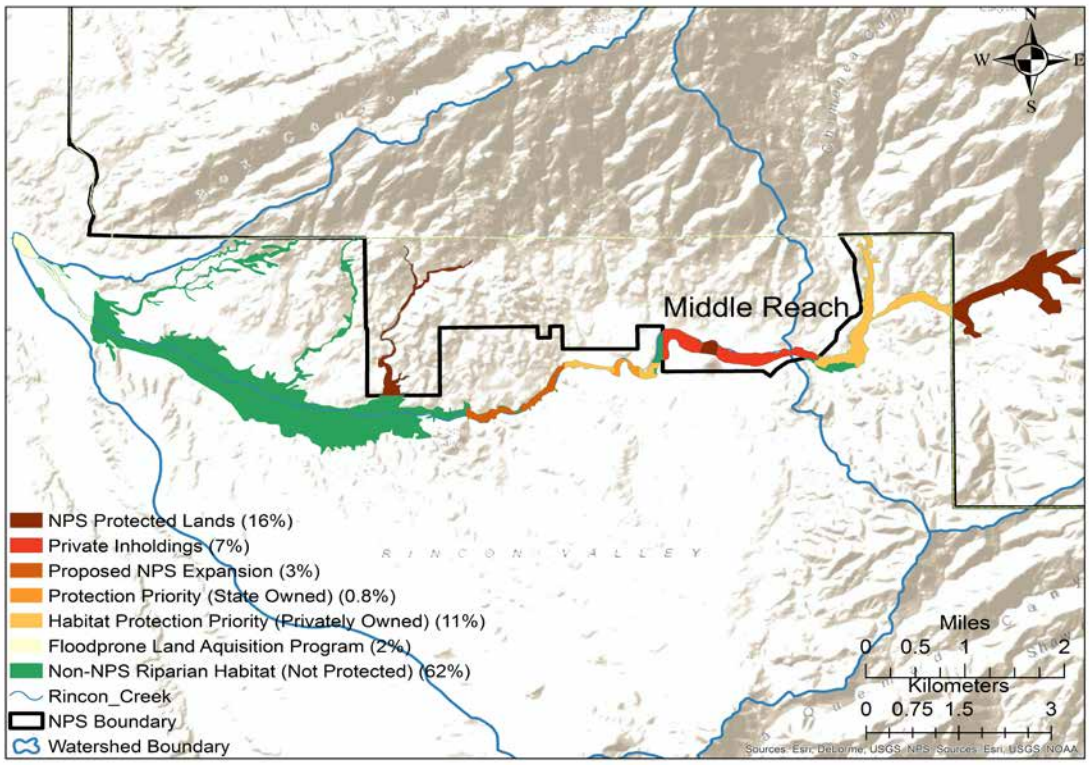

Figure 4.12.4-5. Map of various land use types of riparian habitat along Rincon Creek.

Change in Threatened, Endangered, or Rare Plants

Frequency and Cover

Only one sensitive plant species was found in SODN monitoring plots: Palmer's century plant (*Agave palmeri*). Frequency data were not reported, but the species occurred in one of the eight RMD foothills plots. Percent cover was relatively low overall (0.36%). The remaining six species are expected to occur in low elevation areas of Saguaro NP but were not present in SODN monitoring plots. Since this measure is based on change over time, we could not assess the condition of rare plants.

Conservation Potential of Rincon Creek

Land Use Type (% area)

The Rincon Creek riparian area includes 720 ha (1,779 ac) of mapped riparian habitat (Figure 4.12.4-5). Of this area, 18% is protected as either NPS lands within Saguaro NP (16%) or as Pima County lands that were acquired as part of the floodplain lands acquisition program (2%). Private inholdings located within middle reach represent 7% of the total riparian area. These lands are unprotected despite being located within the park boundary. Saguaro NP is working toward acquiring some of these parcels, one of which was acquired in 2016.

Priority areas for protection represent 15% of the total mapped riparian area. This included privately owned areas of high priority (11%), state owned areas of high priority (0.8%), and privately held land proposed for expansion of Saguaro NP (3%). These are areas that have been identified for potential acquisition by the state with 2015 bond election monies (Pima County 2016a). The remaining 62% of riparian habitat is unprotected, privately held land with no planned protection projects. Much of this land is privately held. Overall, 33% of the riparian habitat along Rincon Creek is either protected or planned for protection, and most of the planned protection projects are located on either side of the creek's middle reach. Since the majority of riparian habitat along Rincon Creek is unprotected, this measure warrants significant concern.

Prevalence of Native Vegetation Along Rincon Creek

Species Richness

Nineteen species of key herbaceous perennials, trees, and shrubs were recorded

in floodplain and terrace plots (Table 4.12.4-6). These included many species commonly associated with riparian areas such as Freemont cottonwood, Gooding's willow (*Salix gooddingii*), Arizona walnut (*Juglans major*), sycamore, and velvet ash, among others. In active floodplain plots, 15 species were recorded and 16 on terrace plots. Thirteen of the 19 species were found on both floodplain and terrace surfaces. The relatively high species richness indicates good condition for this measure.

Species Wetland Status

Of the 19 key species documented in both terrace and floodplain transects along Rincon Creek's middle reach, seven were considered upland species, three were considered facultative upland species, four were considered facultative species, three were considered facultative wetland species, and one species is mixed between facultative wetland and facultative (Table 4.12.4-6). No species was considered an obligate wetlands species. Twelve of the 19 species were given a facultative or facultative wetland designation. We consider the condition for this measure to be good since the majority of species present indicate maintenance of riparian-wetland soil moisture characteristics.

Total Percent Cover (for key species)

Riparian woodlands dominate floodplain surfaces with an average cover of 64% (Table 4.12.4-7). Terrace surfaces were a mix of riparian woodland and mesquite bosque plant communities. Cover for terrace plots averaged 75% (Table 4.12.4-8) and total cover appeared to increase downstream (Briggs et al. 2003). These data indicate that vegetative cover is in good condition for terrace plots, but may warrant moderate concern for floodplain plots, although the threshold for what is considered good is highly dependent on the specific riparian area and this may be adequate cover for Rincon Creek. Floodplain plots are subject to intense floods that likely remove entire trees, which would reduce cover. Taken together, the average cover of the entire riparian area is 70%. For these reasons, we consider vegetation cover to be in good condition.

Table 4.12.4-6. Wetland designation of common trees and shrubs found along Rincon Creek's middle reach.

Species	Common Name	Wetland Status
Herbaceous Perennials		
Senna leptocarpa	Senna	UPL
Shrubs		
Acacia [Vachellia) constricta	Whitethorn acacia	UPL
Acacia [Senegalia] greggii	catclaw acacia	FACU
Baccharis salicifolia	mule-fat	FAC
Baccharis sarothroides	desertbroom	FACU
Brickellia coulteri	Coulter's brickellbush	UPL
Celtis reticulata	netleaf hackberry	FAC
Eysenhardtia orthocarpa	Tahitian kidneywood	UPL
Gossypium thurberi	Thurber's cotton	
Hymenoclea monogyra	singlewhorl burrobrush	UPL
Lycium sp.	wolfberry	FACW/FAC
Mimosa biuncifera	catclaw mimosa	UPL
Ziziphus obtusifolia	lotebush	UPL
Trees		
Fraxinus velutina	velvet ash	FAC
Juglans major	Arizona walnut	FAC
Platanus wrightii	Arizona sycamore	FACW
Populus fremontii	Fremont cottonwood	FACW
Prosopis velutina	velvet mesquite	FACU
Salix gooddingii	Gooding's willow	FACW

* USDA Plants Database Wetland Status (2016). Wetlands status definitions are as follows:

UPL = obligate upland; almost never occurs in wetlands.

FACU = facultative upland; usually occurs in non-wetlands, but may occur in wetlands.

FAC = Facultative; occurs in wetlands and non-wetlands.

FACW = Facultative wetland; usually occurs in wetlands, but may occur in non-wetlands.

OBL = Obligate wetland; almost always occurs in wetlands.

Age-class Distribution

Briggs et al. (2003) reported on two age classes: seedling/sapling and adult. Transects in the floodplain indicated recruitment of juveniles by the higher number of seedlings/saplings vs. adults (Table 4.12.4-7), but this was not the case for transects located in the terrace plant community (Table 4.12.4-8). We did not assign a condition for this measure because of the conflicting results and because data were limited.

Prevalence of Non-native Plants

New Non-native Species Detected (2004-2014): Rincon Creek

Of 26 non-native species listed in 2014 that were not listed in 2004, at least two are known to occur in along Rincon Creek. They are onionwweed (*Asphodelus fistulosus*) and yellow bluestem, (*Bothriochloa ischaemum*). Tamarisk (*Tamarix spp.*) also occurs along the riparian area. One or more species of tamarisk may be new to the creek, but because they hybridize, it was unclear which or how many species are recent invaders. Furthermore, NPS (2004) did not list tamarisk by species. All species are considered invasive. Tamarisk is a multi-stem tree that has invaded river corridors throughout the southwest. Efforts to control tamarisk in Saguaro NP have been ongoing since the 1980s (Kolb and Backer 2011). Prior to a major flood in 2006, tamarisk was not considered a major issue; however, the flood led to a surge of seedlings, and park

Table 4.12.4-7. Vegetation data floodplain transects along Rincon Creek's middle reach.

Plant Species	Transect F1 Floodplain		Transect G1 Floodplain		Transect G2 Floodplain		Transect G3 Floodplain	
Species	% Cover	Tree age ratio*	% Cover	Tree age ratio*	% Cover	Tree age ratio*	% Cover	Tree age ratio*
Cottonwood	19.63	3:2	46.88	0:4	3.5	0:0	---	0:0
Willow	---	---	11.37	0:0	---	0:0	---	0:0
Velvet Ash	35.63	18:14	11.63	2:0	8.5	11:7	5.5	3:0
Mesquite	---	2:0	-	0:0	1.5	2:1	---	0:0
Hackberry	10.82	9:4	.37	4:1	0.75	4:0	---	0:0
Others (combined)	33.5	---	0	---	8.38	---	---	6:0
Total Average	99.6	---	70.25	---	22.75	---	---	9:0
Species Richness	11		5		12		1	

* Tree age ratio is seedling/sapling:adult

Data from Briggs et al. (2003).

Table 4.12.4-8. Vegetation data terrace transects along Rincon Creek's middle reach.

Plant Species	Transect F1 Terrace		Transect G1 Terrace		Transect G2 Terrace		Transect G3 Terrace	
Species	% Cover	Tree age ratio*	% Cover	Tree age ratio*	% Cover	Tree age ratio*	% Cover	Tree age ratio*
Cottonwood .	---	0:0	27.83	0:3	9	0:0	---	0:0
Willow	---	0:0	---	0:0	---	0:0	---	0:0
Velvet Ash	---	0:0	16.82	2:5	32.92	0:1	7.63	0:0
Mesquite	---	0:3	---	0:0	11.33	8:6	42.19	3:10
Hackberry	21.13	3:6	---	0:0	4.5	7:0	14.56	7:5
Others (combined)	5	---	---	---	---	---	17.97	---
Total Average	99.57	---	44.7	---	70.75	---	82.34	---
Species Richness	5		4		10		9	

* Tree age ratio is seedling/sapling:adult

Data from Briggs et al. (2003).

staff removed literally thousands of young tamarisk plants over the following year. In subsequent years, park staff launched an effort to document and control tamarisk in other drainages in the park. Staff recorded 77 tamarisk plants in eight drainages (Kolb and Backer 2011). In Rincon Creek, 155 individual plants were found, three of which occurred in the park during the 2010-2011 survey. However, during 2006-2011, more than 2,000 tamarisk plants have been treated along Rincon Creek, both inside and outside of the park (Kolb and Backer 2011). Rincon Creek flows in and out of the park at two locations and then flows along much of the park's southern boundary and thus has the potential to influence riparian community structure within the park (Kolb and Backer 2011). Since three new invasive species have been documented along Rincon Creek, we consider this measure to warrant significant concern, especially since this is a critically important habitat type in the park.

Occurrence of Non-native Plants

Buffegrass was mapped in 0.02 ha (0.05 ac) of riparian habitat along Rincon Creek, or 0.01% of the riparian area. All other non-native species were mapped in 5.4 ha (13.3 ac) of riparian habitat, or 4% of the riparian area. Since buffelgrass was mapped in <1% of riparian habitat we consider the condition to warrant moderate concern, but the combination of all other native plants exceeds 1% of riparian habitat, which warrants significant concern. This represents a minimum of non-native plants since only those plants that are treated are mapped and, therefore, does not include all non-native species since only some are actively managed.

Sonoran Desert and Riparian Vegetation

Indicators	Measures
Plant Community Resilience	2 Measures
Erosion Hazard	2 Measures
Fire Hazard	3 Measures
Forest Health	2 Measures
Non-native and Invasive Plants	10 Measures
Threatened, Endangered, or Rare Plants	1 Measure
Conservation Potential of Rincon Creek	1 Measure
Prevalence of Native Veg Along Rincon Cr.	4 Measures
Prevalence of Non-native Plants Along Rincon Cr.	1 Measure

Overall Condition and Trend

To assess the condition of vegetation in low elevation areas of the Saguaro NP we used eight indicators and 25 measures. One indicator and seven measures did not contribute to the overall condition rating. Four measures of non-native and invasive plants and the measure of threatened, endangered, or rare plants were based on repeat monitoring of SODN plots, which will be completed in 2018-2019. Two additional measures were not assigned a condition because data were either limited or no condition thresholds have been established. Therefore, the overall condition rating for low elevation vegetation and soils was based on seven indicators and 18 measures (Table 4.12.4-9).

The high number of measures with varying condition ratings made it difficult to assign an overall condition for low elevation vegetation and soils in the park. Some measures warrant significant concern while other were considered good. However, based on the indicators and measures used in this assessment we consider the overall condition of vegetation and soils in low elevation areas of Saguaro NP to warrant moderate concern. Confidence in this rating is medium since several measures used were of medium confidence (e.g., mapping data) and only one round of SODN sampling has occurred to date. Few data on trend were available, therefore we did not assign a trend. Grazing was ended in the park decades ago, so it is anticipated that impacted plant species will be recovering. Red brome did pose a fire

threat from the 1970s to mid-1990s, but a long series of dry winters has greatly decreased its abundance. However, buffelgrass is widespread and has the potential to increase exponentially. It is uncertain if control efforts are or will be sufficient to prevent or reverse its increase and threat.

Level of Confidence/Key Uncertainties

Level of confidence for many condition ratings was high, particularly for those measures based on SODN monitoring data. Vegetation monitoring plots established by SODN were located via a random, spatially balanced process, and the power to detect change within each stratum was determined to be excellent (Hubbard et al. 2011). Although, SODN's measures for the plant resilience indicator included total cover for native and non-native plants, which confounds the reference conditions as they are currently stated.

Confidence in the condition rating for mapped buffelgrass and other non-native plants was medium. In 2012, aerial surveyors mapped the extent of buffelgrass in the park; however, not all areas were surveyed. Furthermore, small patches of non-native plants are more likely to go undetected, but even small patches of invasive species can spread rapidly and cause substantial harm to native plants. Confidence in the condition rating for new non-native species detected was high. Saguaro NP has a program dedicated to vegetation monitoring and restoration of native plants as well as additional monitoring of vegetation conducted by SODN. Therefore, the number of new non-native species that have invaded the park since 2004 is probably accurate. Continued monitoring and restoration efforts will likely detect new non-native species if they should occur.

We assigned low confidence to the condition ratings for measures of vegetation along Rincon Creek. While the study itself was designed using standard vegetation data collected methods, the data are now 13 years old and do not necessarily represent current conditions. Rincon Creek's middle reach has been influenced by grazing, groundwater pumping, urban encroachment along the boundary of the park and in privately held land along Rincon Creek outside the park. These were a few of the concerns cited in Briggs et al. (2003) thirteen years ago and are still of concern today (NPS 2014b). It is uncertain how the increase in groundwater withdrawal and climate change, among other factors, has influence vegetation there. Although wetland trees may still occur there, this does not necessarily indicate maintenance of adequate groundwater since deciduous trees are deep-rooted and may be able to access groundwater that has fallen below what is necessary for recruitment (Figure 4.12.4-6) (Prichard et al. 1998).

Finally, much of Rincon Creek's riparian area is privately owned. Protected areas occur almost exclusively inside the park. The stretch where Rincon Creek leaves the park before flowing back into the park is of particular concern. None of this area is protected, but there are planned protection projects for this region (Pima County 2016a).

Pima County is concerned about preserving riparian habitat and to that end, has developed the Sonoran Desert Conservation Plan (Pima County 2011b). Riparian habitat in Arizona is one of the highest priority habitats for

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Figure 4.12.4-6. Saguaro National Park protects riparian habitat, which supports 60-75% of Arizona species.

Table 4.12.4-9. Summary of valley bottom, bajada, and foothills vegetation and soils indicators and measures in Saguaro NP.

Indicator	Strata	Measure	Condition	Rationale for Condition
Plant Community Resilience	Foothills	Tree and Shrub Cover (subcanopy)	Good	Tree and shrub cover, combined and individually, indicate good condition since these measures were well below the 30% threshold. Confidence is high. No data on trend are available.
	Foothills	Perennial Grass Cover (field)	Moderate Concern/ Significant Concern	The value is slightly below the criteria for good condition; however, the standard error of the mean overlaps the management assessment point. Confidence is high. No data on trend are available.
Erosion Hazard	Valley bottom/ Bajada/ Foothills	Bare Ground Cover (with no overhead vegetation)	Valley Bottom, Foothills, and TMD Bajada: Good; RMD Bajada: Moderate Concern/ Significant Concern	In valley bottom and the foothills of both districts and in the TMD bajada the threshold for good condition was met; however, in RMD's bajada region the standard error of the mean overlaps the management assessment point for rocky sites and approaches the management assessment point in non-rocky sites. Confidence is high. No data on trend are available.
	Bajada & Foothills	Soil Stability Class Index (no canopy)	Moderate Concern/ Significant Concern	At least one plot in all strata in both districts exhibited an average soil stability class less than two, which warrants moderate to significant concern.
Fire Hazard	Valley Bottom/ Bajada/Foothills	Ratio of Annual Plant Cover to Total Plant Cover (field)	Good	This measure was within the range for good condition for all strata in both districts. Confidence is high. No data on trend are available.
		Extent of Red Brome	Unknown	No condition thresholds have been developed for this measure. Confidence is high. No data on trend are available.
	Bajada	Grass and Forb Combined Cover (field)[1]	Good	Grass and forb cover in the bajada was within the range considered good for each district. Confidence is high. No data on trend are available.
Non-native and Invasive Plants	Valley Bottom/ Bajada/Foothills	Total Cover of All Non-native Plants (field)[1]	Good	Non-native plant cover was low and well below the 5% threshold identified as the trigger point between good and moderate to significant concern. Confidence is high. No data on trend are available.
	Park-wide	New Species Detected (2004-2014)[2]	Moderate Concern/ Significant Concern	Of new non-native species listed in 2014 that were not listed in 2004, 24 are known to occur in low elevation areas of the park. Nine of these species are considered invasive. Condition is deteriorating. Confidence is high.

Table 4.12.4-9. Summary of valley bottom, bajada, and foothills vegetation and soils indicators and measures in Saguaro National Park continued.

Indicator	Strata	Measure	Condition	Rationale for Condition
Non-native and Invasive Plants	Valley Bottom/ Bajada/Foothills	Occurrence of Buffelgrass[2]	Significant Concern: Valley Bottom,Bajada, & RMD Foothills Good: TMD Foothills	In all strata buffelgrass exceeded 1% of the total area, which warrants significant concern, except in the foothills of the TMD, where no buffelgrass was mapped. Confidence is medium. Trend data were not available.
		Occurrence of Non-native Plants[2]	TMD: Moderate Concern RMD: Bajada (Significant Concern), Foothills (Moderate Concern)	The proportion of non-native plants in the TMD was relatively low for each of the three strata (0.05-0.9%). In the RMD's bajada stratum, non-native plants were mapped in 4.7% of the area and 0.8% of the foothills stratum. Confidence is medium. Trend data were not available.
	Park-wide	Buffelgrass Control Effort[2]	Moderate Concern	Overall, buffelgrass control efforts in Saguaro NP have been successful, but require constant effort to limit the spread of existing patches and to prevent new patches from forming. Therefore, we consider this measure to warrant moderate concern.
		Non-native Plant Control Effort (excluding Buffelgrass)[2]	Unknown	The area of all other non-native plants mapped has remained relatively constant as has the area of non-native plants that were treated (excluding buffelgrass), but data on the effectiveness of these treatments is lacking. Therefore, the condition for this measure is unknown.
Conservation Potential of Rincon Creek	Rincon Creek	Land Use Type (%)	Significant Concern	Since the majority of Rincon Creek is unprotected, we consider the condition for this measure to warrant significant concern. Confidence in is high. No trend data were available.
Prevalence of Native Vegetation Along Rincon Creek		Age Class Distribution	Unknown	We did not assign a condition for this measure because of the conflicting results and because data were limited. Confidence is low since these data are 13 years old. No trend data were available.
		Species Richness	Good	At least 19 species of tree, shrub, and forb were documented along Rincon Creek. Confidence in this condition rating is low since these data are 13 years old and do not necessarily represent current condition. No trend data were available.
		Species Wetland Status	Good	Twelve of the 19 species were condidered facultative or facultative wetland, which indicates good condition. Confidence in this condition rating is low since these data are 13 years old. No trend data were available.

Table 4.12.4-9. Summary of valley bottom, bajada, and foothills vegetation and soils indicators and measures in Saguaro National Park continued.

Indicator	Strata	Measure	Condition	Rationale for Condition
Prevalence of Native Plants Along Rincon Creek	Rincon Creek	Percent Total Cover	Good	Vegetation cover averaged 70% across terrace and floodplain plots, but was lower in floodplain plots than in terrace plots. Confidence in this condition rating is low since these data are 13 years old. No trend data were available.
Prevalence of Non-native Plants		New non-native Species Detected (2004-2014)	Significant Concern	Three new non-native plants, all of which are invasive, were documented in 2014 that were not documented in 2004. Condition is deteriorating. Confidence is high.
		Occurrence of Non-native Plants	Moderate Concern/ Significant Concern	Since buffelgrass was mapped in <1% of riparian habitat we consider the condition to warrant moderate concern, but the combination of all other native plants exceeds 1% of riparian habitat, which warrants significant concern. Confidence is medium. No trend data were available.

protection, supporting 60-75% of all Arizona species during some phase of their life cycles (Pima County 2011b).

Threats and Stressors

Of all the stressors on vegetation, climate change has the most potential to influence community composition, vegetation structure, and species richness. The western U.S., and especially the Southwest, has experienced increasing temperatures and decreasing rainfall that have increased tree mortality from a combination of causes, including warmer temperatures, less precipitation, pests, pathogens, and wildfires (Hansen et al. 2014, Potter and Conkling 2016, and Prein et al. 2016). Since 1974 there has been a 25% decrease in precipitation, accompanied by increasing "weather type" intensity (Prein et al. 2016). Plants may be less able to take advantage of periods with intense precipitation that are followed by long intervals of drought.

Climate change has exacerbated the effects of non-native species. Non-native species have been directly linked to the replacement of native species (Tilman 1999), the loss of rare species (King 1985), changes in ecosystem structure, alteration of nutrient cycles and soil chemistry (Ehrenfeld 2003), shifts in community productivity and alteration of fire regime (Vitousek 1990), reduced agricultural productivity, and changes in water availability (D'Antonio and Mahall 1991). The damage caused by these species to natural resources is often irreparable, and our understanding of the consequences incomplete.

Several species of non-native plants have invaded Saguaro NP's desert and desert thornscrub environments, including buffelgrass, red brome, soft feather pappus grass (*Enneapogon cenchroides*), fountain grass, Mediterranean grass (*Schismus barbatus*), Sahara mustard (*Brassica tournefortii*), and Malta starthistle (*Centaurea melitensis*) (NPS 2014a). Many of these non-native species are drought tolerant. As the climate becomes drier, these invasive plants are more likely to spread.

The invasion of non-native species has introduced fire into an environment not adapted to this type of disturbance. Historically, desert and desert thornscrub habitats experienced a fire return interval of approximately every 250 years; however, these drought tolerant, non-native species have significantly shortened the fire return interval causing substantial harm to species not adapted to survive frequent, high

intensity fires (Hubbard et al. 2012). Fire, in turn, promotes further invasion by these non-native species.

Furthermore, recent analyses indicate that nitrogen deposition throughout the majority of both districts exceeds nutrient nitrogen critical loads for sensitive vegetation (Sullivan and McDonnell 2014), suggesting that native plant communities are at elevated risk for harmful effects. Nitrogen favors buffelgrass over native species in similar ecosystems, as it is able to rapidly absorb and assimilate nitrogen (Lyons et al. 2013).

Buffelgrass has the potential to shift biologically rich desert biome to a permanent, single species grassland state (Logan Simpson Design Inc. 2010). In the Tucson Basin, Arizona, which encompasses Saguaro NP, 32% of the habitat was at high risk for ecological impacts to ecosystem structure and function as well as for the natural aesthetics of the desert environment as a result of buffelgrass invasion (Logan Simpson Design Inc. 2010).A buffelgrass suitability model is currently under development by the U.S. Geological Survey (USGS) (D. Backer, pers. comm.). The model will be based largely on the 2012 aerial survey data and will help managers target areas for surveys and control efforts.

Unlike the desert and bajada, fire is a natural and necessary process in semi-desert grasslands with a historic fire return interval of every 5-10 years (Hubbard et al. 2012). Fire promotes the grassland state of this community type and limits the spread and growth of woody species that would otherwise encroach; however, fire suppression has led to invasion by drought-resistent non-native grasses such as Lehmann lovegrass (*Eragrostis lehmanniana*) and encroachment of woody species (Hubbard et al. 2012).

Surface and ground water quantity is an important resource for native vegetation in Saguaro NP. Long-term hydrologic data collected by the USGS provide important information regarding changes in stream discharge since 1952 (NPS 2008). The data collected by the NPS since 2003 supplements the USGS data (NPS 2008). The NPS water right application has not been resolved and development along the southwestern boundary of the RMD has increased dramatically in recent years, adding pressure on already limited water resources in the park (NPS 2014a, Briggs 2008). The wetland plant community is dependent on near-surface soil saturation; however, mature trees and other vegetation in Rincon creek already show signs of water stress and there is a general lack of seedling recruitment, and numerous large cottonwoods have died in the last ten years (D. Swann, pers. comm., Baird et al. 2001). Vegetation structure and health play a key role in bird species diversity and abundance.

4.12.5. Sources of Expertise

Dana Backer, Saguaro NP Restoration Ecologist, Andy Hubbard and Sarah Studd (SODN, NPS) advised on various sections of this assessment. Patty Valentine-Darby is credited with aspects of this assessment related to buffelgrass. This section was authored by Lisa Baril, science writer, Utah State University.

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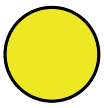
4.13. Grasslands, Woodlands, Forest Vegetation and Soils

Indicators/Measures

- Plant Community Resilience (4 Measures)
- Erosion Hazard (2 Measures)
- Departure from FRI (1 Measure)
- Forest Health (2 Measures)
- Non-native and Invasive Plants (9 Measures)
- Threatened, Endangered, or Rare Plants (1 Measure)

Condition – Trend - Confidence



Moderate Concern- Unknown - Medium

4.13.1. Background and Importance

Saguaro National Park's (NP) Rincon Mountain District (RMD) supports a diverse assemblage of habitat types from wooded shrublands in the bajada to temperate coniferous forests in the mountains (Figure 4.13.1-1). This diversity of vegetative communities is a result of a steep topographical gradient, which ranges from 814 m (2,670 ft) to 2,641 m (8,665 ft) at Mica Mountain, Saguaro NP's tallest peak. This assessment focuses on the mountain environment, which includes grasslands, savannas, woodlands, and forest vegetation types and soils above 1,372 m (4,500 ft) (vegetation in the bajada and foothills is addressed in a separate assessment).

Grasslands, woodlands, and forests represent approximately half of the land area in Saguaro NP (NPS 2014). Woodlands and forests occur only within the RMD, while grasslands and savannas occur in both districts; however, the latter habitat types are limited to small, scattered patches on the Tucson Mountain District's tallest peaks (NPS 2014).

At mid elevation areas in the RMD, Madrean evergreen woodlands represent the dominant vegetation type (Hubbard et al. 2012). These woodlands are characterized by evergreen oaks with hard, stout leaves, such as Emory oak (*Quercus emoryi*), Arizona white oak (*Quercus arizonica*), and Mexican blue oak (*Quercus oblongifolia*) (Hubbard et al. 2012). Mexican pinyon pine (*Pinus cembroides*) and

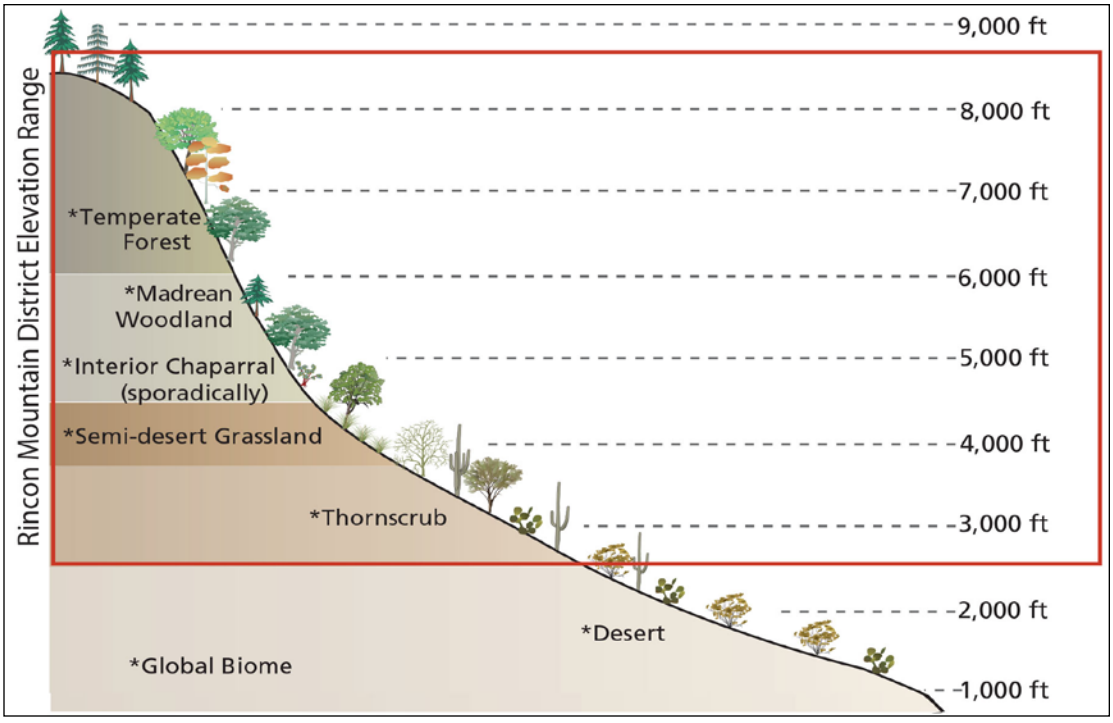


Figure 4.13.1-1 . Plant community types by elevation in the Rincon Mountain District, Saguaro National Park. Figure Credit: Adapted from NPS SODN.

alligator juniper (*Juniperus deppeana*) are also common, and perennial grasses are usually abundant in the understory (Hubbard et al. 2012). Madrean woodlands in the RMD represent the northern end of a biodiversity hotspot known as the Madrean Pine-Oak Woodlands (CEPF 2016).

Madrean woodlands (Figure 4.13.1-2) are occasionally interspersed with interior chaparral consisting of dense stands of manzanita (*Arctostaphylos* spp.) and shrub live oak (*Quercus turbinella*) (Hubbard et al. 2012). The natural fire regime for chaparral includes intense, fast-moving fires that are often stand-replacing (Hubbard et al. 2012).

Above Madrean woodlands, pines (*Pinus* spp.), spruces (*Picea* spp.), dominate the overstory. Ponderosa pine (*P. ponderosa*) is usually the most common species with a generally open forest structure that allows for a grassy understory. On the north-facing slopes at higher elevations, Douglas fir (*Pseudotsuga mensiezii*), ponderosa pine, southwestern white pine (*P. strobiformis*), and white fir (*Abies concolor*) dominate (Powell et al. 2006, NPS 2014).

Deciduous woody trees including Gambel oak (*Quercus gambelii*) and trembling aspen (*Populus tremuloides*) also occur in places in the coniferous forests, especially on colder, north and east facing slopes. These species can emerge from the understory following canopy opening disturbances, such as fire (Hubbard et al. 2012).

Vegetation is one of the most useful indicators of ecological integrity because it forms the foundation of terrestrial ecosystems, comprising nearly 99% of the earth's biomass (Hubbard et al. 2012). Monitoring vegetation dynamics (e.g., productivity, community composition, and life form) can indicate whether ecosystem processes (e.g., nutrient and hydrologic cycles) are functioning properly and/or changing over time. Monitoring vegetation is also a useful indicator of ecosystem integrity since it is immobile and can therefore, be monitored relatively easily over the long-term (Hubbard et al. 2012).

NPS

Figure 4.13.1-2 . Pinyon-juniper forest interspersed with Chihuahua pine.

4.13.2. Data and Methods

We used six indicators with between one and nine measures each for a total of 19 measures to assess the condition of grasslands, woodlands, and forest vegetation and soils in the RMD.

We relied on data from the Sonoran Desert Network's (SODN) Vegetation Monitoring Program, Saguaro NP's Vegetation Monitoring and Restoration Program, Saguaro NP's Fire Program, and the U.S. Forest Service's Forest Health Monitoring Program. For most measures, data are reported for at least one of the three following strata based on elevation (Figure 4.13.2-1):

- Mid-mountain: 1,372 - 1,829 m (4,501-6,000 ft);
- High Mountain: 1,829 - 2,286 m (6,000-7,500 ft); and
- Mountaintop: > 2,286 m (>7,500 ft).

Vegetation was monitored by SODN in each of 38 permanent upland vegetation and soils sampling plots located via a random, spatially balanced process (Hubbard et al. 2012). Twenty plots were located in the mid-mountain range, ten plots in the high mountain range, and eight plots in the mountaintop range (Figure 4.13.2-2). These plots were 20 × 50-m (66 x 164-ft) and contained six transects each (Figure 4.13.2-3). Vegetation was measured along each transect at 0.5-m (1.6-ft) intervals (240 points per plot) in one or more of the three following vegetation layers:

- Field: < 0.5 m (1.6 ft);

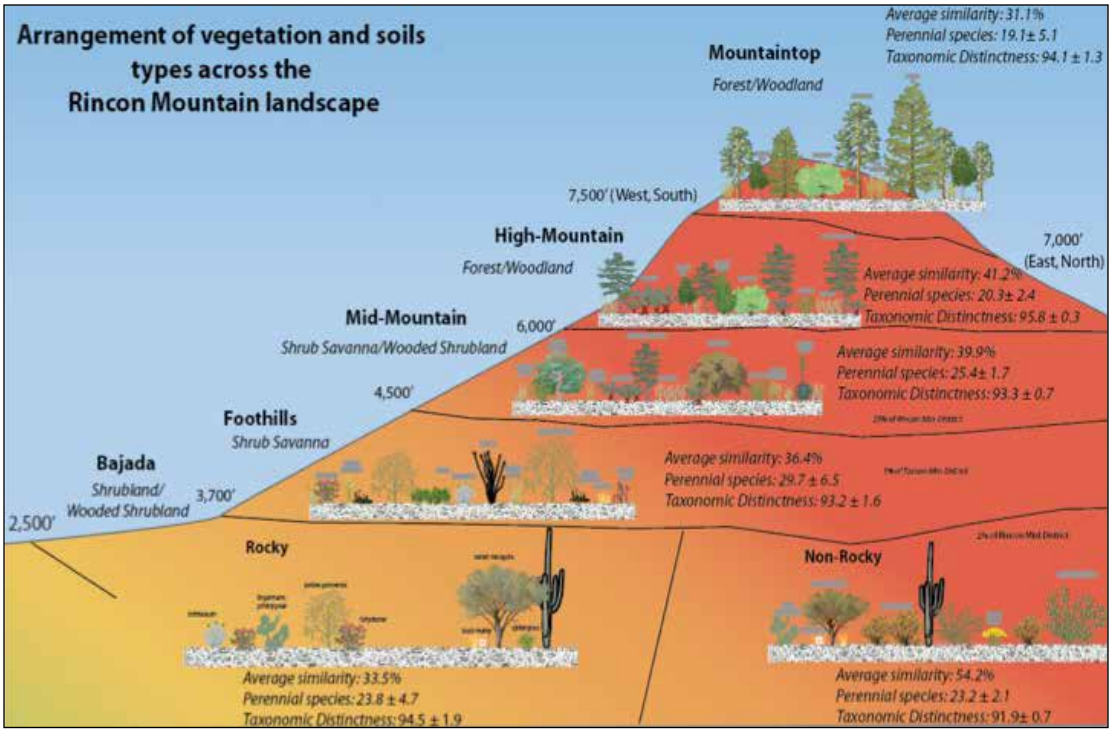


Figure 4.13.2-1. Vegetation and soil type by elevation in the Rincon Mountain District, Saguaro National Park. Figure Credit: NPS SODN.

- Subcanopy: 0.5-2.0 m (1.6-6.6 ft); and
- Canopy: > 2.0 m (>6.6 ft).

Each plot was visited once during 2008-2012. Repeat sampling is scheduled to occur every five years with an expected completion date for the second round of sampling in 2018 (A. Hubbard, pers. comm.).

Indicator/Measures

Plant Community Resilience (Total Tree Cover, Tree and Shrub Cover, Perennial Grass Cover, and Ratio of Annual Plant Cover to Total Plant Cover)

The four following measures address plant community resilience, or the ability of plant communities in the RMD to recover after a disturbance, maintain natural processes (e.g., fire regime), and resist invasion by non-native plants.

Total Tree Cover (%)
Total tree cover was calculated as the absolute proportion of foliar tree cover in the canopy layer within high mountain and mountaintop plots.

Tree and Shrub Cover (%)
This measure was calculated as the absolute proportion of tree and shrub cover in the subcanopy layer within mid-mountain plots.

Perennial Grass Cover (%)
This measure was calculated as the absolute proportion of perennial grass cover in the field layer within mid-mountain plots.

Ratio of Annual Plant Cover to Total Plant Cover
This measure is presented as both a ratio of annual plant cover to total plant cover and as the proportion of total plant cover represented by annual plants in the field layer within mid-mountain plots.

Indicator/Measures

Erosion Hazard (Bare Ground Cover, Soil Stability)

Bare ground cover and the soil class stability index address erosion hazard by wind, water, or disturbance events. The data for these two measures were collected by SODN as part of their vegetation monitoring program within the plots described above.

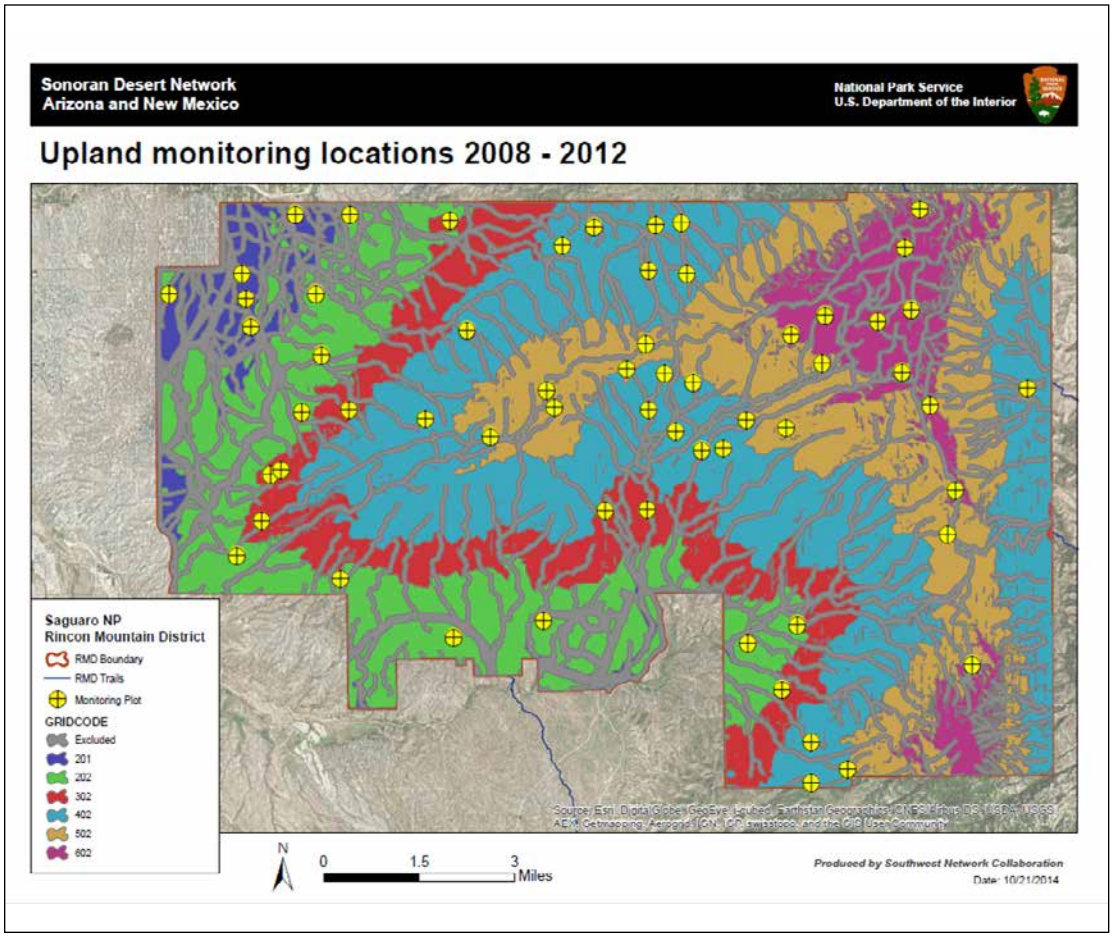


Figure 4.13.2-2. Upland monitoring locations in the Rincon Mountain District (Hubbard et al. 2011).

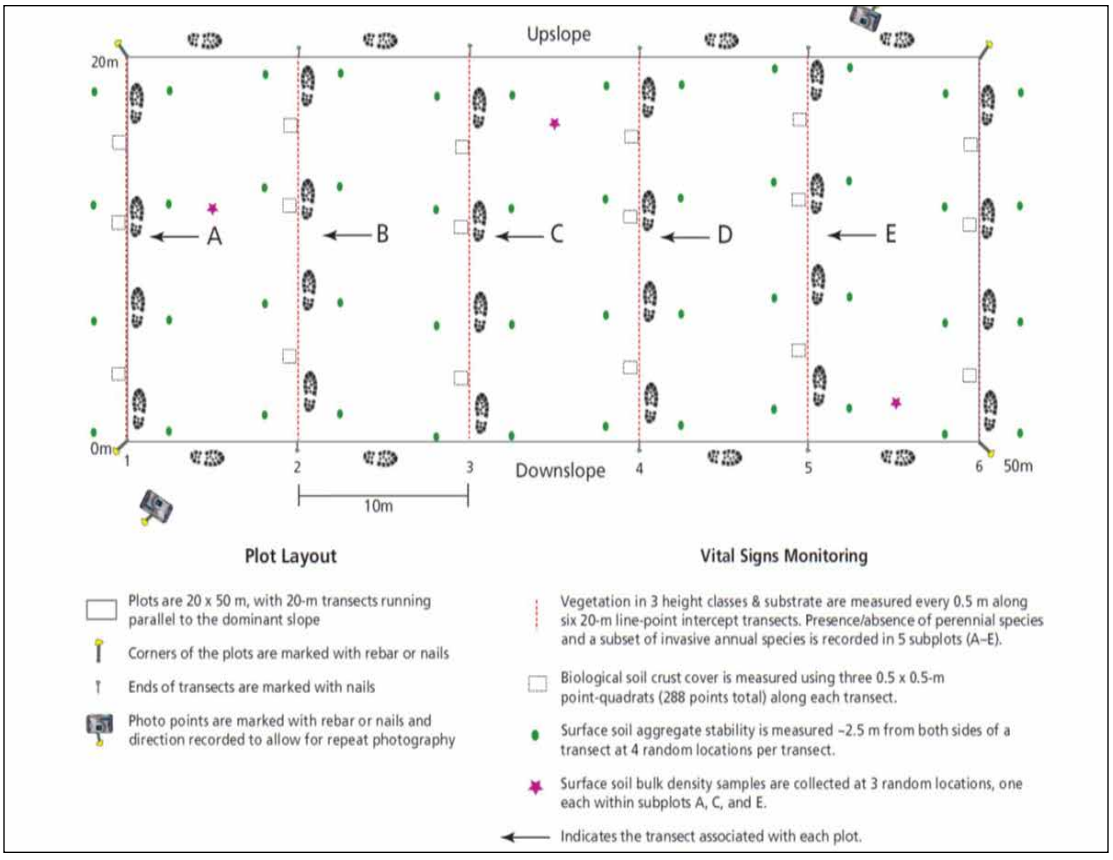


Figure 4.13.2-3. The design of upland vegetation and soils monitoring plots, showing six transects per plot (Hubbard et al. 2011).

Bare Ground Cover (%)

The amount of bare ground is the inverse of soil cover, which was measured without overhead vegetation in all three elevation strata: mid-mountain, high mountain, and mountaintop. Bare ground without overhead vegetation means the soil surface that was exposed to the sky. Bare ground as measured without overhead vegetation is important as it is the most susceptible to erosion, particularly raindrop impact.

Soil Stability- No Canopy

Surface soil aggregate stability was measured at -2.5 m (-8.2 ft) from both sides of each transect at four random locations per transect for a total of 40 samples per plot (Figure 4.13.2-2). The average soil class stability index was calculated for each plot within a stratum using only those samples with no overhead vegetation. The soil stability index ranges on a scale from 0 to 6, with 0 indicating very unstable soils and 6 indicating very stable soils (Herrick et al. 2001; Table 4.13.1-1).

Table 4.13.1-1. Soil Stability Class Index (adapted from Herrick et al. 2001).

Stability Class	Category	Criteria for assignment to stability class
0-1	Very Unstable	50% of structural integrity lost (melts) within 5 seconds of immersion in water AND <10% of soil remains on sieve after 5 dipping cycles, OR soil too unstable to sample (falls through sieve)
1-2	Unstable	50% of structural integrity lost (melts) within 5-30 seconds of immersion in water AND <10% of soil remains on sieve after 5 dipping cycles
2-3	Somewhat Unstable	50% of structural integrity lost (melts) within 30-300 seconds of immersion in water OR <10% of soil remains on sieve after 5 dipping cycles
3-4	Moderately Stable	10-25% of soil remains on sieve after 5 dipping cycles
4-5	Stable	25-75% of soil remains on sieve after 5 dipping cycles
5-6	Very Stable	75-100% of soil remains on sieve after 5 dipping cycles

Indicator/Measure

Departure From Fire Return Interval (Proportion of Area Outside Fire Return Interval)

Fire is a natural ecosystem process within the RMD's mountain environment. The fire return interval for vegetation above 1,327 m (4,501 ft) varies by vegetation type, but averages approximately 10 years (P. Grissom, Saguaro NP, pers. comm.). Historically, fire return intervals varied from as few as 2-6 years to 30 or more years (Figure 4.13.2-4a). However, excessive fuel loads in pine and mixed-conifer forests as a result of decades of fire suppression, along with increased tree death from insect outbreaks, warmer temperatures, and drought has led to an altered fire regime in Saguaro NP (NPS 2007). Suppression can alter plant community structure and composition, and increase fire risk and severity beyond the range of natural variation (NPS 2007).

We calculated the proportion of acres within one, two, and three or more fire return intervals for each elevation strata using spatially explicit fire return interval data provided by Saguaro NP's Fire Management Program. The fire return interval data provided assumes a natural fire return interval of 10 years.

Indicator/Measures

Forest Health (Bark Beetle Infestation, Change in Frequency of Mistletoe)

Bark Beetle Infestation

Bark beetles (Coleoptera: Curculionidae, Scolytinae) are a group of native insects composed of many species that live between the bark and wood of host trees and feed on the tree's phloem tissues (Bentz et al. 2010). Their feeding habits interrupt the flow of nutrients and water in the tree, eventually leading to tree death. Bark beetles are secondary agents of tree death, since they preferentially attack weakened trees (Figure 4.13.2-4b). Although bark beetle outbreaks are a natural ecosystem process, climate change has increased drought stress on western coniferous forests making many millions of hectares of trees

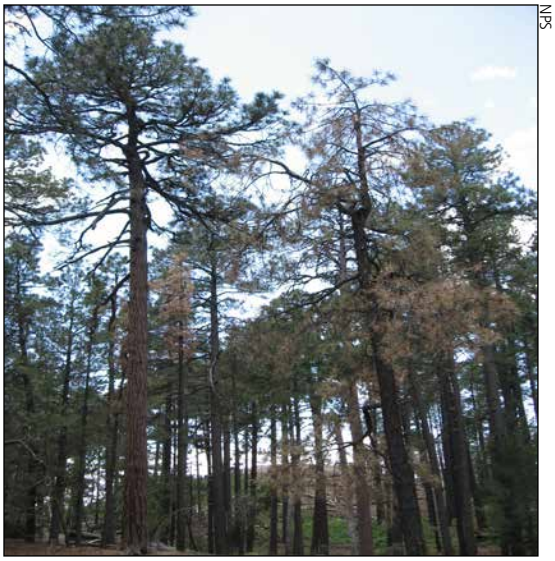


Figure 4.13.2-4. Active forest fire (left) and beetle-killed ponderosa pine trees (right).

available to bark beetle infestation (Bentz et al. 2010). Widespread bark beetle infestation may have undesired effects on vegetation structure and composition, fire behavior and occurrence, and carbon storage (Jenkins et al. 2012, Ghimire et al. 2015, and Potter and Conkling 2016).

We used data provided by the U.S. Forest Service Forest Health Monitoring (FHM) Program (Joyner 2014, Joyner 2015). The FHM Program conducts annual aerial detection surveys across the United States to document tree mortality as a result of bark beetle infestation, including in Saguaro NP (Potter and Conkling 2016). Surveyors documented visible damage to tree crowns and identified, when possible, the damage agent, usually by identifying the host-tree species (Potter and Conkling 2016). The data provided were not separated by elevation strata; therefore, we reported the total number of hectares (acres) affected by bark beetles in the RMD from 2002 to 2015 as reported by the FHM Program (Joyner 2014, Joyner 2015).

Change in Frequency of Mistletoe

There are several species of native mistletoe (*Phoradendron* spp. and *Arceuthobium* spp.) in Saguaro NP, but a lack of fire and changing climate may be altering the host-parasite relationship. Park staff have noted an apparent increase in dwarf mistletoe over the past 5-6 years (P. Grissom, pers. comm.). Mistletoe infestations increase stress on trees, making them less likely to survive drought, insect and other pathogenic outbreaks, and future wildfires (Hessburg et al. 2008).

This measure will be calculated as the change in frequency of mistletoe within each strata. Frequency is the "number of times a plant species/lifeform is encountered in a given number of plots or sample points" (Hubbard et al. 2012). It is a measure based on repeat sampling of SODN's monitoring plots, which will be completed in autumn 2018 (A. Hubbard, pers. comm.). Although this measure cannot be evaluated until the second round of SODN monitoring is completed, we reported data from the first round of sampling (2008-2012).

Indicator/Measures

Non-native and Invasive Plants (New Non-native Species Detected per Plot, Existing Non-native Perennial Species Detected in New Plot or Strata, Change in Buffelgrass Cover, Change in Extent of Buffelgrass, Total Cover of Non-native Plants, Ratio of Non-native Plant Cover to Total Plant Cover, New Non-native Species Detected (2004-2014), Occurrence of Buffelgrass, and Occurrence of Non-native Plants)

Non-native species have been directly linked to the replacement of native species (Tilman 1999), the loss of rare species (King 1985), changes in ecosystem structure, alteration of nutrient cycles and soil chemistry (Ehrenfeld 2003), shifts in community productivity and

alteration of fire regime (Vitousek 1990), reduced agricultural productivity, and changes in water availability (D'Antonio and Mahall 1991). The damage caused by these species to natural resources is often irreparable, and our understanding of the consequences incomplete. Non-native species are second only to habitat destruction as a threat to wildland biodiversity (Wilcove et al. 1998).

According to Saguaro NP's Restoration Ecologist, Dana Backer, there are 125 non-native plants species that have been listed for the park from various sources, including NPSpecies (2015), which includes plants without vouchers and ones that may now be removed; the park's Restoration Management Plan Environmental Assessment (NPS 2014); and the park's Exotic Plant Management Plan Environmental Assessment (NPS 2004). Eighty-seven of these plants are known to be present in the park, and at least 26 of theses species are considered invasive, including buffelgrass (*Pennisetum ciliare* [syn. *Cenchrus ciliare*)] (NPS 2014).

Buffelgrass is a perennial grass native to Africa and is a particularly concerning non-native invasive plant with regards to the Sonoran Desert, but is expanding in elevation with fewer frost-free days (D. Backer, pers. comm.). Where buffelgrass invades, it alters natural ecological processes, competes with and excludes native plants, alters wildlife habitat, and increases the frequency of wildfires (NPS 2011). This plant is of significant concern to Saguaro NP managers and other land management agencies in the Southwest. The presence of buffelgrass can potentially lead to more frequent and intense fires. An experimental study in 2008 revealed that buffelgrass fires may burn hotter, have higher flame lengths, and spread faster than previous or more typical desert fires (NPS 2011).

SODN Monitoring Data

Data for the first six measures described below were collected as part of SODN's Vegetation Monitoring Program. The first four of these measures are based on repeat sampling of plots established by SODN (Hubbard et al. 2011), which will be completed in autumn 2018 (A. Hubbard, pers. comm.). These four measures will be evaluated after the second round of monitoring is completed in 2018. Although these measures are based on change over time, we reported data collected during the first round of SODN sampling. We describe each measure below.

New Non-native Species Detected per Plot

This measure will be calculated as the number of new non-native annual and perennial species found in each sampling plot in all three strata. We reported the total number and provide a list of all non-native species detected within each stratum.

Existing Non-native Perennial Species Detected in New Plot or Strata

This measure will be calculated as the number of non-native, perennial species already known to occur within a stratum that are found in a new plot in each of the three strata. We reported a list of all non-native species recorded in SODN plots as described in the previous measure.

Change in Buffelgrass Cover (%)

This measure will be calculated as the percent change in buffelgrass cover by plot in each of the three strata. In this assessment we report percent cover of buffelgrass recorded during SODN's first round of sampling (2008-2012).

Change in Extent of Buffelgrass (%)

This measure will be calculated as the percent change in the number of plots occupied by buffelgrass in each of the three strata. In this assessment we report initial extent of buffelgrass recorded during SODN's first round of sampling (2008-2012).

Total Cover of Non-native Plants (%)

This measure is based on the percent cover of all non-native plants found in the field layer in each of the three strata.

Ratio of Non-native Plant Cover to Total Plant Cover

This measure is presented as both a ratio of non-native plant cover to total plant cover and as the proportion of total plant cover represented by non-native plants in the field layer within each of the three strata.

Saguaro NP Data

The following three measures are based on data gathered by Saguaro NP's Vegetation Monitoring and Restoration Program.

New Non-native Species Detected (2004-2014)

We compared the list of non-native plants published in Saguaro NP's Exotic Plant Management Plan Environmental Assessment (NPS 2004) to the list of non-native plants published in the Restoration Management Plan Environmental Assessment (NPS 2014) to determine the number of species reported in 2014 that were not reported in 2004. We then subset this list to the species known to occur in upper elevation areas in the RMD according to Dana Backer, Restoration Ecologist, Saguaro NP. This represents the minimum number of known new non-native species in the RMD over a 10-year period.

Occurrence of Buffelgrass

Park staff provided GIS data layers, which included the known extent of buffelgrass in each district. The occurence of buffelgrass extent is based on data from aerial surveys (2012) and ground surveys and treatments (Dana Backer, Restoration Ecologist, Saguaro NP, pers. comm.). We then determined the proportion of area within each strata infested with buffelgrass.

Occurrence of Non-native Plants

As with the occurrence of buffelgrass, we determined the proportion of all non-native plants combined, excluding buffelgrass, that have been mapped during 2012 to 2015 in each of the three strata using GIS data layers provided by Saguaro NP, which includes plants mapped opportunistically. Since few non-natives were mapped during this effort, this represents the minimum extent of non-native plants in Saguaro NP. This represents the total known extent of non-native invasive plant in Saguaro NP (excluding buffelgrass).

Indicator/Measure

Threatened, Endangered or Rare Plants (Cover/Frequency)

This measure is based on change in cover and frequency of threatened, endangered, and rare plants occurring in each stratum. While there are currently no federally listed threatened or endangered plant species in Saguaro NP (U.S. Fish and Wildlife Service 2016), there are three sensitive plant species that are found at higher elevations and that will be evaluated after the second round of SODN monitoring occurs in 2018 (Table 4.13.1-2). The sensitive plant list was developed by the Resource Management Division of the park (email correspondence with D. Backer, 2016). Although this measure is based on change over time, we reported percent cover and frequency data provided by SODN for each of these three species.

4.13.3. Reference Conditions

Reference conditions for this assessment are shown in Table 4.13.3-1. Reference conditions are described for resources in good, moderate concern, and significant concern conditions for each of the six indicators and 19 measures.

Condition thresholds for all data provided by SODN were developed as management assessment points (MAPs). MAPs are "pre-selected points along a continuum of resource-indicator values where scientists and managers have agreed to stop and assess the status or trend of a resource relative to program goals, natural variation, or potential concerns" (Bennetts et al. (2007) as cited in Hubbard et al. (2011)). MAPs serve as trigger points that alert scientists and managers to possible issues.

MAPs were developed jointly by SODN and Saguaro NP staff as part of completing the first round of vegetation monitoring, prior to the reporting process (Hubbard et al. 2011). Condition class thresholds for non-native plant species data provided by Saguaro NP, were developed by NRCA staff, Dana Backer (Restoration Ecologist, Saguaro NP), and Scott Stonum (Chief of

Table 4.13.1-2. Sensitive plant species occurring at higher elevations in Saguaro NP.

Species	Common Name
Carnegiea gigantea *	Saguaro cactus
Agave palmeri *	Palmer's century plant
Graptopetalum rusbyi *	Stone crop

* Saguaro NP special status species.

Table 4.13-3-1. Reference conditions used to assess the current condition of grasslands, woodlands, forest vegetation, and soils in Saguaro National Park.

Indicator	Strata	Measure	Good	Moderate Concern	Significant Concern
Plant Community Resilience	High Mountain and Mountaintop	Total Tree Cover (canopy)[1]	10-30%	<10% or >30%	
	Mid-mountain	Tree and Shrub Cover (subcanopy)[1]	<30%	>30%	
		Perennial Grass Cover (field)[1]	>20%	<20%	
		Ratio of Annual Plants to Total Plant Cover (field)[1]	<1:4 (25% of total)	>1:4 (25% of total)	
Erosion Hazard	Mid-mountain, High Mountain, Mountaintop	Bare Ground Cover (with no overhead vegetation)[1]	≤ 5%	> 5%	
		Soil Stability Class Index (no canopy)[1]	Class 3 or greater on any given plot within a stratum (moderately stable to very stable)	< Class 3 in any given plot in a stratum (unstable to very unstable)	
Departure From Fire Return Interval	Mid-mountain	Proportion of Area Outside Fire Return Interval (FRI)[2]	≥50% within 1 FRI	Less than good and better than significant concern.	≥75% within 3 or more FRI
	High Mountain		≥75% within 2 FRI		≥75% within 3 or more FRI
	Mountaintop		≥50% within 1 FRI		≥50% within 3 or more FRI
Forest Health	Mid-mountain, High Mountain, Mountaintop	Bark Beetle Infestation (hectares)[2]	< 24 ha (<60 ac)	24 - 162 ha (60 - 400 ac)	>162 ha (> 400 ac)
		Change in Frequency of Mistletoe[1]	No increase in frequency within a stratum and within a plot.	Increased frequency within a stratum and within a plot.	
Non-native and Invasive Plants	Mid-mountain, High Mountain, Mountaintop	New Non-native Species Detected per Plot (annual and perennial)[1]	No new non-native species detected in any one plot.	New non-native species detected in any one plot.	
		Existing Non-native Perennial Species Detected in New Plot or Strata[1]	No extent increase from previous monitoring cycle	Any extent increase from previous monitoring cycle	
		Change in Buffelgrass Cover[1]	No % change in cover change within a plot.	Any % change in cover change within a plot.	
		Change in Extent of Buffelgrass (# of plots)[1]	No % change in plots occupied by stratum.	Any % change in plots occupied by stratum.	

Table 4.13.3-1. Reference conditions used to asses the current condition of grasslands, woodlands, forest vegetation, and soils continued.

Indicator	Strata	Measure	Good	Moderate Concern	Significant Concern
Non-native and Invasive Plants	Mid-mountain, High Mountain, and Mountaintop	Total Cover of All Non-native Plants (field)[1]	≤5% total cover	>5% total cover	
		Ratio of Non-native Plant Cover to Total Plant Cover (field)[1]	<1:20 (<5%)	>1:20 (>5%)	
	Rincon Mountain District	New Non-native Species Detected (2004-2014)[3]	No increase, or an increase but none are considered invasive or have become established.	An increase in non-native species, some of which are invasive and have become established.	
	Mid-mountain, High Mountain, Mountaintop	Occurrence of Buffelgrass[3]	No occurrence of buffelgrass by elevation stratum in the park.	<1% buffelgrass infestation by elevation stratum, and it is relatively under control [4]	Buffelgrass occurs in >1% of stratum by elevation, and/or it is not under control [4]
		Occurrence of Non-native Plants[3]	Same as above except measure refers to all other non-native plants combined, excluding buffelgrass.		
Threatened, Endangered or Rare Plant Species	Mid-mountain, High Mountain, Mountaintop	Cover/Frequency[1]	No decrease or increase in cover/frequency	Any decrease in cover/ frequency	

Note: Cover of dead plants, conifer tree density, pine-oak tree density, and proportion of dead trees and their cause of death other than from fire were included as Management Assessment Points (MAPs), but the Sonoran Desert Network (SODN) did not report these data. Therefore, we excluded these measures from this assessment.

[1] Condition class thresholds developed by SODN and Saguaro NP as management assessment points.

[2] Condition class thresholds developed jointly by NRCA staff, Dana Backer (Restoration Ecologist,Saguaro NP), and Scott Stonum (Chief of Resources, Saguaro NP).

[3] Condition class thresholds developed by Perry Grissom (Fire Ecologist, Saguaro NP).

[4] Control means that the infestation is in a state of maintenance or the invasive plant population is less than five percent cover Dana Backer (Restoration Ecologist,Saguaro NP).

Resources, Saguaro NP). Reference conditions for proportion of area outside fire return interval and bark beetle infestation were developed by Perry Grissom (Fire Ecologist, Saguaro NP).

4.13.4. Condition and Trend

Plant Community Resilience

Total Tree Cover (%)

Total tree cover in the canopy layer averaged 23.2% in high mountain plots and 55.7% in mountaintop plots (Table 4.13.4-1). This is considered good condition for the high mountain strata, but warrants moderate to significant concern for the mountaintop strata. The canopy layer in mountaintop plots exceeded 30%, which indicates prolonged lack of disturbance.

Tree and Shrub Cover (%)

Tree and shrub cover in mid-mountain plots averaged well under the 30% threshold for good condition, both individually and when combined (Table 4.13.4-1). Therefore, we consider the condition for this measure to be good.

Table 4.13.4-1. Data for grasslands, woodlands, forest vegetation, and soils.

Indicator	Measure[1]	Mid-mountain (4,501-6,000 ft)	High Mountain (6,000-7,500ft)	Mountaintop (>-7,500 ft)
Plant Community Resilience	Total Tree Cover (canopy)[2]	---	23.2% ± 5.5%	55.7% ± 5.1%
	Tree and Shrub Cover (subcanopy)[2]	7.7% ± 1.6% (tree)	---	---
		10.9% ± 1.7% (shrub)	---	---
	Perennial Grass Cover (field)[2]	21.0% ± 3.2%	---	---
	Ratio of Annual Plant Cover to Total Plant Cover (field)[2]	23:100 (23%)	---	---
Erosion Hazard	Bare Ground Cover (with no overhead vegetation)[2]	2.1% ± 0.3%	1.8% ± 0.7%	0.8% ± 0.2%
	Soil Stability Class Index (no canopy)[2]	3.6 (n = 19) 7 < class 3	3.08 (n = 9) 4 < class 3	4.2 (n = 8) 1 < class 3
Departure From Fire Return Interva[l]	% Area Within 1 Fire Return Interval[3]	0%	6%	14%
	% Area Within 2 Fire Return Intervals[3]	22%	19%	55%
	% Area Within 3 or More Fire Return Intervals[3]	77%	75%	30%
Forest Health	Frequency of Mistletoe	*Phoradendron spp.* (2%)	0%	0%
Non-native and Invasive Plants	Buffelgrass Cover[2]	0%	0%	0%
	Extent of Buffelgrass (# of plots)[2]	0%	0%	0%
	Total Cover of All Non-native Plants (field)[2]	1.62% ± 0.95%	0	0.1% ± 0.1%
	Ratio of Non-native Plant Cover to Total Plant Cover (field)[2]	3.17%	0.09%	0.4%
	New Non-native Species Detected (2004-2014)[3]	7 (1 invasive)		

[1] When reported error = ± 1 standard error.

[2] Data has or will be provided by the Sonoran Desert Network (SODN).

[3] Data used to calculate measure were provided by Saguaro National Park (NP) Fire Management Program.

[3] Data used to determine measure were extracted from NPS 2004 and NPS 2014.

Perennial Grass Cover (%)

Perennial grass cover in mid-mountain plots averaged 21.0%, which indicates good condition (Table 4.13.4-1). However, the standard error of the mean overlaps the management assessment point (25%), suggesting plant community resilience as measured by perennial grass cover may be a potential issue.

Ratio of Annual Plant Cover to Total Plant Cover

This measure averaged 23% in the field layer within the mid-mountain strata and is within the range for good condition, but this value is approaching the management assessment point of 25% (Table 4.13.4-1). Exceeding 25% would indicate the potential for fire outside the historical fire regime.

Erosion Hazard

Bare Ground Cover (%)

Bare ground cover (with no overhead vegetation) was under 5% for each stratum, which indicates good condition and low potential for enhanced soil erosion (Table 4.13.4-1).

Soil Stability

Seven of 19 plots in the mid-mountain stratum had an average soil stability of less than three (Table 4.15.4-1). In the high mountain stratum four of nine plots had an average soil stability class less than three and in mountaintop plots only one of eight plots had a soil stability class less than three. Soil stability class less than three indicates unstable conditions. While most plots in each stratum indicate low potential for erosion, the management assessment points are based on any one plot within a stratum, therefore, this measure warrants moderate to significant concern for particular sites within each stratum.

Departure from Fire Return Interval

Proportion of Area Outside Fire Return Interval

The majority of each of the three strata exceeded one fire return interval (Table 4.13.4-1). For mid-mountain and high mountain strata, 77% and 75% of the total area, respectively, exceeded two fire return intervals. Only a small proportion of high mountain and mountaintop strata were within one fire return interval, and none of the mid-mountain strata was within one fire return interval. Since more than 75% of the mid-mountain stratum was within three or more fire return intervals this measure warrants significant concern for this elevation range. Since less than 75% of the high mountain and mountaintop strata fall within three or more fire return intervals this measure warrants moderate concern for these two elevation ranges; however, the high mountain region is on the cusp of warranting significant concern.

Forest Health

Bark Beetle Infestation

Table 4.13.4-2 shows the number of hectares (acres) affected by bark beetles from

Table 4.13.4-2. Bark beetle conditions and trends of area impacted in Saguaro NP.

Year	Fir engraver ha (ac)	Douglas-fir beetle ha (ac)	Roundheaded pine beetle ha (ac)	Ponderosa pine *Ips* ha (ac)	Western pine beetle ha (ac)	Pinyon pine *Ips* ha (ac)	Cedar bark beetle ha (ac)	Total ha (ac)
2002	0	0	0	198 (489)	0	0	0	198 (489)
2003	0	0	0	57 (140)	0	0	0	57 (140)
2004	0	0	0	4.4 (11)	0	0	0	4.4 (11)
2005	0	0	0	0	0	0	0	0
2006	0	0	0	22 (55)	0	0	0	22 (55)
2007	0	0	14 (34)	0	0	0	0	14 (34)
2008	0	0	1.6 (4)	0.4 (1)	0	0	0	2 (5)
2009	0	0	1.6 (4)	0	0	0	0	1.6 (4)
2010	0	0	8 (20)	0	<2 (<5)	0	0	10 (25)
2011	0	0	0	0	0	0	0	0
2012	0.8 (2)	0	2 (5)	0.4 (1)	0	0.4 (1)	0.4 (1)	4 (10)
2013	0	0	295 (730)	0	0	0	0	295 (730)
2014	1.6 (4)	3.2 (8)	284 (701)	0	0	0	0	289 (713)
2015	16 (40)	0	0	0	0	251 (620)	0	267 (660)

Note: Data extracted from Joyner 2014 and Joyner 2015.

2002-2015 in the RMD (Joyner 2014, Joyner 2015). In 2015, tree mortality decreased over the previous two years but still remained elevated compared to mortality observed during 2003-2012. Surveyors identified seven host-specific bark beetles affecting coniferous forests in the RMD. The roundheaded pine beetle (*Dendroctonus ponderosae*) has affected the most area, followed by ponderosa pine *Ips (Ips pini)* and pinyon pine *Ips (I. confuses)*. Together, these species account for 98% of all bark beetle activity in Saguaro NP. The fir engraver (*Scolytus ventralis*), Douglas fir beetle (*Dendroctonus pseudotsugae*), western pine beetle (*D. brevicomis*) and cedar bark beetle (*Phloesinus* spp.) accounted for the remaining 2% of affected area. Since an average of 54 ha (133 ac) has been impacted by bark beetles in each of the last three years (2013-2015), this measure warrants moderate concern according to the reference condition thresholds established for this measure.

Change in Frequency of Mistletoe

While we could not assess change in frequency of mistletoe, we reported current frequency of mistletoe in SODN monitoring plots. At lease one species of mistletoe was identified in mid-mountain plots (Table 4.13.4-1). A second species could only be identified to genus. Each of these occurred with 1% frequency. Mistletoe did not occur within SODN's high mountain or mountaintop plots. Dwarf mistletoe has been detected in numerous Saguaro NP fire effects plots in high mountain and mountaintop areas, and a US Forest Service Forest Health Protection forest pathologist noted significant populations in 2013 (P. Grissom, fire ecologist pers. comm.).

Non-native and Invasive Plants

New Non-native Species Detected per Plot (annual and perennial)

Five species of non-native plant (two of which are considered invasive) were recorded in SODN monitoring plots across all three strata. All species except one occurred in mid-mountain plots, one species occurred in mountaintop plots, and one species was found in high mountain plots (Table 4.13.4-3). Lehmann lovegrass (*Eragrostis lehmanniana*) was the most widespread species occurring in seven of the 20 mid-mountain plots. Because this measure is based on detection of new non-native species per plot, we could not assign a condition.

Existing Non-native Perennial Species Detected in New Plot or Strata

Only one perennial species, Lehmann lovegrass,was found in SODN monitoring plots, and it occurred in only one of the 20 mid-mountain plots (Table 4.13.4-3). As with the previous measure, we could not assign a condition since this measure is based on change over time.

Change in Buffelgrass Cover (%) & Change in Extent of Buffelgrass (%)

Buffelgrass did not occur in any plot in any of the three strata (Table 4.13.4-1). Since these measures are based on change, we did not assign a condition.

Total Cover of Non-native Plants (%)

Total cover of non-native plants ranged from 0% in high mountain plots to 1.62% in mid-mountain plots (Table 4.13.4-1). Overall, non-native plant cover was low and well below the 5% threshold identified as good condition.

Ratio of Non-native Plant Cover to Total Plant Cover

We expressed the ratio of non-native plant cover to total plant cover as a proportion since this is more intuitive and easily understood when dealing with fractions (Table 4.13.4-1). The proportion of total plant cover comprised of non-native plants was highest (3.17%)

Table 4.13.4-3. Non-native and invasive plant species in vegetation monitoring plots in Saguaro NP.

Species	Life Form	Stratum (# of plots)
*Bromus rubens (*red brome*)**	graminoid (annual)	Mid-mountain (2 of 20)
Conyza bonariensis (asthmaweed)	forb/herb (annual)	Mountaintop (1 of 8)
Eragrostis lehmanniana (Lehmann lovegrass)*	graminoid (perennial)	Mid-mountain (7 of 20)
Ipomoea coccinea (redstart)	forb/ herb/vine (annual)	Mid-mountain (1 of 20)

* Considered invasive in Saguaro NP.

in the mid-mountain stratum and lowest (0.09%) in the high mountain stratum. Since less than 5% of non-native plants comprised the total plant cover, this measure is in good condition for all three strata.

New Non-native Species Detected (2004-2014)
Parkwide, there were 68 species non-native species listed in the Exotic Plant Management Plan (2004) and 87 species listed in the Restoration Management Plan Environmental Assessment (2014). Of these, 26 non-native species were listed in 2014 that were not listed in 2004, seven of which are known to occur in the RMD (Table 4.13.4-4). The one invasive species, cheatgrass (*Bromus tectorum*), is an annual that can spread rapidly (NPS 2004). This species can drastically alter near-surface soil moisture regimes as well as fire regimes (NPS 2004). Since at least seven known new non-native species have invaded upper elevation areas in the RMD, this measure warrants moderate to significant concern.

Occurrence of Buffelgrass
Figure 4.13.4-1 shows the occurrence of buffelgrass by elevation strata in the RMD. Within the district, 746 ha (1,843 ac) of buffelgrass has been mapped, and the majority (96%) of buffelgrass occurs below 1,372 m (4,500 ft). A small amount of buffelgrass (27 ha (67 ac) occurs in the mid-mountain strata along the boundary with the foothills, representing 0.3% of the mid-mountain strata. No buffelgrass has been mapped in high mountain or mountaintop strata. This could mean that 1) high elevation areas (i.e., >1,372 m (>4,500 ft)) are relatively resistent to invasion by buffelgrass, 2) buffelgrass has not reached these areas yet; and/or 3) high elevation areas have not yet been comprehensively surveyed for buffelgrass. Since buffelgrass occurs in less than 1% of the mid-mountain strata and 0% of the high mountain or mountaintop strata, the condition for this measure is good.

Table 4.13.4-4. List of new non-native species in the RMD from 2004-2014.

Species Name	Common Name
*Bromus tectorum**	cheatgrass
Conyza bonariensis	flaxleaved fleabane
Cyperus esculentus	yellow nutsedge
Descurainia sophia	herb sophia
Galinsoga parviflora	gallant soldier
Opuntia engelmanii var. linguiformus	cow's tongue prickly pear
Sisymbrium altissimum	tumble mustard

* Considered an invasive species by Saguaro NP.

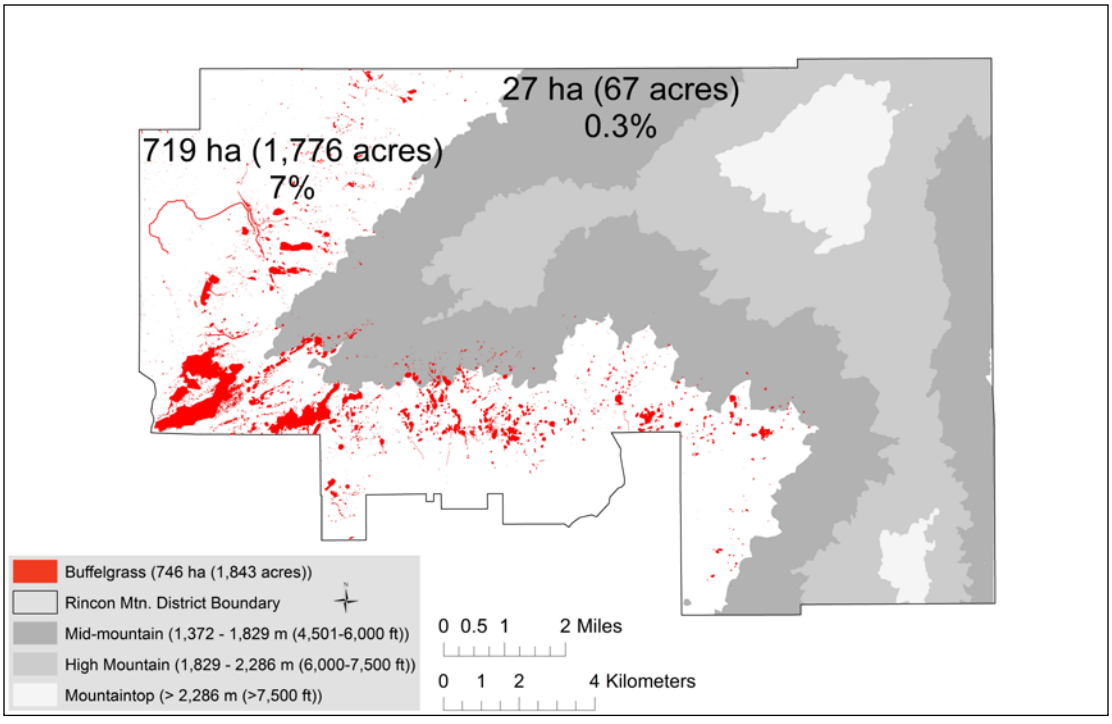


Figure 4.13.4-1. Buffelgrass occurrence by elevation strata in the Rincon Mountain District.

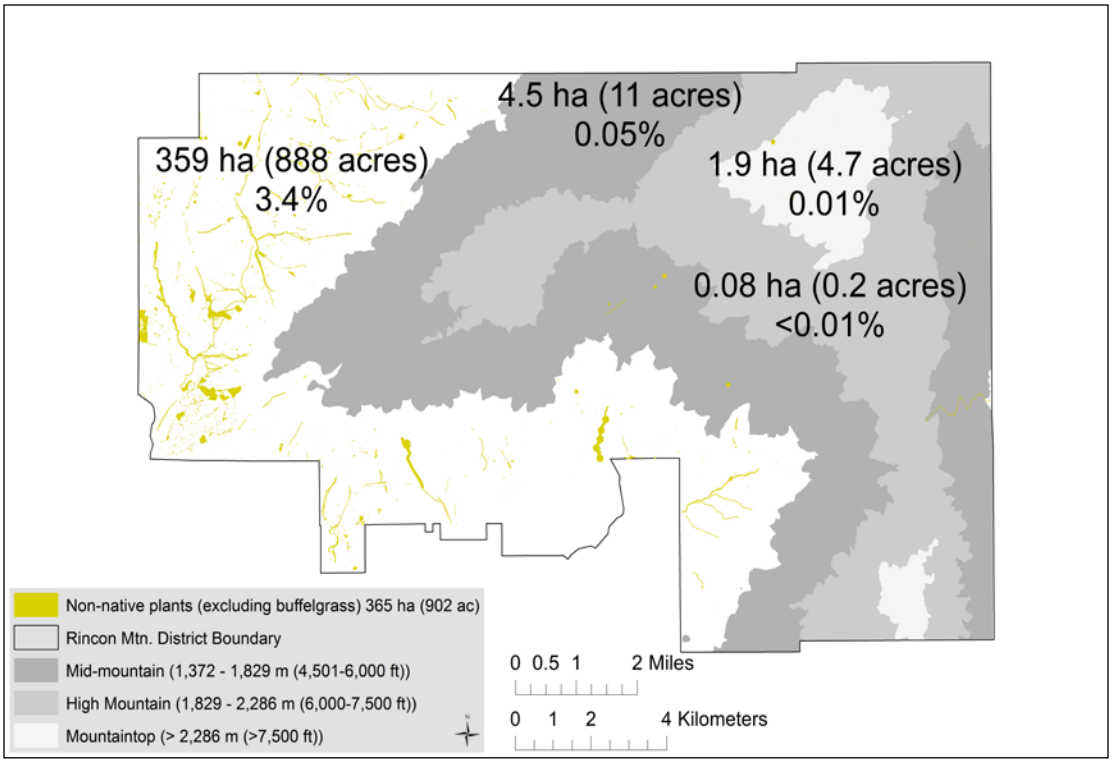


Figure 4.13.4-2. Non-native plant occurrence (excluding buffelgrass) by elevation strata in the Rincon Mountain District.

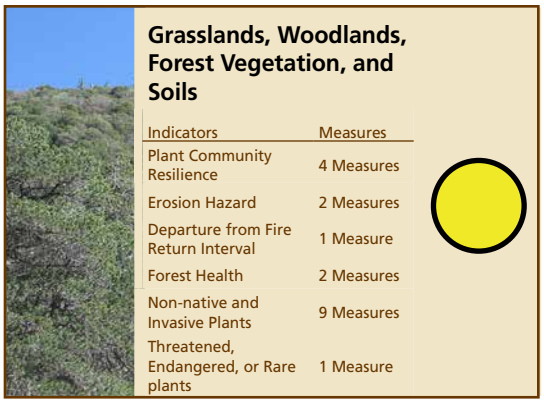
Occurrence of Non-native Plants (excluding buffelgrass)

In the RMD, 365 ha (902 ac) of non-native plants have been mapped (Figure 4.13.4-2). The vast majority (98%) of mapped non-native plants in the RMD occur below 1,371 m (4,500 ft). Of the remaining 2%, most occur in the mid-mountain range; however, non-native plants only represent 0.05% of this stratum. In the high mountain and mountaintop strata, the area mapped is <0.01% and 0.01%, respectively. As with buffelgrass, this suggests that the mountain environment is relatively resistent to invasion by non-native species, in part because of cooler temperatures and a shorter growing season. Additionally, there are fewer vectors, limiting access to higher elevation (i.e., lack of roads and few trails), which has reduced the opportunity for non-native species to become established there. However, the difficulty of surveying this region has prevented extensive surveys. The higher mapped area of non-natives in the mid-mountain range compared with the other two strata suggests this lower elevation environment may be more suitable for invasion by non-native species, especially when considering the effects climate change has on the spread of non-native species. Finally, the majority of non-native species arrive first with human assistance in the desert and must be adapted to the desert in order to survive there. Few are likely to be able to survive in higher, cooler sites.

Change in Threatened, Endangered, or Rare Plants

Frequency and Cover

Only one sensitive plant species was found in SODN monitoring plots: Palmer's century plant (*Agave palmeri*). Frequency data were not reported, but the species occurred in three of the 20 mid-mountain plots and two of the ten high mountain plots. Percent cover was relatively low overall (<1%) in both strata. The remaining two sensitive species expected to occur within the elevation range of this assessment were not detected in SODN monitoring plots.



Overall Condition and Trend

To assess the condition of vegetation in upper elevation areas of the RMD we used five indicators and 13 measures (Table 4.13.4-5). We describe an additional indicator and six measures that are based on long-term monitoring in SODN vegetation plots, but since these additional measures are based on change over time, and only one round of monitoring has been completed, we were unable to use them to evaluate vegetation condition in the RMD. Overall, we consider the condition of vegetation in upper elevation areas of the RMD to warrant moderate concern. While some measures indicate good condition others indicate potential issues. The two measures for which trend could be determined indicate deteriorating conditions (i.e., new non-native and invasive plants, bark beetle infestation). However, the deteriorating condition of new non-native plants is likely due to lack of previous detection and baseline data for these upper elevation areas. Because of the lack of trend data for most measures, we did not assign an overall trend for this assessment.

The four plant community resilience measures are generally in good condition with the exception of canopy cover in the mountaintop environment. High canopy cover in the mountaintop stratum indicates lack of canopy opening disturbances. The two measures of erosion hazard are somewhat conflicting. Bare soil cover indicatives good condition, while soil stability varies across the landscape. The majority of plots within each stratum indicate low potential for erosion, but there are some areas where this may be an issue. Although no condition class thresholds were identified for the proportion of area outside of the normal fire return interval, the results presented in this assessment suggest there is some cause for concern. The majority of area within each of the three strata exceeded two fire return intervals. The one indicator of forest health (bark beetle infestation) also indicates cause for concern. Bark beetle infestation has increased since 2002, especially during the last three years for which data were reported (2013-2015). The five measures of non-native and invasive plants indicate overall good condition for high elevation areas. Some concern is warranted for the mid-mountain stratum, however. Mapping efforts suggest that non-native plants are encroaching at the lower boundary of the mid-mountain stratum. We also acknowledge that this could be an artifact of where the boundary is located. If moved up or down tens of meters, the area of mapped non-natives would change accordingly. Furthermore, variations in aspect, soil characteristics, and water resources affect the upper and lower limits of each stratum. Within SODN monitoring plots, non-native plants rarely occur and represent only a small fraction of total plant cover.

Level of Confidence/Key Uncertainties

The level of confidence for most condition ratings was medium, but this will improve over time, especially after analysis of the park's fire effects data is complete and as more forest health studies are conducted. Vegetation monitoring plots established by SODN were located via a random, spatially balanced process, and the power to detect change within each stratum was determined to be excellent (Hubbard et al. 2011) over time. Although, SODN's measures for the plant resilience indicator included total cover for native and non-native plants, which confounds the reference conditions as they are currently stated.

Fire return interval data were based on spatially explicit GIS data of departure from fire return intervals, however, Saguaro NP lacks an adequate vegetation map for mapping fire return intervals; therefore, confidence in this condition rating was medium. Bark beetle mapping data are dependent on accurate determination of the agent of disturbance,

Table 4.13.4-5. Summary of the grassland, woodland, and forest vegetation and soils indicators, measures, and condition rationale.

Indicator	Strata	Measure	Condition	Rationale for Condition
Plant Community Resilience	High Mountain and Mountaintop	Total Tree Cover (canopy)	High Mountain: Good Mountaintop: Moderate Concern/ Significant Concern	Canopy cover for high mountain plots fell within the range for good condition (23.2%), while mountaintop plots (53.7%) exceeded 30%. Confidence is medium. No data on trend are available.
	Mid-mountain	Tree and Shrub Cover (subcanopy)	Good	Tree and shrub cover, combined and individually, indicate good condition since these measures were well below the 30% threshold. Confidence is medium. No data on trend are available.
		Perennial Grass Cover (field)	Good	The value meets the criteria for good condition; however, the standard error of the mean overlaps the management assessment point. Confidence is medium. No data on trend are available.
		Ratio of Annual Plant Cover to Total Plant Cover (field)	Good	This measure was within the range for good condition (23)%; however, is approaching the threshold of 25%. Confidence is medium. No data on trend are available.
Erosion Hazard	Mid-mountain, High Mountain, Mountaintop	Bare Ground Cover (with no overhead vegetation)	Good	This measure averaged <5% for each stratum, which indicates low potential for erosion. Confidence is medium. No data on trend are available.
		Soil Stability Class Index (no canopy)	Mid-mountain & High Mountain: Moderate Concern/ Significant Concern; Mountaintop: No Data	Soil stability for each stratum averaged >3, which indicates good condition; however, the condition rating is based on any one plot and at least one plot in each stratum averaged <3. Confidence is medium. No trend data are available.
Departure From Fire Return Interval	Mid-mountain, High Mountain, Mountaintop	Proportion of Area Outside Fire Return Interval	Unknown	Since more than 75% of the mid-mountain stratum was within three or more fire return intervals, this measure warrants significant concern for this elevation range. Less than 75% of the high mountain and mountaintop strata fall within three or more fire return intervals, therefore, this measure warrants moderate concern for these two elevation ranges, however, the high mountain region is on the cusp of warranting significant concern. Confidence is medium. No trend data are available.
Forest Health	Mid-mountain, High Mountain, Mountaintop	Bark Beetle Infestation (hectares)	Moderate Concern	Since an average of 54 ha (133 ac) has been impacted by bark beetles in each of the last three years (2013-2015), this measure warrants moderate concern. Confidence is medium.

Table 4.13.4-5. Summary of the grassland, woodland, and forest vegetation and soils indicators, measures and condition rationale continued.

Indicator	Strata	Measure	Condition	Rationale for Condition
Non-native and Invasive Plants	Mid-mountain, High Mountain, Mountaintop	Total Cover of All Non-native Plants (field)	Good	Overall, non-native plant cover was low and well below the 5% threshold identified as good condition. Confidence is medium. Trend data are not available.
		Ratio of Non-native Plant Cover to Total Plant Cover (field)	Good	The proportion of total plant cover comprised of non-native plants was highest (3.17%) in the mid-mountain stratum and lowest (0.09%) in the high mountain stratum. Since less than 5% (1:20) of non-native plants comprised the total plant cover, this measure is in good condition for all three strata. Confidence in medium. No data on trend are available.
	Rincon Mountain District	New Non-native Species Detected (2004-2014)	Moderate Concern/ Significant Concern	Since seven known new non-native species have invaded upper elevation areas in the RMD, this measure warrants moderate to significant concern. The condition is deteriorating. Confidence is medium.
	Mid-mountain, High Mountain, Mountaintop	Occurrence of Buffelgrass	Good	Since buffelgrass occurs in less than 1% of the mid-mountain strata and 0% of the high mountain or mountaintop strata, the condition for this measure is good. Trend data are not available. Confidence is medium.
		Occurrence of Non-native Plants	Good	Non-native plants (excluding buffelgrass) represent 0.05% of the mid-mountain stratum, <0.01% of the high mountain stratum, and 0.01% of the mountaintop stratum. This is below the 1% threshold. Trend data are not available. Confidence is medium.

which is usually based on identification of the host tree. However, in mixed forests, such as those occurring in Saguaro NP, identification can be difficult. Furthermore, the sum of the area infested does not necessarily equal the total area infested since multiple agents may be reported in a given mapping unit (Potter and Conkling 2016). Therefore, the total acres may be an overestimate of the actual area infested with bark beetles. Confidence in the condition rating for mapped buffelgrass and other non-native plants was also medium. An aerial survey of the extent of buffelgrass in the park was conducted in 2012, however, not all areas were surveyed. Furthermore, small patches of non-native plants are more likely to go undetected, but even small patches of invasive species can spread rapidly and cause substantial harm to native plants.

Threats and Stressors

Of all the stressors on vegetation, climate change has the most potential to influence community composition, forest structure, and species richness. The western U.S., and especially the Southwest, has experienced increasing temperatures and decreasing rainfall that have increased tree mortality from a combination of causes, including warmer temperatures, less precipitation, pests, pathogens, and wildfires (Hansen et al. 2014, Potter and Conkling 2016, and Prein et al. 2016). Since 1974 there has been a 25% decrease in precipitation, accompanied by increasing "weather type" intensity (Prein et al. 2016). Plants may be less able to take advantage of periods with intense precipitation that are followed by long intervals of drought. Furthermore, increased temperature has the potential to shift biomes

northward and higher in elevation, which may increase the potential for Saguaro NP to lose species adapted to higher elevation areas.

The effects of climate change are evident in the increase in bark beetle activity in the park. Not all bark beetle activity should be considered a threat to forest health and stand structure. Some level of thinning and tree mortality is expected, and can promote overall forest health by killing weakened trees, which makes resources available to other, healthy trees (Potter and Conkling 2016). However, bark beetle outbreaks are likely to increase northward and upward in elevation with climate change. Warmer temperatures also accelerate bark beetle life cycles. These factors are expected to lead to more severe bark beetle outbreaks. In the intermountain west, an estimated 1,018,930 ha (2,517,831 ac) of forest were impacted by bark beetles in 2015 (Potter and Conkling 2016). This large scale tree death has led to a redistribution of carbon stores from the live overstory to downed woody material, which may have consequences for fire activity (Potter and Conkling 2016).

It has long been assumed that increasing tree death caused by bark beetles would lead to greater fire frequency and higher fire severity, but a growing number of studies show that this is not the case (Black et al. 2013, Hart et al. 2015, and Meigs et al. 2016). Fire is a natural and necessary ecosystem process in high elevation coniferous forests. Fire allows for the growth of deciduous woody trees to emerge from the understory, maintains a relatively open canopy for the growth of understory grasses and shrubs, and creates a mosaic of different aged stands of trees that different species rely on (e.g., cavity nesting birds). Decades of fires suppression have led to altered vegetation structure and composition that may take multiple fire cycles to return to natural conditions (NPS 2007). Saguaro NP uses prescribed fire as a tool to return forest structure and composition to a more natural, pre-suppression state (NPS 2007).

Climate change may also impact other native species including mistletoe. The southwestern dwarf mistletoe (*Arceuthobium vaginatum*), for example, is a native species, but lack of fire and changing climate may be altering the host-parasite relationship. Park staff have noted an apparent increase in dwarf mistletoe during the last five or six years (although no formal monitoring has been conducted) (P. Grissom, Fire Ecologist, Saguaro NP). Although SODN monitoring data indicate low occurrence of mistletoe, a 2013 ground-based insect and disease activity assessment found a high infestation of southwestern dwarf mistletoe on Mica Mountain (Fairweather 2013). The infestation has reduced tree stand vigor and increased susceptibility to mortality from bark beetles (Fairweather 2013).

Vegetation comprises 99% of the earth's biomass. Thus, monitoring vegetation structure, composition, vigor, soil characteristics and other measures will provide important information on ecosystem structure and function.

4.13.5. Sources of Expertise

Dana Backer, Restoration Ecologist, and Perry Grissom, Fire Ecologist (Saguaro NP) and Andy Hubbard and Sarah Studd (SODN, NPS) advised on various sections of this assessment. Patty Valentine-Darby is credited with aspects of this assessment related to buffelgrass. This section was authored by Lisa Baril, science writer, Utah State University.

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4.14. Biological Soil Crusts

Indicators/Measures

- Biological Soil Crust (1 Measure)

Condition – Trend - Confidence

Moderate Concern – Unchanging – High

4.14.1. Background and Importance

Biological soil crusts (BSC) (Figure 4.14.1-1) are communities of cyanobacteria, green algae, microfungi, mosses, liverworts and lichens that live on the surface of desert soils (USGS Canyonlands Research Station 2015). In arid and semi-arid environments, these highly specialized communities live in the open spaces between vascular plants and, in some areas, may make up to 70% of the living vegetative cover (Belnap et al. 2001). BSC live in all the dryland regions of the world (Rosentreter et al. 2007). Because the primary components of biological soil crusts are photosynthetic, they require exposure to sunlight. Soil crust cover is limited in areas with high vascular plant cover (Belnap et al. 2001 and Rosentreter et al. 2007).

These communities live in an intimate association with soil particle within in the upper few millimeters of soil (Rosentreter et al. 2007). Cyanobacteria, especially the large filamentous species, are the pioneering species of soil crust communities and provide much of its cohesive properties. After filamentous cyanobacteria stabilize the soil, other species of cyanobacteria, followed by lichens and bryophytes (mosses and liverworts) colonize (Rosentreter et al. 2007). Lichens and bryophytes usually grow exclusively on upper surface of the soil.

Biological soil crusts provide many ecosystem services including stabilizing soils, providing carbon to soils via photosynthesis, fixing atmospheric nitrogen, and increasing the bio-availability of phosphorus (Rosentreter et al. 2007).

Cyanobacteria dominate biological soil crusts in the Sonoran Desert, with gelatinous (nitrogen-fixing) lichens (e.g., *Collema*), squamulose lichens and short mosses also present (Belnap et al. 2001). Most soil crust

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Figure 4.14.1-1. Biological soil crust dominated by *Selaginella sp.* in Saguaro NP.

growth occurs during cool moist periods, which occur in the winter in the Sonoran Desert (Belnap et al. 2001). Where freezing is rare, BSC surfaces are flat or rugose with small soil pinnacles less than 3 cm (1.2 in) in height (Rosentreter et al. 2007). In Saguaro NP, BSC are generally mostly flat and occur underneath a thin layer of gravel (Jayne Belnap, personal communication, 2015). BSC on granitic substrates have generally a low biomass of cyanobacteria and abundant lichens (mostly *Collema* and *Placidium*). Cover and biomass of BSC on metamorphic substrates are generally very low (Jayne Belnap, personal communication, 2015). In the Sonoran Desert, lichens and mosses are strongly restricted to north slopes (Nash et al. 1977).

Biological soil crusts are sensitive to many types of disturbance. Disturbances may decrease species diversity and cause a loss of biomass surface cover of soil crust components (Belnap et al. 2001). While BSC have strong tensile strength, they do not have much compressional strength, and hence are highly susceptible to mechanical disturbances (Belnap et al. 2001). Trampling and vehicles both compress and shear soil crusts, but vehicles also turn soils over (Belnap and Eldridge 2003), and tracks made by vehicles can also channel water (Belnap et al. 2001). Herbicides have been shown to impact growth and reproduction in laboratory settings, but the effects seem more pronounced in controlled settings than in the field (Belnap and Eldridge 2003). Soil crusts are highly susceptible to damage by hot fires (Belnap and Eldridge 2003). Climate change may impact soil crusts by altering the community structure as mosses and lichens respond differently to changes in temperature and precipitation patterns (Sasha Reed, personal communication, 2015).

The impact of disturbance is influenced by its type, timing, frequency and severity (Belnap et al. 2001). Disturbances during dry seasons have greater impact because the organisms in soil crusts are less able to recover (Belnap and Eldridge 2003). Biological soil crusts also recover more easily when the disturbance does not remove the crustal material (Belnap and Eldridge 2003).

4.14.2. Data and Methods

In assessing current condition and trend for BSC at Saguaro NP, we used one indicator, with one measure. The biological soil crust indicator with the mature soil crust cover measure assesses the percent of ground cover that is made up of mature BSC in upland plots (Figure 4.14.2-1) monitored by the Sonoran Desert Network (SODN).

Besides the SODN monitoring data, information on biological soil crusts in Saguaro NP is extremely limited. A 1991 study found no correlation between presence of soil crusts and epidural browning of saguaro cacti (Belnap 1992).

Indicator/Measure

Biological Soil Crust (Mature Soil Crust Cover)

Biological soil crusts in Saguaro NP are monitored by the SODN as part of the Terrestrial Vegetation and Soils Monitoring Protocol (Hubbard et al. 2012). The goal of uplands vegetation monitoring is to gain a comprehensive understanding of terrestrial ecosystems in NPS sites within the SODN. Vegetation and soils are monitored together in order to obtain a complete picture of ecological function (Hubbard et al. 2012).

Biological soil crusts are one of six vegetation and soils vital signs monitored by the SODN in the Terrestrial Vegetation and Soils protocol (NPS 2012). BSC cover is monitored part of the soil cover assessment. Soil cover is the percentage of material (litter, duff, bedrock, gravel, rocks, vegetation, and biological soil crusts) covering the soil surface (Hubbard et al. 2012).

Mature biological soil crusts contain lichens and bryophytes that only occur in late successional crusts and their presence or absence provides information about a site's disturbance history (Belnap et al. 2001).

For the BSC subset of soil cover, growth forms for lichens and for morphological groups

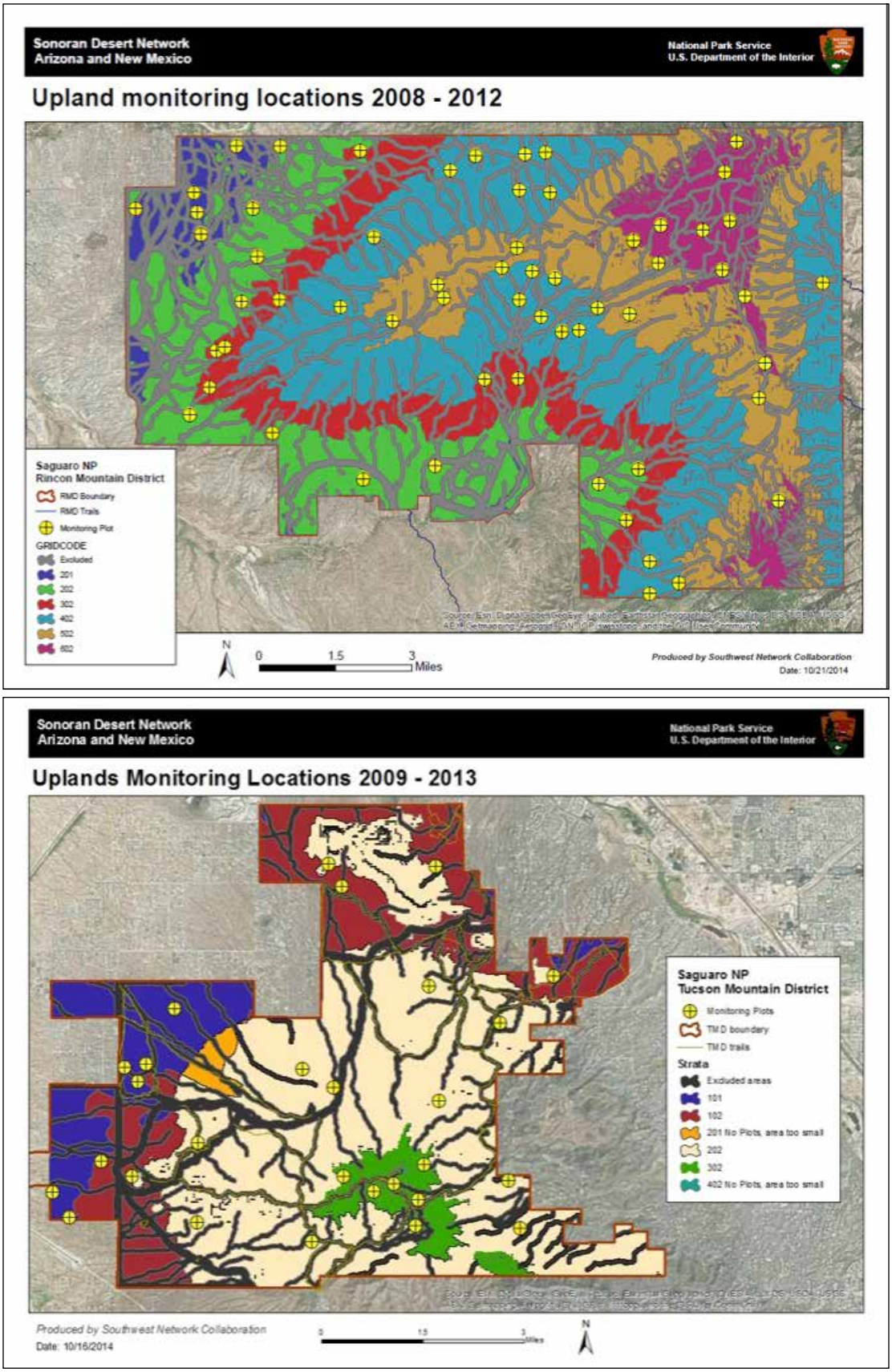

Figure 4.14.2-1. Upland monitoring locations in the Rincon Mountain District (top) and the Tucson Mountain District (bottom) (Hubbard et al. 2014).

of bryophytes and cyanobacteria (light and dark) are recorded (Hubbard et al. 2012). Cyanobacteria and bryophytes are identified at the morphological group level because they are extremely difficult to differentiate in the field. Darkness of cyanobacteria is an indicator of the biomass of the cyanobacteria and soil stability, with darker cyanobacteria indicating more stable soils with more biomass (Rosentreter et al. 2007). Documenting the morphological group of bryophytes additionally provides information on soil stability, seedling establishment, hydrology and carbon fixation (Rosentreter et al. 2007).

BSC was monitored in permanent upland vegetation and soils sampling plots (Figure 4.14.2-2) located via a random, spatially-balanced process (Hubbard et al. 2012). These plots were 20 × 50-m, and contain six transects (Figure 4.14.2-2). Soil crusts were measured along the transects at 0.5-m intervals. Additionally, BSC cover was measured in 18 0.25-m^2 point-quadrats located adjacent to the transects within the study plots (Figure 4.14.2-2) (Hubbard et al. 2012).

Sites for upland monitoring within Saguaro NP were stratified on the basis of elevation and soil rock-fragment class. Lower elevation strata within the RMD in which BSC would be expected to grow are (Hubbard et al. 2010):

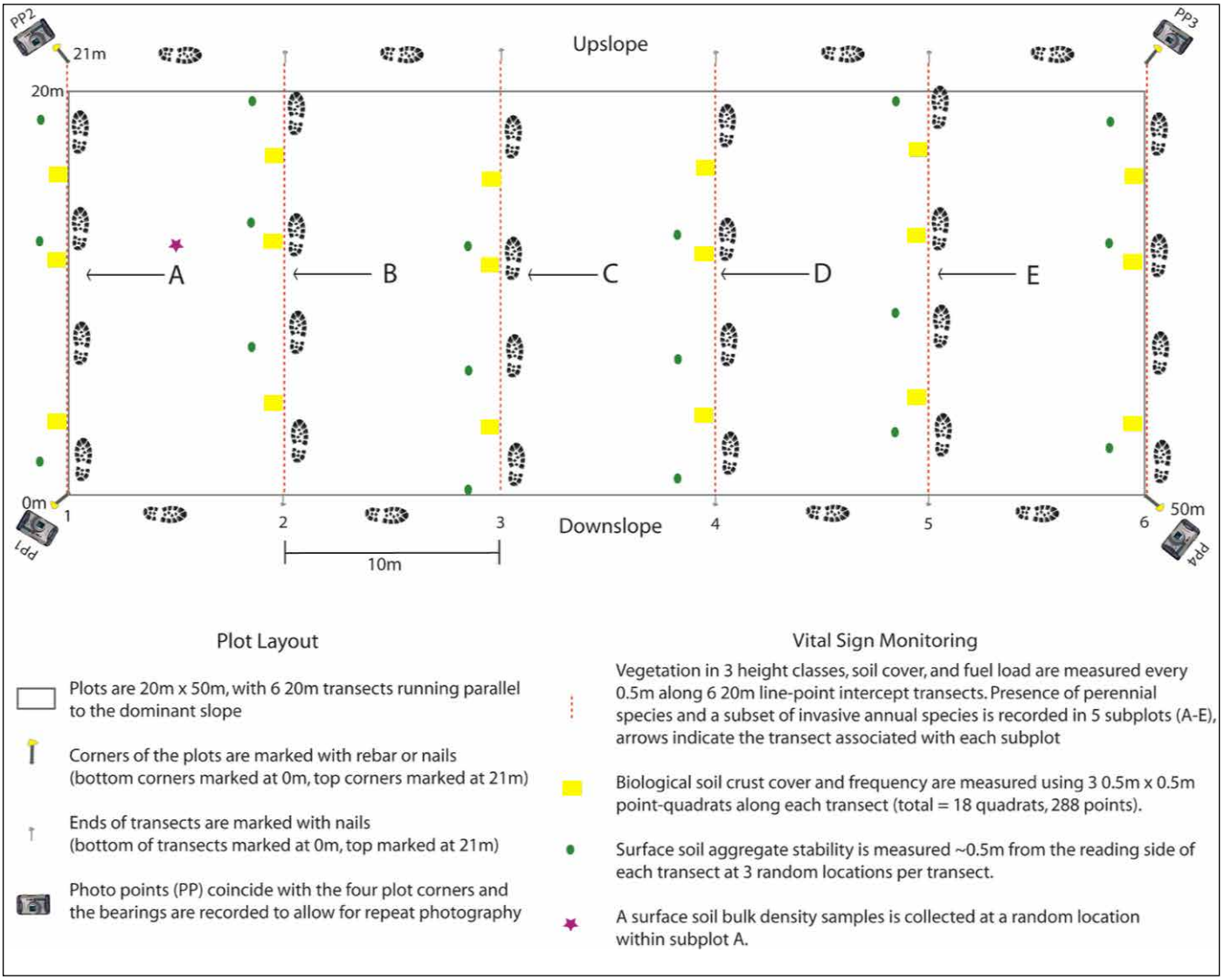

Figure 4.14.2-2. The design of upland vegetation and soils monitoring plots, showing six transects per plots. 0.5x0.5 m plots used to monitor biological soil crusts in SODN terrestrial vegetation and soils sampling plots are shown in yellow. (Hubbard et al. 2012).

- Non-Rocky Bajada: 760–1370 m (2501–3700 ft), <35% rock fragments,
- Rocky Bajada: 760–1370 m (2501–3700 ft), 35–90% rock fragments,
- Foothills: 1130–1370 m (3701–4500 ft), 35–90% rock fragments,
- Mid-Mountain: 1370–1830 m (4501–6000 ft), 35–90% rock fragments.

Strata within the Tucson Mountain District are (Hubbard et al. 2011):

- Valley-bottom: < 760 m (<2,501 ft),
- Rocky Bajada: 60–1370 m (2501–3700 ft)', 35–90% rock fragments,
- Foothills: 1130–1370 m (3701–4500 ft), 35–90% rock fragments.

We used the BSC data from the point-quadrats (NPS 2015) because of how plant litter is treated in the point-quadrats versus the transects. Along the transects, plant litter is counted even it is a single twig or leaf, and in the quadrats, litter is only recorded when it is embedded in the surface (Cheryl McIntyre, personal communication, 2015). The point-quadrats provide cover data for available habitat for BSC.

Percent cover was reported for total light cyanobacteria, dark cyanobacteria, lichens, and bryophytes in available habitat. Available habitat excluded areas covered by duff, embedded litter, rock (>76 mm), bedrock, or vegetation bases. Available habitat focuses on ground cover independent of vegetation canopy cover.

Mature soil crusts consisted of dark cyanobacteria, lichens or bryophytes. Percent cover was calculated for available habitat for including gravel (size 2-76 mm) and excluding gravel. Biological soil crusts may incorporate gravel-size soil particles, but is more likely to do so for smaller grain sizes, with larger-grained gravel not providing available habitat. The actual percent cover of available habitat is likely between the values including and excluding gravel.

In addition to percent cover for BSC groups (cyanobacteria, lichens and bryophytes), values for *Selaginella sp.* (Arizona spikemoss) were recorded. Although it is a vascular plant, it is low growing and SODN and Saguaro NP staff thinks it can function like BSC in terms of soil stability and erosion resistance (Cheryl McIntyre, personal communication, 2015).

Tables 4.14.2-1 and 4.14.2-2 report percent cover of available habitat, with and without gravel respectively, for the non-rocky bajada, rocky bajada, foothills, and rocky mid-mountain strata for the RMD (NPS 2015). We did not report on BSC for the rocky high-mountain and rocky mountain-top strata since BSC is not likely to be well developed in woodlands and forest above 1830 m (6000 ft).

Table 4.14.2-1. Biological soil crust cover in available habitat in the Rincon Mountain District.

Substrate	Non-rocky Bajada	Rocky bajada	Foothills	Rocky mid-mountain
Total Light Cyanobacteria	12.5±2.4%	1.5±0.6%	1.3±0.8%	2.7±1.2%
Dark Cyanobacteria	1.5±0.9%	0.6±0.6%	0.2±0.1%	0.4±0.3%
Lichens	0.7±0.4%	0.7±0.4%	1.5±0.8%	0.5±0.5%
Bryophytes	- -	0.5±0.4%	0.1±0.1%	0.6±0.2%
Total Mature Biological Soil Crust	**2.1±1.2%**	**1.8±0.8%**	**1.8±0.8%**	**1.5±0.7%**
Selaginella	- -	1.4±1.4%	9.0±4.8%	0.9±0.6%
Mature BSC + *Selaginella*	2.1±1.2%	3.2±1.5%	10.9±5.5%	2.4±1.2%

Information is from the SODN Uplands Master Soil Tables for SAGU (NPS 2015) and consists of the average values for the quadrats in monitoring plots in each stratum. Available habitat excluded areas covered by duff, embedded litter, rock, bedrock, or vegetation bases (excluding *Selaginella sp.*). Measurements were by point-quadrats.

Bryophytes consist of mosses and liverworts.

Mature biological soil crust consists of dark cyanobacteria, lichens, or bryophytes as determined by morphological group.

Table 4.14.2-2. Biological soil crust in available habitat excluding areas covered by gravel in the Rincon Mountain District.

Substrate	Non-rocky Bajada	Rocky bajada	Foothills	Rocky mid-mountain
Total Light Cyanobacteria	27.4±3.6%	6.1±3.8%	3.0±2.1%	8.6±5.0%
Dark Cyanobacteria	2.6±1.1%	1.4±1.1%	0.6±0.4%	0.6±0.4%
Lichens	1.3±0.6%	4.4±3.9%	3.0±2.1%	1.2±1.2%
Bryophytes	- -	1.7±1.5%	0.6±0.4%	1.9±0.9%
Total Mature Biological Soil Crust	**4.0±1.7%**	**7.5±3.9%**	**3.7±1.2%**	**3.7±1.5%**
Selaginella	- -	3.9±3.9%	18.0±8.8%*	2.6%±.8%
Mature + *Selaginella*	4.0±1.7%	11.4±4.9%	21.8±9.9%*	6.3±2.7%

Information is from the SODN Uplands Master Soil Tables for SAGU (NPS 2015) and consists of the average values for the quadrats in monitoring plots in each stratum. Available habitat excluded areas covered by duff, embedded litter, rock, bedrock, or vegetation (excluding *Selaginella*). Measurements were by point-quadrats.

Bryophytes consist of mosses and liverworts.

Mature biological soil crust consists of dark cyanobacteria, lichens, or bryophytes as determined by morphological group.

* Values do not meet SODN's statistical power criteria.

Tables 4.14.2-3 and 4.14.2-4 report percent cover of available habitat, with and without gravel respectively, for BSC for the valley bottom, rocky bajada and foothills strata in the TMD (NPS 2015).

4.14.3. Reference Conditions

The reference conditions by which biological soil crust condition was assessed are listed in Table 4.14.3-1. Good condition was assigned to strata with mature BSC (the cumulative percentage of dark cyanobacteria, lichens and bryophytes) in at least 2% of available habitat based on best professional judgement of SODN and Saguaro NP staff that is informed by ecological site descriptions of the dominant ecological sites within the lower elevations of Saguaro NP, Nash (1977), and Bowker and Belnap (2008) (Cheryl McIntyre, personal communication, 2015) and surveys of the Flagstaff Area Parks (Bowker and Belnap 2008). Moderate condition was assigned to strata with slightly less than 2% mature BSC cover. Strata with less than 1% mature BSC cover were considered to be of significant concern.

Table 4.14.2-3. Biological soil crust in available habitat in the Tucson Mountain District.

Substrate	Valley bottom	Bajada	Foothills
Total Light Cyanobacteria	8.0±2.4%	2.4±1.0%	2.4±0.6%
Dark Cyanobacteria	0.4±0.3%	0.5±0.2%	- -
Lichens	0.0±0.0%	0.7±0.4%	0.1±0.1%
Bryophytes	0.1±0.1%	- -	0.0±0.0%
Total Mature Biological Soil Crust	**0.5±0.3%**	**1.2±0.5%**	**0.1±0.1%**
Selaginella	- -	13.9±6.4%[1]	5.4±3.5%
Mature + Selaginella	0.5±0.3%	15.1±6.3%[1]	5.5±3.5%

Information is from the SODN Uplands Master Soil Tables for SAGU (NPS 2015) and consists of the average values for the quadrats in monitoring plots in each stratum. Available habitat excluded areas covered by duff, embedded litter, rock, bedrock, or vegetation (excluding *Selaginella*). Measurements were by point-quadrats.

Bryophytes consist of mosses and liverworts.

Mature biological soil crust consists of dark cyanobacteria, lichens, or bryophytes as determined by morphological group.

[1]Values do not meet SODN's statistical power criteria.

Table 4.14.2-4. Biological soil crust in available habitat excluding areas covered by gravel in the Tucson Mountain District.

Substrate	Valley bottom	Bajada	Foothills
Total Light Cyanobacteria	24.0±4.4%	6.2±2.7%	9.5±2.9%
Dark Cyanobacteria	1.5±1.2%	1.8±1.1%	- -
Lichens	0.1±0.1%	3.2±2.6%	0.2±0.2%
Bryophytes	0.4±0.4%	- -	- -
Total Mature Biological Soil Crust	**2.0±1.6%**	**5.1±3.7%**	**0.2±0.2%**
Selaginella	- -	23.4±9.8%*	16.3±10.8%*
Mature + *Selaginella*	2.0±1.6%	28.5±9.5%*	16.5±10.9%*

Information is from the SODN Uplands Master Soil Tables for SAGU (NPS 2015) and consists of the average values for the quadrats in monitoring plots in each stratum. Available habitat excluded areas covered by duff, embedded litter, rock, bedrock, or vegetation (excluding *Selaginella*). Measurements were by point-quadrats.

Bryophytes consist of mosses and liverworts.

Mature biological soil crust consists of dark cyanobacteria, lichens, or bryophytes as determined by morphological group.

*Values do not meet SODN's statistical power criteria.

Ecological Site Descriptions from the Natural Resources Conservation Service for Sandy Loam Upland, Shallow Hills, Granitic Upland, Granitic Hills, Limy Upland and Loamy Upland, which are the sites described for Saguaro NP, generally characterize these sites with low percent cover (0-10%) for BSC (NRCS 2015). Descriptions for the Limy Upland and Loamy Upland are for 5-25% and 15-30% cover of BSC, respectively.

4.14.4. Condition and Trend

We used one indicator with a single measure, mature soil crust cover, to assess the condition of biological soil crust in Saguaro NP (Table 4.14.4-1). Percent cover of mature biological soil crusts, which consisted of dark cyanobacteria, lichens or bryophytes, in quadrats in soil monitoring plots was calculated both including and excluding gravel because available habitat for BSC likely includes smaller sized gravel, but probably excludes larger gravel clasts.

In general, mature biological soil crusts had higher percent cover in the RMD compared to the TMD. Percent cover values for mature soil crusts including gravel ranged from 1.5% for the rocky mid-mountain stratum to 2.1% in the non-rocky bajada. Percent cover of mature BSC in areas that excluded gravel increased to 3.7% in the rocky mid-mountain to 4.0% in the non-rocky bajada. Percent cover for rocky bajada increased to 7.5% from 1.8% when gravel was excluded. For the foothills stratum, it increased from 1.8% to 3.7%. Given our reference condition was 2.0% cover of available habitat, we find that the biological soil crusts in the RMD is in good condition for all strata.

Overall, mature biological soil crusts occupied a lower percentage of cover in the TMD. In the valley bottom stratum, mature BSC cover was only 0.5% of available habitat including gravel, and 2.0% excluding gravel. However, light cyanobacteria cover was abundant ranging from 8.0% of available habitat including gravel, and 24.0% excluding gravel.

The bajada stratum in the TMD had 1.2% of available habitat (including gravel) and 5.1%

Table 4.14.3-1. Reference conditions used to assess the current condition of biological soil crust.

Indicator	Measure	Good	Moderate Concern	Significant Concern
Biological Soil Crust	Soil Crust Cover	At least 2% of available habitat cover has mature biological soil crust.	Slightly less than 2% of available habitat cover has mature biological soil crust.	Less than 1% of available habitat cover has mature biological soil crust.

Table 4.14.4-1. Summary of the biological soil crust indicators, measures, and condition rationale.

Indicator of Condition	Measure	Condition	Rationale for Condition.
Biological Soil Crust	Soil Crust Cover	Moderate	Soil crusts were in good condition in all strata assessed in the RMD. In the TMD, biological soil crusts were only in good condition in the bajada stratum. Percent cover for BSC was in moderate condition in valley bottom, and of significant concern in the foothills stratum in the TMD.

excluding gravel as available habitat. And in the foothills, only 0.1% of available habitat had BSC, including gravel and 0.2% when the available habitat was calculated to exclude gravel. *Selaginella* was abundant in both the bajada and foothills strata in the TMD.

Table 4.14.4-2 shows the condition of each strata in both districts. The four strata in the RMD were all in good condition. In the TMD, only the bajada stratum was in good condition. The valley bottom was in moderate condition, and in the condition of significant concern in the foothills.

It is not known why mature biological soil crusts occupied less available habitat in the TMD versus the Rincon Mountains. Similar amounts of light cyanobacteria were present in both districts, so it is possible that the Tucson Mountains have experienced more recent disturbances to their biological soil crusts. Further, physical and chemical characteristics of soils can influence the development of BSC (Belnap et al. 2001), and the Tucson and Rincon Mountains have very different bedrock geology (Graham 2010). The difference is likely driven by climate as well. The TMD is drier and warmer than the RMD, which would likely lead to less cover of lichen and bryophytes in the Tucson Mountains (C. McIntyre, pers. comm. 2015).

Overall Conditional and Trend

In general, BSC is in moderate condition in Saguaro NP. Biological soil crusts are in good condition in the RMD and in the bajada stratum in the TMD. They are in moderate condition in the valley bottom, and in the condition of significant concern in the foothills stratum in the TMD. Absent disturbances that had occurred in those two strata that are did not impact other areas of the park, and/or differences in the chemical and physical characteristics in the soils, the lower percent coverage of mature BSC in these strata is unexplained.

The condition of BSC in Saguaro NP is considered to be stable. Saguaro NP is closed to off trail hiking below 1370 m (4500 ft), which limits trampling, a major type of disturbance that impacts BSC. The presence of nonnative exotic plants can also lead to decreased BSC cover and species richness (Belnap et al. 2001). The impact of *Cenchrus ciliaris* (buffelgrass) infestations on biological soil crust has been identified as a research need by the Southern Arizona Buffelgrass Coordination Center (Southern Arizona Buffelgrass Coordination Center 2010).

Table 4.14.4-2. Biological Soil Crust in the Tucson Mountain District.

District & Strata	Mature BCS (% cover)[1]	Condition
RMD non-rocky bajada	2.1-4.0	Good
RMD rocky bajada	1.8-7.5	Good
RMD foothills	1.8-3.7	Good
RMD rocky mid-mountain	1.5-3.7	Good
TMD valley bottom	0.5-2.0	Moderate
TMD bajada	1.2-5.1	Good
TMD foothills	0.1-0.2	Significant Concern

RMD = Rincon Mountain District. TMD = Tucson Mountain District.

[1]Percent cover is for available habitat including and excluding gravel. Available habitat excludes duff, embedded littter, rock, bedrock or vegetation (excluding *Selaninella).*

Information is from NPS (2015).

Individual species within biological soil crust communities respond differently to herbicide applications, and exposure to herbicide could either kill or alter soil crust species composition (Belnap and Eldridge 2003). Staging areas for ground-based herbicide treatments for invasive non-native plants may also disturb BSC (NPS 2014).

Wildfire can also impact on BSC. Fire causes a loss of cover, biomass and species diversity (Belnap and Eldridge 2003). Low intensity fires have fewer impacts to BSC, but non-native grasses can change fire intensities in desert environments (Warren and St. Clair 2009).

BSC do not appear to be sensitive to air pollution (Belnap et al. 2001). In the few studies that have been conducted, no differences in species composition between control sites and sites near pollution sources have not been found.

Level of Confidence/Key Uncertainties

Overall, our confidence in this assessment is high. Uplands vegetation soils and vegetation monitoring by the SODN provides a methodology to detect broad-scale changes in soil characteristics within the context of ecosystem stressors and processes (Hubbard et al. 2012).

Relatively little specific research has been done on BSC in the Sonoran Desert, and further understanding of soil crusts in that hot desert environment would aid in the development of reference conditions for BSC in Saguaro NP, which at this time is based on the limited information that is available. Another uncertainty is how bedrock substrate may influence biological soil crust development. Additionally, it is not known why the percent cover for mature BSC in the valley bottom and foothills strata in the TMD were not in good condition.

4.14.5. Sources of Expertise

Jayne Belnap and Sasha Reed are Research Ecologists at the USGS Canyonlands Research Station. Cheryl McIntyre is a Physical Scientist with the Chihuahuan Desert Network. Allyson Mathis, a science writer for Utah State University, authored this section.

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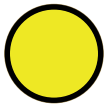
4.15. Mammals

Indicators/Measures

- Species Occurrence (2 Measures)
- Population Status / Abundance (2 Measures)
- Habitat Corridors and Connectivity (1 Measure)

Condition – Trend - Confidence



Moderate Concern- Varied - High

4.15.1. Background and Importance

Saguaro NP's location in southeastern Arizona places it within an area characterized as having the greatest mammalian diversity in North America north of Mexico (Turner et al. 1995). Both tropical mammal species (e.g., white-nosed coatis [*Nasua narica*]) and more northern species (e.g., black bear [*Ursus americanus*]) inhabit the area (Figure 4.15.1-1). With its large range in elevation, the Rincon Mountain District (RMD) includes a number of biotic communities, including (but not limited to) Sonoran desertscrub, riparian forest and woodland (in canyon bottoms), oak savannah, and mixed conifer forest. The smaller, lower Tucson Mountain District (TMD) contains fewer biotic communities and is generally dominated by desert plants. Due to these differences in habitat, there are differences in mammal species occurrence between the two districts.

The first comprehensive surveys of mammals at the national park were conducted by the University of Arizona and NPS in 2001-2002 for both the RMD and the TMD (Swann and Powell [2006] and Swann and Powell [2007], respectively). Prior to this time, some work was done, especially in the RMD, and a few of the studies provided valuable information on mammals (see Swann and Powell 2006, 2007 for review). The most recent survey (2011-2012) of mammals in both districts of the park focused on medium and large mammals using the relatively new technology of infrared-triggered cameras to sample mammals (Swann and Perkins 2013a). Recent information on specific mammal species within the park is also available through targeted monitoring for the subject species.

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Figure 4.15.1-1. The white-nosed coati (*Nasua narica*) is one of the many mammals known to occur at Saguaro NP.

4.15.2. Data and Methods

This assessment is based on three indicators, species occurrence, population status or abundance of selected species, and habitat corridors and connectivity, which have a total of five measures. The species occurrence measures are 1) presence/absence of medium and large mammals, and 2) presence/absence of small mammals and bats. The reason for using two separate measures for this indicator is described in the following paragraph. The second indicator focuses on the status or abundance of 1) the endangered lesser long-nosed bat (*Leptonycteris yerbabuenae*), and 2) deer- mule deer (*Odocoileus hemionus*) and white-tailed deer (*Odocoileus virginianus*). The habitat corridors and connectivity indicator has one measure that focuses on the park and the surrounding landscape.

Indicators/Measures

Species Occurrence (Presence/Absence)

Species Occurrence: Presence/Absence

We used a variety of surveys and studies to assess condition under this indicator. Two separate measures were used, one for the species occurrence of medium and large mammals, and one for the species occurrence of small mammals and bats, because these groups of mammals have not been surveyed or monitored equally at the park. Although both groups were inventoried during the comprehensive surveys of Swann and Powell (2006 and 2007, RMD and TMD, respectively), those surveys were conducted in the early 2000s. More recent comprehensive surveys have not been conducted on small mammals and bats as a group (or groups), but as noted previously, a camera trap study was conducted for medium and large mammals in 2011-2012 (Swann and Perkins 2013a).

The sources used to assess both measures are described below. In addition to the primary data sources described, we also used the NPSpecies list of mammals for the park, which we obtained from IRMA in September, 2014 (NPS 2014). We reviewed the NPSpecies list for potential species not included on other lists, and we used it for supporting information in some cases. Note that we used most of the sources described below to assess mammals under both measures, except that Swann and Perkins (2013a and 2013b) applies only to medium and large mammals. Also note that surveys and studies conducted prior to the Swann and Powell (2006, 2007) inventories generally were not reviewed as part of this assessment, because the Swann and Powell (2006, 2007) inventories and the Swann (2011, 2012) reports (described below) include species observations from earlier surveys.

To assess the condition of medium and large mammals at Saguaro NP, we compared camera trap survey results (and incidental observations) from Swann and Powell (2006 and 2007) to those from Swann and Perkins (2013a). This compared species occurrence over a roughly 10-year period (i.e., from 1999-2005 to 2011-2012 for the RMD, and 2001-2005 to 2011-2012 for the TMD).We looked for differences in the species observed in the two periods, such as whether any species were observed in the earlier period but not in the later period.

For small mammals and bats, since we had no recent survey information for comparison to the Swann and Powell (2006, 2007) data, we assembled a species list based on the 2001-2002 inventory and other miscellaneous studies.

For some species, we also included notes on historical occurrence from Swann (2011 and 2012); this included information on several medium and large mammal species believed to be extirpated from the park.

Primary Data Sources

Swann and Powell (2006)

Swann and Powell (2006) reports on the first comprehensive survey of mammals in the RMD. Field work was conducted in 2001-2002, except that for medium and large mammals, which was conducted from January 1999-June 2005 (because park personnel had started this work prior to the start of the larger University of Arizona effort). Five different field methods were used to survey for mammals: trapping for small mammals using Sherman live traps in grids; infrared-triggered photography (or camera

trapping) for medium and large mammals in random and non-random sites; mist-netting for bats at sites with surface water; pitfall traps (3-quart buckets [19 cm tall by 14 cm wide]) for pocket gophers and shrews; and incidental observations for all sizes or groups of mammals. The work described in Swann and Powell (2006) was part of a larger inventory for plants and vertebrates at the RMD by the University of Arizona (i.e., Powell et al. 2006).

Swann and Powell (2007)
The work described in Swann and Powell (2007) is similar to that in Swann and Powell (2006), except that the work was conducted in the TMD. It reports on the first comprehensive survey of mammals in the district. Field work was conducted in 2001-2002, except that for medium and large mammals, which was conducted from March 2002-March 2005, in addition to May 2001-June 2002. Four different field methods were used to survey for mammals: trapping for small mammals using Sherman live traps in grids; infrared-triggered photography (or camera trapping) for medium and large mammals; for bats, mist-netting at sites with surface water, and roost searches at three abandoned mines; and incidental observations for all sizes or groups of mammals. The work described in Swann and Powell (2007) was part of a larger inventory for plants and vertebrates at the TMD by the University of Arizona (i.e., Powell et al. 2007).

Swann (2011)
Swann (2011) summarizes current and historic information on each of the mammal species that occur in the RMD. Information provided on the species includes, as available, species descriptions, lists of specimens and photographs that document occurrence in the park, voucher photos, distribution maps, summaries of historic records, and information on abundance.

Swann (2012)
This report is comparable to Swann (2011), except it addresses mammals in the TMD.

Swann and Perkins (2013a)
In an effort to monitor the park's mammals, Swann and Perkins (2013a) estimated species richness of large and medium-sized mammals using infrared-triggered cameras (or camera traps). The field work was conducted in both districts of the park from May 2011 to August 2012. The researchers used a stratified random design whereby they stratified the districts by elevation, established and randomly selected grids 1km^2 in size, and established random points within grids for camera trap placement. Four elevational strata were used in the RMD, and two were used in the TMD. Four camera traps were used in each plot sampled, and cameras were set-up for six weeks at a time. Overall, Swann and Perkins (2013a) sampled a total of 353 camera locations in 90 plots for 14,693 camera nights. They accumulated 4,751 photos of medium to large mammals (over 2,600 in the RMD and over 2,100 in the TMD), as well as photos of animals belonging to other groups.

Swann and Perkins (2013b)
This publication reports on the same monitoring work as that described above, but only for the RMD. There are, however, some differences in the number of photos used in the two reports or publications, and therefore some minor differences in results.

Indicators/Measures

Population Status/Abundance (Lesser Long-nosed Bat and Deer)

Population Status/Abundance for Selected Species: Lesser Long-nosed Bat

The lesser long-nosed bat was listed by the U.S. Fish and Wildlife Service (USFWS) as endangered in 1988, primarily due to loss of roosting habitat and vulnerability to disturbance of maternity colonies and other roosting sites. The species is recognized as an important pollinator of columnar cacti such as saguaro (*Carnegiea gigantea*) and organ pipe (*Stenocereus thurberi*) cacti and agaves (McAuliffe 1993); the bat feeds on the nectar, pollen, and fruit of these plants. The species is known to occur (roost) in at least one area of the park in the RMD. Records of the lesser long-nosed bat in the park date back to 1960 (Cockrum and Petryszyn 1991).

Within the U.S., lesser long-nosed bats occur only in Arizona and New Mexico (USFWS

2015a). The species migrates between its wintering grounds in parts of Mexico, and its breeding/summering grounds in northern Mexico and southern Arizona and New Mexico. Its migrations coincide with the availability of the nectar, pollen, and fruit of columnar cacti, the nectar and pollen of blooming agaves, and increasingly, the sugar solutions in backyard hummingbird feeders (SNP 2014). Phenology and movements are not well understood for the species, but it appears that they arrive in the U.S. in the spring (as early as April) when pregnant females form large maternity colonies in traditional roosts. They give birth in early summer. Male bats and nonbreeding bats arrive in the U.S. later than the pregnant females (in July; Diamond 2013), and they form smaller, more flexible colonies (SNP 2014).

As discussed in SNP (2014), "regional survey data suggest that lesser long-nosed bats are using agave flowers (*Agave palmeri*) found at higher elevations (3,000-7,000') in the fall, when they appear in the RMD, and/or have discovered how to take advantage of backyard hummingbird feeders in Tucson as a food source." Around the time that the species was federally-listed, the park began surveys for its occurrence (Sidner 1991). In Sidner's (1991) May to September survey, she found the species in only one location (cave/crevice) within the park, although she surveyed a number of caves and mines in both districts. This one location in the RMD was known as a roost site prior to the Sidner (1991) study. Small numbers of lesser long-nosed bats were observed in May, July, and/or August at least as far back as 1960 (Sidner 1991).

There was also a maternity colony of lesser long-nosed bats near the park in the past, in Colossal Cave (south of the RMD). The maternity colony was known to have had more than 5,000 individuals, but it disappeared after an exhaust-fan system was installed in the cave in 1961 (Sidner 1991, Swann 2011).

It is important to note that when the lesser long-nosed bats are in the Tucson area and using the RMD roost in the late summer/early fall, they appear to use several roosts in the area, at least some of which are unknown (Natasha Kline, Saguaro NP, pers. comm.). They appear to switch between these roost sites, probably based on food availability and perhaps weather. Their use of these roosts may also be affected by their use of hummingbird feeders in the area.

To address the status or abundance of the lesser long-nosed bat at the park, we used surveys that have been conducted at the park specifically for this species in the one, known roost site. The most recent surveys were conducted by Sandy Wolf and others, Bat Research and Consulting (Wolf 2011, 2013a, 2013b, 2014, 2015). Although not a primary source of information, we also provide some information on and from the first surveys for the lesser long-nosed bat at the park- those by Ronnie Sidner (Sidner 1991) and Ronnie Sidner and Russell Davis (Sidner and Davis 1994). The surveys and their methods are described briefly below.

To assess condition, we made a rough, qualitative comparison of the results of the recent roost counts. We also incorporated into the assessment some findings of the recent remote monitoring of the roost by the Arizona Game and Fish Department (AGFD; Diamond 2013), also described below.

Primary Data Sources- Bats

Sidner and Davis (1994)

Sidner and Davis (1994) visited known bat roosts in the park on 13 occasions from April 1992 to July 1994. They also used mist-nets on four occasions near sources of water. The lesser long-nosed bat was not the focus of this study. Visual estimates inside caves of the number of bats using roosts were made, as well as external counts as bats emerged.

Wolf (2011, 2013a, 2013b, 2014, 2015)

Bat Research and Consulting (BRC) has conducted surveys of the lesser long-nosed bat roost in the RMD for several years. The most recent year for which we have data is 2015. In the more recent years, BRC has added an external survey, reported to be the more accurate method, to the internal survey. This description of the survey was taken from the 2013 count report (i.e., Wolf 2013b), but note that there have been some differences

in the number and type of surveys that have been conducted over the years. Also note that at least two other species of bats use the roost (cave myotis [*Myotis velifer*] and Mexican long-tongued bat [*Choeronycteris mexicana*]), and BRC reports on those species as well.

The surveys are conducted some number of times during the period that the species inhabits southeastern Arizona. In the last few years, surveys were conducted in: August and September in 2015; May-October in 2014; August, September, and October in 2013; September only in 2012; and August, September, and November in 2011. The internal surveys are conducted inside the cave during the day with the use of a video-camera. The external surveys are conducted using video-cameras to record bats emerging from the roost site in the evening.

Diamond (2013)
This work was conducted in both 2012 and 2013 at Saguaro NP. Bat activity was monitored in the roost at the RMD using an experimental device developed for monitoring large bat colonies (Diamond 2013). The equipment records the nearby level of acoustic activity, measured in calls per minute. This monitoring method characterizes daily and seasonal trends in bat activity, but it does not distinguish between different species of bats, and it does not provide estimates of bat numbers. The monitoring device was used to monitor activity patterns from August to October in both years.

Population Status/Abundance for Selected Species: Deer
Our second measure under the status of selected species indicator is the status or occurrence of mule deer and white-tailed deer at the national park. Both species are important members of the ecosystem due to their roles as browsers of vegetation and prey for large predators (Beaupré 2012), and they are popular among park visitors and the public. The occurrence of mule deer in the RMD has been relatively well described and studied in a number of studies and monitoring efforts (see Bucci 2007). The occurrence of the mule deer in the TMD is less well known, but some information is available (Swann 2012). White-tailed deer (Figure 4.15.2-1) have been addressed along with mule deer in some of these studies. To assess this measure, we looked at the districts individually, but also examined the status of the species at the park as a whole.

Mule deer were historically the dominant deer species in desert and grassland areas of the park (Swann 2011). As reported by Sumner (1951) for the RMD, they occurred below 5,000 ft (1,524 m) in elevation, and white-tailed deer occurred above 7,000 ft (2,134 m). A shift in occurrence from mule deer to white-tailed deer occurred at approximately 6,000 ft (1,829 m; Beaupré 2012, based on Sumner's data). Mule deer were reported in the Tucon MD as far back as 1936 (Swann 2012). Throughout the 1930s-1980s, mule deer were reported as common in the TMD (Swann 2012). There were no reports of white-tailed deer in the Tucon MD area historically, but it has been suggested that they occurred at one time (Swann 2012).

Reports of declining populations of mule deer in the RMD date back to the late 1930s (see Swann 2011, Bucci 2007), and Swann and Powell (2006) noted that the species appears to have been in decline for at least the past 50 years. It was suggested at the time that the early declines were largely due to disease, predation (primarily mountain lions), forage, and drought (as reported in Annual Wildlife Reports, see Bucci [2007] and Swann [2011]). In more recent years, a shift has been

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Figure 4.15.2-1. White-tailed deer (*Odocoileus virginianus*) in Rincon Creek, RMD.

observed in the distribution of the two deer species. Mule deer appear to have declined in the park, and white-tailed deer are now seen in lower elevation areas in the RMD, including in the Cactus Forest Loop Drive (Swann 2011).

Primary Data Sources- Deer

Our main sources of information for this measure were Bucci (2007), Swann and Powell (2006, 2007), Swann (2011, 2012), Beaupré (2012), Swann and Perkins (2013a), and a dataset provided by the park on deer in the RMD. Several of these reports were described under the previous indicator; the others are described below.

Bucci (2007)

Bucci (2007) contains a summary of some of the major studies and monitoring efforts that have been conducted on the park's deer. The author examined studies and datasets and looked at trends in the number of deer observed in the park. We used the report for its description of the Gerald Day monitoring effort in the RMD (described below) and helicopter surveys for deer conducted by the AGFD and park in 1989 and 2000-2006, as well as for a general reference on the park studies and two species of deer.

Day/Park Deer Dataset

Park personnel provided us with the dataset collected by Gerald Day, a biologist with the AGFD. It contains information collected from 1960-1974. Park personnel began collecting information using the same methods as Day in 2008, and they continue to collect the information today. The most recent data we have is for 2015. Day collected the information on deer as part of a study on collared peccary (or javelina, *Pecari tajacu*; Day 1977). He collected data on the number and species of deer observed along 18 designated survey routes located in the lower elevations of the district (Bucci 2007). Using binoculars, Day observed deer while he walked along the routes, which were up to four air miles in length. Surveys were carried out in November, December, or January beginning at sunrise. Bucci (2007) pointed out that the surveys were not located in what was considered the most desirable habitat for white-tailed deer.

Helicopter Surveys

The AGFD, in conjunction with Saguaro NP, conducted helicopter surveys in the park in 1989 and 2000-2006 (Bucci 2007). The surveys were conducted in the RMD in these years, but only in 2006 in the TMD. Surveys were conducted on winter mornings for approximately 1.3 to 2 hours. In the RMD, survey routes were similar in 2000-2006. The number of individual deer, gender, and whether they were adults or young was recorded, as well as other information (e.g., on vegetation, number of antler points).

Beaupré (2012)

Beaupré (2012) examined whether changes in vegetation cover within the RMD and urban development (via housing density) outside of the park may have caused the distribution shift in deer species from mainly mule deer to white-tailed deer in the lower elevations of the park. Specifically, her research "assessed whether there is a correlation between the timing of the decline in mule deer with a change in vegetation on the park and an increase in housing density outside the park" (Beaupré 2012). As described, her objectives were to: analyze the historical vegetation composition at the park; assess how vegetation cover changes relate to habitat preferences of the two deer species; and assess whether mule deer habitat may have been lost due to increased housing density.

Indicators/Measure

Habitat Corridors and Connectivity (Connectivity with Surrounding Landscape)

Habitat Corridors and Connectivity: Connectivity with Surrounding Landscape

As described elsewhere in this document, Saguaro NP consists of 91,000 acres (36,826 ha) in two districts that are separated by the City of Tucson (2014 population estimate, 527,972 people, U.S. Census Bureau 2016). On the east side of Tucson is the RMD, which encompasses much of the Rincon Mountain range and its west and southwest foothills and adjacent lowlands. On the west side of Tucson is the TMD, which includes much

of the Tucson Mountains and foothills. The broader landscape in which the park occurs has undergone significant change since the park was established as a national monument in 1933 and expanded to include the TMD in 1962. The following paragraph, from Monahan et al. (2013, page xi), summarizes these changes and provides an introduction to this indicator.

> Like many protected areas in the western United States, Saguaro National Park has experienced rapid urban growth outside of its boundaries. When the Park was first established as a National Monument in 1933, the nearby city of Tucson had fewer than 40,000 residents, and the city was more than 20 miles distant along poorly developed dirt roads. Today, Tucson has nearly 1 million residents, and a multitude of human pressures associated with this growth and development pose distinct challenges to Park natural resources. Roads carve up natural landscapes and impede connectivity for wildlife, urban and agricultural development further fragment and erode the remaining natural areas, and housing proximate to the Park enables residents and pets to transgress its boundaries. Hence, despite the best possible resource management practices being implemented inside the Park, external anthropogenic landscape stressors originating from such sources as population, housing, and roads require Park managers, planners, and interpreters to confront the tricky questions of how such landscape dynamics affect the status and trend of key defining Park resources.

A study that was conducted several years ago on roads within and bordering Saguaro NP indicated that a substantial number of vertebrates were road-killed during the years of the study (1994-1996 in the TMD, and 1996-1999 in the RMD). Gerow et al. (2010) estimated that over the study period an average of 29,377 (SE 6,807) vertebrates, or about 1.1 vertebrates/km/day (SE 0.24) were killed annually on the park's network of roads. For the RMD, this amounted to an estimated 8,778 (SE 1,664) vertebrates, and for the TMD, the figure was an estimated 20,599 (SE 6,601) vertebrates. The majority of the roadkills were amphibians and small reptiles, followed by mammals, then birds. More than 4,000 mammals were estimated to have died every year on the park's roads. Although these estimates are more than 15 yrs old, they remain relevant as park visitation has remained high and development has increased outside the park.

The issue we focus on here is habitat connectivity for wildlife, and specifically, for mammals. As described above, development has met the boundaries of not only the park, but also that of other protected areas in the vicinity, such as Tucson Mountain Park and Coronado National Forest. This has resulted in the loss of wildlife habitat in the Tucson Basin and foothills, as well as corridors for safe travel to mountain ranges nearby (Saguaro NP 2007).

To assess the condition of mammals under this indicator, we used one measure to focus on habitat connectivity of each district with adjacent or surrounding habitat outside of park borders. Connectivity between the two park units is also addressed. To assess the measure, we reviewed a few recent reports examining connectivity of the park with the surrounding landscape. Some of these reports focused on the needs and movements of specific species (e.g., Haynes et al. 2010, Bellantoni and Krausman 1990), while others were more general in scope. Ultimately, our assessment was based primarily on the results of one study, that by Perkl et al. (2015). Perkl et al. (2015) used current and projected data to assess (through modeling) landscape connectivity for wildlife.

The main studies used for this indicator are described below, and other secondary sources are cited and described, as appropriate, in the Condition section.

Primary Data Sources- Habitat Corridors and Connectivity

Perkl et al. (2015)

Perkl et al. (2015) conducted a "connectivity threats assessment" for the park using connectivity modeling. As described by the authors, their main goal was to assess existing and projected threats to landscape connectivity to: both districts of Saguaro NP; the complex of protected lands in the larger Tucson region; and areas of the landscape to the east of the RMD, such as the San Pedro River Valley. To accomplish this goal, they modeled structural landscape corridors to reflect current landscape conditions and those projected for the future throughout the region.

In their baseline scenario (to reflect current conditions) and projected scenario (to reflect future conditions) modeling efforts, the authors modeled "least-cost" corridors between 16 landscape block pairs (Table 4.15.2-1). The corridors have high landscape integrity, or naturalness, and represent the most natural (and probably the most permeable) structural connections between each of the landscape block pairs (Perkl et al. 2015). These are paths of likely wildlife movement; they usually consist of areas with lower levels of human disturbance or modification. However, note that among the assumptions and caveats discussed in Perkl et al. (2015), one was that the modeled corridors may not actually be passable for some species "given real-world barriers such as structures, roads, fencing, and other infrastructure of landscape alterations. For example, many of the corridors cross Interstate 10..., which ...may be an impassable barrier to certain species."

It is also important to note that the analysis did not focus on particular species or groups of wildlife. For a full description of the methods and assumptions of the study and modeling, see Perkl et al. (2015).

4.15.3. Reference Conditions

Reference conditions for this assessment are shown in Table 4.15.3-1. Reference conditions are described for resources in good, moderate concern, and significant concern conditions for each of the three indicators and five measures.

4.15.4. Condition and Trend

Approximately 70 species of mammals have been recorded at Saguaro NP during surveys by Swann and Powell (2006, 2007) and Swann and Perkins (2013a) and other observations (Tables 4.15.4-1 and 4.15.4-2). This number includes three non-native domestic species (domestic cat [*Felis catus*], cattle [*Bos taurus*], and dog [*Canis familiaris*]), as well as the non-native Abert's squirrel (*Sciurus aberti*). Six of the ~70 species were documented within the park in the past (1900-1999), but are now believed to be extirpated (Swann 2011, Swann 2012, Swann and Perkins 2013a); these species are the grizzly bear (*Ursus arctos*), Mexican gray wolf (*Canis lupus baileyi*), bighorn sheep (*Ovis canadensis*), jaguar (*Panthera onca*), North American porcupine

Table 4.15.2-1. Landscape block pairs used in baseline and projected scenarios corridor modeling of Perkl et al. (2015). Connections were modeled between the block A and block B pairs.

Landscape Block A	Landscape Block B	Landscape Block A	Landscape Block B
Ironwood Forest NM	**TMD**	Coronado NF	Cascabel
Ironwood Forest NM	Pusch Ridge Wilderness	Muleshoe Ranch CMA	Cascabel
TMD	Pusch Ridge Wilderness	**RMD**	Muleshoe Ranch CMA
Tucson Mountain Park	**RMD**	Coronado NF, north	Muleshoe Ranch CMA
Pusch Ridge Wilderness	**RMD**	Coronado NF, north	Cascabel
Coronado NF, southwest	**RMD**	Coronado NF, north	Coronado NF, east
Las Cienegas NCA	**RMD**	Coronado NF, east	Cascabel
Coronado NF, south	Coronado NF	Coronado NF, south	Coronado NF, east

NM = National Monument; MD = Mountain District; NCA = National Conservation Area; NF = National Forest; CMA = Cooperative Management Area.

Table 4.15.3-1. Reference conditions used to assess the current condition of native mammals at Saguaro NP.

Indicators	Measures	Good	Moderate Concern	Significant Concern
Species Occurrence	Presence / absence of medium and large mammals	We consider condition to be good if the number of native species found in the park has increased or remained the same over time (in more recent years, not including species extirpated in the early/ mid 1900s).	We consider condition to be of moderate concern if the number of native species found in the park has decreased by only one or a few species in recent years.	We consider condition to be of significant concern if the number of native species found in the park has decreased by more than a few species in recent years, especially when the subject native species were previously sighted more than rarely.
	Presence / absence of small mammals and bats			
Population Status / Abundance of Selected Species	Status / abundance of lesser long-nosed bat	We consider condition to be good if estimated numbers of the subject species are approximately the same or increasing based on the information available.	We consider condition to be of moderate concern if estimated numbers of species have decreased or may be decreasing somewhat.	We consider condition to be of significant concern if estimated numbers of species have decreased substantially and/or may continue to do so.
	Status / abundance of deer (mule and white-tailed deer)			
Habitat Corridors and Connectivity	Connectivity with surrounding landscape (measured by modeled habitat corridors)	We consider condition to be good if multiple corridors exist, providing connectivity for mammals between the park and surrounding landscape, and these corridors do not appear to be threatened by future development.	We consider condition to be of moderate concern if few corridors exist to provide connectivity for mammals between the park and surrounding landscape, and these corridors appear to be threatened by future development.	We consider condition to be of significant concern if only one or no corridors exist to provide connectivity for mammals between the park and surrounding landscape.

(*Erethizon dorsatum*), and banner-tailed kangaroo rat (*Dipodomys spectabilis*). All of the species recorded for the park are listed in either one or the other of the first two tables in this section of the condition assessment. Also note that we included information in the tables on whether species have any special listing status (i.e., federally-listed with the USFWS, or listed as Species of Greatest Conservation Need [SGCN, tiers 1a or 1b] with the State; USFWS 2015b, AGFD 2012).

Species Occurrence: Presence/Absence—Medium and Large Mammals

Based on the two sets of surveys (Swann and Powell 2006 and 2007, and Swann and Perkins 2013a) used for this portion of the assessment, a total of 36 medium and large mammal species have been recorded in the two districts, including the non-native species and the extirpated species (Table 4.15.4-1).

Based on the RMD comparison, all of the native species that were observed during the earlier survey (i.e., Swann and Powell 2006) were observed during the later survey (i.e., Swann and Perkins 2013a). None of the five medium and large mammal species believed to be extirpated from the RMD (grizzly bear, Mexican gray wolf, bighorn sheep, jaguar, and North American porcupine) were observed during either the 2011-2012 surveys or the 1999-2005 surveys (Swann and Powell 2006, Swann 2011, Swann and Perkins 2013a). However, see note #4 below Table 4.15.4-1 regarding an observation of a bighorn sheep in 2015.

Regarding the non-native species, Swann and Powell (2006) reported observing domestic cattle and domestic dog in the RMD, and the domestic cat had been documented with a photograph. None of these three species were observed during the 2011-2012 camera trapping, but Swann (2011) notes that all three species are known to occur in the RMD area at times (Swann and Perkins 2013a). Abert's squirrel was observed during both surveys.

Based on the TMD comparison, four native mammal species that were recorded during the earlier survey (Swann and Powell 2007) were not recorded during the later survey (Swann and Perkins 2013a); these four species are the common (or white-backed) hog-nosed skunk (*Conepatus mesoleucus*),

Table 4.15.4-1. Medium and large mammal species (including squirrels) recorded in Saguaro NP districts during surveys. Non-native species are in bold font.

Common Name	Scientific Name	Swann & Powell (2006) RMD	Swann & Powell (2007) TMD	Swann & Perkins (2013a) RMD	Swann & Perkins (2013a) TMD	NP-Species
Abert's squirrel [1]	***Sciurus aberti*** **[1]**	**X**		**X**		**X**
American badger	*Taxidea taxus*	X	X	X	X	X
American black bear	*Ursus americanus*	X		X		X
Antelope jackrabbit [2]	*Lepus alleni* [2]	X	X	X	X	X
Arizona gray squirrel [2]	*Sciurus arizonensis* [2]	X		X		X
Bighorn sheep [2, 3, 4]	*Ovis canadensis* [2, 3, 4]					
Black-tailed jackrabbit	*Lepus californicus*	X	X	X	X	X
Bobcat	*Lynx rufus*	X	X	X	X	X
Cliff chipmunk	*Tamias dorsalis*	X		X		X
Collared peccary (javelina)	*Pecari tajacu*	X	X	X	X	X
Common gray fox	*Urocyon cinereoargenteus*	X	X	X	X	X
Common (or white-backed) hog-nosed skunk	*Conepatus mesoleucus*	X	X	X		X
Coyote	*Canis latrans*	X	X	X	X	X
Desert cottontail	*Sylvilagus audubonii*	X	X	X	X	X
Domestic cattle	***Bos taurus***	**X**		**X[5]**	**X[5]**	**X**
Eastern cottontail	*Sylvilagus floridanus*	X		X		
Domestic cat	***Felis catus***	**X**	**X**	**X[5]**	**X[5]**	**X**
Domestic dog	***Canis familiaris***	**X**	**X**	**X[5]**	**X**	**X**
Mexican gray wolf [2, 3]	*Canis lupus baileyi* [2, 3]					
Grizzly bear [3]	*Ursus arctos* [3]					
Harris's antelope squirrel [2]	*Ammospermophilus harrisii* [2]	X	X	X	X	X
Hooded skunk	*Mephitis macroura*	X	X	X	X	X
Jaguar [2, 3]	*Panthera onca* [2, 3]					
Kit fox [2]	*Vulpes macrotis* [2]		X		X	X
Mountain lion	*Puma concolor*	X	X	X	X	X
Mule deer	*Odocoileus hemionus*	X	X	X	X	X
North American porcupine [3]	*Erethizon dorsatum* [3]					
Northern raccoon	*Procyon lotor*	X	X	X		X
Ringtail	*Bassariscus astutus*	X	X	X	X	X
Rock squirrel	*Spermophilus variegatus*	X	X	X	X	X
Round-tailed ground squirrel	*Spermophilus tereticaudus*	X	X	X	X	X
Striped skunk	*Mephitis mephitis*	X	X	X		X
Virginia opossum [6]	*Didelphis virginiana californica* [6]	X		X		
Western spotted skunk	*Spilogale gracilis*	X	X	X		X
White-nosed coati [7]	*Nasua narica* [7]	X		X		X
White-tailed deer [2]	*Odocoileus virginianus* [2]	X		X		X

Data Sources: by Swann and Powell (2006, 2007) in 1999-2005 (RMD) and 2001-2005 (TMD), and Swann and Perkins (2013a) in 2011-2012. The list was also compared to Swann (2011, 2012) for other species or occurrences to include (see additional footnotes).

Table 4.15.4-1. Medium and large mammal species recorded in Saguaro NP continued.

[1] Non-native species; see Swann (2011) for summary of literature on this species in the park.

[2] Listed as a Species of Greatest Conservation Need (SGCN, Tier 1a or 1b [out of 1a-1c]) with the State (AGFD 2012). No species here that have been observed since 2000 are federally-listed as endangered/threatened. For white-tailed deer, the listing is only for *couesi* subspecies.

[3] Swann & Perkins (2013b) reported as "confirmed 1900-1999 only." Swann (2011) considers the species extirpated (or extirpated or very rare in the case of the porcupine). Swann (2012) noted bighorn sheep, gray wolf, and North American porcupine has having occurred or probably occurred in TMD.

[4] Species was observed recently in the park on two separate occasions: a) one animal that had been translocated by AGFD into the nearby Santa Catalina Mountains was observed in 2015 in the RMD; and b) two young rams were observed in the TMD in 2016 (probably from west of the park from the population in Ironwood Forest NM [Silverbell Mts]; Don Swann, Saguaro NP, pers. comm.).

[5] Species not recorded during the Swann and Perkins (2013a) surveys, but reported as known to occur at times per Swann (2011, 2012).

[6] Species confirmed in TMD in 2009 (Swann 2012).

[7] One probable sighting (~2001) and one possible sighting (1975) of individuals in the TMD (Swann 2012).

Table 4.15.4-2. Species of bats and small nocturnal rodents recorded in Saguaro NP during surveys.

Common Name	Scientific Name	Swann & Powell (2006) RMD	Swann & Powell (2007) TMD	Swann (2011) RMD [1]	Swann (2012) TMD [1]	NPSpecies
Small Nocturnal Rodents						
Arizona cotton rat	*Sigmodon arizonae*	X				X
Arizona pocket mouse [2]	*Perognathus amplus* [2]		X	X		X
Bailey's pocket mouse	*Chaetodipus baileyi*	X	X			X
Banner-tailed kangaroo rat [3]	*Dipodomys spectabilis* [3]			X [3]		
Botta's pocket gopher	*Thomomys bottae*	X			X [4]	X
Brush mouse	*Peromyscus boylii*	X	X [4]			X
Cactus mouse	*Peromyscus eremicus*	X	X			X
Deer mouse	*Peromyscus maniculatus*			X[5]		X
Desert shrew	*Notiosorex crawfordi*			X		X
Fulvous harvest mouse	*Reithrodontomys fulvescens*	X				X
Merriam's kangaroo rat	*Dipodomys merriami*	X	X			X
Mexican woodrat	*Neotoma mexicana*	X				X
Rock pocket mouse	*Chaetodipus intermedius*	X	X			X
Sonoran Desert pocket mouse	*Chaetodipus penicillatus*	X	X			X
Southern grasshopper mouse	*Onychomys torridus*	X [6]			X	X
Western harvest mouse	*Reithrodontomys megalotis*	X				X
Western white-throated woodrat	*Neotoma albigula*	X	X			X
White-footed mouse	*Peromyscus leucopis*			X[7]		X
Yellow-nosed cotton rat	*Sigmodon ochrognathus*	X				X
Bats						
Big brown bat	*Eptesicus fuscus*	X			X	X
Brazilian (or Mexican) free-tailed bat [2]	*Tadarida brasiliensis* [2]	X				X

Table 4.15.4-2. Species of bats and small nocturnal rodents recorded in Saguaro NP continued.

Common Name	Scientific Name	Powell et al. (2006) RMD	Powell et al. (2007) TMD	Swann (2011) RMD [1]	Swann (2012) TMD [1]	NPSpecies
California leaf-nosed bat [2]	*Macrotus californicus* [2]		X			X
California myotis	*Myotis californicus*	X				X
Canyon bat [8]	*Parastrellus hesperus* [8]		X	X		X [8]
Cave myotis [2]	*Myotis velifer* [2]	X	X			X
Fringed myotis	*Myotis thysanodes*	X				X
Hoary bat	*Lasiurus cinereus*	X				X
Lesser long-nosed bat [2, 9]	*Leptonycteris yerbabuenae* [2, 9]	X				X
Long-legged myotis	*Myotis volans*	X				X
Mexican long-tongued bat	*Choeronycteris mexicana*	X			X	X
Pallid bat	*Antrozous pallidus*	X				X
Pocketed free-tailed bat [2]	*Nyctinomops femorosaccus* [2]	X				X
Silver-haired bat	*Lasionycteris noctivagans*	X				X
Southwestern myotis	*Myotis auriculus*	X				X
Townsend's big-eared bat	*Corynorhinus townsendii*	X			X	X
Western red bat [2]	*Lasiurus blossevillii* [2]	X				X
Western small-footed myotis	*Myotis ciliolabrum*			X		X [10]
Yuma myotis [2]	*Myotis yumanensis* [2]			X		X

Data Sources: Swann and Powell (2006) in the RMD and Swann and Powell (2007) in the TMD in 2001-2002. The species list from the 2001-2002 surveys was also compared to Swann (2011, 2012) for the corresponding district to determine whether additional species should be included here; "X"s are shown in the Swann (2011, 2012) columns for a given species only when the species was not reported by Swann and Powell (2006, 2007) for the corresponding district. None of the species shown are non-native.

[1] We generally did not include species in the table from Swann (2011, 2012) that had an "unknown" status (this is a small number of species). Exceptions to this rule are indicated in the footnotes.

[2] Listed as a Species of Greatest Conservation Need (SGCN, Tier 1a or 1b [out of 1a-1c]) with the State (AGFD 2012). The lesser long-nosed bat is also listed as endangered with USFWS (USFWS 2015b).

[3] Species is probably extirpated; captured in the RMD in the 1940s (Swann 2011).

[4] Species not confirmed.

[5] This species was confirmed in the past, but its current status is unknown (Swann 2011).

[6] This species was confirmed by a road-killed animal (Swann and Powell 2006).

[7] This species may occur in the park, but no specimens exist to support the one record of the species (Swann 2011).

[8] Previously known as Western pipistrelle (*Pipistrellus hesperus*).

[9] There are some inconsistencies in the use of the scientific name of this species. USFWS refers to it as *Leptonycteris curasoae yerbabuenae*; IUCN refers to it as *L. yerbabuenae*; and recent park documents refer to it as *L. curasoae*. IUCN (http://www.iucnredlist.org/details/136659/0) reports that some recent references support considering them distinct species, with *L. yerbabuenae* being the one in the U.S.

[10] NPSpecies lists this species (*M. ciliolabrum*) as a synonym of *M. leibii*. Swann (2011) lists as *M. ciliolabrum*.

Northern raccoon (*Procyon lotor*), striped skunk (*Mephitis mephitis*), and Western spotted skunk (*Spilogale gracilis*). [Note that Appendix X of Swann and Perkins {2013a} indicates that the striped skunk was recorded with cameras, but this is an error (Don Swann, Saguaro NP, pers. comm.)].

Similar to the situation in the RMD, the 2001-2005 and 2011-2012 sampling failed to document a few species that are believed to be extirpated from the TMD- North American porcupine, Mexican gray wolf, and bighorn sheep. However, see note #4 below Table 4.15.4-1 regarding an observation of two bighorn sheep in the TMD in 2016.

Regarding the domestic non-native species, only the dog was observed during the 2011-2012 period and during the earlier 2001-2005 surveys in the TMD. However, Swann (2012) notes that all three species are known to occur in the district on occasion. Also, a cat skull was collected in the district by Swann and Powell (2007).

Medium and Large Mammals- Summary

For the entire park, there are five medium and large mammal species believed to be extirpated (Swann 2011 and 2012, Swann and Perkins 2013a). All five were once documented in the RMD, and three were documented in the TMD (Swann and Perkins 2013a). In the RMD: grizzly bears were last recorded in the early 1920s; Mexican gray wolves in 1948; bighorn sheep in the 1950s (but see Table 4.15.4-1 note #4); jaguars in the 1930s; and porcupines in the early 1990s (Swann and Perkins 2013a). In the TMD: the bighorn sheep was last recorded in the 1950s (but see Table 4.15.4-1 note #4); the Mexican gray wolf in the 1930s or 1940s; and the porcupine in the 1960s. Porcupines may be experiencing a regional decline, possibly due to increased mountain lion predation (Brown and Babb 2009, as cited by Swann and Perkins 2013a).

Based on our assessment of species occurrence by comparing the Swann and Powell (2006, 2007) and Swann and Perkins (2013a) surveys, no species were missing in the RMD comparison. For the TMD, there were four native species (common hog-nosed skunk, Northern raccoon, striped skunk, and Western spotted skunk) that were not recorded during the more recent survey. These species were not observed even though the 2011-2012 study had a greater number of camera-nights than the earlier inventory (Swann and Perkins 2013a). Swann and Perkins (2013a) suggested that the four species probably still occur in the TMD and would be observed with additional sampling effort. Since the 2013 report, park employees and partners have continued sampling in the Tucson Mountains (Don Swann, Saguaro NP, pers. comm.). In 2015, one park partner observed two Western spotted skunks on the east side of the TMD, and another partner observed a racoon. Swann and Perkins (2013a) also stated that "TMD is considered highly vulnerable to species extirpations because it is becoming increasingly isolated due to development outside of its boundaries."

Although there is some uncertainty regarding the status of at least two of the species (common hog-nosed skunk and striped skunk), we consider the condition of medium and large mammals under this indicator/measure to be of moderate concern at this time. In addition to the uncertain status of the two skunk species in the TMD, the North American porcupine has apparently disappeared from the RMD fairly recently, with the last record being in the early 1990s. There is insufficient data to determine trends at this time.

Species Occurrence: Presence/Absence—Small Mammals and Bats

As previously mentioned, there has been no recent, comprehensive survey of small mammals and bats that we can use to compare to the surveys conducted in 2001-2002 by Swann and Powell (2006 and 2007) for the RMD and TMD. Therefore, we can not determine current condition for this measure. However, Table 4.15.4-2 lists the species recorded in each district by the corresponding survey. We also reviewed Swann (2011), Swann (2012), and the NPSpecies list for the park (NPS 2014), to determine whether additional species should be added to the table (note that the NPSpecies list does not distinguish by district). Finally, we also reviewed other relatively recent surveys or studies on bats and small mammals (e.g., Wolf 2011, 2013a, and 2013b; Edwards and Swann 2003), but found no additional species that should be included for the two districts.

A total of 38 small mammal (excluding squirrels) and bat species have been recorded in Saguaro NP during the 2001-2002 surveys and other observations (Table 4.15.4-2). One of the species, banner-tailed kangaroo rat, was included in Swann (2011) as probably extirpated; it was captured in the RMD in the 1940s, but not since that time. Note that squirrels (several species) were included in Table 4.15.4-1 because they were detected

during the camera trapping study in 2011-2012.

Thirty-seven of the species of small mammals (excluding squirrels) and bats have been recorded in the RMD (only the California leaf-nosed bat [*Macrotus californicus*] has not been recorded, although it is likely to occur [Swann 2011]), and 16 of the species have been recorded in the TMD (Table 4.15.4-2). Some of the species that have not yet been documented in the TMD are likely to occur there (Swann 2012).

The University of Arizona-NPS inventories (i.e., Swann and Powell 2006 and 2007) are the most comprehensive surveys of small mammals and bats to date in the park, and they provide a firm baseline for future monitoring and assessment. However, the surveys are now more than 10 years old, and we have no comparable efforts upon which to judge current condtion. Therefore, overall, current condition (species occurrence) of bats and small mammals at the park is unknown.

Although the only bat species addressed individually in this condition assessment is the lesser long-nosed bat, it is worth noting that a bat survey was conducted in mines in the Tucson Mountains, including within Saguaro NP, in 2004-2005 (Wolf and Dalton 2005). The focus of this study was on the California leaf-nosed bat (*Macrotus californicus*) and the cave myotis (*Myotis velifer*), both of which occur within the park and are SGCN. The surveys from this study are the most comprehensive data available to date on these species in the TMD.

Population Status/Abundance for Selected Species: Lesser Long-nosed Bat

Lesser long-nosed bats (Figure 4.15.4-1) have been monitored at their roost in the RMD since 1991 (Sidner 1991). Roost counts have been conducted in many years, but not in every year; counts are conducted when funding allows (Natasha Kline, Saguaro NP, pers. comm.). For this assessment of species status, we used all recent, available data (Table 4.15.4-3). We also present data from the first few years of monitoring.

Based on the information presented, the current condition under this indicator/measure is good, because the status of the species in the park appears stable. Roost count data from 2005-2014 varies from over 30,000 to a few hundred individuals (Table 4.15.4-3), but this variation is expected, as the bats are believed to utilize several different local roosts when in the area (e.g., in the Santa Catalina Mountains just north of Tucson; Wolf 2014). Also, as reported by Wolf (2013b), there is annual variation in when the bats arrive, when their abundance peaks, and when they depart. She further suggests that the abundance of bats at the RMD roost "may be connected to the abundance and phenology of agaves in southeastern Arizona, which also vary from year to year." It is believed that lesser long-nosed bats may have departed the roost earlier than usual in 2014 due to heavy rains that occurred in the first part of September that washed water into the cave (Wolf 2014). The number of lesser long-nosed bats using the cave was very low during the surveys in 2015, but only two surveys were conducted, and rains also occurred during the survey period. If, however, low numbers continued to be observed in the RMD for a few more years and their overall numbers in the area (at hummingbird feeders and other local roosts) went down, there would be cause for concern.

The two years of remote monitoring of the roost by the AGFD indicated that lesser long-nosed bat activity levels were higher in 2013 compared to 2012, suggesting that

NPS

Figure 4.15.4-1. Lesser long-nosed bat (*Leptonycteris yerbabuenae*) near RMD.

Table 4.15.4-3. Estimates of the number of lesser long-nosed bats using the roost in the RMD.

Year (Month(s))	Source	Number of Bats Estimated	Comments
1991 (May-July)	Sidner (1991)	1 (in May); 1 (in July); and 1 juvenile skeleton in June	internal surveys
1992-1993	Sidner & Davis (1994)	1992 (May): 0 1993 (March, May, June): 1 in May	internal surveys
2005	Wolf (2013a)	Internal survey = 3,000	
2006	Wolf (2013a)	Internal survey = 10,000	
2008	Wolf (2013a)	Internal survey = 10,000	
2011 (Aug., Sept.,Nov.)	Wolf (2011)	Internal survey in September ~ 36,000	Internal survey in August =1,000; No bats in November
2012 (Sept.)	Wolf (2013a)	External survey in September = 14,611 [Internal survey =12,550]	external surveys reported to be the more accurate method
2013 (Aug., Sept., Oct.)	Wolf (2013b)	External survey in September = 12,765	Sept. survey had highest number of the three months
2014 (May, June, July, Aug., Sept., Oct.)	Wolf (2014)	Internal survey in August = ~150	Either 0 or small number of bats in the other months; heavy rains in early September may have led to bats leaving prior to Sept. survey.
2015 (Aug., Sept.)	Wolf (2015)	1 (in Aug.); 1 (in Sept.)	internal surveys

more bats may have been using the roost in 2013 compared to 2012 (Diamond 2013). The estimated numbers from the surveys reported in Table 4.15.4-3 indicate that a generally similar number used the roost in these two years.

Population Status/Abundance for Selected Species: Deer

RMD

As noted in the Data and Methods section, several sources of information exist on deer in the RMD. To assess deer, we relied most heavily on the Day/NPS monitoring dataset, the 1989 and 2000-2006 helicopter surveys, and the camera trap data from 1999-2005 (Swann and Powell 2006) and 2011-2012 (Swann and Perkins 2013a). Beaupré (2012) was also used and provided important interpretation of these data.

Based on the Day dataset (1960-1974) and the more recent data (2008-2015) collected by the park, the numbers of mule deer observed during surveys in the RMD were substantially lower in 2008-2015 compared to 1960 to 1974 (Figure 4.15.4-2). In contrast, white-tailed deer numbers observed, which were low in the areas surveyed in 1960-1974, were higher during 2008-2015. Additionally, based on these data, the overall number of deer observed (i.e., both species combined) appeared to be lower in the 2008-2015 period compared to the 1960-1974 period.

Although helicopter surveys were conducted in 1989 and 2000-2006 by AGFD and Saguaro NP, survey routes were similar only for 2000-2006 (Bucci 2007). The numbers of deer observed were higher in 1989 (compared to 2000-2006) for both mule deer and white-tailed deer (except for 2006 for white-tailed deer), but especially for mule deer (Table 4.15.4-4; Bucci 2007). The number of mule deer recorded in 1989 was substantially higher than in any year from 2000-2006. Also, the number of white-tailed deer observed was higher than the number of mule deer observed in every year from 2000-2006.

Beaupré (2012) points to the 1990-2000 time period as the time when white-tailed deer became more common than mule deer in the lower elevations of the district. She concluded that the shift in deer occurrence in the lower elevations of the RMD was probably due,

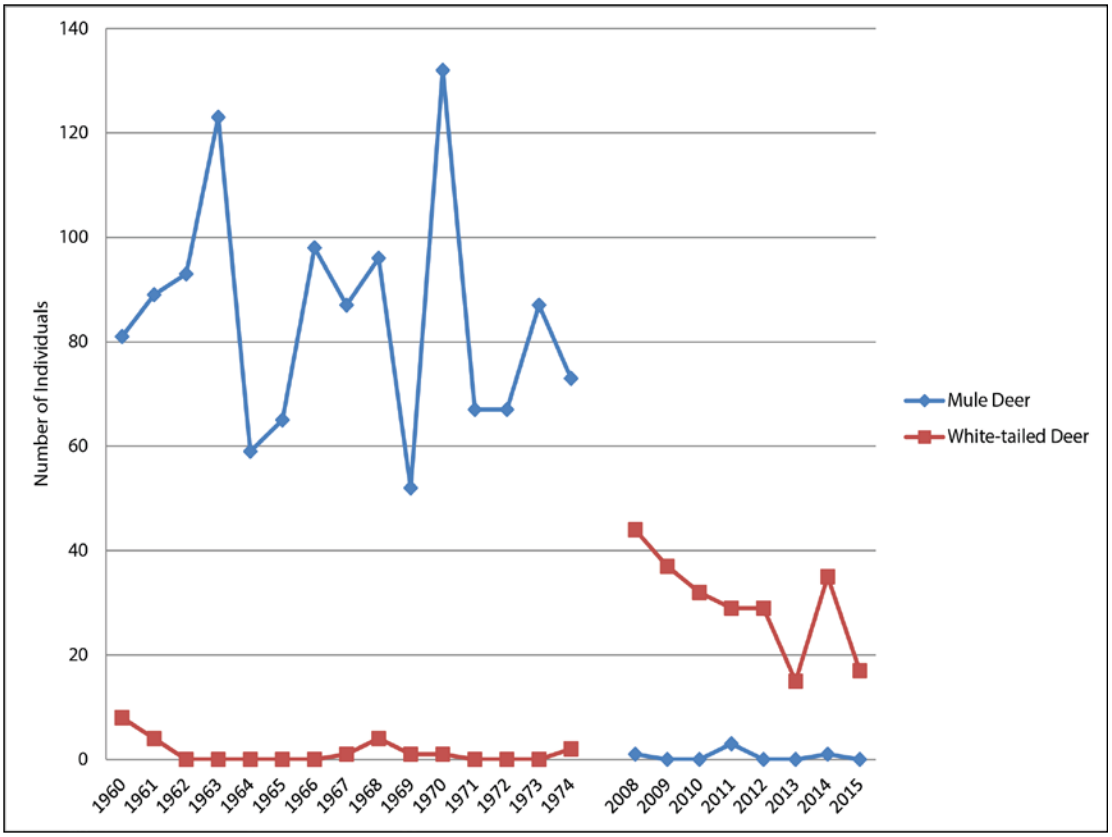

Figure 4.15.4-2. The number of mule deer and white-tailed deer observed on routes in the RMD, 1960-1974 (Day) and 2008-2015 (Saguaro NP); dataset and figure provided by Natasha Kline, Saguaro NP.

at least partially, to an increase in vegetative cover. Compared to white-tailed deer, mule deer prefer more open areas (Lingle and Wilson 2001, as cited by Beaupré 2012). Additionally, the lower elevation areas of the RMD are also closest to park boundaries. Habitat for the mule deer in adjacent areas outside of the park has probably decreased over the 1990-2000 period due to large increases in housing density (Beaupré 2012).

During the infrared-triggered camera study discussed earlier (1999-2005), mule deer were only photographed below 4,000 ft (1,219 m) in elevation (Swann and Powell 2006). In this "low elevation" strata, 28 mule deer were photographed, compared to 104 white-tailed deer. White-tailed deer were also photographed in the "middle" and "high" strata.

Similarly, Swann and Perkins (2013a) reported the mule deer as one of the least photographed species during their camera trap study in the RMD in May 2011 to August 2012, and the white-tailed deer as one of the most commonly photographed species. Swann and Perkins (2013b) reported, for the May 2011-March 2012 period, nearly 400 photographs of white-tailed deer and fewer than six of mule deer.

These various surveys provide evidence that the mule deer has declined in distribution and area occupied (Swann and Perkins 2013a). As suggested in the recent study by Beaupré (2012), the causes are probably the loss of habitat outside the park and increasing shrubby vegetation inside the park. Based on this decrease, we consider the condition of mule deer in the RMD to be of significant concern. The current trend is unclear; numbers may or may not continue to decrease. The condition of white-tailed deer does not appear to be of concern at this time, as they have expanded their distribution and area occupied. Swann (2011) wrote that white-tailed deer are now "very common" in the park, being found throughout the RMD "from desert areas to the highest elevations."

TMD

Few data exist to address deer condition in the TMD. The only data or information available are from camera trap data from (2001-2005) from Swann and Powell (2007), the 2006

helicopter survey (described by Bucci 2007), and camera trap data from 2011-2012 from Swann and Perkins (2013a).

From 2001-2005, Swann and Powell (2007) recorded 52 photographs of mule deer, and no photographs of white-tailed deer. During the 2006 helicopter survey of deer in the TMD, 16 mule deer were counted (six bucks, six does, and four fawns; Bucci 2007). No white-tailed deer were recorded during the survey. During their 2011-2012 camera trap study, Swann and Perkins (2013a) found that the mule deer was the fourth most commonly observed species, with 208 photographs. For some perspective, the three most commonly photographed mammals were the desert cottontail (*Sylvilagus audubonii*), collared peccary (*Pecari tajacu*), and black-tailed jackrabbit (*Lepus californicus*), with 622 photos, 478 photos, and 464 photos, respectively. No white-tailed deer were observed during the study.

Although these data as a group do not provide a firm basis from which to judge current condition (the data are not as extensive as for the RMD and the most recent data are from 2012), we do not perceive any obvious concerns at this time. Although the white-tailed deer had been reported in the past by at least one observer, the species has never been confirmed in the TMD (Swann and Perkins 2013a). We consider current condition to be unknown in the TMD based on the lack of data from the last few years, but have no obvious concerns for deer in the TMD based on these studies. However, the relatively small size of the district, coupled with development outside of its borders, is of concern.

Deer- Summary

Based on the information presented here, the condition of mule deer within the park is of significant concern, primarily due to their observed decline in the RMD. The condition of mule deer in the TMD does not appear to be a concern at this time, but data are sparse (and there are none since 2012). The condition of white-tailed deer at the park (RMD) appears to be good, as their numbers have increased in recent years, at least in the lower elevations of the park.

Table 4.15.4-4. Number of mule and white-tailed deer recorded during helicopter surveys in 1989 and 2000-2006 in the RMD.

Date	# Mule Deer Counted	# White-tailed Deer Counted
February 1989	94	48
January 2000	0	8
January 2001	3	19
January 2002	12	26
January 2003	6	32
January 2004	7	40
January 2005	2	26
January 2006	10	49

Note: Surveys conducted by AGFD and Saguaro NP. Information obtained from Bucci (2007 [Table 10 and Table 11]).

Habitat Corridors and Connectivity:
Connectivity with Surrounding Landscape

We organized this discussion by district, but note that some of the discussion involves both districts of the park.

RMD

The RMD is adjacent to (and west of) Coronado National Forest, and a high level of naturalness (i.e., intact landscape) exists to the east and south of the district (Perkl et al. 2015; Figure 4.15.4-3). Lower naturalness (i.e., a less intact landscape) exists to the north of the district, and, especially, to the west of the district (City of Tucson). The corridor modeling conducted by Perkl et al. (2015) indicated four corridors that were relatively direct routes to areas of protected land, although not necessarily short, and one corridor between the RMD and Tucson Mountain Park (via the TMD; Figure 4.15.4-3). The first four corridors are between the RMD and Pusch Ridge Wilderness, Muleshoe Ranch Cooperative Management Area, Las Cienegas National Conservation Area, and Coronado National Forest (NF) southwest. The corridor between the RMD and Tucson Mountain Park (via the TMD)

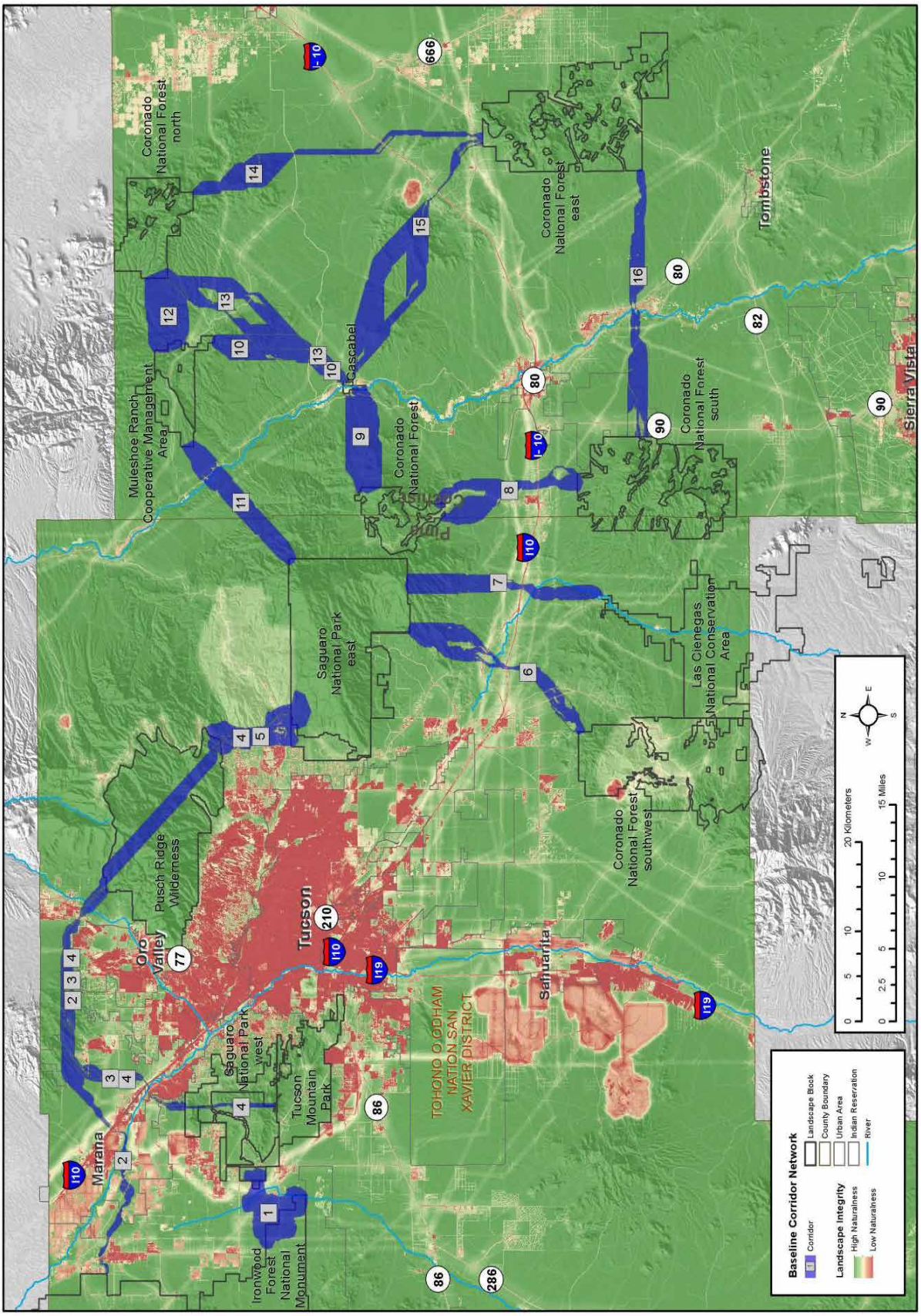

Figure 4.15.4-3. Baseline scenario corridor network (Map 2) from Perkl et al. (2015). Modeled corridors (with numbers) are shown in blue, and connect landscape blocks (e.g., Saguaro NP east and Coronado National Forest southwest). Map shading color (green, yellow, orange-red) indicates the integrity of the landscape (i.e., green indicates "high naturalness", and orange-red indicates "low naturalness."

heads north to Pusch Ridge Wilderness, then northwest and west towards Marana, but south, crossing I-10 and down into the northern portion of the TMD.

The projected scenario corridor modeling results (for future landscape conditions) indicated some changes in the least-cost corridors for wildlife. The greatest change was that the connection between the RMD (or Pusch Ridge Wilderness) and the TMD/ Tucson Mountain Park by way of north of Tucson disappears in the future. A different corridor between these areas was indicated well to the south of the RMD (and south of Tucson and Sahuarita), and it would be substantially longer. The next largest change involving the RMD appeared to be in the corridor between the district and Coronado National Forest, southwest.

TMD

The TMD is adjacent to (and north of) Tucson Mountain Park. However, under the baseline scenario (current condition), low naturalness occurs to the east (City of Tucson), and in places to the northeast and northwest (Perkl et al. 2015; Figure 4.15.4-3). The corridor modeling indicated only a few corridors involving the TMD. The first is a relatively short connection between the district and Ironwood Forest National Monument, which lies to the west of the district. A second corridor was indicated from the district to the Pusch Ridge Wilderness, by way of heading north from the district, crossing I-10, continuing north of Marana, and then heading east and then southeast to Pusch Ridge Wilderness (or in the opposite direction; this is basically the same corridor as described above between the RMD and TMD/Tucson Mountain Park). From the southeast corner of Pusch Ridge Wilderness, there is also a corridor between the wilderness and the RMD, thereby providing a connection between the TMD and the RMD. Under the baseline scenario, this was the only corridor between the two districts.

The projected scenario corridor modeling results (for future landscape conditions) involving the TMD also indicated some changes in the least-cost corridors for wildlife. This significant change was described above for the RMD; the corridor between the district and Pusch Ridge Wilderness (and therefore, the RMD) would disappear. As described above, however, a new, longer southern corridor was indicated. The other corridor, that between the TMD and Ironwood Forest NM, remained relatively unchanged under the projected scenario. Also with the projected scenario, except for Tucson Mountain Park and Ironwood Forest NM to the west, low naturalness (development) would essentially encircle the district.

Summary and Significance of these Modeled Corridors, and Conclusions about Connectivity for Mammals

The corridors from the baseline modeling (Figure 4.15.4-3) that would disappear under the projected modeling represent "areas of present day connectivity that are most threatened by projected development" (Perkl et al. 2015). The authors reported that 79.6% of the total network would be altered from the original baseline corridors by projected urban growth. Additionally, from the baseline corridors network to the projected corridors network, there was a 40.8% increase in size. This means that wildlife would need to make longer and less direct movements within the corridor network.

Although our use of the Perkl et al. (2015) analysis for this measure is general and qualitative, we conclude that, based on the information presented here, the current condition of connectivity for the RMD is good to moderate. A number of modeled corridors exist, and land to the east and south, except for I-10 to the south, shows a high level of naturalness (Perkl et al. 2015; Figure 4.15.4-3). Land immediately to the north of the district shows a lower level of naturalness, and that to the west of the district (City of Tucson), of course, shows a low level of naturalness within a relatively short distance. Under the projected scenario, development would increase between Interstate 10 (south of the district) and the west end of the district. A long-term concern for the park is also the vulnerability of corridors to the east of the RMD to future development. If development up the San Pedro River corridor begins to

increase rapidly, as it could in the future, it would cut off the connectivity of the RMD to the mountain ranges to the east and have a long-term negative impact on the mammal community (Don Swann, Saguaro NP, pers. comm.).

Except for the Tucson Mountain Park to its south, the TMD is relatively more surrounded by development at the current time (Figure 4.15.4-3). A modeled corridor, which based on the analysis, is projected to exist in the future, connects the district to Ironwood Forest NM. The baseline (current) modeled corridor between the district and Pusch Ridge Wilderness (and RMD), would require the crossing of I-10 and passage along an indirect route. A connection between the TMD and RMD would become even longer and more circuitous under the projected (future) scenario. For these reasons, we consider current condition under this measure for the TMD to be of significant concern.

Additional support for the conclusions under this measure is provided from a few of the reports reviewed for the assessment. For example, in Haynes et al.'s (2010) study on mountain lions and bobcats of the Tucson Mountains, they point out that the Tucson Mountains are the most endangered of all of Pima County's sky islands due to the small size of the range and the increasing human development that surrounds it. They report that mountain lions currently have no travel corridors to or from the mountains that are not compromised, and bobcats have been similarly, but much less affected. The most likely path for mountain lions to take at this time is to the west of the Tucson Mountains. "It is still likely that mountain lions can weave through the low density housing and the Central Arizona Project Canal crossings to connect with the open desert of Avra Valley, the Tohono O' Odham Indian Reservation, and the Roskruge Mountains to the west" (Haynes et al. 2010).

Mammals

Indicators	Measures
Species Occurrence	1 Measure
Population Status	2 Measures
Habitat Connectivity	1 Measure

Overall Condition and Trend

For assessing the condition of mammals at Saguaro NP, we used three indicators with a total of five measures. All three indicators/measures are summarized in Table 4.15.4-5. It was somewhat challenging to determine an overall condition based on the different measures and their individual, varying conditions. We acknowledge that there is some subjectivity in our conclusions, but we attempted to base the analyses and their conclusions on the most recent information available and the reference conditions outlined previously.

Overall, we consider the condition of mammals at Saguaro NP to be of moderate concern. Although condition under some measures was considered to be good (such as the status of endangered lesser long-nosed bats), that of others was considered of moderate concern (presence/absence of medium and large mammals) or even of significant concern (status of mule deer in the RMD, habitat connectivity for the TMD).

Although we do not have sufficient information to estimate trends for some indicators/measures, we consider the overall trend in condition as varied. For example, the population status of the lesser long-nosed bat appears good with an unchanging trend at the present time, while the condition of habitat connectivity with the surrounding landscape appear to be declining. As population growth and development continue to increase in the Tucson area, which is projected to occur (e.g., Monahan et al. 2013), more pressure will be placed on protected areas (and their wildlife) in the region, and this includes the two park districts. In their study of mule deer and collared peccary in the RMD, Bellantoni and Krausman (1990) summarized the situation a number of years ago: Human population growth and development of lands in the vicinity of Saguaro NP is leading to a decrease in wildlife habitat outside the park,

Table 4.15.4-5. Summary of the mammals indicators, measures, and condition rationale.

Indicator	Measures	Condition	Rationale for Condition
Species Occurrence:	Presence / absence of medium and large mammals (including squirrels)	RMD: Good TMD: Moderate Concern Overall: Moderate Concern	For the RMD, we considered condition to be good based on the comparison of medium and large mammal species observed during the 1999-2005 survey and 2011-2012 survey. All species observed during the earlier survey were observed during the later survey (when including non-random camera results). For the TMD, condition is considered to be of moderate concern, because four native species that were observed in the earlier survey were not observed in the later survey. Two of the four species were observed by park partners in 2015. It is possible that the other two species may still occur in the park, but their occurrence is unknown at this time. There is insufficient data to determine trends at this time.
	Presence / absence of small mammals and bats (excluding squirrels)	Unknown	Approximately 37 species of small mammals and bats have been recorded in the RMD, and 16 species have been recorded in the TMD. The Swann and Powell (2006 and 2007) surveys in 2001-2002 are the most comprehensive surveys of these species as a group to date. The results of the surveys provide a baseline for future monitoring and assessment. However, because there are no current, comparable surveys by which to judge condition, species occurrence of small mammals and bats in the park is unknown at this time.
Population Status / Abundance of Selected Species	Status of Lesser long-nosed bats	Good with an unchanging trend	Based on available information from lesser long-nosed bat roost surveys in the RMD, current condition of this species in the park appears stable, and therefore in good condition. Roost count data from 2005-2014 varies from 30,000 to a few hundred, but this variation is expected, as the bats are believed to utilize several different local roosts when in the area. In 2014 it was believed that bats may have vacated the roost early due to heavy rains that washed water into the cave.
	Status of mule and white-tailed deer	Mule deer: Significant concern White-tailed deer: Good	The condition of mule deer within the park is of significant concern, primarily due to their observed decline in the RMD. The condition of mule deer in the TMD does not appear to be a concern at this time, but data are sparse. A reported decline in numbers has been occurring in the RMD for decades (Swann and Powell 2006), and monitoring data indicate low numbers observed for 2000-2006 and 2008-2015. The condition of white-tailed deer at the park (RMD) appears to be good, as their numbers have increased in recent years, at least in the lower elevations of the RMD. White-tailed deer have never been confirmed in the TMD. While mule deer have declined and white-tailed deer have increased in the RMD, it is unclear whether the species are continuing to decrease/increase (respectively).
Habitat Corridors / Connectivity	Connectivity within surrounding landscape	RMD: Good to Moderate TMD: Significant Concern	Connectivity with the surrounding landscape is good to moderate for the RMD. Based on Perkl et al. (2015) a number of modeled corridors exist, connecting the district with the surrounding landscape, and high naturalness exists to the east and south (except for near I-10). The modeled corridor that would be projected to change the most with future development is the one that connects the district to the TMD. Condition for the TMD is of significant concern. More development surrounds the district, and this is projected to increase in the future. In addition to its location adjacent to Tucson Mountain Park, the district currently has two modeled corridors (one of which connects it to RMD). Under the projected scenario, this corridor would disappear and be replaced by a longer, more circuitous route. As taken into account with the projected scenario modeling, negative trends are expected to continue.

degradation or elimination of travel corridors for wildlife to and from the park, a decrease in wildlife outside of the park, and fragmentation of the habitat that remains.

4.15.5. Sources of Expertise

No outside experts were consulted for this resource topic. However, Don Swann and Natasha Kline, biologists with Saguaro NP, provided substantial input on this assessment.

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4.16. Birds

Indicators/Measures

- Occupancy of Species Common in SODN (1 Measure)
- Species Richness in SODN Survey Area (1 Measure)
- Species Richness & Abundance (2 Measures)
- Status of Threatened & Endangered Species (3 Measures)
- Extirpated Species (1 Measure)
- Non-native Species (1 Measure)

Condition – Trend - Confidence

Good - Varied - Medium

4.16.1. Background and Importance

The National Park Service's mission is to manage park resources "unimpaired for future generations." Protecting and managing some of our nation's most significant natural resources requires basic knowledge of the condition of ecosystems and species that occur in national parks. Birds are a highly visible component of many ecosystems (Figure 4.16.1-1), and changes in bird populations may indicate changes in the biotic or abiotic components of the environment upon which they depend (Canterbury et al. 2000, Bryce et al. 2002). Relative to other vertebrates, birds are also highly detectable and can be efficiently surveyed with the use of numerous standardized methods (Bibby et al. 2000, Buckland et al. 2001). Changes in bird population and community parameters can be an important element of a comprehensive, long-term monitoring program, such as that being implemented for the Sonoran Desert Network (SODN) parks and other network parks (e.g., in the Southern Plains, Northern Great Plains, and Chihuahuan Desert Networks; Mau-Crimmins et al. 2005, Beaupré et al. 2013). Another compelling reason to monitor birds in SODN and other parks is that birds themselves are inherently valuable. The high aesthetic and spiritual values that humans place on native wildlife are acknowledged in the agency's Organic Act: "to conserve . . . the wildlife therein . . . unimpaired for the enjoyment of future generations." Bird watching, in particular, is a popular, longstanding recreational pastime

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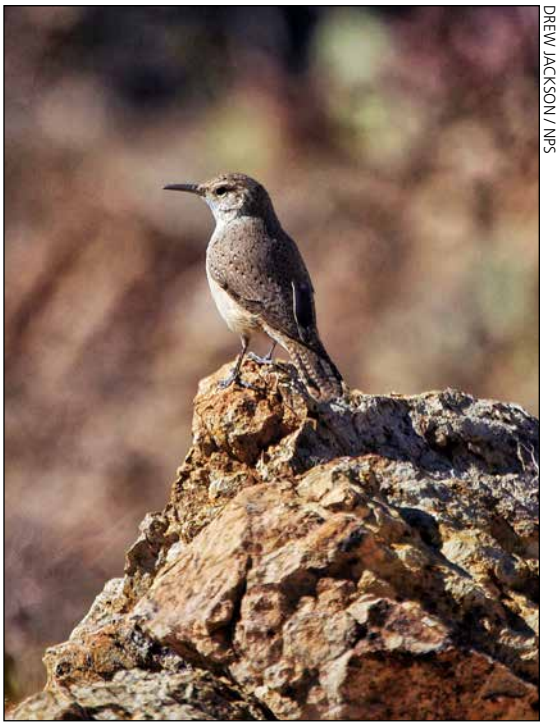

DREW JACKSON / NPS

Figure 4.16.1-1. Cactus Wren (*Campylorhynchus brunneicapillus*) (left), and Rock Wren (*Salpinctes obsoletus*), (right) are bird species common in both districts of Saguaro NP.

in the United States and forms the basis of a large and sustainable industry (Sekercioglu 2002).

The SODN began annual monitoring of birds at Saguaro National Park (NP) and the other SODN parks in the spring (breeding season) of 2007- almost 75 years after the monument was established. With two park districts, and their ranges in elevation and dominant vegetation types, a variety of habitats are available to birds within Saguaro NP. Within the park, SODN monitors birds in upland habitats (desert scrub, forest, and woodland) and riparian habitat. According to previous studies, the riparian woodland along Rincon Creek contains the greatest diversity of birds in the park, including breeding populations of species such as Yellow-billed Cuckoo (*Coccyzus americanus*) and Gray Hawk (*Buteo plagiatus*), and it is considered one of the most significant areas for birds in the Tucson area (Powell 2004, Conway et al. 2012).

This condition assessment addresses birds at Saguaro NP through the use of data from the SODN annual breeding season surveys, as well as through the use of other studies and inventories that have been conducted in the park. Information is presented on the overall number and types of species that have been recorded in the park (e.g., Figure 4.16.1-2) from past inventories and current lists, including species that are federally listed as endangered or threatened. Immediately below, we also provide a history of the study and inventory of birds in the park prior to the annual network monitoring. Threats that birds face in Saguaro NP and elsewhere are addressed in the last section of this condition assessment.

NIC PERKINS / NPS

Figure 4.16.1-2. Elf Owl (*Micrathene whitneyi*), one of the many species documented in Saguaro NP.

Previous Inventory and Research

In 2001-2003, the University of Arizona conducted surveys for birds within the Rincon Mountain District (RMD) and Tucson Mountain District (TMD; Powell [2006] and Powell [2007], respectively [contained in Powell et al. 2006 and Powell et al. 2007, respectively]). Although earlier research on birds had been conducted in both districts, the University of Arizona inventories were the most comprehensive and well-documented to date. They used a total of four survey methods, consisting of variable circular-plot counts for diurnal breeding birds and spring migrants, nocturnal surveys for owls, line transects for diurnal birds in the non-breeding season, and incidental surveys. The surveys in 2001-2003 in the RMD recorded 173 species, and those in the TMD in 2001-2002 recorded 73 species. Powell (2006 and 2007) also provided a summary of research and other work on birds in the RMD and TMD prior to the University of Arizona surveys (dating back to 1956), and as this information is interesting and informative, we provide the summaries here in their near entirety. Note that these summaries address research from about 1956 to the middle 2000s.

RMD

Monson and Smith (1985) compiled a checklist for both districts of the park, but there is no documentation of the data used to create the list. The list includes abundance categories for each major vegetation community, and this information was likely based on Gale Monson's extensive knowledge of the distribution and relative abundance of birds in similar vegetation communities in the region.

A few studies have investigated songbird community composition in the Sonoran desertscrub on the west side of the district near the Cactus Forest Loop Drive (Johnson and Haight 1991 as cited in Powell (2006), see also Mannan and Bibles 1989 as cited in Powell (2006)) and in the Rincon Valley (Boal and Mannan 1996 as cited in Powell (2006), Frederici 1998 as cited in Powell (2006), Powell 1999 as cited in Powell (2006), 2004). Only two multi-species, non-raptor studies have taken place in the higher elevations of the district (Marshall 1956, Short 2002 as cited in Powell (2006)) and one Breeding Bird Atlas block was located at Juniper Basin - in woodland (pinyon juniper) habitat in the mid-elevation area of the district (see Short 1996 as cited in Powell (2006), N. Kline, Biologist, pers. comm.). No studies have occurred on the east slope of the Rincon Mountains. In the 1980s the park was concerned about the impact of non-native cavity-nesting birds on native species and they commissioned studies to investigate this (Mannan and Bibles 1989, Kerpez and Smith 1990 (all as cited in Powell (2006)). Because of the active fire management program, park personnel have been interested in the effects of fire on the Mexican Spotted Owl (Willey 1998a as cited in Powell 2006) and songbirds (Short 2002 as cited in Powell (2006)) in the high elevation areas of the district. Periodic raptor surveys were contracted (Felley and Corman 1993 as cited in Powell (2006), Berner and Mannan 1992 as cited in NPS (2014) and Powell (2006), Bailey 1994 as cited in Powell (2006), Griscom 2000 as cited in Powell (2006)). Park personnel surveyed three Breeding Bird Atlas blocks within the district (Short 1996 as cited in Powell (2006)) and those results are reported in Corman and Wise-Gervais (2005) as cited in Powell (2006). The Tucson Bird Count (TBC) includes three low-elevation sites in the park, including Rincon Creek (TBC 2005). Single species studies have included the Elf Owl (Goad and Mannan 1987, Steidl 2003, both as cited in Powell (2006)), Mexican Spotted Owl (Willey 1997, 1998b, Anderson and Schon 1999 Steidl and Knipps 1999 all as cited in Powell (2006),), Buff-breasted Flycatcher (Conway and Kirkpatrick 2001 as cited in Powell (2006), they also noted other species; Kirkpatrick et al. 2006 as cited in Powell (2006)), and Purple Martin (Stutchbury 1991 as cited in Powell (2006)). Park personnel survey periodically for the Cactus Ferruginous Pygmy-Owl and Mexican Spotted Owl and park staff file annual reports to the U.S. Fish and Wildlife Service (Saguaro NP, unpubl. reports) on monitoring and relevant management activities related to these species.

TMD

Prior to our work, there had been no comprehensive and well-documented bird inventory for the Tucson Mountain District of Saguaro National Park. Monson and Smith (1985) compiled a checklist, but there is no documentation for the list, though it was probably based on observations in the district. Yensen (1973 as cited in Powell (2006)) studied bird communities at four sites on the west side of the Tucson Mountains. The park surveyed for breeding birds in one Breeding Bird Atlas block (Avra Valley) on the west side of the district (Short 1996 as cited in Powell (2006)). Those results are reported in Corman and Wise-Guervais (2005) as cited in Powell (2006). There was a Breeding Bird Survey route approximately 25 km northwest of the district in the Avra Valley which was surveyed from 1992 to 2002 (Sauer et al. 2005 as cited in Powell (2007)). The Tucson Bird Count has conducted counts along the eastern edge of the district (TBC 2005). Mannan and Bibles (1989) (as cited in Powell (2006)) studied

the impact of non-native species on native cavity-nesting species. Single species studies have included the Purple Martin (Stutchbury 1991 as cited in Powell (2006)) and Elf Owl (Bob Steidl, unpubl. data). Park personnel survey periodically for the Cactus Ferruginous Pygmy-Owl and park staff file annual reports on monitoring and relevant management activities related to this species to the U.S. Fish and Wildlife Service (Saguaro NP, unpubl. reports).

4.16.2. Data and Methods

In 2007, the SODN began systematic surveys of birds at Saguaro NP as part of the SODN Inventory and Monitoring program. No data were collected in 2014, but data collection resumed in 2015. There are now eight years of data for the park. Although these data will enable quantitative evaluation of trends in birds in the future, such analyses are only just now beginning to be explored (Gould 2015). Five years of data are about the minimum required to attempt such analyses, and additional years of data will render analyses more reliable (Rob Bennetts, Southern Plains Network [SOPN] Program Manager, pers. comm.). Results of exploratory analyses of Gould (2015), using data from 2009-2013, were used in this assessment to present information on occupancy of some species within the park (the data were truncated and excluded data from 2007-2008 due to inconsistencies). We also used the data to address species richness within the areas sampled.

A number of other sources of information, especially Powell (2006 and 2007) and a 2016 comprehensive list of bird species in the park, were also used for the condition assessment and are described below.

This condition assessment for birds at Saguaro NP is based on the use of six indicators. The first indicator is occupancy of species common in the SODN (with one measure); the second indicator is species richness in areas surveyed by SODN (with one measure); the third indicator is species richness and abundance category using the 2016 comprehensive bird list (two measures); the fourth indicator is the status of federally threatened and endangered species (three measures); the fifth indicator is extirpated bird species (one measure); and the sixth indicator is non-native bird species (one measure). The indicators/measures are described in detail below, as are the data and information sources used in the assessment.

Indicator/Measure

Occupancy of Species Common in the SODN (Change Over Time in 11 Species)

Occupancy of Species Common in the SODN (11 Species)

This indicator is occupancy of species common in the SODN, and the measure is change in occupancy over time. Occupancy is defined as the proportion of sampling units, sites, patches, or habitat units occupied by a species (Bailey and Adams 2005). By monitoring occupancy, information can be obtained on changes in the status of a species over broad areas (Bailey and Adams 2005). It serves as an indicator of changes in distribution and allows for explicit estimates of local extinction and colonization rates (Beaupré et al. 2013).

Occupancy is assessed for only some species in the park because a certain amount of data is required for the analysis, and this level of data was only available for some species. It is important to note that the species analyzed were those that had the greatest number of detections (i.e., the species recorded at the greatest number of sample sites or points) within the SODN parks- not within Saguaro NP specifically. The SODN includes a total of 11 parks in southern Arizona and New Mexico. Data from all parks combined were used to estimate a detection probability for each species. If detection probability can be pooled across parks (explicitly evaluated in the model selection), then this enables more precise estimates of occupancy itself. Occupancy estimates were then produced by park as appropriate (results and models used to estimate occupancy are shown in the Condition section; for most of the species occupancy estimates are specific to Saguaro NP, while for others, estimates apply to the species throughout the network).

Occupancy was assessed using the annual SODN monitoring data (for 2009-2013), which was analyzed by Gould (2015). The particular data used from Saguaro NP and the other network parks is described in Gould (2015). We obtained occupancy estimates of 11 species from this report. It should be noted that Gould (2015) contains preliminary analyses of these five years of annual monitoring data. Additional analyses of these data may be forthcoming in the near future (Rob Bennetts, SOPN Program Manager, pers. comm.). It should also be noted that the results presented by Gould (2015) do not allow for an assessment of trends at this time. However, such analyses of trends will be possible in the future with additional years of data. We refer the reader to Gould (2015) for details on the analyses, but we present some information from Gould (2015) immediately below:

> Occupancy modeling offers a recently developed means of estimating percent area occupied while accounting for imperfect detectability (MacKenzie et al. 2006 as cited in Gould (2015)). Typically, occupancy estimation requires repeat visits to sites to estimate detectability, but spatial replication can be used in some circumstances in place of temporal replication (Kendall and White 2009, Hines et al. 2010, Pavlacky et al. 2012 all as cited in Gould (2015)). The approach provides a measure that: (1) explicitly enables estimation of local extinctions and colonization of sites; (2) accounts for imperfect detectability of individual species; (3) enables estimation of confidence intervals; (4) is comparable across sites; and (5) has become a widely accepted approach for reliable estimates of percent area occupied (MacKenzie et al. 2006 as cited in Gould (2015)). As a major part of this task I have explored the possibility of pooling information over space (strata and/or park units) to enable estimation for less common species and/or improve precision of estimates in other circumstances.

After creation of the data input files, Gould (2015) used program MARK (White and Burnham 1999) and the multi-season occupancy model of MacKenzie et al. (2003, 2006 as cited in Gould (2015)) to estimate occupancy and detection probability (Gould 2015). Occupancy estimates either by park unit or habitat type within a park unit (it varies by species, depending on the data) were obtained from Gould (2015), and are presented in the Condition section, for the following species: American Robin (*Turdus migratorius*), Cassin's Kingbird (*Tyrannus vociferans*), Canyon Towhee (*Melozone fusca*), Canyon Wren (*Catherpes mexicanus*), Gambel's Quail (*Callipepla gambelii*), Gilded Flicker (*Colaptes chrysoides*), Ladder-backed Woodpecker (*Picoides scalaris*), Lesser Goldfinch (*Carduelis psaltria*), Phainopepla (*Phainopepla nitens*), Summer Tanager (*Piranga rubra*), and Verdin (*Auriparus flaviceps*). Note that in his analyses, Gould (2015) treated the two districts of Saguaro NP as separate locations or parks.

Indicator/Measure

Species Richness in SODN Survey Areas (Change Over Time)

Species Richness in SODN Survey Areas

Species richness in the SODN survey area is the second indicator used in this assessment, and the measure is change over time. Species richness is defined as the number of species present/recorded in a given area. In the case of the SODN dataset and analysis, the species richness results apply to the area sampled, which is described and shown in two figures later in this section.

Species richness was estimated, using the SODN monitoring data, for the TMD (uplands) and for the RMD (uplands and riparian habitat, separate). For this analysis, data were used from 2009-2013 and 2015. Unlike with occupancy, estimates of species richness over time were obtained. It should be noted, however, that the time period is short (six years). The analysis was conducted by Robert Gitzen of Auburn University. The following description of the methods was provided by Dr. Gitzen:

Species richness was estimated by year for SAGW (TMD) Upland, SAGE (RMD) Upland, and SAGE Riparian for 2009-2015, excluding 2014 when no data were available. Data from each zone-habitat-year combination were analyzed separately (i.e., producing 18 separate estimates, six yearly estimates for each of the three zone-habitat combinations). Species richness was estimated using closed-population mark-recapture models (Williams et al. [2001] provides a thorough review) using species-level detection history as input data. The richness estimates are estimates of total avian species richness for the three zone (unit)-habitat combinations, excluding species not detectable with the survey protocol and applying to the portion of each unit-habitat combination from which the selected transects were chosen.

The logic for this analysis incorporates the following ideas and assumptions: 1) The total number of species observed in a survey season is likely an underestimate of actual species richness during that period (i.e., there likely were species present but not detected). 2) Using individual transects (uplands) or points (riparian) as replicate samples of the unit's (i.e., unit x habitat x year) species pool, standard mark-recapture estimators can estimate total species richness, heuristically by estimating the number of species present but not observed on any transect or point that year; 3) In this context, detection probability refers to the probability of detecting a species on each transect or point, given that the species truly is present in the unit; 4) Detection probability varies widely among species as a result of varying distributions and abundance, as well as variable behavior and other factors potentially affecting observability. Key assumptions are a) that the pool of species present within a park was constant across surveys within a year for a unit; b) species were identified correctly; and c) the probability of detecting a species on a transect (point) was independent of whether the species was detected at another transect (point) within that unit-habitat, assuming the species was present at both.

For upland analyses, the detection history for a species each year consisted of a sequence of zeros and ones corresponding to whether or not a species was detected on any included visits to any point within that transect. The input data for analyses was the set of detection histories for all species observed on at least one transect for that unit-habitat-year. The SAGE riparian sampling covered a single transect, so detection history was constructed using points on this transect as distinct samples. Species richness was calculated using Chao's model "Mth" (Chao et al. 1992) estimator in program CAPTURE (White et al. 1978) through program MARK (White and Burnham 1999). This estimator is a non-parametric approach that allows for variable detectability among species; the Mth version of Chao's estimator also allowed for across species systematic changes in detectability among transects (upland) or points (riparian).

It may also be of interest to some readers that other, more sophisticated, methods of analysis are being explored for analyzing the species richness data for Saguaro NP and other parks in the SODN (Robert Gitzen, Auburn University, pers. comm.).

A preliminary examination was also conducted as to whether there was a detectable linear trend in estimated species richness for each unit by habitat combination from 2009-2015. According to Dr. Gitzen:

> We used weighted least-squares linear regression, with estimated species richness as the response variable,

Year as the predictor variable, and the inverse squared estimated standard error of each richness estimate as its weight. These inverse-variance weights were incorporated to account for variable precision in the estimates of species richness.

Again, it is important to note that the species richness estimates from the SODN dataset are limited both temporally and spatially. Estimates were made starting in 2009, and the survey points cover only some areas of the park. Survey points and transects are shown below, in the Data Sources section.

Indicator/Measures

Species Richness & Abundance Category using the 2016 Comprehensive Bird List (Species Richness and Change in Abundance)

This indicator has two measures based on the 2016 comprehensive park bird list: 1) species richness in each of the park districts, and 2) change in abundance category for individual bird species in the TMD. We describe both measures in greater detail in this section.

Recall that the second indicator in this overall bird assessment is species richness in areas surveyed by SODN. Although this indicator is quantitative (which is desirable), it is limited both temporally and spatially. To examine species richness in a different way, we looked at the overall number of species that have been recorded in each park district using the 2016 comprehensive bird list, which includes observations dating back to the 1950s.

The second measure under this indicator is change in species abundance category for species in the TMD, in which we compared the abundance category for each species from the 2016 comprehensive bird list to that on the 1985 park bird list. If a species was assigned an abundance category in 2016 that was lower than that estimated in 1985, we considered the species to have dropped in abundance category. We acknowledge that this measure is subjective in several ways. First, the abundance categories in 1985 and 2016 are subjective, although they were assigned by knowledgeable professionals. Second, the abundance categories used in the two lists differed somewhat, and we matched them up as closely as possible based on their definitions. Assistance in matching up similar categories between the two lists was provided by N. Kline, park biologist. After we compared the abundance categories for each species in the TMD from the 2016 and 1985 lists, we emerged with a list of species that had decreased (or increased) in abundance category. This list was then provided to N. Kline, and she reviewed data from Christmas Bird Counts (CBC; 1993-2016) to see whether that dataset supported (or did not support) a drop (or increase) in abundance category for each species. This list, along with whether CBC data corroborated the findings of the comparison, was also reviewed by two avian experts, Moez Ali and Larry Norris (both of whom also participated in producing the 2016 bird list). Results are presented in the Condition section, along with whether or not CBC data corroborated a change in abundance category. Christmas Bird Counts, which were started by the National Audubon Society, are conducted in December-January of each year. Although it varies depending on the number of volunteers available, there are usually two routes surveyed in the TMD, one in the backcountry and one that covers all of the developed areas (i.e., the visitor center, picnic areas, trailheads, and short trails; Natasha Kline, Saguaro NP, pers. comm.).

Again, it is acknowledged that this measure is a very coarse and subjective means of assessing whether some species in the park may have changed in abundance over time. The confidence level provided in the condition section for this measure will reflect this relatively low level of confidence. However, we believed it was worthwhile to include this measure because park biologists expressed concerns that at least in the lower elevations of the park, some species of resident birds appear to be less common in the park than they were a few decades ago (Natasha Kline, biologist, Saguaro NP, pers. comm.). However, they have no concrete data to support these observations. The 2016 comprehensive park list is described in the Data Sources section below (including

information on the compilers/reviewers of the list).

Indicator/Measure
Status of Federally Listed Threatened and Endangered Species (3 Species)

We accessed the U.S. Fish and Wildlife Service's (USFWS's) Endangered Species database for Arizona on December 14, 2015, and cross-referenced the list with the comprehensive 2016 park list to determine which species known to occur at the park are listed under the Endangered Species Act (ESA). Three species were identified as endangered (one species) or threatened (two species). Although not part of the measure, we also identified which species are Wildlife of Special Concern in Arizona. Our main source for this information was a recent park document- *Restoration Management Plan Environmental Assessment* (NPS 2014), but also USFWS (2015).

Indicator/Measure
Extirpated Species (#)

We relied primarily on Powell et al. (2006) and Powell et al. (2007) and personal communication with Saguaro NP biologists to determine the number of bird species that are known to be extirpated in Saguaro NP. The bird chapters of the Powell et al. (2006, 2007) inventory reports (i.e., Powell [2006] and Powell [2007)] include discussion and observations from previous reports, studies, and lists that assisted in the analysis. The Powell reports were described previously.

Indicator/Measure
Non-native Bird Species (#)

This indicator had one measure, the number of non-native bird species. We relied on Powell (2006) and Powell (2007), NPSpecies, and the comprehensive 2016 park list to determine the number of non-native birds known to occur in Saguaro NP.

Primary Data Sources

The primary data sources for this condition assessment of birds are the annual SODN surveys conducted at the park in 2007-2013 and 2015, the comprehensive bird list obtained from the park in early 2016, and the bird inventories by the University of Arizona (i.e., Powell et al. 2006 and 2007 [more specifically, Powell 2006 and 2007]). Each of these data sources are described below. As mentioned previously under the indicator/measure descriptions, we obtained estimates of occupancy of common SODN species and species richness (in areas sampled by SODN) directly from Gould (2015) and the Gitzen analyses, but these two sets of analyses were of the SODN annual monitoring data.

Annual SODN Surveys at the National Park in 2007-2013 & 2015

The SODN used point-transect surveys (Buckland et al. 2001) during the breeding season to estimate and monitor bird population parameters at Saguaro NP (Ali et al. 2014). The number of transects used (or points counted) may have varied slightly over the years (2007-2013 and 2015). In 2013, 16 transects were surveyed (Figures 4.16.2-1 and 4.16.2-2). Eleven transects were in the RMD and five were in the TMD. Of those in the RMD, 10 were in the upland habitat class (desert scrub, forest, or woodland habitat types), and one was in the riparian habitat class. The five transects in the TMD were in upland desert scrub habitat. All transects at the park had six to eight points each, and all were visited twice (in most years). The total number of point counts conducted at Saguaro NP in 2013, for example, was 211 (Ali et al. 2014).

In every year, all birds detected at a given point were recorded. Observers spent six minutes at each point along the transect and used a rangefinder to estimate the linear distance to each bird or group detected. This protocol of spending six minutes per site is consistent with other efforts being conducted in the SODN and other NPS networks (Beaupré et al. 2013). After counts were completed, observers used a handheld GPS (Global Positioning System) unit to locate successive survey points. While walking between points, observers noted only species that were not recorded during the count period; sometimes these represented species that had not been previously reported for the park. It should be

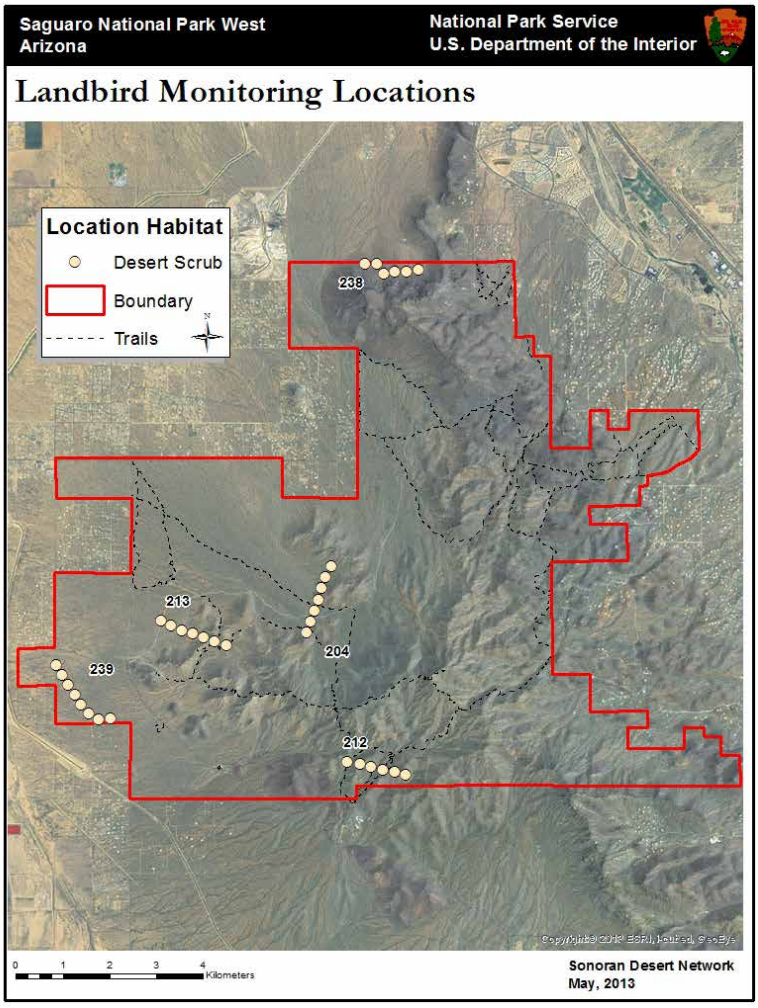

Figure 4.16.2-1. Survey points sampled during SODN annual breeding season monitoring at Saguaro NP's TMD in 2007-2013 and 2015.

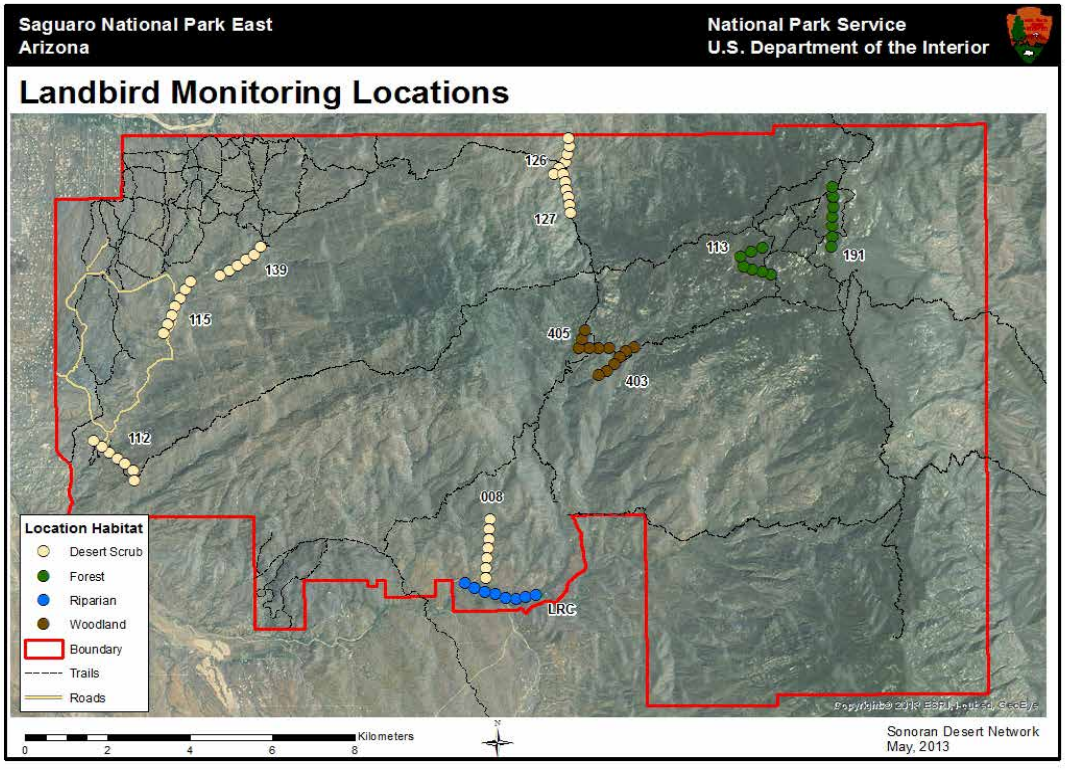

Figure 4.16.2-2. Survey points sampled during SODN annual breeding season monitoring at Saguaro NP's RMD in 2007-2013 and 2015.

noted that although surveys are conducted during the breeding season, some species recorded may not be breeding in the park. Field technicians note evidence of breeding when such evidence is observed; however, birds with no such evidence may or may not be breeding in the park.

Note that in the SODN monitoring scheme, transects are considered the sampling unit for each habitat, and points are the sampling units for a given transect. However, Gould (2015) considered the survey points as independent sampling in this first effort to analyze the data.

2016 Comprehensive Bird List for Saguaro NP
The comprehensive bird list, obtained in March 2016 from Natasha Kline, Saguaro NP biologist, contains a separate list for each park district. Saguaro's bird list is compiled from several sources, most of which are documented in the SODN plant and vertebrate inventory reports (i.e., Powell et al. 2006, Powell et al. 2007). The majority of the species are from the park's original bird list published by the Southwest Parks and Monument Association and compiled by Gale Monson and Linwood Smith (1985); this was revised once (in 1999) by N. Kline to include species observed by park biologists and cooperators. Other species on the list have been added from observations by researchers or biologists conducting bird surveys (e.g., SODN annual breeding season surveys, Christmas Bird Counts, Tucson Bird Counts, Arizona Breeding Bird Atlas, or surveys on newly acquired lands), or incidentally on species-specific studies (i.e., for Peregrine Falcon, Mexican Spotted Owl, Northern Goshawk, Cactus Ferruginous Pygmy-Owl), or opportunistically when conducting some other kind of field work in the park. The list also includes credible or documented (ideally by a photo) sightings from park staff, volunteers, and, sometimes, visitors. Finally, some records were mined from publications, particularly early ones like Marshall (1956). The 2016 comprehensive bird list was produced by Natasha Kline, Larry Norris, Moez Ali, and SODN staff (Kristen Bonebrake, as well as Laura Palacios, Anna Iwaki, and Alice Wondrak-Biel). The first three of these individuals are listed in section 4.16.5, Sources of Expertise.

The 2016 comprehensive bird list includes information for each species on: breeding status in the park, habitat types used, the season(s) present, and the qualitative abundance category (i.e., abundant, common, uncommon, rare, occasional, and accidental). We present an abbreviated version of the 2016 list (providing species names only, by district) later in this assessment.

4.16.3. Reference Conditions

Reference conditions for this assessment are shown in Table 4.16.3-1. Reference conditions are described for resources in good, moderate concern, and significant concern conditions for each of the indicators/measures.

4.16.4. Condition and Trend

Occupancy of Species Common in SODN

As described earlier in this assessment, using the annual SODN monitoring data, occupancy was estimated for 11 bird species that occur in the park. These 11 species are not necessarily the most common species in Saguaro NP, but rather, some of the most commonly detected within the SODN; these are species that were recorded at a relatively high proportion of the points sampled in the network. To provide a general indication of how common each species is within each park district (based on the SODN dataset), we determined the total number of individuals of each species recorded per district relative to the total number of individual birds recorded per Saguaro NP district. We found that of these 11 species, Verdin accounted for 5.8% of all individual birds recorded in the TMD and 2.7% in the RMD, and Gambel's Quail accounted for 6.9% of all individual birds recorded in the TMD and 5.1% in the RMD. The other nine species accounted for lower proportions of the total number of individual birds counted.

The occupancy estimates for the eleven species are shown in Table 4.16.4-1. Occupancy in the areas sampled was estimated to be 0.90 or higher for seven of the species (Gambel's Quail, Gilded Flicker, Ladder-backed Woodpecker, Lesser Goldfinch, Phainopepla

Table 4.16.3-1. Reference conditions used to assess the current condition of bird species at Saguaro NP.

Indicator	Measure	Good	Moderate Concern	Significant Concern
Occupancy of Species Common in SODN (11 Species)	Change in occupancy over time	For each native species, estimated occupancy is within the range of natural variation without an underlying or overall decreasing trend.	Estimated occupancy decreased somewhat (outside of the range of natural variation) for a small number of native species.	Estimated occupancy decreased for a relatively large number of native species, or substantial declines in occupancy occurred for one or more key native species.
Species Richness in SODN Annual Survey Areas	Change in species richness over time	Overall species richness is not decreasing (over the time for which SODN data exist), and species richness is not decreasing for specific groups or guilds.	There are possible slight decreases in species richness (over the time for which SODN data exist), but not across all groups or guilds.	Overall species richness is decreasing (over the time for which SODN data exist), or there are substantial decreases across some groups or guilds.
Species Richness & Abundance Category using 2016 Comprehensive Park Bird List	# of native species recorded per district according to 2016 list	No reference conditions were developed.		
	Change in abundance comparing 2016 list to previous list (1985) for TMD.	No or very few species changed (dropped) in abundance category (e.g., from common to rare) from the 1985 list to the 2016 list.	A small to moderate number of species changed (dropped) in abundance category (e.g., from common to rare) from the 1985 list to the 2016 list.	A moderate to large number of species changed (dropped) in abundance category (e.g., from common to rare) from the 1985 list to the 2016 list.
Status of Threatened & Endangered Species	Southwestern Willow Flycatcher, Mexican Spotted Owl, Yellow-billed Cuckoo	We consider the condition to be good if the estimated numbers of the subject species are approximately the same or increasing based on the information available.	We consider condition to be of moderate concern if estimated numbers of the species have decreased or may be decreasing somewhat.	We consider the condition to be of significant concern if the estimated numbers of species have decreased substantially and/or may continue to do so.
Extirpated Bird Species	# of species extirpated over time	We consider the condition to be good if none, or only a few, native species have been extirpated in the park.	We consider the condition to be moderate if a few native species have been extirpated in the park.	We consider the condition to be of significant concern if many native species have been extirpated in the park.
Non-native Bird Species	# and significance of non-native species	We consider the condition to be good if one or only a few non-native species occur in the park and their presence does not disrupt ecosystem function.	We consider the condition to be moderate if only a few non-native species occur in the park and their presence causes some disruption to ecosystem function (or other native species).	We consider the condition to be of significant concern if many non-native species occur in the park and their presence causes significant disruption to ecosystem function (or other native species).

[Figure 4.16.4-1], Summer Tanager, and Verdin) in at least some of the habitats/districts. Additionally, estimated occupancy of at least two of the other species (Cassin's Kingbird and Canyon Towhee) was 0.66 or higher. It would be desirable to have occupancy estimates for a larger subset of species, but this is the best information available from this dataset at this time. Although no information on trends is available from this analysis, in the future, with additional years of survey data, the assessment of trends in occupancy will be possible (Beaupré et al. 2013). Monitoring changes in the proportion of sampling units occupied by species over time is one of the main components of the landbird monitoring program for the SODN and other networks (SOPN, Chihuahuan Desert Network, and Northern Great Plains Network; Beaupré et al. 2013).

In summary, the current condition of birds under this indicator/measure using the reference conditions presented in Table 4.16.3-1 is unknown. However, occupancy estimates are provided for a number of species that occur in the park.

Table 4.16.4-1. Estimates of occupancy for a subset of bird species that occur at Saguaro NP and that are common in the SODN. Occupancy was estimated (by Gould 2015) over a 5-year period from 2009-2013 using SODN annual monitoring data.

Species Name	Occupancy Estimate (SE)	Park Unit- Habitat [2]	Model used for occupancy estimate [3, 4]
American Robin	0.18 (0.04)	RMD- UPL	Occupancy varies among parks (2nd-ranked model)
Cassin's Kingbird	0.66 (0.11)	RMD- RIP	Occupancy varies among parks
Canyon Towhee	0.74 (0.06)	RMD (UPL & RIP)	Occupancy varies among parks
	0.70 (0.07)	TMD	
Canyon Wren	0.16 (SE not reported)	RMD- UPL	Occupancy varies among parks
	Not reported [1]	TMD	
Gambel's Quail	0.68 (0.06)	RMD- UPL	Occupancy varies among units
	1.0 (<0.001)	RMD- RIP	
	0.90 (0.03)	TMD	
Gilded Flicker	>0.90	RMD- RIP	Occupancy varies among units
	Not reported [1]	RMD- UPL	
	>0.90	TMD	
Ladder-backed Woodpecker	0.90 (0.12)	RMD (RIP & UPL)	Occupancy varies among parks
	0.54 (0.10)	TMD	
Lesser Goldfinch	0.96 to 0.95 over time (SE not reported)	RMD (RIP & UPL) & TMD	Occupancy varies by time (there is a linear trend) [5]
Phainopepla	0.74 to 0.97 (increased over the 7-yr period)	RMD (RIP & UPL)	Occupancy varies by time (there is a linear trend) [5]
Summer Tanager	0.91 (0.03)	RMD- RIP	Occupancy varies among habitats [5]
Verdin	0.50 (0.05)	RMD- UPL	Occupancy varies among units
	0.91 (0.001)	RMD-RIP	
	0.92 (0.02)	TMD	

[1] Gould (2015) did not report the specific occupancy estimate for this species in this case; only a range was provided (which we do not report).
[2] Note that Saguaro NP units were treated as separate locations or parks for the analyses. Gould (2015) does not use the term "unit" in the same way we have elsewhere in the condition assessment (see Note 4 below). Also for the analyses, four of the habitat strata (e.g., desert scrub, semi-desert grass) were condensed into one upland habitat category (designated as UPL above). The other strata consisted of riparian habitat (RIP above).
[3] Note that unless there was a valid reason to do otherwise, the model used to estimate occupancy was the one with the lowest AIC value (Gould 2015).
[4] Occupancy models allowed for variation as a function of unit (park and habitat-specific, e.g. riparian sites at RMD), park (refers to the park unit combining over habitats), habitat (refers to upland versus riparian habitats combined over parks), and time (year-specific and a linear trend) (Gould 2015).
[5] Occupancy estimates under this model are not unique to Saguaro NP (but rather, to all of the parks used in the analysis).

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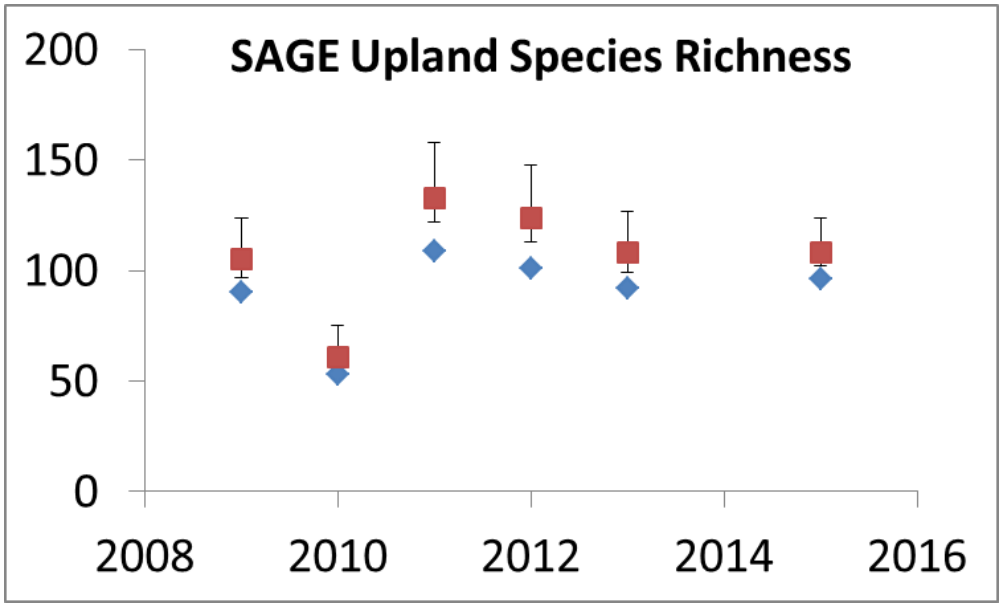
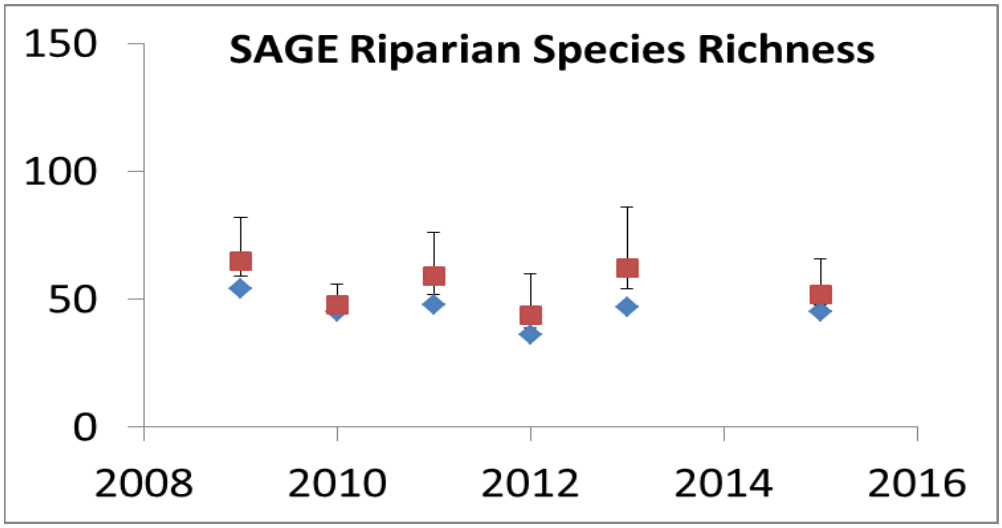
Figure 4.16.4-1. Phainopepla (*Phainopepla nitens*), one of the bird species known to occur in the park and for which occupancy was estimated using the SODN annual monitoring dataset.

Species Richness in SODN Annual Survey Areas

Species richness was estimated for the RMD (upland and riparian habitat separately) and the TMD (upland habitat) for 2009-2015 (except for 2014) during the breeding season. Although there appeared to be some year to year differences, especially for upland habitat in the RMD, overall, there were no significant trends over time (Figure 4.16.4-2). Dr. Gitzen reported "Regression models that allowed separate trends for the three unit-habitat combinations or that modeled a single





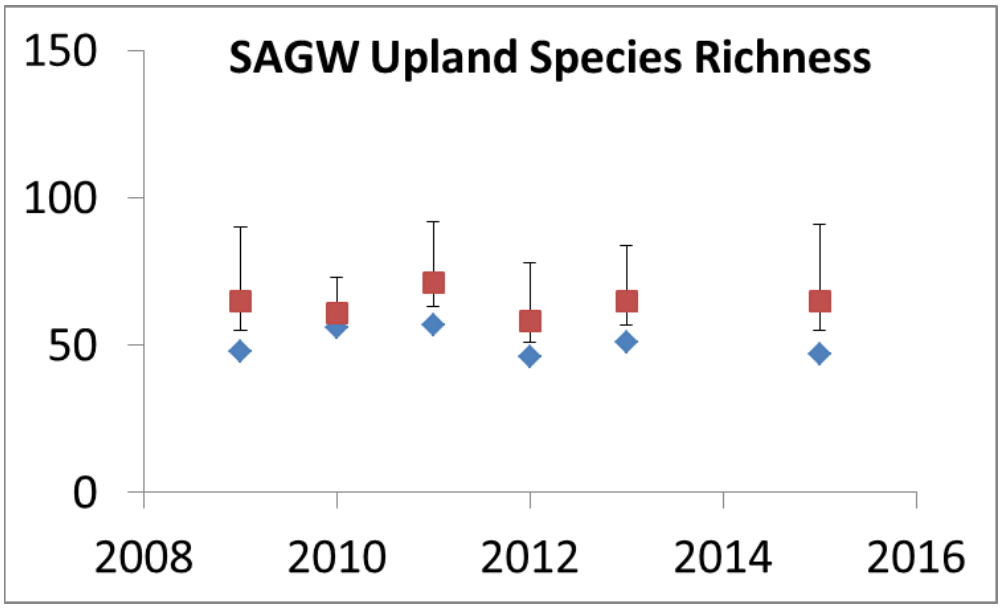


Figure 4.16.4-2. Species richness estimates in areas sampled during SODN annual breeding season surveys. Red squares are estimates of species richness with 95% confidence intervals, and blue diamonds are the number of species actually observed. Figure Credit: Robert Gitzen (2015).

common trend both failed to detect evidence of unit-habitat specific or overall trends."

Although six years is a relatively short time period when discussing trends in species richness, it appears that species richness during the breeding season has been fairly stable in each of the three areas/habitats sampled. Based on our reference conditions and the available data and analysis, we consider the condition of birds under this measure (in the areas sampled by SODN) to be good at this time, with an unchanging trend. Note that the next indicator/measure examines species richness in a broader context, although it is not based on standardized monitoring data.

Species Richness & Abundance Category using 2016 Comprehensive Park Bird List

Number of Native Species Recorded per District according to 2016 List

There have been a total of 222 bird species recorded at Saguaro NP according to the comprehensive park bird list (Appendix E) provided by Saguaro NP biologist N. Kline in March 2016. Nearly all of the 222 species have been recorded in the RMD (i.e., 220), while 157 have been recorded in the TMD. The only birds on the list that have not been recorded in the RMD are the Black-crowned Night-Heron (*Nycticorax nycticorax*) and Calliope Hummingbird (*Stellula calliope*). Sixty-five of the species were recorded in the RMD but not in the TMD.

The measure under this indicator focuses on native species. If we exclude the four non-native species that have been recorded in the park (in both districts), a total of 216 native species have been recorded in the RMD, and 153 native species have been recorded in the TMD. The four non-native bird species are addressed in a separate indicator/measure.

Although we developed no reference conditions for this measure, the information provides a more complete picture of species richness in the park overall and in each district (compared to the species richness indicator/measure based on the SODN dataset, which, although quantitative, is based on only six years of sampling, breeding season [only] surveys, and a limited number of transects).

Table 4.16.4-2. Species in the TMD of Saguaro NP (primarily permanent and winter residents) which had a decrease in abundance category from 1985 to 2016 park lists, and for which Christmas Bird Count data corroborated a decline.

Species Name
American Kestrel
Black-chinned Sparrow
Costa's Hummingbird
Crissal Thrasher
House Sparrow (non-native)
House Wren
Inca Dove
Lark Bunting
Lincoln's Sparrow
Mountain Bluebird
Northern Harrier
Ruby-crowned Kinglet
Sage Sparrow
Tree Swallow
Vesper Sparrow
Western Bluebird
Wilson's Warbler
White-throated Sparrow

Note: The abundance categories for the 1985 and 2016 lists were based on local professionals' experience and knowledge- not on actual data.

Change in Species Abundance Category, Comparing 2016 List to 1985 List, TMD

As described in the Data and Methods section, our assessment under this measure focused on whether the assigned abundance category for each species on the 2016 comprehensive park bird list changed from the 1985 category or not, and if it changed, whether it increased or decreased (reflecting a *potential* increase or decrease in abundance). As described previously, this is a coarse, subjective analysis.

Our comparison of abundance category for species in the TMD revealed that 18 species dropped in abundance category from 1985 to 2016 (Table 4.16.4-2). One of these species is the non-native House Sparrow. For these 18 species, the Christmas Bird Count data (for 1993-2016) supported the drop in abundance category (i.e., qualitatively, the overall trend for these species was down during this time period).

Table 4.16.4-3. Species at Saguaro NP TMD (primarily summer or transient species) which had a decrease in abundance category from 1985 to 2016 park lists, but for which Christmas Bird Count data was unable to corroborate a population decline.

Species Name
Bendire's Thrasher
Lazuli Bunting
Loggerhead Shrike
Western Kingbird
Western Wood-Pewee
Willow Flycatcher

Notes: CBC data is collected in winter.

The abundance categories for both the 1985 and 2016 lists were based on local professionals' experience and knowledge- not on actual data.

Table 4.16.4-4. Species at Saguaro NP TMD (permanent or winter residents) which had an increase in abundance category from 1985 to 2016 park lists, and for which Christmas Bird Count data corroborated an increase.

Species Name
Anna's Hummingbird
Common Raven
Northern Mockingbird
White-crowned Sparrow
White-throated Swift
Yellow-rumped Warbler *

* CBC data did not corroborate an increase, but park personnel believe the species has become more abundant in the TMD.

Note: The abundance categories for both the 1985 and 2016 lists were based on local professionals' experience and knowledge- not on actual data.

There are an additional six species in the TMD which dropped in abundance category from 1985 to 2016, but for which CBC data could not corroborate a drop in category (Table 4.16.4-3). Note that CBC data are collected in winter, and some of the species in the table are summer or transient species.

Finally, our comparison revealed that a small number of species in the TMD (six species) increased in abundance category from 1985 to 2016 park lists (Table 4.16.4-4). These species are considered permanent or winter residents, and CBC data supported the increase in abundance category.

Based on our reference conditions for this measure, we consider condition for birds under the measure to be of moderate concern, as a small to moderate number of species dropped in abundance category from the 1985 to 2016 list. Our confidence in this analysis, however, for the reasons described in the Data and Methods section, is relatively low. We do, however, believe that the analysis was a worthwhile exercise as a way to address whether some species in the park may have changed in apparent abundance over time. Because this measure is a coarse and subjective analysis, we did not attempt any more detailed analysis or interpretation for the individual species.

Federally Threatened and Endangered Species (and State Wildlife of Special Concern)

Three bird species that are listed by the USFWS as endangered or threatened under the ESA are known to occur in Saguaro NP (NPS 2014; USFWS 2014). These are the Southwestern Willow Flycatcher (*Empidonax traillii extimus*; endangered), the Mexican Spotted Owl (MSO; *Strix occidentalis lucida*; threatened), and the Yellow-billed Cuckoo (*Coccyzus americanus; threatened*). Designated critical habitat for the MSO also occurs within the park. Also, two species, Cactus Ferruginous Pygmy-Owl (*Glaucidium brasilianum cactorum*) and American Peregrine Falcon (*Falco peregrinus anatum*), were once listed but were delisted in 1999 and 2006, respectively. These species are discussed briefly below, but only the three species presently listed under the ESA are part of this indicator/measure (three measures).

Southwestern Willow Flycatcher

The following information on the Southwestern Willow Flycatcher is from NPS (2014; Restoration Management Plan Environmental Assessment):

> This endangered songbird is a riparian (cottonwood/willow, mixed broadleaf and tamarisk) obligate, and has become very rare with the loss of

> this habitat in the southwest over the last century (Pima County 2001 as cited in NPS 2014). It is a neotropical migrant, present in Arizona from April through September (Pima County 2001 as cited in NPS 2014).
>
> Southwestern Willow Flycatchers are transient visitors in the spring to Saguaro NP in the riparian areas along Rincon and Chimenea creeks (Powell et al. 2006). This species has not been documented breeding in the park, and it appears SNP does not contain sufficient quality riparian habitat to support breeding.

It is uncertain whether the endangered subspecies has been recorded during the SODN annual monitoring surveys (for 2007-2013 and 2015). The Willow Flycatcher has been recorded during the surveys, and while it is probable that the observation was of the Southwestern Willow Flycatcher, this is uncertain (Moez Ali, pers. comm.). Because of limited information on the occurrence and status of this species, the condition for this measure is unknown.

Mexican Spotted Owl

NPS (2014) contains the following information on the Mexican Spotted Owl:

> The threatened Mexican Spotted Owl (MSO) is one of three spotted owl subspecies. They occupy a variety of habitat types ranging from dense mixed conifer forests to steep-walled, rocky canyons, favoring sites with complex structure (USFWS 1995 as cited in NPS (2014)). Nest sites are generally located in closed canopy forests or on ledges in steep-walled canyons. These owls are threatened by habitat loss from logging and wildfire and by displacement by the con-generic barred owl (USFWS 2011 as cited in NPS (2014)).
>
> In 1995, telemetry studies of MSO documented five territories within the RMD (Willey 1997). Since then, each has been designated a Protected Activity Center (PAC) per the MSO Recovery Plan (USFWS 1995 as cited in NPS (2014)), and is managed as such, including regular monitoring and strict regulation of permitted activities. All five sites appear to be consistently occupied, though sometimes by only one bird or a non-breeding pair (Kline 2012 as cited in NPS (2014)). In February 2001, the USFWS designated virtually all of the RMD above 6,000 feet as critical habitat for the MSO. In the park, wildfire is the biggest threat to MSO and their habitat. The Helens 2 Wildfire in Summer 2003 affected a large portion of MSO habitat on the north slope of the Rincons.

The Mexican Spotted Owl population in the park appears to be stable (Saguaro NP 2013). However, the park's MSO surveys in 2015 indicated that their distribution on Mica Mountain likely has been affected by wildfire (Helens 2) and Great Horned Owls, which may be more numerous due to habitat changes from the Helens 2 fire (N. Kline, Saguaro NP, pers. comm.). Therefore, we consider the condition for this measure to be good, but there is some concern for the species on Mica Mountain. No Mexican Spotted Owls have been recorded during the SODN annual monitoring surveys (for 2007-2013 and 2015).

Yellow-billed Cuckoo

The Yellow-billed Cuckoo (i.e., the western DPS [Distinct Population Segment] of the Yellow-billed Cuckoo) was listed as threatened by the USFWS in late 2014 (USFWS 2014). Within the park, the species has been recorded during the annual SODN surveys, and Powell et al. (2006) reported breeding by one to two pairs along Rincon Creek in the park (NPS 2014). NPS (2014) includes the following information on the species:

> The Yellow-billed Cuckoo is a neotropical migratory bird, designated by the USFWS as a candidate species for listing... [note that the cuckoo has been listed as threatened since the publication of

> this report] due to loss of habitat (USFWS 2013 as cited in NPS (2014)). Yellow-billed Cuckoos are found throughout Arizona below 5,000 feet, generally in large blocks of riparian woodlands (cottonwood, willow, or tamarisk galleries) where they breed (USFWS 2013 as cited in NPS (2014)).

This species is considered rare in the park and only found in some years along Rincon Creek, where it occasionally breeds (N. Kline, Saguaro NP, pers. comm.). Because of limited information on the status of this species, the condition for this measure is unknown.

Cactus Ferruginous Pygmy-Owl

The Cactus Ferruginous Pygmy-Owl, a small, diurnal owl, was federally delisted in 2006, but it remains of substantial interest to Saguaro NP. As described by NPS (2014), both districts of the park are potential habitat for the species.

> The Cactus Ferruginous Pygmy-Owl (CFPO) is a small (less than 7" long), long-tailed, earless diurnal owl. Although historic accounts associated this species with riparian areas in Arizona, more recent sightings of CFPOs in the state have generally been in densely vegetated Sonoran desertscrub or mesquite woodlands, with a well-developed canopy and understory from 1,000 to 4,000 feet (Pima County 2001 as cited in NPS 2014). The species was proposed for listing as federally endangered in 1993 due to a dramatic decline in its abundance and distribution in the U.S. in the last 50 years (USFWS 1993 as cited in NPS (2014)). Critical Habitat was designated in 2002, including the entire TMD. The CFPO was delisted in 2006, due to a reanalysis of its taxonomy, distribution, and threats, but it remains a species of special concern in the park.
>
> Both districts of Saguaro NP contain potential habitat for CFPO – virtually all of the TMD and areas of the RMD below 4,000 feet (some 40,000 acres total). From 1994-2004, over 800 surveys for CFPO within and nearby Saguaro NP were conducted by Saguaro NP staff, AGFD biologists, private contractors, and volunteers. Despite several credible reports from the 1980s, this extensive survey effort resulted in only one confirmed detection of a non-breeding owl in Box Canyon in October 1995, which was reported by NPS employee Andy Hubbard (and Tani Hubbard), SODN Program Manager (N. Kline, Biologist, pers. comm.).

American Peregrine Falcon

The Peregrine Falcon is known to occur, and nest, within the national park. NPS (2014) described the species' occurrence within the park and provided a species description (below). The Peregrine Falcon has also been detected during the annual breeding season surveys conducted by SODN.

> This large, striking falcon is primarily a hunter of small to medium-sized birds often associated with water (e.g., waterfowl, shorebirds, swallows). Along with a proximity to water, the most important habitat characteristic needed by this species is the presence of tall cliffs. Within this habitat, Peregrines nest on ledges, potholes or in small caves on sheer cliff faces that are relatively inaccessible to mammalian predators and that also provide protection from weather extremes.
>
> Four known Peregrine Falcon nest sites exist in the RMD, and all are on cliff faces in remote backcountry areas (Berner and Mannan 1992 as cited in NPS (2014) and Powell (2006)). Two of these sites are monitored annually and appear to be regularly occupied.

Arizona Wildlife of Special Concern

Although they are not listed or described in detail here, nineteen animal species that are known to occur or may occur in the park (not just birds) are listed as Wildlife of

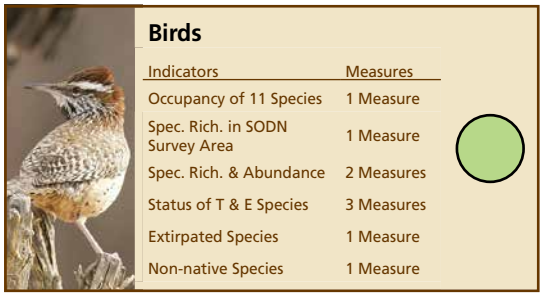
Special Concern in Arizona (WSCA; AGFD 1996, as cited in NPS 2014). All of the birds described above are WSCA, as are several additional bird species (e.g., Northern Goshawk [*Accipiter gentilis*]; Gray Hawk [*Asturina nitida*]; Common Black-Hawk [*Buteogallus anthracinus*]; Buff-breasted Flycatcher [*Empidonax trailii extimus*]; and Elegant Trogon [*Trogon elegans*]; NPS 2014). Additional species may be listed as Species of Greatest Conservation Need with the State (Arizona Game and Fish Department [AGFD] 2012).

Extirpated Bird Species

Three species may have been historically present in the park, including Aplomado Falcon (*Falco femoralis*), California Condor (*Gymnogyps californianus*), and Thick-billed Parrot (*Rhynchopsitta pachyrhyncha*), but this is unconfirmed (Powell 2006). Since there are no confirmed extirpated bird species in Saguaro NP, the condition for this measure is considered good. The likelihood that no bird species have been extirpated in the park is due to the high mobility of birds and the presence of unique habitat types and generally high quality of those habitat types compared with regions outside of the park. For example, deciduous woody vegetation along Rincon Creek provides exceptional habitat to a variety of riparian-dependent bird species such as the Yellow Warbler (*Setophaga petechia*) and Song Sparrow (*Melospiza melodii*), and mature stands of saguaro cacti are important habitat refuges for Gila Woodpecker and Cactus Wren (*Campylorhynchus brunneicapillus*) (Powell 2006, Powell 2007).

Non-native Bird Species

There are four non-native bird species found in Saguaro NP. They are the European Starling (*Sturnus vulgaris*), House Sparrow (*Passer domesticus*), Rock Pigeon (*Columba livia*), and Eurasian Collared-Dove (*Streptopelia decaocto)* (Powell 2006 and N. Kline, Saguaro NP, pers. comm.). The species with the greatest potential impact on native species is the starling (and possibly House Sparrow) because it competes with native birds for nesting cavities, particularly cavities in saguaro cacti, but a study on the effects of non-native cavity nesting species on native cavity nesters found little cause for concern (Mannan and Bibles 1989 as cited in Powell (2006)). However, an increase in housing density surrounding the park may lead to an increase in their distribution in the park. Although all four species of non-native birds occur in both districts, their distribution is limited and their effects on native birds appears minor at this time; therefore, the condition for this measure is considered good. Additionally, House Sparrow was one of the species in the TMD for which a drop in abundance category from the 1985 park list to the 2016 comprehensive list occurred (see previous indicator/measure).



Overall Condition

In this assessment of birds at Saguaro NP, we used six indicators, each with one to three measures, to assess condition. Two indicators were quantitative (the first two), and the remaining indicators were qualitative in nature. These indicators and measures are summarized in Table 4.16.4-5.

The two quantitative indicators/measures used the SODN landbird monitoring dataset (2007-2014 & 2015, although the analyses excluded the first two years of data). Although occupancy was estimated for eleven species, current condition is unknown under the indicator/measure. This is because this is the first time occupancy has been estimated using the SODN dataset, and the intent is for occupancy to be monitored as changes in occupancy over time. The occupancy estimates presented in the report, however, represent a baseline for future assessment. Condition under the second indicator/measure (species richness in the areas surveyed by SODN) was judged to be good and unchanging at this time, as no significant trends were found over the 2009-2015 monitoring period.

Table 4.16.4-5. Summary of the birds indicators, measures, and condition rationale.

Indicator	Measure	Condition	Condition Rationale
Occupancy of Species Common in the SODN	Change in occupancy over time	Unknown	Occupancy was estimated for 11 species that occur at the park that are common in the SODN. Occupancy was estimated at 0.90 or higher for seven of the species (Gambel's Quail, Gilded Flicker, Ladder-backed Woodpecker, Lesser Goldfinch, Phainopepla, Summer Tanager, and Verdin) in at least some of the habitats/ districts in the areas sampled. Estimated occupancy of at least two of the other species (Cassin's Kingbird and Canyon Towhee) was 0.66 or higher. No information on trends is available from this analysis at this time. Under our reference conditions (which are defined using trends in occupancy), condition is unknown.
Species Richness in SODN Annual Survey Areas	Change in species richness over time	Good, with an unchanging trend	Species richness in the areas sampled by SODN was estimated separately for: upland habitat and riparian habitat in the RMD, and upland habitat in the TMD (2009-2015). Although there appeared to be some year to year differences, especially for upland habitat in the RMD, overall, there were no significant trends over time. Using our reference conditions, species richness in the areas sampled is unchanging, and therefore good.
Species Richness & Abundance Category using 2016 Comprehensive Park Bird List	# of native species recorded per district according to 2016 list	NA	A total of 218 native bird species have been recorded in the park, with 216 native species recorded in the RMD, and 153 in the TMD. Four additional non-native bird species have been documented in both districts of the park.
	Change in abundance category, comparing 2016 list to previous list (1985) for TMD.	Moderate condition, but with relatively low confidence	Our comparison of abundance category for species in the TMD revealed that 18 species dropped in abundance category from 1985 to 2016 lists (with one of the species being a non-native), and the drop was supported by CBC data. An additional six species in the TMD dropped in abundance category from 1985 to 2016, but CBC data could not be used to support the category drop. Although our confidence level in this analysis is low due to its subjective nature, we consider condition moderate under the measure, with a declining trend.
Status of Threatened and Endangered Species	Southwestern Willow Flycatcher	Unknown	There is not enough information to assign a condition.
	Yellow-billed Cuckoo		
	Mexican Spotted Owl	Good	There are five breeding territories in the RMD and all appear to be occupied in most years. SNP (2013) reported that the Mexican Spotted Owl population in the park appears to be stable. However, there is some concern for the species on Mica Mountain due to wildfire effects (Helens 2 fire).
Extirpated Bird Species	# of Species	Good	Since there are no confirmed extirpated bird species in Saguaro NP, the condition for this measure is considered good.
Non-native Bird Species	# and Significance of Species	Good	Although four species of non-native birds occur in both districts, their distribution is limited and their effects on native birds appears to be minor. The trend appears unchanging.

Although condition was not determined under the third indicator/measure, species richness using the 2016 comprehensive bird list, it is clear that a large number of species have been recorded in the park over the years- 216 native species in the RMD and 153 in the TMD, for a total of 218 native species overall. Although we did not present this measure with reference conditions, we presented the information to provide a look at species richness in the park in a broader context (both spatially and temporally, although qualitatively) than the previous indicator/ measure.

The second measure under the third indicator revealed that there was a drop in qualitative abundance category from the 1985 park bird list to the 2016 list for 18-24 species. Although the analysis was subjective, it should be noted that the abundance categories for both lists were designated by local bird experts (although different ones in the two periods). The moderate condition for this measure suggests that a possible decrease in abundance for some bird species in the TMD is an area that deserves further analysis.

The last three indicators focused on federally threatened and endangered species, extirpated bird species, and non-native bird species, respectively. Under the first of these indicators, current condition is unknown for two of the three measures (i.e., species) and considered good for the third. The remaining two indicators/measures are considered to be in good condition.

Overall, of the eight measures we used with reference conditions, four were judged to be in good condition. One was judged to be in moderate condition, and the condition of birds under three were judged to be unknown. Although the use of a different set of indicators and measures may have led to a different conclusion, we consider condition under our set of indicators and measures to be good. Trends, where estimated varied. For example, species richness using the SODN monitoring dataset appeared stable and unchanging, while the trend in species abundance category using the 1985 and 2016 species lists declined somewhat (although this was a subjective analysis).

Level of Confidence/Key Uncertainties

Part of this assessment is based on a number of years of annual SODN breeding bird surveys (2007-2015 overall, although the data were truncated for the analyses) in both the RMD and the TMD. The two indicators/ measures used with this dataset are core components of the inventory and monitoring efforts of the SODN and other networks for birds at this time (Beaupré et al. 2013). The continued collection of data will enable further, and perhaps different, analyses in the future. It should be remembered, however, that the dataset, and therefore the measures, are limited in space (to the areas sampled) and time (five to six years, and during the breeding season only). Additionally, the occupancy data only address 11 species out of the over 200 that occur in the park.

To complement the indicators/measures using the SODN monitoring dataset, we included measures for endangered and threatened species, extirpated species, and non-native bird species. We also looked at species richness in a more general way using the 2016 comprehensive bird species list, which includes records of birds at least back to the 1950s. For species in the TMD, we also compared their abundance categories from the 1985 bird species list and the 2016 bird species list to look for drops in abundance category (which could mean *potential* drops in abundance in the park). Although our confidence level in this particular measure was relatively low due to its subjective nature, it was an attempt (in the absence of available data) to look for potential decreases in apparent abundance of species within the park.

Threats to Birds

As with other types of wildlife, birds in Saguaro NP, the surrounding area, and throughout their ranges face an array of potential threats. In Saguaro NP and its vicinity, threats include habitat loss, development and changes in surrounding land uses, groundwater depletion and decreased surface water availability, effects of climate change,

wildfire, and impacts from fire management. Additional threats may exist from non-native species, such as feral cats. Saguaro NP has been described as one of the most imperiled national parks due to urban sprawl (Hansen et al. 2014) and climate change (Saunders et al. 2009). Migratory bird species face additional threats throughout their range (although these threats are generally not limited to migratory species), including loss or degradation of habitat due to development, agriculture, and forestry activities, collisions with vehicles and man-made structures (e.g., buildings, wind turbines, communication towers, and electrical lines), poisoning, and landscape changes due to climate change (USFWS 2016). The federal Migratory Bird Treaty Act protects more than 1,000 species of birds, and many of these species are experiencing population declines because of increased threats within their range (USFWS 2016).

As discussed in various sections of the overall condition assessment, the human population and development are increasing in the Tucson area. The greater Tucson metropolitan area is one of the fastest growing population centers in the U.S. According to the 2010 census, Pima County's population is 980,263 and is projected to reach 1.45 million by 2041 (Pima Association of Governments 2016). In 2000, 55% of the private land surrounding Saguaro NP was undeveloped, but exurban development is expected to increase 38% by 2030 and 105% by 2060 (Hansen et al. 2014). Such increases in population and development surrounding the park lead to loss and alteration of habitat outside the park and place additional strains on the habitat and resources within the park. For example, population/development increases may lead to increases in abundance and types of non-native species, increased predation of native species by non-native species (e.g. feral cats), air pollution, demands on water resources, diseases, and road-killed animals, as well as a reduction in habitat connectivity.

Riparian woodlands in the Southwest, such as along Rincon Creek in Saguaro NP, are extremely valuable to breeding, wintering, and migrating birds, and often have greater species diversity than adjacent habitats (Conway et al. 2012). Kirkpatrick et al. (2009) found that riparian areas had 68% more species and 75% more individual birds than adjacent uplands. Concerns exist over water in Rincon Creek and the wildlife that depend upon this valuable park resource.

As discussed in the assessment of Surface Water Quantity in the Middle Reach of Rincon Creek, the overall condition for water quantity in the middle reach of the creek warrants moderate to significant concern. None of the measures used in the assessment (trend in mean annual discharge, minimum daily discharge per month, number of dry days per year in Pool A, and number of no-flow days per year at the USGS gage) were considered good. Although the data were variable, all of the measures indicated a trend toward drier conditions in recent years.

A recent study shows that the desert Southwest, already a dry region, has become drier, shifting the region into an overall drier climate pattern (Prein et al. 2016).The occurrence of wildlife and plants along and in the middle reach of Rincon Creek depends on streamflow and pools located within the creek. While surface water quantity is important for all wildlife and plants, some species are more dependent on reliable water sources than others. For example, at least four species that have been recorded along the creek are riparian obligate species, Song Sparrow (*Melospiza melodii*), Yellow-billed Cuckoo (*Coccyzus americanus*), Abert's Towhee (*Melozone aberti*) and Gray Hawk.

Conway et al. (2012) studied the bird community along Rincon Creek to determine its response (and recovery) from drought effects, including decreased surface and ground water, increased plant mortality, and decreased plant cover. The researchers found that both plants and birds along the creek had largely recovered within four years after the 2006 drought, "indicating that riparian woodlands and riparian birds may be somewhat resilient (over the long-term) to the effects of an occasional drought." However, they also cautioned that climate change may alter the "normal drought regime outside of the naturally occurring cycle

through a combination of decreased winter precipitation, increased temperatures, and increases in the frequency, size, and duration of drought." Other researchers found that drought can lead to delays in the initiation of nesting in Sonoran Desert birds, which may influence nesting success and productivity (McCreedy and van Riper 2015).

Based on their study of birds in riparian woodlands in 29 sites in southeastern Arizona (including Rincon Creek), Kirkpatrick et al. (2009) suggested that if long-term drought conditions lead to ground water levels decreasing such that surface water flows are reduced or eliminated, populations of breeding and migrant species that are positively associated with surface water would probably decline. They also suggested that populations of additional species would be affected if the ground water levels decreased to the point that riparian vegetation was adversely affected.

Bird species in the RMD and similar mountainous areas may be especially susceptible to the effects of climate change (Conway no date). As noted, temperature has also increased in the Southwest (Hansen et al. 2014, Prein et al. 2016). Increased temperature has the potential to shift biomes northward and higher in elevation, which may increase the potential for Saguaro NP to lose species adapted to higher elevation areas. If species need to shift their distribution upslope in response to changing climate, for example, they may find smaller and smaller areas of suitable habitat and be more at risk of local extirpation (Murphy and Weis 1990, as cited in Conway no date). A recent assessment by the U.S. Forest Service studied the vulnerability of wildlife (not just birds) in the sky islands of the Southwest. Coe et al. (2012) examined historical and projected climate and vegetation trends in relation to Coronado National Forest in southeast Arizona, and assessed the potential effects of future changes in climate on 30 species of terrestrial vertebrates inhabiting the Coronado National Forest. For this region of the country, a decrease in forested areas is projected, in addition to increases in temperature and aridity. Coe et al. (2012) found that all of the 30 species they assessed were vulnerable relative to at least some of the criteria they examined. One of the species with the largest "vulnerability score" was the Elegant Trogon (*Trogon elegans*), a species that has been recorded in Saguaro NP. Impacts to their habitat (e.g., an overall reduction in suitable habitat) appeared to play at least some role in the vulnerability of most species. Seven other avian species were assessed in the study, with nearly all having been recorded in the RMD.

A shift away from more natural fire regimes due to invasive plant species and climate change is also of concern. Both wildfire and prescribed fires can lead to impacts on bird species. As discussed previously for the Mexican Spotted Owl, their distribution on Mica Mountain appears to have been affected by the Helens 2 fire.

Prescribed fires may lead to changes in habitat that are undesirable for some bird species (and desirable for others; Short 2002 as cited in Powell (2006)). The magnitude of changes in habitat depend on factors such as pre-fire vegetation, fire behavior, weather, and their interactions. The extent of understory fires can vary substantially (e.g., burning little vegetation below 3 m, to scorching vegetation up to 20 m). Short (2002 as cited in Powell (2006)) studied prescribed fires in national park units in Arizona, including Saguaro NP, to determine the short-term effects of burning the understory on vegetation, arthropods, and birds in ponderosa pine forests. The researcher found that, similar to past researchers' reports, understory fires affected the availability of food, especially arthropods. Various species may also respond to changes in litter cover, seed availability, quality or quantity of nectar sources, abundance of foraging perches, availability of nest sites, cover from foliage, and other habitat attributes.

Several human-adapted, non-native species (birds and mammals mentioned here) occur in Saguaro NP (i.e., House Sparrow, Rock Pigeon, European Starling, Eurasian Collared-Dove, feral cat, domestic dog, and domestic cow). Although the three non-native mammals have not established populations

within the park, their presence may influence local biodiversity through overgrazing native vegetation and erosion of riparian areas, spreading invasive species such as buffelgrass, and through direct mortality of native species (e.g., feral cats killing native birds). Throughout the U.S., free-ranging domestic cats may be responsible for as many as one billion bird deaths each year (Wildlife Society 2011, Loss et al. 2013). In general, non-native species may become more predominant as development in close proximity to the park increases. Some native species have also become invasive and a threat to native songbirds including the Brown-headed and Bronzed Cowbirds (*Molothrus ater* and *Molothrus ater*) and probably Great-tailed Grackle (*Quiscalus mexicanus*) (N. Kline, Biologist, pers. comm.).

4.16.5. Sources of Expertise

Robert Gitzen conducted the quantitative species richness analysis and provided a description of the work. He is an Assistant Professor in the School of Forestry and Wildlife Sciences at Auburn University, Auburn, Alabama. He has worked extensively with NPS on design of long-term monitoring studies and analyses of inventory and monitoring data.

The occupancy analyses were conducted by William R. Gould, who is with the Applied Statistics Program at New Mexico State University. The information presented in the condition assessment was taken from *An Evaluation of Landbird Occupancy Monitoring by the Sonoran and Chihuahuan Desert Monitoring Networks* (i.e., Gould 2015).

Input and information for this assessment was provided by Natasha Kline (in particular) and Don Swann of Saguaro NP. Moez Ali, an avian expert, participated in updating the comprehensive bird list for the park, and participated in many of the SODN annual monitoring surveys. Mr. Ali recently became the lead for field efforts for the bird monitoring in the SODN as well as the Chihuahuan Desert and Southern Plains Networks. He also provided input on our comparison of the 1985 and 2016 bird lists. Larry Norris also participated in updating the comprehensive bird list for the park and provided input on the comparison of the list to the 1985 list for this assessment. Mr. Norris, now retired from the NPS after 33 years of service, was the NPS Southwest Research Coordinator. He is now an adjunct professor and a research associate at the University of Arizona and assists desert parks in their bird monitoring. Rob Bennetts, Program Manager, NPS Southern Plains Inventory and Monitoring Network, provided assistance with general interpretation of the results of the Gould report. Patty Valentine-Darby authored the assessment, with contributions from Lisa Baril.

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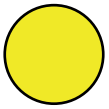
4.17. Herpetofauna

Indicators/Measures

- Species Occurrence (1 Measure)
- Population Status/Abundance of Selected Species (2 Measures)
- Occurrence of Herpetofauna Diseases (2 Measures)
- Presence of Non-native Species (1 Measure)
- Habitat Corridors & Connectivity (1 Measure)

Condition - Trend - Confidence Level



Moderate Concern - Insufficient Data - Medium/High

4.17.1. Background and Importance

The American Southwest is well known for its abundance and diversity of reptiles. The region is less well known for its amphibians, but they are abundant in some habitats, particularly during favorable weather conditions. Amphibians and reptiles are, together, referred to as herpetofauna (Figure 4.17.1-1).

Herpetofauna are important members of aquatic and terrestrial ecosystems. Amphibians constitute an important part of the food web; they consume insects and other invertebrates, and they are prey for a long list of fish, reptile, bird, and mammal species. Reptiles too serve as both predators and prey for many animals, such as small mammals, birds, and other reptiles. Amphibians are viewed as indicators of wetland ecosystem health. They are sensitive to a variety of threats due to their permeable skin and complex life histories, and, thus, can serve as early indicators of ecosystem change when monitored over long time scales. Like other wildlife, herpetofauna are also of aesthetic value to visitors of national park units.

Both the Rincon Mountains and the Tucson Mountains are in juxtaposition with several major biogeographic provinces, including the Sonoran Desert, the Rocky Mountain region, the Chihuahuan Desert, and the Madrean "sky islands" region (described in Flesch et

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Figure 4.17.1-1. Great Plains toad (*Anaxyrus cognatus*; left) and Sonoran desert tortoise (*Gopherus morafkai*; right), two herpetofauna species that are found in both districts at Saguaro NP.

al. 2006, 2007). Amphibian and reptile species representative of each of these regions can be found in the Rincon Mountain District (RMD) and the Tucson Mountain District (TMD), but there are differences in species occurrence between the two districts (Flesch et al. 2006, 2007). For example, a number of herpetofauna species that occur in the RMD have not been observed in the TMD, with most of the differences probably due to the species' ranges and the differences in location and elevation of the two districts. Another difference is the lack of suitable aquatic habitat in the TMD (Flesch et al. 2007). Herpetofauna in Saguaro NP have been relatively well-studied because of the park's location near Tucson (Flesch et al. 2006).

4.17.2. Data and Methods

This assessment is based on five indicators, each having one or two measures. Those with two measures are population status/abundance of selected species and occurrence of herpetofauna diseases. The first of these has a measure for 1) the Sonoran desert tortoise (*Gopherus morafkai;* U.S. Fish and Wildlife Service [USFWS] 2013), and 2) the lowland leopard frog (*Lithobates yavapaiensis*), each being a separate measure. The occurrence of herpetofauna diseases indicator has measures for 1) a disease affecting the desert tortoise (upper respiratory tract disease), and 2) a disease affecting amphibians (chytridiomycosis). Although we use one indicator/measure focusing on habitat in this assessment, it should be noted that other main sections of this condition assessment are related to habitat condition for amphibians and reptiles (and all wildlife) within the park. These sections include those on the vegetative or ecological communities in the park (Sonoran Desert, Grasslands/Savanna, Woodland/Shrubland, Forest, and Riparian), as well as Non-native, Invasive Plant Species, and Springs, Tinajas, and Seeps. We refer the reader to those sections. For example, the condition of tinajas in the RMD is important for the lowland leopard frog and other species that use the pools. That assessment included indicators for water availability and amount of sediment in tinajas. Both factors affect their suitability as habitat for herpetofauna species.

Indicators/Measure

Species Occurrence (Presence or Absence)

Species Occurrence: Presence/Absence

There is no recent, group-wide information available to assess current condition of species occurrence, so we used the results of 2001-2002 surveys by Flesch et al. (2006 and 2007) to address the occurrence of amphibian and reptile species at the national park. The surveys were the first effort to assemble a well-documented species list and to quantify relative abundance and species richness of herpetofauna in each district (Flesch et al. 2006, 2007). In the survey reports, the authors also compared their results to previous information collected on the park's herpetofauna. Both the Tucson Mountains and the Rincon Mountains have been studied over the years by herpetologists, and several species lists were assembled for each district (e.g., Lowe and Holm 1991; Flesch et al. 2006, 2007).

The Occurrence of Species of Conservation Concern

We also used the surveys by Flesch et al. (2006, 2007) to determine whether species of conservation concern occur in the park. We compared the list of species observed during 2001-2002 (and past) surveys to a federal list of endangered and threatened species that occur in Pima County (USFWS 2015a) and those of Greatest Conservation Need in Arizona (Arizona Game and Fish Department [AGFD] 2012). Under the State's Wildlife Action Plan (formerly the Comprehensive Wildlife Conservation Strategy), wildlife species may be listed as Tier 1a or 1b (or 1c, although we do not consider those relatively lower-priority species here). Federally listed species and candidate species, as well as those for which a signed conservation agreement exists, or those that require monitoring after delisting, fall into the Tier 1a cateogry (AGFD 2012).

Primary Data Sources

Flesch et al. (2006)

Flesch et al. (2006) reports on their effort (the first) to quantify the distribution and

abundance of herpetofauna species in the RMD, as well as to provide information on habitat and document species occurrence. Field work was conducted in 2001-2002. Although the exact sampling time frame varied for the different sampling methods used, overall, sampling was conducted from April to September. Four sampling methods were used to survey for amphibians and reptiles: intensive plot-based surveys at random locations that were constrained by time and area; extensive non-plot-based surveys that were selected randomly and non-randomly and allowed to vary in time and area; road surveys conducted by driving slowly along roads and looking for animals, usually after sunset; and incidental observations made while sampling under the other methods. Full details of the sampling methods are contained in Flesch et al. (2006). The amphibian and reptile surveys were part of a larger inventory for plants and vertebrates at the RMD by the University of Arizona (i.e., Powell et al. 2006).

Flesch et al. (2007)

The work described in Flesch et al. (2007) is similar to that in Flesch et al. (2006), except that the work was conducted in the TMD. It reports on the first effort to provide a well-documented herpetofauna species list and to quantify relative abundance and species richness in the district. Field work was conducted in 2001-2002. Four different survey methods were used: intensive plot-based surveys at random locations that were constrained by time and area; extensive non-plot-based surveys that were selected randomly and non-randomly and allowed to vary in time and area; road surveys conducted by driving slowly along a road and looking for animals, usually after sunset; and pitfall trapping, a live, passive sampling technique often used for species that are more difficult to observe. Sampling periods varied among the four survey methods, but overall, sampling was conducted from April-September of both years (and October 2002 for pitfall trapping). Full details of the sampling methods are contained in Flesch et al. (2007). The amphibian and reptile surveys were part of a larger inventory for plants and vertebrates at the TMD by the University of Arizona (i.e., Powell et al. 2007).

Indicators/Measures

Population Status/Abundance (Sonoran Desert Tortoise and Lowland Leopard Frog)

Population Status/Abundance for Selected Species: Sonoran Desert Tortoise

The Sonoran desert tortoise inhabits both the Rincon and TMDs in Saguaro NP. The Sonoran desert tortoise (*Gopherus morafkai*) was a candidate for listing under the Endangered Species Act (USFWS 2015a, b), but in October of 2015, the USFWS determined that listing the species as endangered or threatened was not warranted (USFWS 2015b). The State of Arizona has prohibited the removal of all desert tortoises from the wild since 1988 (AGFD 2015). The recognized scientific name for the desert tortoise was *Gopherus agassizii* until relatively recently (USFWS 2013). However, Murphy et al. (2011) provided evidence from genetic analyses that the Sonoran population of the desert tortoise should be considered a separate species, *G. morafkai*, from the Mohave population (USFWS 2013). The USFWS accepted the distinction between the two species. The Sonoran desert tortoise is known to occur in 11 counties in Arizona, including Pima County (USFWS 2015c). The Mohave desert tortoise (*Gopherus agassizii*) is listed by the USFWS as a theatened species. It is known to occur in eight counties in California, one in Utah, and two in Arizona (not including the Sonoran desert; USFWS 2015d). The ranges of the two species are split by the Colorado River (AGFD 2015).

The desert tortoise is long-lived, with a life span as long as >50 years in the wild (Zylstra and Swann 2009). Individuals begin breeding around 12-20 years of age (AGFD 2015). They breed during the summer, and females lay an average of 3-12 eggs in a nest inside or near a burrow entrance. The eggs hatch in September or October, near the end of the rainy season. Only one clutch of eggs is layed per year (compared to tortoises in the Mohave Desert which can lay two clutches per year). Although the hatchling desert tortoises have many predators, adults have few natural predators, with the primary one being the mountain lion. The desert tortoise

is well-adapted to its desert existence, and the species' adaptations include spending part of their lives in burrows (AGFD 2015).

Tortoises in the national park have been found to inhabit areas at higher elevations than tortoises in other parts of the Sonoran Desert (Zylstra and Swann 2009). They usually occur below 4,000 ft (1,220 m) in elevation in Arizona, while in the park, for example, a population occurs on the south side of the Rincon Mountains at 4,600-4,900 ft (1,400-1,500 m). A tortoise in the park, observed in the year 2000, holds the record for occurring at the highest elevation known for the species (7,808 ft [2,380 m]; Zylstra and Swann 2009). Based on a recent study in the park, tortoises are more likely to occur in steep and mainly east-facing sites (and less likely on north-facing slopes; Zylstra 2008a).

Research on the desert tortoise in Saguaro NP began in the 1980s. The more than a dozen studies that have been conducted have provided information on diet, effects of fire, seasonal activity and movement patterns, genetics, reproduction, disease, tortoise numbers, and techniques for monitoring (Zylstra and Swann 2009). Zylstra and Swann (2009) summarized each of these studies in their 2009 report.

To address the status/abundance of the desert tortoise at the park, we relied on surveys and studies that have been conducted at the park in the past. The most recent study was conducted in 2010-2011 and estimated adult density in plots in both districts (Gray and Steidl 2015). Adult density (and occupancy) in both districts was also estimated in 2005-2006 (Zylstra 2008a, Zylstra et al. 2010). Additionally, adult tortoise densities were estimated at sites within both districts in the 1980s and 1990s. The main sources used for the assessment are described below.

Primary Data Sources: Desert Tortoise

Gray and Steidl (2015)

This publication presents the most recent estimates available of Sonoran desert tortoise density in the park. Gray and Steidl (2015) estimated density using 50 4-ha (200 m x 200 m) plots located in both the Rincon and TMDs. The plots were located in areas between 750 and 1,200 m in elevation. Fifteen plots were established in the TMD and 35 plots were established in the RMD. Twenty-five plots were surveyed in 2010, and 25 different plots were surveyed in 2011. The researchers estimated density across the plots. The overall purpose of their work was to study the effects of buffelgrass (*Pennisetum ciliare*) on the demography and condition of the Sonoran desert tortoise (Gray and Steidl 2015).

Zylstra et al. (2010)

This study examined the use of two methods to monitor the Sonoran desert tortoise. The authors compared the efficiency and statistical power of line transect distance sampling and site occupancy. In so doing, they provided density estimates for adult tortoises in the RMD in 2005, the TMD in 2006, and the entire sampling area in 2005-2006, as well as site occupancy for the entire area for 2005-2006. Overall, the researchers surveyed 120 1-km transects to estimate density and 40 3-ha plots five times each to estimate occupancy. Although not directly relevant for assessing condition, Zylstra et al. (2010) found that monitoring occupancy was more efficient than monitoring density, and that occupancy had greater statistical power to detect annual declines in occupancy (compared to distance sampling detecting annual density declines).

Zylstra and Swann (2009) and Wirt and Colleagues

As previously mentioned, Zylstra and Swann (2009) summarized past research conducted on the desert tortoise in the national park. We used this report for details on the mark-recapture study on the species in the late 1990s. In 1996-1997, Wirt and colleagues conducted mark-recapture surveys at three 1-km^2 (0.39-mi^2) monitoring plots. All three plots were surveyed in 1996: two in the RMD (Javelina Picnic Area plot and Mother's Day Fire plot), and one in the TMD (Panther Peak plot). Two of the plots were surveyed again in 1997 (Javelina Picnic Area and Panther Peak plots). The Mother's Day site had burned in 1994.

Population Status/Abundance for Selected Species: Lowland Leopard Frog

The lowland leopard frog (*Lithobates yavapaiensis*) occurs in montane canyons of the RMD. As discussed previously, it is a Species of Greatest Conservation Need in Arizona (AGFD 2012) and a species of special interest to Saguaro NP personnel. According to park reports, it is probably the most threatened species of amphibian or reptile in the district (e.g., Flesch et al. 2006). As discussed in greater detail below, the lowland leopard frog has been surveyed within the district for more than 16 years. A number of studies have also been conducted on the species concerning effects on habitat from post-wildfire sedimentation, disease, habitat characteristics, and surface water availability.

The overall, current range of the lowland leopard frog is in central and southeastern Arizona, southwest New Mexico, and, most likely, northwestern Chihuahua and northern Sonora, Mexico (AGFD 2006). In central and southeastern Arizona, the majority (almost 60%) of localities are in Gila, Maricopa, and Yavapai counties. The species reportedly has declined substantially in the southeastern part of the state, and is gone from the southwestern part of the state. In general, the greatest threats to the species are from the alteration and fragmentation of its habitat, as well as the introduction of non-native species (i.e., fish, crayfish, and frogs [especially American bullfrogs], that are predatory and competitive; AGFD 2006). Other factors, such as disease, are also important and are discussed in the condition assessment.

In the RMD, the leopard frogs have lost habitat due to tinajas being filled by coarse sandy gravel after severe, stand-replacing wildfires in areas above the tinajas (Parker 2006). For example, during the two years after the 1999 Box Canyon fire, tinajas associated with the Loma Verde Wash were filled with sediment. This area had contained one of the largest breeding populations in the park.

Lowland leopard frogs breed mainly from January to May in Arizona, although some populations may also breed in summer and early fall after the start of summer rains (AGFD 2006).Within the RMD, leopard frogs consistently breed in both spring and fall (Erin Zylstra, University of Arizona, School of Natural Resources, pers. comm.). The species may breed in a variety of natural and man-made aquatic habitats, with most historical areas being small to medium-sized streams and rivers. Within the RMD, leopard frogs occur primarily in pools along low-order, intermittent streams below 1500 m (4,922 ft) in elevation; however, they may also occur in pools at higher elevations and in isolated cattle tanks located north of the park on U.S. Forest Service-managed property (Zylstra et al. 2013). There is much variation among seasons and years in stream flow and connectivity between the pools, with connection more likely during wet periods in late winter and during monsoons.

To address the status/abundace of the lowland leopard frog at the national park, we used the results of 16 years of surveys for the species, described and analyzed in Zylstra et al. (2013). This study is described briefly below. Note that the last year for which detailed survey results are available is 2011; the park has continued to monitor leopard frogs since that time, but has not yet analyzed or published the results. We present general results since 2011 using a personal communication with park staff and/or researchers.

Primary Data Source: Leopard Frog

Zylstra et al. (2013)

"Population dynamics of lowland leopard frogs in the Rincon Mountains, Arizona" used 16 years of lowland leopard frog survey data in the RMD to assess frog populations and determine factors that affect their distribution and abundance over time (Zylstra et al. 2013). Park staff surveyed the major drainages in the park in 1996 to identify potential habitat for the species and to select pools (likely to have water for most of the year) for long-term monitoring (Figure 4.17.2-1). Data were collected between 1996 and 2011. Over the study period, 470 visual encounter surveys were conducted during the spring (1 May-15 July; 257 surveys) and fall (1 October - 31 December; 213 surveys). Two geographic scales (drainages [n=9] and pool complexes [n=71]) were used to examine patterns of

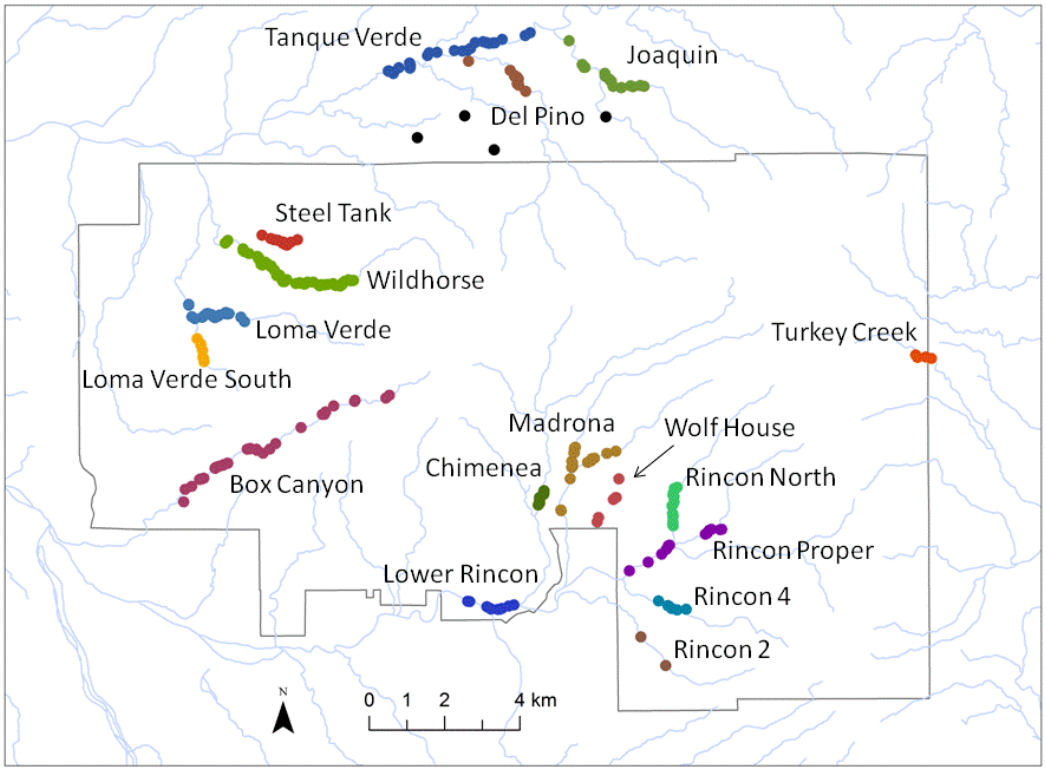

Figure 4.17.2-1. Drainage segments and tanks surveyed for lowland leopard frogs in and near Saguaro NP between 1996 and 2011. Figure Credit: Zylstra et al. (2013).

adult frog occupancy. Patterns of abundance were examined at 34 pool complexes in five drainages. The researchers used linear models to assess spatial variation in counts of adult leopard frogs and hierarchical models to examine variation in occupancy and abundance in relation to various environmental factors (Zylstra et al. 2013).

Indicators/Measures

Occurrence of Herpetofauna Diseases (Upper Respiratory Tract Disease & Chytridiomycosis)

Occurrence of Herpetofauna Diseases: Upper Respiratory Tract Disease (and Causative Agent)

A widespread upper respiratory tract disease (URTD) caused by the bacterium *Mycoplasma agassizii,* as well as *M. testudineum,* (Jacobson et al. 2014) is of concern for the Sonoran desert tortoise. This contagious disease may be part of the cause of population declines in desert tortoises (*Gopherus agassizii*) in the Mohave Desert (Ivanyi et al. 2000). In the Sonoran Desert, URTD has not been implicated in any die-offs of desert tortoises (Jones 2008), but the disease has been documented, including in the Tucson area. Clinical signs of the disease include a runny or wet nose and eyes. It is possible for clinical signs to occur, go away, and return again (Jacobson et al. 2014). This highly contagious disease is spread through close contact between tortoises (such as during courtship or combat).

We assessed this measure using primarily one study, namely Jones (2008). Jones (2008) conducted her field work in 2002-2005, so the results are now more than 10 years old. Her work consisted of three main components and included study sites in Pima, Mohave, and Maricopa counties. For our limited assessment, we discuss some of her overall results and some of her observations at a few study sites within Saguaro NP.

Primary Data Source: URTD

Jones (2008)

The purpose of her research was to determine: "1) the prevalence of URTD across an urban gradient in Greater Tucson, 2) the relationship between URTD and captive and free-ranging tortoises in Mohave, Maricopa, and Pima counties in Arizona, and 3) the effects of URTD on desert tortoise home range size and winter temperature selection" (Jones 2008). To address the first component, she

used enzyme-linked immunosorbent assay to detect anti-*M. agassizii* antibodies in plasma samples, which indicates previous exposure, and polymerase chain reaction (PCR) to look for *M. agassizii* DNA in tortoise nasal flush samples, which indicates a current infection (Jones 2008). She collected samples from captive desert tortoises and from free-ranging tortoises from three categories (suburban, high-visitor use, and remote sites). At least three sites were in Saguaro NP, two in the TMD (one a suburban site and one a high-visitor-use site) and one in the RMD (a high-visitor-use site).

Occurrence of Herpetofauna Diseases: Chytridiomycosis (and Causative Agent)

This measure focuses on the occurrence of the amphibian chytrid fungus *Batrachochytrium dendrobatidis* (*Bd*), and the disease it causes, in two amphibian species in the national park, the lowland leopard frog and the canyon tree frog (*Hyla arenicolor*). These two species are used in this measure because information is available on them from a recent study by Ratzlaff (2012). Additionally, as discussed elsewhere in the condition assessment, the lowland leopard frog is of interest because it is a species of conservation concern and probably the most at-risk species in the RMD (Flesch et al. 2006).

The disease chytridiomycosis is considered a significant threat to amphibians worldwide, causing population declines and species extinctions. The disease is thought to have originated in Africa, spreading rapidly since the 1970s (Australia Department of Environment and Heritage 2006). The fungus attacks keratin in the skin of amphibians. The water-dependent fungus spreads via free-swimming zoospores, which colonize amphibian skin and develop into zoosprangia. The fungus is believed to be able to persist in aquatic environments without amphibians. Amphibian larvae are not usually lethally affected, but they can carry the fungus in mouthparts and toe tips during later stages of development. The life stage that appears to suffer the highest mortality is newly metamorphosed froglets (AmphibiaWeb 2015). Some amphibian species (including bullfrogs) can carry the fungus without being killed by it, and they can serve as vectors of the pathogen to more susceptible species.

The responses of amphibian populations infected with the fungus range from no perceptible impact, to mass mortality events, to severe decline without recovery. In the western U.S., chytridiomycosis is thought responsible for the decline of the boreal toad (*Anaxyrus boreas*) in the southern Rocky Mountains (U.S. Geological Survey 2000). Reports of the disease in the Southwest include infections in lowland leopard frogs and Chiricahua leopard frogs (*Lithobates chiricahuensis*) in eastern, central, and southern Arizona (Bradley et al. 2002); large numbers of dead and dying frogs were found in eight different sites, while larval stages appeared unaffected. The chytrid fungus has also been documented in lowland leopard frogs in the Rincon Mountains on several occasions, during winter, since the year 2000 (Ratzlaff 2012, citing Saguaro NP unpublished data).

Primary Data Sources: Chytridiomycosis

This measure was assessed using one recent report on chytrid fungus infection in amphibians in the Rincon Mountains. Ratzlaff (2012) studied patterns of chytrid fungus infection in three species of amphibians in the Rincon Mountains and surrounding Tucson Basin, but for the condition assessment, we focused on her results for frogs within the Rincon Mountains only. She studied lowland leopard frogs and canyon tree frogs in streams in three canyons in the Rincon Mountains, Chimenea Canyon (within the park), Widlhorse Canyon (within the park), and Tanque Verde Canyon (i.e., Joaquin Canyon and Tanque Verde Creek; just north of the north border of the park). The researcher collected samples by swabbing frogs and used quantitative PCR to analyze the samples. She looked at both prevalence and infection intensity for amphibians: in different life stages, at different locations, at different elevations, and across seasons. Prevalence was defined as the percentage of frogs that tested positive for *Bd*, and for frogs that tested positive for the fungus, infection intensity was reported as the number of zoospores. She collected samples from adults

and metamorphs (i.e., frogs estimated to have metamorphosed within the last 30 days), and from tadpoles, from Fall 2008-Summer 2010.

Indicators/Measure
Presence of Non-native Species (Effects on Herpetofauna)

Presence of Non-native Species: Effects on Herpetofauna

In general, non-native animal species are known to have many potential adverse effects on native species of wildlife. Non-native (including feral) species may prey on native species, compete with them for food and other resources, impact habitat, and introduce and/or spread disease. In some cases, amphibians and/or reptiles in the Southwest have experienced population declines or changes in distribution due to species such as American bullfrogs (e.g., Rosen and Schwalbe 1995), fish (e.g., Nowak 2006), and crayfish (e.g., Marks 2006, Arizona Invasive Species Advisory Council 2008). For example, the American bullfrog is thought to be a primary cause of declines of leopard frogs (including the federally-threatened Chiricahua leopard frog) and gartersnakes in Cochise County (Rosen and Schwalbe 1995).

Under this indicator/measure, we addressed four non-native animal species that have been recorded in the national park, but focused on the occurrence and effects of one (due to the information available and the observed impacts). These four animal species are the Mediterranean gecko, American bullfrog, tiger salamander, and domestic or feral dog. Emphasis is on the domestic or feral dog, primarily in relation to the Sonoran desert tortoise. We also considered the feral hog, which has not been documented in the park, but has been reported in Pima County (as early as 2004) and other parts of the state (Verde Independent 2012).

For this aspect of the assessment, we used information on the presence and effects (if reported) of non-native species from the various reports already mentioned in the condition assessment (e.g., Flesch et al. 2006, 2007). We also used Zylstra (2008b), described below, for its discussion of domestic free- ranging dogs and desert tortoises. At least as of 2008, sightings of free-ranging dogs in the park were not uncommon, especially in the TMD (Zylstra 2008b). Free-ranging dogs have also been recorded recently in the TMD by wildlife cameras (Don Swann, Biologist, Saguaro NP, pers. comm.).

Zylstra (2008b)

For Zylstra's (2008b) study, she looked at information that had been collected on more than 230 tortoises in the park in 2005-2007. Detailed information and photographs were available on each of the tortoises (123 from the RMD and 113 from the TMD). Less detailed information regarding health and shell condition was also available on tortoises (more than 150) for the period between 1989 and 2004. For the 2005-2007 group of tortoises, she looked at the amount of damage to the shell and limbs, the location of moderate or severe damage, the probable cause of the damage, and, if the damage was from predation, the most likely type of mammalian predator (Zylstra 2008b). The tortoises were placed into one of three groups: tortoises with injuries likely caused by dogs, those with injuries possibly or likely caused by dogs, and those without dog-related injuries. For tortoises in the 1989-2004 group, she placed animals into one of two groups: those having injuries possibly caused by dogs (animals with moderate to severe trauma to the gular or marginals), or tortoises without these injuries.

Indicators/Measure
Habitat Corridors and Connectivity (Connectivity of Habitat)

Habitat Corridors and Connectivity: Connectivity of Habitat

Note that some of the discussion presented here is the same as that used in the comparable indicator/measure in the Mammal section of the condition assessment. For the sake of clarity and completeness, we present some of the information again here.

As described throughout this document, Saguaro NP consists of two districts that are separated by the City of Tucson. On the east side of Tucson is the RMD, which encompasses much of the Rincon Mountain

range and its west and southwest foothills and adjacent lowlands. On the west side of Tucson is the TMD, which includes much of the Tucson Mountains and foothills. The broader landscape in which the park occurs has undergone significant change since the park's establishment. The following paragraph, from Monahan et al. (2013, page xi), summarizes these changes and provides an introduction to this indicator.

> Like many protected areas in the western United States, Saguaro National Park has experienced rapid urban growth outside of its boundaries. When the Park was first established as a National Monument in 1933, the nearby city of Tucson had fewer than 40,000 residents, and the city was more than 20 miles distant along poorly developed dirt roads. Today, Tucson has nearly 1 million residents, and a multitude of human pressures associated with this growth and development pose distinct challenges to Park natural resources. Roads carve up natural landscapes and impede connectivity for wildlife, urban and agricultural development further fragment and erode the remaining natural areas, and housing proximate to the Park enable residents and pets to transgress its boundaries. Hence, despite the best possible resource management practices being implemented inside the Park, external anthropogenic landscape stressors originating from such sources as population, housing, and roads require Park managers, planners, and interpreters to confront the tricky questions of how such landscape dynamics affect the status and trend of key defining Park resources.

The issue we focus on here is habitat connectivity for amphibians and reptiles. As described above, development has met the boundaries of not only the park, but also that of other protected areas in the vicinity, such as Tucson Mountain Park and Coronado National Forest. This has resulted in the loss of wildlife habitat in the Tucson Basin and foothills, as well as corridors for safe travel to mountain ranges nearby (Saguaro NP 2007). Habitat connectivity is an issue for various species. For example, one of the reasons that the lowland leopard frog is considered sensitive is the loss of connectivity between historic valley bottom populations and the upland populations in the national park (Don Swann, Saguaro NP, pers. comm.). The valley bottom populations included those in the wetlands associated with the Santa Cruz River in downtown Tucson and near Mission San Xavier del Bac south of downtown. Habitat connectivity may also be an issue for some lowland reptiles in the TMD, particularly the sidewinder (*Crotalus cerastes*) and desert iguana (*Dipsosaurus dorsalis*; Don Swann, Saguaro NP, pers. comm., Flesch et al. 2007).

To assess the condition of herpetofauna under this measure, we primarily used the results of Perkl et al. (2015), which used current and projected data to assess (through modeling) landscape connectivity for wildlife in the general Tucson area. We also used a study on movements of the desert tortoise (i.e., Edwards et al. 2004), described briefly in the Condition section, as supporting information.

Primary Data Sources- Habitat Connectivity

Perkl et al. (2015)

Perkl et al. (2015) conducted a "connectivity threats assessment" for the park using connectivity modeling. As described by the authors, their main goal was to assess existing and projected threats to landscape connectivity: to both districts of Saguaro NP; to the complex of protected lands in the larger Tucson region; and to areas of the landscape to the east of the RMD, such as the San Pedro River Valley. To accomplish this goal, they modeled structural landscape corridors to reflect current landscape conditions and those projected for the future throughout the region. Note that we provide fewer details on this study here than we did in the Mammal section of the condition assessment; see that section and the original study for more information.

In their baseline scenario (to reflect current conditions) and projected scenario (to reflect future conditions) modeling efforts, the authors modeled "least-cost" corridors between 16 landscape block pairs. The corridors have high landscape integrity, or naturalness, and represent the most natural (and probably the most permeable) structural connections between each of the landscape block pairs (Perkl et al. 2015). These are paths of likely wildlife movement; they usually consist of areas with lower levels of human disturbance and/or modification. However, note that among the assumptions and caveats discussed in Perkl et al. (2015), one was that the modeled corridors may not actually be passable for some species "given real-world barriers such as structures, roads, fencing, and other infrastructure of landscape alterations. For example, many of the corridors cross Interstate 10..., which ...may be an impassable barrier to certain species." It is also important to note that the analysis did not focus on particular species or groups of wildlife.

4.17.3. Reference Conditions

Reference conditions for this assessment are shown in Table 4.17.3-1. Reference conditions are described for resources in good, moderate concern, and significant concern conditions for each of the five indicators and their measures.

4.17.4. Condition and Trend

A total of approximately 61 species of amphibians and reptiles were recorded at Saguaro NP during 2001-2002 surveys by The University of Arizona (Flesch et al. 2006, 2007) or during past studies (and mentioned in the Flesch et al. reports) or more recently by the park (Table 4.17.4-1). Nine of these species are amphibians, and 52 are reptiles (e.g., Figure 4.17.4-1). Three of the 61 species are non-native, the American bullfrog (*Lithobates catesbeiana*) the Mediterranean house gecko (*Hemidactylus turcicus*), and the tiger salamander (*Ambystoma tigrinum*). One species (spotted leaf-nosed snake [*Phyllorhynchus decurtatus*]) was recently documented for the first time by park staff.

Table 4.17.4-1 also includes information on whether species have any special listing status (i.e., federally-listed with the USFWS, or listed as Species of Greatest Conservation Need [SGCN, Tiers 1a or 1b] with the State; USFWS 2015a, AGFD 2012). Fifteen species are SGCN. One species, the Sonoran desert tortoise, was a federal candidate species but now has no federal status (USFWS 2015b).

Species Occurrence: Presence or Absence

RMD

In the RMD, 46 herpetofauna species (seven amphibians and 39 reptiles) were documented during the 2001-2002 surveys of Flesch et al. (2006). Of the reptiles, 19 species are lizards, 18 are snakes, and two are turtles. Eleven additional species (two amphibians and nine reptiles) were either recorded during earlier surveys or there is a photo or voucher specimen documenting their (earlier) occurrence (see Table 4.17.4-1).

Flesch et al. (2006) detected 3,066 individuals using the three sampling methods (intensive, extensive, and road surveys) and 1,225 individuals through incidental observations. Combining all survey methods, the ornate tree lizard (*Urosaurus ornatus*) was the most-detected species. Based on the intensive survey data, species richness was highest in the low elevation stratum and lowest in the high elevation stratum (and moderate at the middle elevation stratum).

The American bullfrog was observed in the district in the decade prior to the release of the 2006 survey report, and at that time it

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Figure 4.17.4-1. The Gila monster (*Heloderma suspectum*) is a large, stout-bodied lizard that may be found in either of Saguaro NP's two districts.

Table 4.17.3-1. Reference conditions used to assess the current condition of herpetofauna at Saguaro NP.

Indicators	Measures	Good	Moderate Concern	Significant Concern
Species Occurrence	Presence or absence	We consider condition to be good if the number of native species found in the park has increased or remained the same over time.	We consider condition to be of moderate concern if the number of native species found in the park has decreased by only one or a few species in recent years.	We consider condition to be of significant concern if the number of native species found in the park has decreased by more than a few species in recent years, especially when the subject native species were previously sighted more than rarely.
Population Status / Abundance of Selected Species	Status / abundance of Sonoran desert tortoise	We consider condition to be good if estimated numbers of the subject species are approximately the same or increasing based on the information available.	We consider condition to be of moderate concern if estimated numbers of the subject species have decreased or may be decreasing somewhat.	We consider condition to be of significant concern if estimated numbers of the subject species have decreased substantially and/or may continue to do so.
	Status / abundance of Lowland leopard frog			
Occurrence/ Prevalence of Herpetofauna Diseases	Occurrence of Upper respiratory tract disease (URTD) and/or *Mycoplasma* in desert tortoise	There is no/has been no detectable occurrence of *Mycoplasma agassizii* or URTD in desert tortoises in the park (or Chytrid fungus [*Bd*] or chytridiomycosis for amphibians).	The causal agent of the disease has been detected in the park but animals are not showing symptoms of the disease; or animals have shown symptoms but recovered; or the incidence of the causal agent or symptoms has been low.	A substantial number of animals show signs of the disease, or it is widespread; or populations have been adversely affected by the disease.
	Occurrence of chytrid fungus (*Bd*) in lowland leopard frogs and canyon tree frogs			
Presence of Non-native, Invasive Species	Effects on herpetofauna from non-natives	Condition is considered to be good if non-native species (amphibians, reptiles, or other groups) are having no known impacts on native herpetofauna in the park.	Condition is considered to be of moderate concern if non-native species are having some impacts on native herpetofauna.	Condition is considered to be of significant concern if non-native species are affecting native herpetofauna and could lead to population level impacts.
Habitat Corridors & Connectivity	Connectivity with surrounding landscape (measured by modeled habitat corridors)	We consider condition to be good if multiple corridors exist, providing connectivity for herpetofauna between the park and surrounding landscape, and these corridors do not appear to be threatened by future development.	We consider condition to be of moderate concern if few corridors exist to provide connectivity for herpetofauna between the park and surrounding landscape, and these corridors appear to be threatened by future development.	We consider condition to be of significant concern if only one or no corridors exist to provide connectivity for herpetofauna between the park and surrounding landscape.

was reported "only during wet summers, and then only as dispersing juveniles that do not persist (Saguaro NP, unpublished records)" (Flesch et al. 2006). The Mediterranean house gecko appears to only occur in buildings in the Administration area. Therefore, these non-native species did not appear to pose a serious threat to native herpetofauna species at the time of the Flesch et al. (2006) report, and nothing appears to have changed over the past decade in this regard. Even though a few bullfrogs have been observed in 2014, neither species appears to be a threat at this time (Don Swann, Saguaro NP, pers. comm.). The tiger salamanders that have been recorded in the park are also non-native; there is a native tiger salamander that occurs in southern Arizona, but it is the non-native one that has been recorded in the park (Don Swann, Saguaro NP, pers. comm.). Fourteen species of conservation concern have been recorded for the RMD.

Table 4.17.4-1. Amphibian and reptile species recorded in the districts of Saguaro NP during surveys. Species in bold font are non-native species.

Common Name	Scientific Name	TMD (Flesch et al. 2007)	RMD (Flesch et al. 2006)	NPSpecies (2014)
Amphibians				
American bullfrog	***Lithobates catesbeiana***		**X[1]**	**X**
Canyon treefrog	*Hyla arenicolor*		X	X
Couch's spadefoot	*Scaphiopus couchii*	X	X	X
Great Plains toad	*Anaxyrus cognatus*	X	X	X
Lowland leopard frog [2]	*Lithobates yavapaiensis* [2]		X	X
Mexican spadefoot	*Spea multiplicata*		X	X
Red-spotted toad	*Anaxyrus punctatus*	X	X	X
Sonoran Desert toad [2]	*Incilius alvarius* [2]	X	X	X
Tiger salamander [3]	***Ambystoma tigrinum*[3]**		**X [3]**	
Reptiles				
Arizona black rattlesnake	*Crotalus cerberus*		X	X
Black-necked garter snake	*Thamnophis cyrtopsis*		X	X
Black-tailed rattlesnake	*Crotalus molossus*	X	X	X
Canyon spotted whiptail [2]	*Aspidoscelis burti* [2]		X	X
Clark's spiny lizard	*Sceloporus clarkii*	X	X	X
Coachwhip	*Coluber flagellum*	X	X	X
Common kingsnake	*Lampropeltis getula*	X[1]	X	X
Common lesser earless lizard	*Holbrookia maculata*	X	X	X
Common side-blotched lizard	*Uta stansburiana*	X	X	X
Desert iguana	*Dipsosaurus dorsalis*	X		X
Desert nightsnake	*Hypsiglena chlorophaea*	X	X	X
Desert spiny lizard	*Sceloporus magister*	X	X	X
Eastern collared lizard	*Crotaphytus collaris*		X	X
Eastern fence lizard (also known as Plateau lizard)	*Sceloporus tristichus*		X	X
Eastern patch-nosed snake	*Salvadora grahamiae*		X	X
Gila monster [2]	*Heloderma suspectum* [2]	X	X	X
Gila spotted whiptail [2]	*Aspidoscelis flagellicauda* [2]		X	X
Glossy snake	*Arizona elegans*	X	X[1]	X
Gopher snake	*Pituophis catenifer*	X	X	X
Great Plains skink	*Plestiodon obsoletus*		X	X
Greater earless lizard	*Cophosaurus texanus*		X	X
Greater short-horned lizard	*Phrynosoma hernandesi*		X	X
Ground snake	*Sonora semiannulata*		X	X
Long-nosed leopard lizard	*Gambelia wislizenii*	X	X [1]	X
Long-nosed snake	*Rhinocheilus lecontei*	X	X	X
Madrean alligator lizard	*Elgaria kingii*		X	X

Table 4.17.4-1. Amphibian and reptile species recorded in Saguaro NP continued.

Common Name	Scientific Name	TMD (Flesch et al.) 2007	RMD (Flesch et al.) 2006	NPSpecies (2014)
Mediterranean house gecko	***Hemidactylus turcicus***		**X [1]**	not on npspecies
Mohave rattlesnake	*Crotalus scutulatus*	X	X	X
Ornate box turtle (aka Western box turtle) [2]	*Terrapene ornata* [2]		X[1]	X
Ornate tree lizard	*Urosaurus ornatus*	X	X	X
Regal horned lizard [2]	*Phrynosoma solare* [2]	X	X	X
Ring-necked snake	*Diadophis punctatus*		X	X
Saddled leaf-nosed snake [2]	*Phyllorhynchus browni* [2]	X[1]	X[1]	X
Sidewinder	*Crotalus cerastes*	X		X
Smith's black-headed snake	*Tantilla hobartsmithi*		X[1]	X
Sonora mud turtle [2]	*Kinosternon sonoriense* [2]		X	X
Sonoran collared lizard [2]	*Crotaphytus nebrius* [2]	X		not on npspecies
Sonoran coral snake [2]	*Micruroides euryxanthus* [2]	X	X	X
Sonoran desert tortoise [2, 4, 5]	*Gopherus morafkai* [2, 4, 5]	X	X	X
Sonoran lyresnake	*Trimorphodon lambda*	X	X[1]	X
Sonoran mountain kingsnake	*Lampropeltis pyromelana*		X	X
Sonoran spotted whiptail	*Aspidoscelis sonorae*	X	X	X
Sonoran whipsnake [2]	*Coluber bilineatus* [2]	X	X	X
Spotted leaf-nosed snake [6]	*Phyllorhynchus decurtatus* [6]			
Tiger rattlesnake [2]	*Crotalus tigris* [2]	X	X	X
Tiger whiptail	*Aspidoscelis tigris*	X	X	X
Variable sandsnake [2]	*Chilomeniscus stramineus* [2]	X[1]	X[1]	X
Western banded gecko	*Coleonyx variegatus*	X	X	X
Western diamond-backed rattlesnake	*Crotalus atrox*	X	X	X
Western patch-nosed snake	*Salvadora hexalepis*	X	X	X
Western threadsnake	*Leptotyphlops humilis*	X	X[1]	X
Zebra-tailed lizard	*Callisaurus draconoides*	X	X	X

Data Sources: 2001-2002 by the University of Arizona inventory (Flesch et al. 2007 and Flesch et al. 2006, respectively). Common and scientific names follow Brennan (2015); a number of changes have been made to scientific names since the Flesch et al. reports.

[1] Species not detected during sampling in 2001-2002, but listed in the report as being recorded during earlier surveys and/or a photo or voucher specimen exists.

[2] Listed as a Species of Greatest Conservation Need (SGCN, Tier 1a or 1b [out of 1a-1c]) with the State (AGFD 2012).

[3] Species was observed near Rincon Creek by park staff in 2001.

[4] Species was considered a candidate for listing under the Endangered Species Act (USFWS 2015a, c) until late 2015 (USFWS 2015b).

[5] Species used to be considered the Sonoran population of the desert tortoise (*Gopherus agassizii*), but USFWS (based on recent genetic analyses by researchers) now considers it as a separate species (USFWS 2013, USFWS 2015a).

[6] Species was documented (photographed and a specimen collected) for the first time in the park (in the TMD) by park staff in 2015.

TMD

In the TMD, four species of amphibians and 30 species of reptiles were recorded during the 2001-2002 surveys. Fifteen snake, 14 lizard, and one tortoise species accounted for the reptiles. The researchers detected 1,397 individuals using the four sampling methods, and 305 individuals by way of incidental observations. The most common species recorded during intensive and extensive surveys were tiger whiptail (*Aspidoscelis tigris*), zebra-tailed lizard (*Callisaurus draconoides*), and common side-blotched lizard (*Uta stansburiana*), and the most common snake was the Western diamond-backed rattlesnake (*Crotalus atrox*). Flesch et al. (2007) reported that they probably detected most of the species that occur in the district during their surveys. Only three additional species were documented in the TMD prior to the 2001-2002 surveys (see Table 4.17.4-1); these three species may have been missed by the surveys due to the timing of the surveys and/or the nature or abundance of the species (Flesch et al. 2007). The three non-native species have not been observed in the district. Flesch et al. (2007) reported that the non-native American bullfrog occurs in the Santa Cruz River, and although individuals may move into the district on occasion, sufficient habitat would not be available to them there. In general, the researchers found that species richness and abundance of lizards and snakes was greater in the bajada zone than in the mountains or the area between the two zones. Ten species of conservation concern have been recorded for the TMD.

Summary

The University of Arizona-NPS inventories (i.e., Flesch et al. 2006 and 2007) are the most comprehensive surveys of herpetofauna to date in the park, and they provide a firm baseline for future monitoring and assessment. However, the surveys are now more than 10 years old, and we have no comparable efforts upon which to judge current condtion of species occurrence. Therefore, overall, current condition (species occurrence) of amphibians and reptiles at the park is unknown. It should be noted, however, that park staff informally monitor reptiles and amphibians at the park on a continuing basis. Observations made and photographs taken by park staff and visitors are maintained by Don Swann (Don Swann, Saguaro NP, pers. comm.).

Population Status/Abundance for Selected Species: Desert tortoise

For this assessment of species status for the Sonoran desert tortoise, we used data from Gray and Steidl (2015), Zylstra et al. (2010), and Wirt and colleagues (as reported in Zylstra and Swann 2009; Table 4.17.4-2).

The most recent estimates of Sonoran desert tortoise density are for 2010-2011 (Gray and Steidl 2015). These researchers estimated density using 50 4-ha plots. The plots were located in both the Rincon and TMD and were between 750 and 1,200 m in elevation. Twenty-five plots were surveyed in 2010, and 25 different plots were surveyed in 2011 (15 in the TMD and 35 in the RMD). The density of adult tortoises averaged 0.35 individuals per hectare (SE = 0.04) across all the plots. Although not a focus of this condition assessment, the researchers found that the density of tortoises was approximately the same in areas with no buffelgrass cover and in those with 25% buffelgrass cover (Gray and Steidl 2015).

Based on the Zylstra et al. (2010) work, tortoise density in 2005 in the RMD (in the western section of the district below 1,150 m in elevation) was estimated to be 0.36 adults per hectare (or 36 adults per km^2). That for tortoises in 2006 in the TMD (in the entire district below 1,150 m in elevation) was estimated to be 0.23 adults per hectare (or 23 adults per km^2). The density estimate for the entire park (i.e., in the areas surveyed) for those years was estimated as 0.30 adults per hectare. Additionally, Zylstra et al. (2010) found that tortoise occupancy of 3-ha plots across both study areas was 0.72.

Density estimates from the 1990s, using a different method (mark-recapture) in three specific areas, are also shown in the table. Zylstra et al. (2010) reported that their estimates were similar to others for southern Arizona using distance-sampling and mark-recapture, and they are within the wide range

Table 4.17.4-2. Estimates of desert tortoise density (and occupancy) for 2010-2011, 2005-2006 and 1996-1997 in Saguaro NP.

Source	District	Year	Specific Location/ Area	Tortoise Density	Other Information/ Notes
Gray and Steidl (2015)	Both combined	2010-2011	Plots located between 750 & 1,200 m elevation	0.35 adults/ha (or 35 adults/km^2) [Average across all plots]	SE = 0.04
Zylstra et al. (2010)	RMD	2005	Western section of RMD below 1,150 m elevation	0.36 adults/ha (or 36 adults/km^2)	95% CI = 0.14-0.58 (per ha)
	TMD	2006	Entire district below 1,150 m	0.23 adults/ha (or 23 adults/km^2)	95% CI = 0.03-0.43 (per ha)
	Overall (across study areas)	2005 and 2006	see above	0.30 adults/ha (or 30 adults/km^2)	95% CI = 0.17-0.43 (per ha)
			-----	-----	Occupancy of 3-ha plots across study areas = 0.72 (95% CI = 0.56-0.89)
Wirt and colleagues (reported in Zylstra and Swann 2009)	RMD	1996 and 1997	Javelina Picnic Area plot	39-49 adults/ km^2 (or 0.39-0.49 adults/ha)	Only a range was reported by Zylstra & Swann (2009) for these years and two areas
	TMD		Panther Peak plot		
	RMD	1996	Mother's Day Fire plot	33 adults/km^2 (or 0.33 adults/ha)	-----

of estimates from long-term tortoise sampling using mark-recapture in the Sonoran Desert in Arizona.

Although this is only a general, qualitative comparison of density estimates of tortoises from the mid-1990s to 2010-2011, it does not appear that there have been any substantial changes in estimated density. Although the most recent estimates (both districts combined) are now approximately five years old, the Sonoran desert tortoise is a long-lived species (and five years is not a substantial amount of time relative to its life span). We consider current condition under this indicator to be good at this time.

Also note that the condition of the desert tortoise is addressed in other contexts in this overall section on herpetofauna. For example, the tortoise is discussed under indicators on disease, threats due to non-native species (domestic/feral dogs), and habitat connectivity.

Population Status/Abundance for Selected Species: Lowland Leopard Frog

Zylstra et al. (2013) presents a number of important pieces of information on the lowland leopard frog. However, some of this information is outside of the scope of this condition assessment, so we focus here on estimated occupancy of pool complexes and drainages, and estimated abundance of adult frogs in five drainages.

In 1996, the researchers classified 398 pools in 17 drainage segments, as well as four tanks, as potential habitat for the lowland leopard frog (Zylstra et a. 2013). Drainage segments consisted of an average of 23.2 (6.5 SE) pools. Adjacent pools were an average of 123 m (403.5 ft) apart, and ranged from 0 to 1,396 m (4,580 ft) apart. Based on distance between pools, pools were grouped into 105 pool complexes, with an average of 3.2 (0.3 SE) pools per complex.

Based on their analyses of the survey data for nine drainages, Zylstra et al. (2013) found that occupancy of drainages varied from 0.55 to 0.95 during the study period; however, they found no evidence of a linear trend over

time (Figure 4.17.4-2, bottom graphic). They modeled occupancy in 71 pool complexes in nine drainages, and found that occupancy varied from 0.27 to 0.55 (Figure 4.17.4-2, top graphic), and again, there was no evidence of a linear trend over time. For abundance analyses, they included data for 34 pool complexes in five drainages and found that adult frog abundance per drainage each season varied from 1 to 367 over the study period. Although abundance varied, there was no strong evidence of a linear trend over time in any of the drainages (Figure 4.17.4-3).

Although occupancy and abundance of lowland leopard frogs in the study varied substantially over space and time, estimated trends were not significant. Researchers also found that complexes or drainages with more pools experienced lower local extinction rates of frog populations, and that these rates decreased as water availablity increased. As Zylstra et al. (2013) summarized it,

> "in contrast to other leopard frog populations in the desert southwest, these long-term data suggest that populations of lowland leopard frogs in and near Saguaro NP are not declining precipitously but are fluctuating widely in response to variation in environmental conditions. Clearly, availability of surface water is integral to population dynamics of lowland leopard frogs, as even with a fairly coarse measure of water availability, we observed strong associations between surface water and rates of extinction, recruitment, and survival."

The most recent data used in the analyses are from 2011; although data since 2011 have been collected, they have not been analyzed and published to date (as of February 2016). However, current occupancy rates of drainages are approximately equal to or lower than the lowest rates observed between 1996

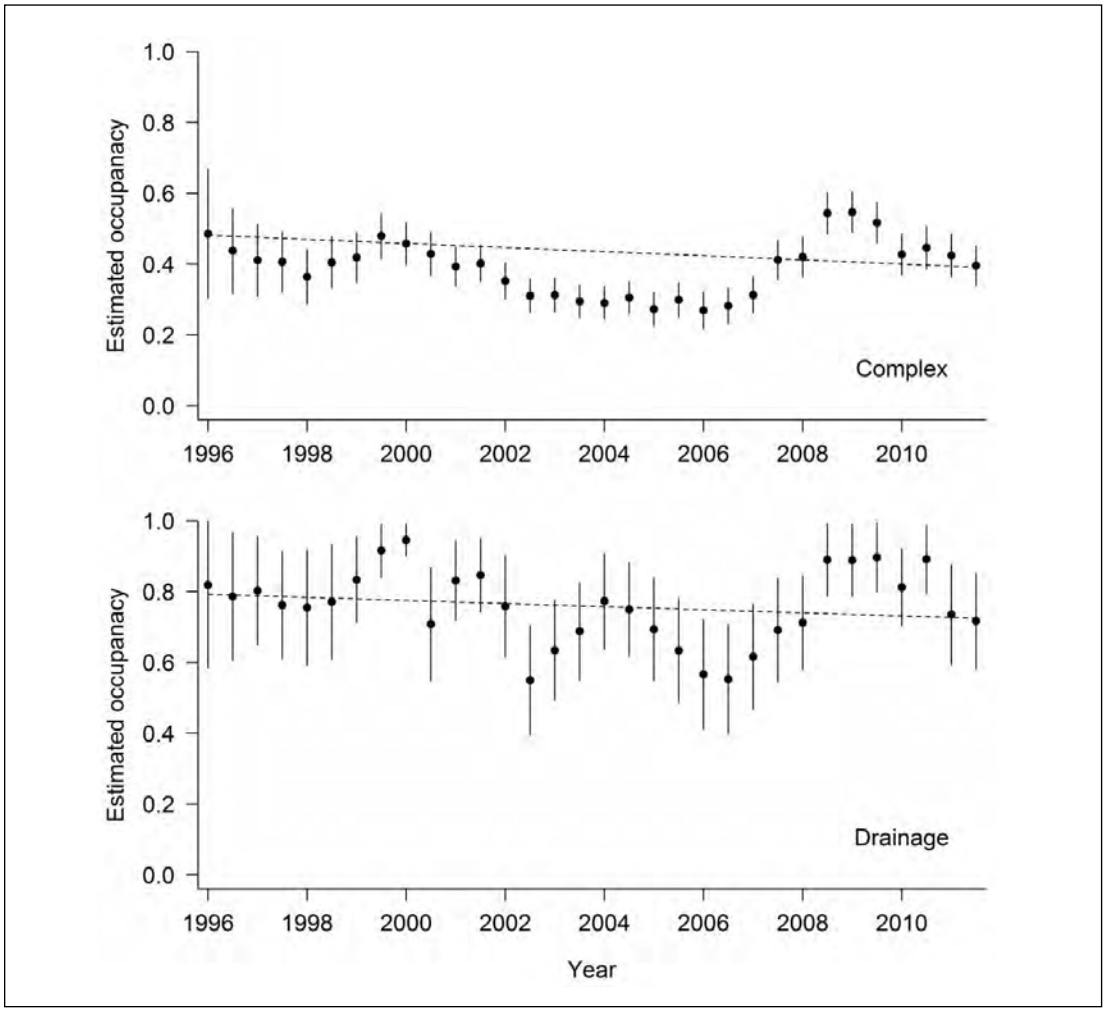

Figure 4.17.4-2. Estimated occupancy (+/- 1 SE) of pool complexes and drainages in the Rincon Mountains each spring and fall season between 1996 and 2011. Estimated trends in occupancy (dashed lines) were not significant at the complex (P-value = 0.70) or drainage scale (P-value = 0.65). Figure Credit: Zylstra et al. (2013).

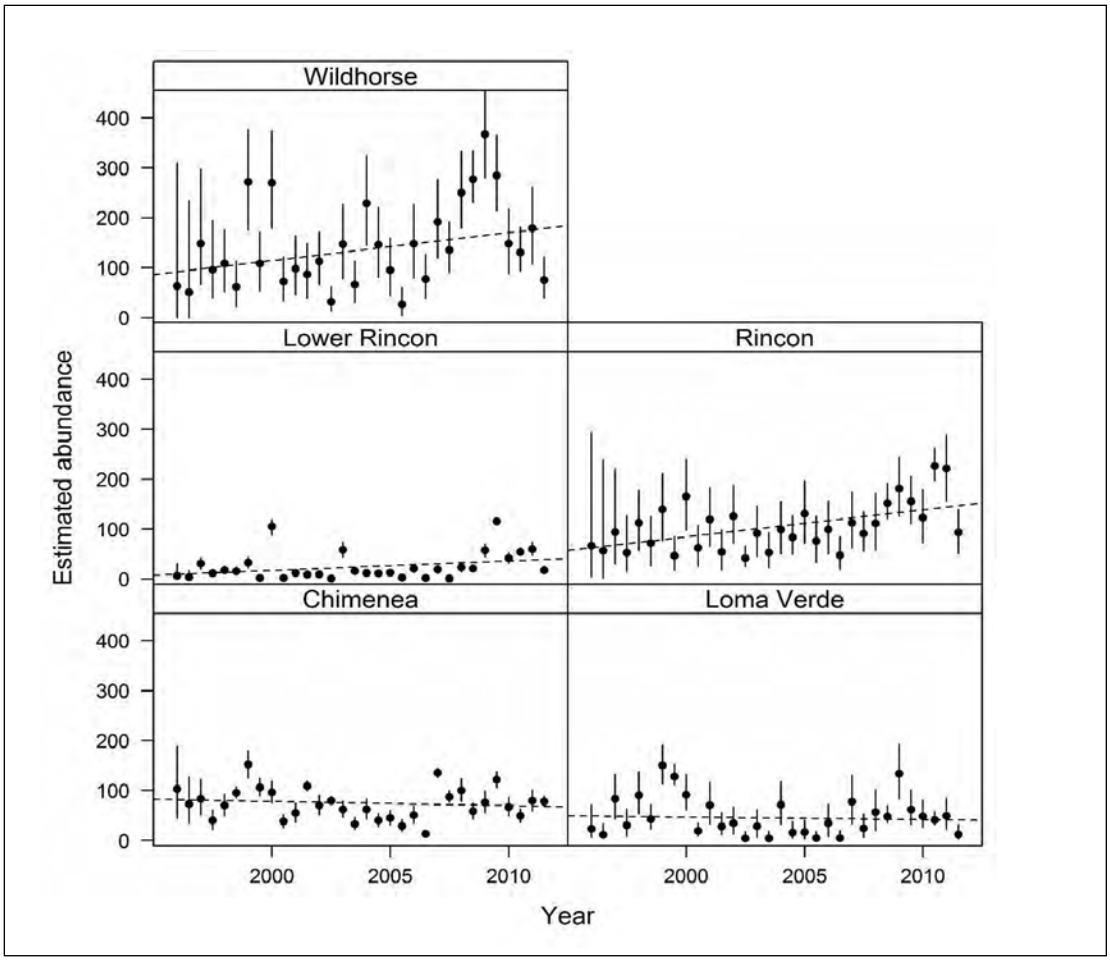

Figure 4.17.4-3. Estimated abundance of adult frogs (with 95% CI) in each of five drainages in the Rincon Mountains during spring and fall seasons between 1996 and 2011. Estimated trends in abundance (dashed lines) were not significant (all P-values >0.10). The "Rincon" drainage includes pools in Rincon proper and Rincon North; the "Loma Verde" drainage includes pools in Loma Verde proper and Loma Verde South. Figure Credit: Zylstra et al. (2013).

and 2011 (Erin Zylstra, University of Arizona, School of Natural Resources, pers. comm.). It is unclear as to whether this is part of normal fluctuations or part of a more systematic decline (Erin Zylstra, University of Arizona, School of Natural Resources, pers. comm.). Based on the available information, we consider the population status/abundance/ occupancy of the lowland leopard frog in the RMD to be of moderate concern. Although a decreasing trend in occupancy or abundance was not observed from 1996-2011, the species is uncommon and vulnerable in the park, and with its wide population fluctuations in response to variations in environmental conditions, could be considered at risk of extirpation.

Also note that the condition of the lowland leopard frog is addressed in other contexts in this overall section on herpetofauna. For example, the species is discussed under indicators on disease, threats due to invasive species, and habitat connectivity.

Occurrence of Herpetofauna Diseases: Upper Respiratory Tract Disease (and Causative Agent)

In her study of URTD in Sonoran desert tortoises, Jones (2008) found that antibody prevalence was highest in suburban sites in the Tucson area, in which tortoises were 2.3 times more likely to show exposure to *M. agassizii* compared to tortoises in other categories (high-visitor use and remote sites). However, there was a high percentage of desert tortoises showing exposure to *M. agassizii* in all categories she studied, suggesting that there may be a link between urbanization and URTD (Jones 2008). Her study results also suggested that captive tortoises may serve as a reservoir of *M. agassizii* for wild populations, especially for tortoises living at the interface of urban-desert areas.

Of the three sites sampled in the national park, one was in the RMD and two were in the TMD. Of 25 turtles sampled in the RMD (Mother's Day Fire site), antibodies to *M.*

agassizii were present in 13 of the samples (tortoises), absent in eight of the samples, and suspect in four. Nine of the tortoises showed clinical signs of the disease. For the first site in the TMD (Panther Peak Wash), of 19 tortoises sampled, antibodies to *M. agassizii* were present in 10 of the samples (tortoises), absent in eight of the samples, and suspect in one. Eight tortoises showed clinical signs of the disease. For the second site in the TMD (Visitor Center), of four tortoises, antibodies to *M. agassizii* were present in one of the samples, and absent in three of the samples. One tortoise showed symptoms of the disease. All of these three sites were either in the suburban category or high-visitor-use category.

Although this study did not focus on Sonoran desert tortoises in Saguaro NP alone, it provided information on the occurrence of URTD and its causative agent in the park and surrounding area, providing more evidence that *M. agassizii* is widespread among desert tortoises in the Sonoran Desert (Jones 2008).

These data are now more than 10 years old, so current prevalence of *M. agassizii* or the disease are unknown. However, given that once a tortoise has been infected with *Mycoplasma*, it can remain a carrier for life (Jacobson 1992), and outbreaks of the disease can potentially occur with added environmental stresses, human impacts, and the escape or release of captive ill tortoises (Jacobson et al. 2014), we chose to take a somewhat conservative approach and determine a condition (rather than conclude an unknown condition). We consider condition for this indicator/measure to be of moderate concern. If sampling within the park had been more widespread (with similar results), we may have considered condition to be of significant concern. Additionally, as stated previously, there have been no reports of population level declines due to the disease in Sonoran desert tortoises.

Occurrence of Herpetofauna Diseases: Chytridiomycosis (and Causative Agent)

From her sampling in 2008-2010 in the Rincon Mountains, Ratzlaff (2012) found that both amphibian species sampled were infected with *Bd* in all three canyons sampled (although levels of prevalence and infection intensity varied). She found that, when averaged across all sites, prevalence and infection intensity was higher for the lowland leopard frog (Figure 4.17.4-4, left) than for the canyon tree frog (Figure 4.17.4-4, right) (prevalence of 0.49 [95% CI = 0.44-0.54] for lowland leopard frog and 0.23 [95% CI = 0.20-0.26] for canyon tree frog; mean number of zoospores 2,461 [95% CI =1,447-4,185] for lowland leopard frog and 274 [95% CI =172-436] for canyon tree frog). Results for the lowland leopard frog included that prevalence and infection intensity of *Bd* were associated with location and the interaction between location and elevation, and that infection intensity was correlated with elevation. Results for the canyon tree frog included that prevalence and infection intensity were associated with location and season, as well as the interactions of location and elevation and location and season. The interaction between location and life stage was also important in the prevalence of *Bd* in the canyon tree frog. Among the three canyons sampled, amphibians in Wildhorse Canyon had the relatively lowest prevalence and infection intensity of *Bd*. For lowland leopard frogs only, prevalence of *Bd* for the

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Figure 4.17.4-4. Lowland leopard frog (left) and canyon tree frog (right).

three canyons was as follows: for Wildhorse, 0.05 (95% CI = 0.03-0.09); for Chimenea, 0.81 (95% CI = 0.74-0.87); and for Tanque Verde, 0.92 (95% CI = 0.83-0.96). Infection intensity followed the same general pattern.

In consideration of our reference conditions, we consider condition under this measure to be of moderate concern. Chytrid fungus has been found in at least two amphibian species in the park, and the prevalence was relatively high for lowland leopard frogs in at least two of the locations sampled (although one was north of the park). We do note, however, that these data area now at least five years old. Because this measure deals with disease, we chose to take a conservative approach, judging the condition to be of moderate concern (and not unknown at this time). We do however, have somehwat lower confidence in the assessment due to the lack of more recent data. As discussed in a previous section of the condition assessment, although occupancy and abundance of lowland leopard frogs have varied over the 16-year period for which data are available (1996-2011), they have not declined precipitously as have other populations in the Southwest (Zylstra et al. 2013). Ratzlaff (2012) pointed out that no *Bd*-related declines have been reported in either Chimenea or Wildhorse canyons since monitoring began in 1996. Population declines in Tanque Verde Canyon (north of the park) in 2010, however, may have been related to infection with *Bd* (Ratzlaff 2012).

Presence of Non-native Species: Effects on Herpetofauna

Domestic or feral free-ranging dogs

Zylstra (2008b) found that desert tortoises in the TMD appeared to be more affected by free-ranging dogs than tortoises in the RMD. In the TMD, 15.0% of tortoises (17 out of 113) had injuries that were considered likely caused by dogs, and additional tortoises (five) had injuries that were considered possibly caused by dogs. In the RMD, 0.8% of tortoises (1 of 123) had injuries that were considered likely caused by dogs, and additional tortoises (three) had injuries that were possibly caused by dogs. There were two areas of the TMD that had relatively higher proportions of tortoises with injuries possibly or likely caused by dogs; these were the area just south of Panther Peak (44.4% of tortoises with injuries possibly or likely caused by dogs) and the area south of the visitor center (between Kinney and Mile Wide Roads; 37.5% of tortoises).

The author also found that adult male tortoises were more likely than females to have injuries likely caused by dogs, and that the probability of a tortoise having injuries likely caused by dogs was higher for tortoises closer to development compared to those in more remote areas. Male tortoises may be more likely to encounter free-ranging dogs because they often have larger home ranges compared to females (Zylstra 2008b). Finally, it also appeared that the proportion of tortoises with injuries was greater in 2006-2007 compared to the earlier period (1996-1997).

Even though the data used for the Zylstra (2008b) study are nearly a decade old, we expect that the situation has not changed substantially for the better in the last several years. This is because development outside of the park has continued over this time period. Additionally, Swann and Perkins (2013) observed domestic dogs in the TMD during their 2011-2012 study using camera traps, and park staff have documented dogs via the cameras more recently (Don Swann, Saguaro NP, pers. comm.).

Other Non-native Species

As discussed in the Species Occurrence section, the Mediterranean house gecko was reported only in buildings in the administration area of the RMD (Flesch et al. 2006). These non-native geckos were not observed during the 2001-2002 field sampling, but park staff posessed a photo and voucher specimen of them. It was also reported that the species did not appear to pose a serious threat to native herpetofauna at the time, and this appears to remain the case. They appear to be confined to only a few buildings, and they are not observed very often (Don Swann, Saguaro NP, pers. comm.).

As also mentioned in the Species Occurrence section, the American bullfrog was observed in the RMD in the decade prior to the release

of the 2006 survey report, and at that time it was reported "only during wet summers, and then only as dispersing juveniles that do not persist (Saguaro NP, unpublished records)" (Flesch et al. 2006). For the TMD, Flesch et al. (2007) reported that the non-native species occurs in the Santa Cruz River, and although individuals may move into the district on occasion, sufficient habitat would not be available to them there. In 2014, Erin Zylstra captured and removed two adult bullfrogs from the park, and believes they occur in the park occasionally (but pose little threat; Erin Zylstra, University of Arizona, School of Natural Resources, pers. comm.).

The non-native tiger salamander that has been recorded in the park is very rare (Don Swann, Saguaro NP, pers. comm.).

Finally, the feral hog is not considered a threat to native species of amphibians and reptiles in Saguaro NP at the present time. This is because it is currently not known to occur within or immediately near the park. However, as feral hogs increase in distribution or abundance within Arizona and adjacent states (Verde Independent 2012, Cruz 2014), the species may become an issue for the park in the future. Feral hogs have been detected on wildlife cameras near Cascabel, which is along the San Pedro River directly east of the Rincon Mountains (Don Swann, Saguaro NP, pers. comm.). Feral hogs are a concern for a number of reasons. The activities of feral hogs can lead to negative effects on habitat and wildlife. The hogs' extensive rooting, trampling, and wallowing activities disturb soil and vegetation, leading to damage to native plants, compaction of soils, and increased turbidity in riparian areas (Hamrick et al. 2011). Reduced water quality from turbidity and bacterial contamination (from feces) can affect a variety of native aquatic life, such as fish, amphibians, and insect larvae. Feral hogs may also compete with wildlife, such as deer, for space and food items (e.g., acorns), as well as prey on native reptiles, amphibians, small mammals, bird eggs, and, occasionally, birds (Taylor 2003, Hamrick et al. 2011).

Summary- Effects on Herpetofauna from Non-Native Animal Species

Based on the preceding discussion, the main concern for native herpetofauna from non-native species at the current time is that for desert tortoises from feral or domestic free-ranging dogs. Although harassment, injuries, or deaths of other native reptiles or amphibians due to dogs within the park have not been reported, it is possible that they also occur. Overall, we consider condition under this indicator to be of moderate concern at this time (good in the RMD and of moderate concern in the TMD).

Habitat Corridors and Connectivity: Connectivity of Habitat

The primary source of information used to assess condition under this indicator/measure was Perkl et al. (2015), which focused on connectivity with the surrounding landscape. Here we do not present the same level of detail for the results of the Perkl et al. analysis as we did in the Mammals section, and we refer the reader to that section for more detail (including a map). Based on corridor modeling for the baseline scenario/current condition, high naturalness exists to the east and south of the RMD; lower naturalness exists to the north, and, especially, to the west of the district (City of Tucson; Perkl et al. 2015). The corridor modeling conducted by Perkl et al. (2015) indicated four corridors (for the RMD) that were relatively direct routes to areas of protected land, although not necessarily short, and one corridor between the RMD and the TMD (and Tucson Mountain Park). Under the projected scenario corridor modeling results (for future landscape conditions) there were some changes in these corridors for wildlife. The greatest change is that the connection between the RMD and the TMD and Tucson Mountain Park is expected to disappear. A significantly different and longer corridor between these areas would take its place.

Under the baseline scenario/current condition for the TMD, low naturalness occurs to the east (City of Tucson), and in places to the northeast and northwest, of the district (Perkl et al. 2015). The corridor modeling indicated only a few corridors involving the TMD,

within one being the indirect route between the two districts of the park described above. The projected scenario corridor modeling results (for future landscape conditions) involving the TMD also indicated some changes in these corridors. Again, the corridor that would connect the two districts would disappear. As described above, however, a new, longer corridor was indicated. Also with the projected scenario, except for the Tucson Mountain Park and the Ironwood Forest NM to the west, low naturalness/development would essentially encircle the district.

Overall, the corridors from the baseline modeling that would disappear under the projected modeling represent "areas of present day connectivity that are most threatened by projected development" (Perkl et al. 2015). The authors reported that nearly 80% of the total network would be altered from the original baseline corridors by projected urban growth. Also, from the baseline corridors network to the projected corridors network, there would be a 40.8% increase in size, which means that wildlife would need to make longer and less direct movements within the corridor network.

In assessing this indicator/measure, we also reviewed a report focusing on the desert tortoise. This information source looked at movements between populations of Sonoran desert tortoise in southern Arizona, with a population in the RMD being the most southern of the populations studied. Edwards et al. (2004) took blood samples from tortoises (170) in nine different mountain ranges to look at the amount of genetic differentiation among the populations. These authors stated that the loss of habitat is probably the greatest threat to populations of this species in and near areas that are dramatically growing (e.g., Tucson and Phoenix), citing the substantial area of habitat in the foothills of the Rincon, Tucson, Santa Catalina, and Tortolita Mountains that had been recently developed. Development, including roads, also creates barriers to movement of tortoises and other animals, which could limit gene flow among populations.

Edwards et al. (2004) found that all but two pairs of mountain ranges they examined had man-made barriers that would limit or prevent natural movements by tortoises. One tortoise with a radio transimitter moved 32 km (19.9 mi) during the study (over the course of a year; Edwards et al. 2005) from the Rincon Mountains to an adjacent range; however, several man-made barriers (e.g., a highway, fences, and railroad tracks), which researchers helped her cross, were in her path. Using their genetic analyses, the researchers learned that tortoises in the area they studied dispersed historically between mountain ranges (allowing for the flow of genetic material), and that movements between populations may be vital in enabling small tortoise populations to persist. Therefore, they suggested the first step in maintaining the populations is maintaining landscape connectivity (Edwards et al. 2004). This study demonstrates that the Sonoran desert tortoise is one of the herpetofauna species for which habitat connectivity is important, as well as providing support to the Perkl et al. (2015) analysis regarding the threats posed to habitat connectivity from development (even though the two studies did not have the same overall study area).

Finally, although we did not directly use the study to assess habitat connectivity, we examined the results of a study within Saguaro NP on road-killed animals (i.e., Gerow et al. 2010). Not surprisingly, the study showed that the roads in and along the boundaries of the park are affecting the connectivity of the habitat within the park and with adjacent areas, at least for some species. Gerow et al. (2010) conducted driving surveys for road-killed animals about once per week in each district on the total network of roads (27.3 miles [43.9 km] in the TMD, and 20.3 miles [32.7 km] in the RMD). Surveys were conducted for three years (1994-1996) in the TMD, and for four years (1996-1999) in the RMD. Gerow et al. (2010) estimated that an average of 29,377 (SE 6,807) vertebrates, or about 1.1 vertebrates/km/day (SE 0.24) were killed annually from 1994-1999 on the park's roads. Many more were killed in the TMD than in the RMD, and the majority of the roadkills were amphibians and reptiles. An average of more

than 12,000 reptiles and 12,000 amphibians were estimated to have died every year on the park's roads. Although these estimated numbers were from 1994-1999, more than 15 years ago, they are probably still relevant today because traffic on the roads within and along the borders of the districts has probably not decreased; if anything, the numbers have probably increased (especially on roads bordering the park and City of Tucson, and on Picture Rocks Road, a major commuter road [Monahan et al. 2013]).

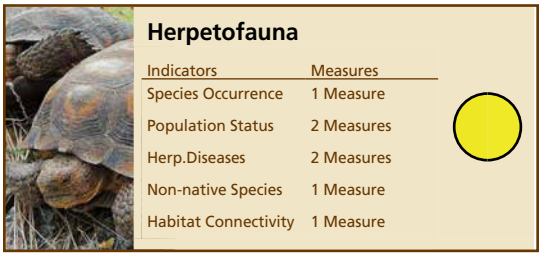
Summary of Habitat Connectivity for Herpetofauna

We believe the Perkl et al. (2015) report generally indicates that the current condition of connectivity for the RMD is good to moderate, while that for the TMD is of significant concern. For both districts, the modeled future level of connectedness with surrounding lands would decrease. Also, the corridors to the east of the RMD are vulnerable to future development, and that is a substantial long-term concern of the park (Don Swann, Saguaro NP, pers. comm.). If development in the San Pedro River corridor begins to increase rapidly, as it could in the future, it would eliminate the connectivity of the RMD to the mountain ranges to the east.

The study of Edwards et al. (2004) supports the case that connectivity of the park with surrounding lands is important and of concern. Although within the park, only tortoises in the RMD were included in their study, a site within the Tucson Mountains outside of the park was also used. This study showed that it is important for species such as the tortoise to make long-distance movements to allow the flow of genetic material between populations.

The Gerow et al. (2010) study also provides some information related to habitat connectivity, and it showed that amphibians and reptiles were most impacted (compared to other groups and measured by mortality) by roads within and bordering the park. Also, the fragmentation of their habitat, whether it results in mortality or not, is of concern.

Based on the sources of information described under this measure, we consider the condition of habitat connectivity for herpetofauna to be of good to moderate concern for the RMD and of significant concern for the TMD.



Overall Condition and Trend

To assess the condition of amphibians and reptiles at Saguaro NP, we used five indicators with one or two measures each. All five indicators and their measures are summarized in Table 4.17.4-3. It was somewhat challenging to determine an overall condition based on the different measures and their individual, varying conditions. We acknowledge that there is some subjectivity in our conclusions, but we attempted to base the analyses and their conclusions on the most recent information available and the reference conditions outlined previously.

Overall, we consider the condition of herpetofauna at Saguaro NP to be of moderate concern. Although condition under some measures was considered to be good (e.g., the effects of non-native species in the RMD), that of others was considered of moderate concern (e.g., URTD in Sonoran desert tortoise) or even of significant concern (i.e., habitat connectivity for the TMD). A few of the measures were considered to have an unknown condition due to a lack of current data; however, valuable information exists related to the measures for use in future assessments. Overall, based on this set of indicators and measures, we judged condition to be of moderate concern.

We do not have sufficient information to justify an overall trend in condition, but as population growth and development continue to increase in the Tucson area, which is projected to occur (e.g., Monahan et al. 2013), more pressure will be placed on protected areas (and their wildlife) in the region, and this includes the

Table 4.17.4-3. Summary of the herpetofauna indicators, measures, and condition rationale.

Indicator	Measures	Condition	Rationale for Condition
Species Occurrence:	Presence or absence of herpetofauna species	RMD: Unknown TMD: Unknown	We considered condition to be unknown in both districts because no group-wide, comprehensive surveys have been conducted in the park since 2001-2002. Of 61 species of amphibians and reptiles recorded during the surveys (or during past studies), 46 species were documented in the RMD and 34 species were documented in the TMD. Out of the 61 species, 9 are amphibians and 52 are reptiles. Three of the 61 species are non-native, including the American bullfrog. Fifteen of the species recorded are considered SGCN with the State.
Population Status / Abundace of Selected Species	Sonoran desert tortoise	Good	Estimates of density for the tortoise are available from three different studies (from 1996-1997, 2005-2006, and 2010-2011). There are differences in the methods of the three studies, but in general, there do not appear to be any obvious concerns with density (i.e., substantial changes) over these years. Zylstra et al. (2010) estimated density and occupancy and found their density estimates to be similar to others for southern Arizona using similar methods. They reported a density estimate for the entire park (in the areas surveyed) of 0.30 adults per hectare and an occupancy estimate in 3-ha plots across both study areas of 0.72. The estimated average density from 2010-2011 was 0.35 tortoises per ha across all the plots.
	Lowland leopard frog	RMD: Moderate Concern TMD: NA	Based on 16 years of monitoring of lowland leopard frogs in the park (RMD), as well as observations on occupancy and abundance from the last few years (2011-2015), condition is considered to be of moderate concern. Zylstra et al. (2013) reported 1) estimates of occupancy of drainages and pool complexes, and 2) abundance in 34 pool complexes. Although occupancy and abundance of lowland leopard frogs in the study varied substantially over space and time (in response to environmental conditions), estimated trends were not significant. However, it is unclear whether occupancy rates since 2011 (in drainages) are part of normal fluctuations or part of a more systematic decline. Also, the species is uncommon and vulnerable in the park.
Occurrence of Herpetofauna Diseases	Upper Respiratory Tract Disease in Desert tortoise	Moderate Concern	Desert tortoises were sampled in the park for evidence of antibodies to *M. agassizii* and for clinical signs of URTD. A total of 48 tortoises were sampled in three sites in the park in 2002-2005 (Jones 2008). At one site in the RMD, 52% of tortoises had antibodies to *M. agassizii*, and at two sites (combined) in the TMD, 47.8% of tortoises had antibodies. For the three sites combined, 37.5% of animals showed clinical signs of URTD. Although these data are more than 10 years old, we chose to assign condition (moderate concern) because once a tortoise has been infected it can remain a carrier for life. We have only moderate confidence in our assessment due to the lack of more recent data.
	Amphibian chytrid fungus (*Bd*)	RMD: Moderate Concern TMD: NA	Sampling in 2008-2010 in the Rincon Mountains revealed that both amphibian species tested showed infection with *Bd* in all three canyons sampled (Ratzlaff 2012). Levels of prevalence and infection intensity varied. When averaged across all sites, prevalence and infection intensity was higher for the lowland leopard frog than for the canyon tree frog. Among the canyons sampled, Wildhorse had the relatively lowest prevalence and infection intensity of *Bd*. For leopard frogs, Chimenea and Tanque Verde canyons had substantially higher prevalence and infection intensity than Wildhorse. Sixteen years of leopard frog monitoring in the park (1996-2011) has not pointed to population decreases due to the amphibian chytrid fungus. We consider condition to be of moderate concern, but have only moderate confidence due to the lack of current data.
Presence of Non-native Species	Effects on herpetofauna	RMD: Good TMD: Moderate Concern	Three non-native herpetofauna species were discussed, plus the domestic/feral dog. The main species of concern at this time is the domestic/feral dog and its impact on the desert tortoise. Based on 2005-2007 sampling, desert tortoises were more affected by free-ranging dogs in the TMD than in the RMD where 15% and 0.8% of tortoises, respectively, had injuries that were considered likely caused by dogs; additional animals had injuries possibly caused by dogs.Two areas of the TMD (area south of Panther Peak and south of the visitor center) had relatively higher proprtions of tortoises with injuries. Injuries were higher in 2006-2007 compared to an earlier period. The feral hog was also discussed, but does not occur in the park.

Table 4.17.4-3. Summary of the herpetofauna indicators, measures, and condition rationale continued.

Indicator	Measures	Condition	Rationale for Condition
Habitat Connectivity and Corridors	Habitat connectivity within the landscape	RMD: Good to Moderate Concern TMD: Significant Concern	Connectivity with the surrounding landscape is good to moderate for the RMD. Based on Perkl et al. (2015), a number of modeled corridors exist and high naturalness exists to the east and south (except for near I-10). The modeled corridor that would be projected to change the most with future development is the one that connects the district to the TMD. Condition for the TMD is of significant concern. More development surrounds the district, and this is projected to increase in the future. In addition to its location adjacent to Tucson Mountain Park, the district currently has two modeled corridors (one of which connects it to RMD). Under the projected scenario, this corridor would disappear and be replaced by a longer, more circuitous route. As taken into account with the projected scenario modeling, negative trends are expected to continue.

two park districts. In their study of mule deer and collared peccary in the RMD, Bellantoni and Krausman (1990) summarized the situation a number of years ago: Human population growth and development of lands in the vicinity of Saguaro NP is leading to a decrease in wildlife habitat outside the park, degradation or elimination of travel corridors for wildlife to and from the park, a decrease in wildlife outside of the park, and fragmentation of the habitat that remains.

Level of Confidence/Key Uncertainties

Amphibians and reptiles are an interesting and significant component of the wildlife at Saguaro NM, and they have been the subject of a number of surveys and studies over the last 20 years. Although we based our assessment on a number of these studies, there are some uncertainties related to our assessment. The main reason for uncertainty is that in several cases where studies and/or monitoring has been conducted, the work has not been conducted in the last few years (or longer). This does not take away from the value of the information contained in the studies, but it leads to somewhat lower confidence in our judgement of current condition. Because we have a number of indicators and measures in this assessment, we consider overall confidence to be medium to high.

4.17.5. Sources of Expertise

Although no outside experts were initially consulted for this resource topic, Erin Zylstra, University of Arizona, School of Natural Resources, reviewed the draft assessment and provided comments. Ms. Zylstra is a PhD candidate studying lowland leopard frog demographics in relation to climate and amphibian disease, and she received her MS working on occupancy analysis of desert tortoise populations. The section was also reviewed by Don Swann, biologist with Saguaro NP. The assessment was based on studies and monitoring conducted for the national park, and was written by Patty Valentine-Darby.

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A cactus ranger netting invertebrates during Saguaro National Park's 2014 Bioblitz.

Chapter 5: Summary of Natural Resource Condition Assessment Findings

5.1. NRCA Findings and State of the Park Reporting

Saguaro National Park's (NP) Natural Resource Condition Assessment (NRCA) scoping workshop was held in conjunction with the park's State of the Park (SotP) workshop. As part of the stewardship of national parks for the American people, the National Park Service has begun to develop SotP reports to assess the overall status of each park's resources.

The key purposes of each SotP report are to:

- provide to visitors and the American public a snapshot of the status and trend in the condition of a park's priority resources and values;
- summarize and communicate complex scientific, scholarly, and park operations factual information and expert opinion using non-technical language and a visual format;
- highlight park stewardship activities and accomplishments to maintain or improve the SotP; and
- identify key issues and challenges facing the park to help inform park management planning (NPS 2012).

The NRCA summarizes the scientific information for Saguaro NP's SotP natural resource conditions, which are presented in Table 5.1-1. Condition findings for each individual resource are presented in Tables 5.1-2 - 5.1-17 (refer to the park's SotP full report for more detailed information).

In summary, 87.5% (14 /16) of the natural resource conditions were considered to be of moderate concern or worse. The only resources evaluated as in good condition were birds and biodiversity. Although, saguaro cactus condition was assessed as good to moderate. Landscape-scale resources, air quality, and Rincon Creek water quantity were considered most impacted and are of significant concern.

Table 5.1-1. State of the Park natural resource condition summary.

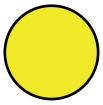
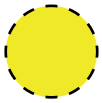
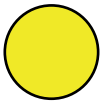
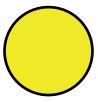
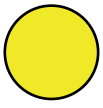
Priority Resource or Value	Condition Status/Trend	Rationale
Natural Resources		
Viewshed		Viewsheds are considered an important part of the visitor experience, and features on the landscape influence the enjoyment and appreciation of a park. One indicator, scenic integrity, and three measures were used to evaluate the viewshed from seven key observation points. Conditions ranged from good to moderate concern, depending upon whether the observer was facing into or away from the park. Housing and road densities are high and scenic conservation potential for viewshed preservation is of moderate to significant concern for an overall condition rating of moderate concern.
Night Sky		Quantitative measures of sky brightness (all-sky light pollution ratio, maximum vertical and horizontal Illuminance, and zenith sky brightness) and a qualitative assessment of sky quality (the Bortle Dark Sky Scale) were used to assess the condition of the night sky at multiple locations in Saguaro NP. Based on the park's non-urban character and the preponderance of wilderness in the park, the night sky resource condition at Saguaro NP is poor and warrants significant concern.
Soundscape		Two indicators with three measures were used to assess the condition of the soundscape. Acoustical monitoring data used were from 2016 , as well as 2011 and 2004/2005. Based on the sites monitored and the information available, the soundscape was determined to be of moderate to significant concern, with an unknown trend.
Air Quality		For assessing the condition of air quality, we used three air quality indicators. We consider the overall condition of air quality to be of moderate to significant concern, with unchanging trends for ozone and an improving trend for visibility on both the clearest and haziest days at both monitoring locations. Trends for the four wet deposition measures could not be determined since no monitoring sites are located within the requisite distances to be representative of the trends at the park.
Surface Water Quantity - Middle Reach of Rincon Creek		For assessing surface water quantity in the middle reach of Rincon Creek, we used one indicator with four measures. The overall condition for this resource warrants moderate to significant concern, and the condition is deteriorating None of the measures were considered good based on the reference conditions. Assigning conditions was somewhat difficult because of high variability in the data, but all measures indicate a trend toward drier conditions in recent years.
Tinajas, Springs, and Seeps		For assessing water availability and quality in tinajas and springs in Saguaro NP, we used two indicators with a total of ten measures. Overall, the condition of tinaja and spring water quality is largely unknown. Both trend in water presence and water persistence in tinajas are in good condition, but prolonged drought periods warrant significant concern. Percent sediment volume is in good to moderate concern condition and has improved over time. The overall trend could not be determined and confidence is low as a result of insufficient data.
Groundwater Tucson Mountain District		Three indicators and three measures were used to assess TMD's groundwater resource. All three measures were assessed as moderate concern. Current water levels at the park's monitoring well are similar the reference period and overall flow follows a north to south trajectory but several factors create much uncertainty. The shallow well conditions are variable, and one of the wells can no longer supply during the driest times. The overall trend is stable and the confidence level in the assessment is medium.
Groundwater Rincon Mountain District		Six indicators and measures were used to assess Rincon Mountain District's groundwater resource. Multiple unique groundwater systems are present within the boundaries of the district. Conditions for most of these systems were assessed as moderate concern, with the exception of the detachment-fault related groundwater, which was of significant concern and the upper-plate system, which is unknown. Trends and confidence levels varied depending upon the groundwater system, but overall the trend is deteriorating and the confidence level in the assessment is medium.

Table 5.1.1. State of the Park natural resource condition summary continued.

Priority Resource or Value	Condition Status/Trend	Rationale
Biodiversity		For assessing biodiversity we used four indicators with between three and four measures each. The overall condition of biodiversity is considered good. Species richness for major taxonomic groups is high and many native Arizona species are found within the park and with the exception of plants, few non-native species occur in the park. However, six mammal species and a number of plant species have been extirpated. The loss of plants and mammals suggests concerns for other groups and warrants the deteriorating condition assigned to this resource.
Saguaro Cactus		We used three indicators (with five measures total), as well as the >70 years of research on the species in the park, to assess the condition of saguaro cacti. The indicators focused on saguaro population status/health, historic integrity and appearance of saguaro cacti on the landscape, and habitat availability and quality. Condition under the various measures varied, with the overall condition considered to be good to moderate concern. Trends varied, although three measures were considered to be improving.
Desert and Riparian Vegetation and Soils		Measures of plant community resilience, erosion hazard, fire hazard, non-native plants, rare plants, and vegetation and land use around Rincon Creek were used to assess the condition of vegetation and soils occurring below 1,372 m (4,501 ft) in the park. The overall condition warrants moderate concern. While some measures indicate good condition (i.e., tree and shrub cover; grass and forb cover) others indicate significant issues (i.e., buffelgrass occurrence). Because of the lack of trend data for most measures, we did not assign an overall trend for this assessment.
Grasslands, Woodlands, and Forests Vegetation and Soils		Measures of plant community resilience, erosion hazard, departure from fire return interval, forest health, non-native plants, and rare plants were used to assess the condition of vegetation and soils occurring above 1,372 m (4,501 ft) in the RMD. The overall condition warrants moderate concern. While some measures indicate good condition (e.g., perennial grass cover) others indicate potential issues (e.g., soil stability index). Because of the lack of trend data for most measures, we did not assign an overall trend for this assessment.
Biological Soil Crusts		One indicator and measure were used to assess condition. Biological soil crusts are in good condition in the Rincon Mountain District and in the bajada stratification in the Tucson Mountain District. They are in moderate condition in the valley bottom, and in the condition of significant concern in the foothills stratification in the Tucson Mountain District. The overall condition was considered to be moderate with a stable trend.
Mammals		To assess the condition of mammals, we used three indicators with a total of five measures. The indicators looked at species occurrence, the status of an endangered bat species and two species of deer, and habitat connectivity. Overall, mammal condition is of moderate concern. Sufficient information is lacking to estimate trends for some indicators/measures, and the overall trend in condition is varied. For example, the status of the lesser long-nosed bat appears good with an unchanging trend, while condition with regards to habitat connectivity appears to be declining.
Birds		We used six indicators, each with one to three measures, to assess the condition of birds at Saguaro NP. Two indicators were quantitative and four were qualitative in nature. Overall, of eight measures with reference conditions, four were assessed to be in good condition. One was judged to be in moderate condition, and the condition of birds under three were assessed to be unknown. We consider condition under our set of indicators/measures to be good. Trends, where estimated, varied.
Herpetofauna		To assess the condition of amphibians and reptiles at Saguaro NP, we used five indicators with one or two measures each. Overall, we considered the condition of herpetofauna at the park to be of moderate concern. Condition under the measures ranged from good to significant concern, with the condition of one measure unknown due to lack of current data. We do not have sufficient information to justify an overall trend at this time. We have a medium to high level of confidence in the assessment.

NPS

A sweeping view looking west toward the city of Tucson, Arizona from Rincon Peak.

Table 5.1-2. Summary of overall viewshed condition, indicators and measures, and rationale for assigning condition assessment at Saguaro National Park.

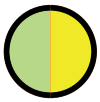
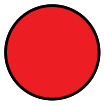
Viewshed			
Indicators of Condition	Specific Measures	Condition Status/Trend	Rationale
Scenic Integrity	Conspicuousness of Non-contributing Features		From seven key observation points, two in TMD and five in RMD, the condition of the conspicuousness of non-contributing features ranged from good if looking into the park to moderate concern if looking outside of the park; two exceptions include the north to east view from TMD's North Scenic Drive Trail, and the southwest to northwest views from the Tanque Verde Ridge location, which are of significant concern. The viewsheds from RMD's backcountry sites were considered to be in the best scenic condition compared to the remaining four sites, which are located closer to the city of Tucson.
	Extent of Development		The exurban sprawl adjacent to each district's boundary and high housing and road densities warrant significant concern.
	Degree of Scenic Conservation		While there are some areas where scenic conservation potential is high, many of the land management agencies responsible for the lands that are visible from Saguaro NP's observation points offer no additional protection and/or allow for extractive uses, therefore, we consider the extent of scenic conservation for Saguaro NP to be of moderate to significant concern.

Table 5.1-3. Summary of overall night sky condition, indicators and measures, and rationale for assigning condition assessment at Saguaro National Park.

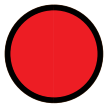
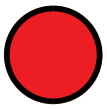
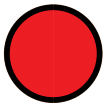
Night Sky				
Indicators of Condition	Specific Measures	Condition Status/ Trend		Rationale
		TMD	RMD	
Sky Brightness	All-sky Light Pollution Ratio			The majority of all ALR measurements from each location, ground-based and modeled, warrant significant concern in Saguaro NP. Within the TMD ALR was estimated as poor for all ground-based measurements and modeled data. Within the RMD the minimum ALR measurement and the median measurement from Rincon Peak warrants moderate concern while all other ALR estimates within the RMD warrant significant concern. These conditions are based on NPS Natural Sounds and Night Skies Division benchmarks for non-urban and parks managed as wilderness, ground-based measurements taken at four locations within the national park, and modeled estimates for specific areas within the park. Data to assess trends were not available. The confidence level is high. The ground-based data were collected by the NPS NSNSD.
	Maximum Vertical Illuminance			Sky brightness as measured by maximum vertical illuminance warrants significant concern at Saguaro NP. Specific benchmarks for condition classes have not been set; however, condition is estimated as poor or of significant concern at both locations within the TMD (Desert View Discovery Nature Trail and Wasson Peak) and both locations within the RMD (Rincon Peak and Mica View picnic area) (J. White, personal communication, November 2015). Data to assess trends were not available. The confidence level is high. These data were collected by the NPS NSNSD.
	Horizontal Illuminance			Sky brightness as measured by horizontal illuminance warrants moderate to significant concern at Saguaro NP. Specific benchmarks for condition classes have not been set; however, condition is estimated as poor or of significant concern within the TMD (Desert View Discovery Nature Trail and Wasson Peak). The measurement from Rincon Peak and at Mica View picnic area within the RMD were estimated to warrant moderate and significant concern respectively (J. White, personal communication, November 2015). Data to assess trends were not available. The confidence level is high. These data were collected by the NPS NSNSD,
	Zenith Sky Brightness			Zenith sky brightness warrants moderate to significant concern at Saguaro NP. The measurements from the Desert View Discovery Nature Trail and Wasson Peak within the TMD warrant significant concern. Within the RMD the measurement from Rincon Peak warrants moderate concern and measurement from the Mica View picnic area warrants significant concern. These conditions are based on the NPS Natural Sounds and Night Skies Division benchmarks for non-urban parks and parks managed as wilderness, and on ground-based measures of zenith sky brightness measured at four locations within the national park. Data to assess trends were not available. The confidence level is high.

Table 5.1.3. Summary of overall night sky condition, indicators and measures, and rationale for assigning condition assessment at Saguaro National Park continued.

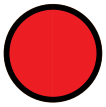
Night Sky				
Indicators of Condition	Specific Measures	Condition Status/ Trend		Rationale
		TMD	RMD	
Sky Quality	Bortle Dark Sky Scale			Sky quality as assessed by the Bortle dark sky scale warrants moderate to significant concern at Saguaro NP. This condition is based on NPS Natural Sounds and Night Skies Division benchmarks for non-urban parks and parks managed as wilderness, and on the qualitative assessment of Bortle class 5 (significant concern) at both the Desert View Discovery Nature Trail and at Wasson Peak in the TMD, Bortle class 4 (moderate concern) at Rincon Peak and class 6 (significant concern) at Mica View picnic area within the RMD. These classes are consistent with a suburban sky at the Desert View Discovery Nature Trail and at Wasson Peak, a rural to suburban transition at Rincon Peak, and a bright suburban sky at Mica View picnic area. Because this measure is qualitative, it has low confidence.

Table 5.1-4. Summary of overall soundscape condition, indicators and measures, and rationale for assigning condition assessment at Saguaro National Park.

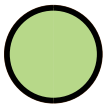
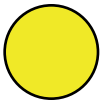
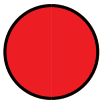
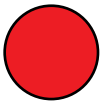
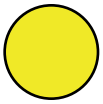
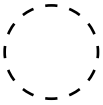
Soundscape			
Indicators of Condition	Specific Measures	Condition Status/Trend	Rationale
Sound Levels	% Time Above Reference Sound Levels		The majority of existing sound levels heard at all sites for which data were available (i.e., 2011 and 2016) were <44.99 dBA, suggesting a relatively quiet environment, so we consider this measure to be in good condition. Confidence in the data and the assessment is high. However, 2004/2005 data were not available for inclusion.
	% Reduction in Listening Area (for non-urban parks): TMD		Analysis for the TMD is based on two sites monitored in 2004/2005 and one site monitored in 2016. Considering both day and night sound levels, three impact values led to a reduction in listening area of 33.9-49.9% (moderate concern) and three a 53.5-98.6% reduction (significant concern). Therefore, overall, we considered condition under this measure as moderate to significant concern. No data are available for trends. Our confidence in the assessment is medium (see text for explanation). In the TMD, existing ambient sound levels (L_{50s} and L_{90s} for day and night) were lowest in the Discovery Trail site.
	% Reduction in Listening Area (for non-urban parks): RMD		Analysis for the RMD is based on one site monitored in 2004/2005, one site monitored in 2011, and two sites from 2016. Considering both day and night sound levels, six impact values led to a reduction in listening area of 30.8-49.9% (each moderate concern), one a 24.1% reduction (good condition), and one a 66.9% reduction (significant concern). Therefore, overall, we considered condition under this measure as moderate concern. No data are available for trends. Our confidence in the assessment is medium (see text for explanation). In the RMD, existing ambient sound levels (L_{50s} and L_{90s} for day and night) were lowest in the Tanque Verde Ridge Trail site.
Geospatial Model	L_{50} Impact		The modeled median impact sound level for the national park was 4.1 dBA, which is considered to be of significant concern based on threshold values for non-urban parks (Turina et al. 2013). This level of sound impact corresponds to a reduction in listening area of >50%. This measure is based on modeled sound levels (rather than on-site measurements), resulting in a medium confidence level.

Table 5.1-5. Summary of overall air quality condition, indicators and measures, and rationale for assigning condition assessment at Saguaro National Park.

Air Quality			
Indicators of Condition	Specific Measures	Condition Status/Trend	Rationale
Visibility	Haze Index		Visibility warrants moderate concern at Saguaro NP based on NPS ARD benchmarks and the 2009–2013 estimated visibility on mid-range days of 6.9 deciviews (dv) above estimated natural conditions. The trend in visibility improved on the 20% clearest days and improved on the 20% haziest days at both monitors (IMPROVE SAGU1 and SAEW1). The Clean Air Act visibility goal requires visibility improvement on the 20% haziest days, with no degradation on the 20% clearest days. The confidence level is high due to the proximity of the monitoring station.
Level of Ozone	Human Health: Annual 4th-Highest 8-hour Concentration		Human health risk from ground-level ozone warrants moderate concern at Saguaro NP. This condition is based on NPS ARD benchmarks and the 2009–2013 estimated ozone of 70.9 parts per billion (ppb). For 2004–2013, the trend in ozone concentration at Saguaro NP remained relatively unchanged and was not statistically significant. The confidence level is high since there is an on-site or nearby ozone monitoring station.
	Vegetation Health: 3-month maximum 12hr W126		Vegetation health risk from ground-level ozone warrants significant concern at Saguaro NP. This condition is based on NPS Air Resources Division benchmarks and the 2009–2013 estimated W126 metric of 14.7 parts per million-hours (ppm-hrs). The W126 metric relates plant response to ozone exposure, however, a risk assessment concluded that plants in Saguaro NP were at low risk for ozone damage (Kohut 2007; Kohut 2004). For 2004–2013, the trend for W126 remained relatively unchanged and was not statistically significant trend. The degree of confidence in the evaluation is high because there is an on-site or nearby ozone monitor.
Wet Deposition	Total N		From 2009-2013, the average estimated wet nitrogen deposition was 3.6 kilograms per hectare per year, warranting significant concern based on NPS ARD benchmarks. No NPS-ARD trend information is available for nitrogen because there are not sufficient on-site or nearby deposition monitoring sites, and as a result, the confidence level for the assessment is medium.
	Total S		From 2009-2013, the average estimated wet sulfur deposition was 1.6 kilograms per hectare per year, warranting moderate condition based on NPS ARD benchmarks. No NPS-ARD trend information is available for sulfur because there are not sufficient on-site or nearby deposition monitoring sites, and as a result, the confidence level for the assessment is medium.
	Mercury		No data exist for the park to evaluate this measure resulting in an unknown condition.
	Predicted Methylmercury Concentration		The predicted concentrations of methylmercury in surface waters at the park are very high as compared to other NPS units, warranting significant concern. No NPS-ARD trend information is available because there are insufficient on-site or nearby deposition monitoring sites. As a result, the confidence level for the assessment is low.

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High water level, Rincon Creek in Saguaro National Park.

Table 5.1-6. Summary of overall surface water quantity in the middle reach of Rincon Creek condition, indicators and measures, and rationale for assigning condition assessment at Saguaro National Park.

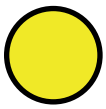
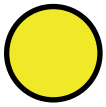
Surface Water Quantity in the Middle Reach of Rincon Creek			
Indicators of Condition	Specific Measures	Condition Status/Trend	Rationale
Water Quantity	Trend in Mean Annual Discharge (1952-2013)		Although there is high variability in the data, the recent decline in this measure warrants moderate to significant concern.
	Minimum Daily Discharge/ Month (2003-2014)		Given the language of "natural flow" in the NPS water right application, it is difficult to determine if the data meet the minimum recommendations because the natural flow is not known; however, since only 4 of 104 months for which there were data met the minimum requirements and the trend in water use since 2003 has increased, the condition for this measure warrants moderate to significant concern.
	Number of Dry Days/Year in Pool A (2003-2013)		Because of variability in the data and the two years with no dry days in Pool A, there is no trend; however, because of the increased number of dry days in recent years, the condition for this measure warrants moderate concern.
	Number of Dry Days/Year at USGS Gage (2003-2013)		Overall, the trend in no-flow days at the USGS gage has increased during 2003-2013. Because of the increased number of no-flow days in recent years, this measure warrants moderate concern.

Table 5.1-7. Summary of overall tinajas, springs, and seeps condition, indicators and measures, and rationale for assigning condition assessment at Saguaro National Park.

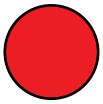
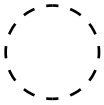
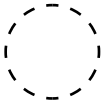
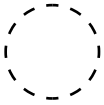
Tinajas, Springs, and Seeps			
Indicators of Condition	Specific Measures	Condition Status/Trend	Rationale
Water Availability	Trend in Water Presence Within Tinajas		Since the proportion of site visits during which water was recorded remained relatively stable over time and averaged 74% during 2004 to 2014, the condition for this measure is good.
	Persistence of Water Within Tinajas		Since more than 75% of all pools are considered reliable (i.e., contain water on at least 50% of all site visits), the condition for this measure is good.
	Palmer Hydrological Drought Index		During January 2004 through December 2014, there were three normal periods, 11 periods of incipient to mild drought and nine periods of moderate to extreme drought. Drought periods lasted between two and 20 months, while non-drought periods lasted between four and six months. Because of the large number and relatively long duration of drought periods compared with non-drought periods, as well as increasing drought severity in recent years, this measure warrants significant concern.
	Percent Sedimentation		Just over half (52%) of the 29 tinajas exhibited less than 30% sediment volume, and 86% of all tinajas exhibited less than 50% sediment volume. Only four of the 29 pools exhibited greater than 50% sediment volume, therefore, we consider the condition of this measure as good to moderate.
Water Quality	Temperature		AZDEQ water quality standards do not apply to water bodies sampled in Saguaro NP; therefore, we cannot assess the condition of this measure.
	pH		The AZDEQ minimum standard was met in all tinajas on each sampling date; however, the pH was greater than the AZDEQ threshold of 9 on ten sampling occasions in six tinajas. All springs were within the range of variation established by AZDEQ. Due to limited data and expected variability over time we did not assign a condition for this measure.
	Specific Conductance		AZDEQ has not defined water quality standards for specific conductance; therefore, we were unable to assess the condition of this measure.
	Turbidity		AZDEQ has not defined water quality standards for turbidity; therefore, we were unable to assess the condition of this measure.
	Dissolved Oxygen		Dissolved oxygen in tinajas and springs was variable, but the standard of 6mg/L was met some of the time. Although natural variation in dissolved oxygen is a reasonable explanation, we consider the condition unknown because of limited data.
	Bacterial Contamination by *E. coli*		Average *E. coli* in tinajas was below 10 MPN, which is well below AZDEQ standard of 126 MPN; however, these data are 13 years old. Therefore, the condition for this measure is unknown.

Table 5.1-8. Summary of overall groundwater condition, indicators and measures, and rationale for assigning condition assessment at Saguaro National Park's Tucson Mountain District.

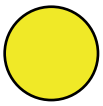
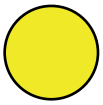
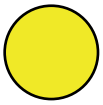
Groundwater - Tucson Mountain District			
Indicators of Condition	Specific Measures	Condition Status/Trend	Rationale
Groundwater Level in Avra Valley aquifer west of the park	Depth to Water <385 feet at Park Monitoring Well ADWR 55-629094		Current water levels at the park monitoring well are similar to the reference period; however, dependence of aquifer water levels on imported Colorado River water and projected shortages in delivery of Colorado River water, in combination with over-allocation of groundwater in Tucson AMA, create uncertainty going forward.
Groundwater flow direction in Avra Valley aquifer	Groundwater Flow Lines Similar to Pre-development South to North Pattern		Overall groundwater flow follows a south to north trajectory, but is significantly perturbed by recharge facilities, recovery wells and continued aquifer depletion to the north.
Groundwater level in shallow alluvial wells	Depth of Water in shallow Wells During Dry Season >20 Feet Above the Well Bottom		One of two shallow wells used for providing water to wildlife is no longer capable of supplying the facility during the driest times of year when it is most needed; the second well meets the measure criteria but it is unknown if this would be sustained if water was pumped for supplying wildlife.

Table 5.1-9. Summary of overall groundwater condition, indicators and measures, and rationale for assigning condition assessment at Saguaro National Park's Rincon Mountain District.

Groundwater - Rincon Mountain District			
Indicators of Condition	Specific Measures	Condition Status/Trend	Rationale
Groundwater Supplying Perennial High Elevation Springs	Presence of Perennial Water Sufficient to Supply Visitors, Wildlife and Aquatic Plants		Climate change is resulting in increased temperatures and reduced snowpack and overall precipitation; Storage appears to be marginal; drying and low flow conditions are reported in 2016; Long-term monitoring is lacking. Trend is deteriorating and confidence level in the assessment is medium.
Mountain Block Fracture Groundwater	Piezometric Level at Well 585628 >3,100 feet		Threatened by climate change and reduced infiltration in case of wildfire; difficult to obtain data due to lack of access. Trend is unknown and confidence level in the assessment is low.
Groundwater Supplying Low Elevation Springs, Pools and Tinajas	All 29 of the Perennial Tinaja Pools on the Park's "Best Pools" List Contain Water Every Time They Are Monitored in June; Over a Five-year Period, The Remaining 18 Pools on the "Best Pools" List Contain Water At Least 95% of the Time When Monitored in June; Depth to Water at Madrona Pack Base Well is <12 Feet at Least 8 Months Per Year.		Climate change and potential for wildfire-related watershed effects are a concern; Storage appears to be marginal; long-term presence-absence monitoring provides strong basis for assessment; Madrona Pack Base well provides indicator in one drainage. Trend is stable and confidence level in the assessment is high.

Table 5.1.9. Summary of overall groundwater condition, indicators and measures, and rationale for assigning condition assessment at Saguaro National Park's Rincon Mountain District continued.

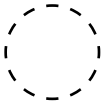
Groundwater - Rincon Mountain District			
Indicators of Condition	Specific Measures	Condition Status/Trend	Rationale
Shallow Groundwater in Rincon Valley and Pantano Formation	Depth to Water at Well 633106 (Lunt) <8 Feet >3 Months/Year and Depth to Water at well 55-633106 <10 Feet >6 Months/Year		Climate change, private groundwater pumping and potential for additional pumping from shallow aquifer are concerns; Water presence is intermittent; storage is negligible; well 55-633106 is accessible and tracks with other shallow wells. Trend is deteriorating and confidence level in the assessment is medium.
Detachment-Fault Related Groundwater	Water Level Elevation in Rincon Valley >3,100 ft		Recent drying of Agua Caliente spring, threatened by climate change and pumping; declining trend 2002-2006; storage unknown; inability to monitor status since 2006. Trend is stable and confidence level in the assessment is low.
Upper-plate Groundwater	Depth to Water Similar to Documented Past Conditions		Except for Rincon Valley, most wells in the upper plate units have not been monitored recently, some are not located in the field, and status remains to be determined. Trend is unknown and confidence level in the assessment is low.

Table 5.1-10. Summary of overall biodiversity condition, indicators and measures, and rationale for assigning condition assessment at Saguaro National Park.

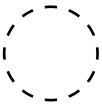
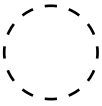
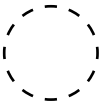
Biodiversity			
Indicators of Condition	Specific Measures	Condition Status/ Trend	Rationale
Proportion of Arizona Species Present in the Park			
Richness	Plants		Nearly half of all species of bird, mammal, and herpetofauna found in Arizona are represented in Saguaro NP. Although fewer plant species in Arizona are represented in the park (32%) than for other groups, the diversity is still relatively high, especially when considering the small area of Saguaro NP relative to Arizona.
	Birds		
	Mammals		
	Herpetofauna		
	Invertebrates		The lack of information prevents us from assigning a condition for this measure. The confidence is low because inventories are incomplete.
	Fungi		
	Bryophytes		
	Lichens		
Proportion of Sonoran Desert Network Species Present in TMD			
Richness	Plants		Between 26% and 61% of native Sonoran Desert species are represented in the TMD. Overall, TMD contains exceptionally high diversity given that the district represents only about 5% of the land area within SODN.
	Birds		
	Mammals		
	Herpetofauna		
	Lichens		The lack of information prevents us from assigning a condition for this measure. The confidence is low because inventories are incomplete.
Proportion of Madrean Sky Islands Present in RMD			
Richness	Plants		Between 51% and 129% of diversity within the Sky Islands Region is represented within the RMD. Richness within the RMD is high compared with known species occurrence throughout the Sky Islands Region considering the district represents less than 1% of the total land area of the Madrean Archipelago, although there the species lists for the Madrean Archipelago are incomplete, therefore, richness is unknown.
	Birds		
	Mammals		
	Herpetofauna		

Table 5.1-10. Summary of overall biodiversity condition, indicators and measures, and rationale for assigning condition assessment at Saguaro National Park continued.

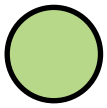
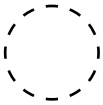
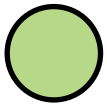
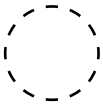
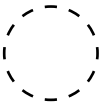
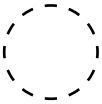
Biodiversity			
Indicators of Condition	Specific Measures	Condition Status/ Trend	Rationale
Proportion of Arizona Species Present in the Park			
Richness	Plants		Nearly half of all species of bird, mammal, and herpetofauna found in Arizona are represented in Saguaro NP. Although fewer plant species in Arizona are represented in the park (32%) than for other groups, the diversity is still relatively high, especially when considering the small area of Saguaro NP relative to Arizona.
	Birds		
	Mammals		
	Herpetofauna		
	Invertebrates		The lack of information prevents us from assigning a condition for this measure. The confidence is low because inventories are incomplete.
	Fungi		
	Bryophytes		
	Lichens		
Proportion of Sonoran Desert Network Species Present in TMD			
Richness	Plants		Between 26% and 61% of native Sonoran Desert species are represented in the TMD. Overall, TMD contains exceptionally high diversity given that the district represents only about 5% of the land area within SODN.
	Birds		
	Mammals		
	Herpetofauna		
	Lichens		The lack of information prevents us from assigning a condition for this measure. The confidence is low because inventories are incomplete.
Proportion of Madrean Sky Islands Present in RMD			
Richness	Plants		Between 51% and 129% of diversity within the Sky Islands Region is represented within the RMD. Richness within the RMD is high compared with known species occurrence throughout the Sky Islands Region considering the district represents less than 1% of the total land area of the Madrean Archipelago, although there the species lists for the Madrean Archipelago are incomplete, therefore, richness is unknown.
	Birds		
	Mammals		
	Herpetofauna		

Table 5.1.10. Summary of overall biodiversity condition, indicators and measures, and rationale for assigning condition assessment at Saguaro National Park continued.

Biodiversity			
Indicators of Condition	Specific Measures	Condition Status/ Trend	Rationale
Extirpated Species	# of Vascular Plants		There are 60 potentially extirpated plant species in Saguaro NP; however, the list has not been finalized. As Saguaro NP continues its long-term plant monitoring program plant species may be added or removed from this list, therefore, we consider the condition for this measure unknown.
	# of Birds		Since there are no confirmed extirpated bird species in Saguaro NP, the condition for this measure is considered good.
	# of Mammals		This measure warrants moderate concern because of the loss of six mammals and increasing loss of habitat connectivity, especially for the TMD.
	# of Herpetofauna		None of the 59 extant reptiles and amphibians in Saguaro NP is considered extirpated.
Non-native Species	# of Vascular Plants		There are 87 non-native plants, 26 of which are considered invasive. Coupled with the ability of non-native plants to spread rapidly and change ecosystem structure and function (e.g. altered fire patterns), the condition for non-native plant species is of significant concern.
	# of Birds		Although four species of non-native bird occur in both districts, their distribution is limited and their effects on native birds is minor.
	# of Mammals		Improved land management practices have eliminated cattle grazing in Saguaro NP and although cows are occasionally found in the RMD, they are not established. Feral cats and dogs in both districts have not established populations and their distribution is limited. Abert's squirrel may have effects on the native Arizona gray squirrel.
	# of Herpetofauna		There are only four non-native reptiles and amphibians in the RMD and none in the TMD, and those that do occur are limited in distribution.
Threatened and Endangered Species	Status of the lesser long-nosed bat		The lesser long-nosed bat was listed as endangered in 1988, and roost counts have been conducted in the park since 1991.There are not enough data to determine a trend in condition for the lesser long-nosed bat, but the number of bats using the known roost generally appears stable over the past several years resulting in a good condition rating.
	Status of the Southwestern Willow Flycatcher		There is not enough information to assign a condition. The Southwestern Willow Flycatcher and the Yellow-billed Cuckoo are listed as endangered and threatened species, respectively by the U.S. Fish and Wildlife Service.
	Status of the Yellow-billed Cuckoo		
	Status of the Mexican Spotted Owl		There are five breeding territories in the RMD and all appear to be occupied in most years and SNP (2013) reported that the Mexican Spotted Owl population in the park appears to be stable.

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Saguaro cactus data collection.

Table 5.1-11. Summary of overall saguaro cactus condition, indicators and measures, and rationale for assigning condition assessment at Saguaro National Park.

Saguaro Cactus			
Indicators of Condition	Specific Measures	Condition Status/Trend	Rationale
Saguaro Cactus Population Status / Health	Saguaro Density and/or Population Size		We consider current condition to be good. Data on the saguaro population are available from a number of studies. Based on population estimates from the three Censuses, the number of saguaros in the park in 2010 had increased by about 65.5% from 1990 numbers. Data from 11 "historic" plots indicated that the saguaro population in the RMD declined between 1941 and 1975, but increased substantially since 1975 (and through 2014). The population in the TMD also increased from 1975 to 2014. Sampling results within Section 17 of the RMD, including the Cactus Forest, also contributed to the assessment. Condition is good, with an improving trend.
	Age (or Size) Class Distribution		Current condition is of moderate concern. There was little to no recruitment in Section 17 of the RMD in the 1940s-1960s. However, due to a surge in recruitment in the 1970s-1990s, in both districts of the park, there are now a large number of young saguaro cacti in both districts. Within the Cactus Forest, the age/size structure of the population has changed substantially, with the population in the 1940s being dominated by tall, mature saguaros, and that at the present time being dominated by shorter, younger saguaro cacti. Based on the available information, the overall trend is increasing, as the age/size class distribution becomes somewhat more even-aged.

Table 5.1.11. Summary of overall saguaro cactus condition, indicators and measures, and rationale for assigning condition assessment at Saguaro National Park continued.

Saguaro Cactus			
Indicators of Condition	Specific Measures	Condition Status/Trend	Rationale
Historic Integrity and Appearance of Saguaro Cacti on the Landscape	Change Over Time		The Cactus Forest has a different appearance today than it did in the 1930s. However, the decline in the number of large saguaros was documented as early as the 1940s, and recent estimates of recruitment for the 1900s showed low recruitment in the first half of the century. Although the appearance of the Cactus Forest may not yet reveal the recovery, there has been an increase in the saguaro population park-wide since the dramatic increase in recruitment starting around the 1970s. Eventually, the appearance of the Cactus Forest will more closely approach that seen in the days of park establishment.
Habitat Availability and Quality	Cover of Nurse Plants		SODN uplands monitoring data from ~2008-2013 for both park districts for nurse plants in the bajada strata (2,501-3,700 ft) indicate that the cover of nurse plants is currently good. For each of the three areas monitored, the percent cover values were above the reference level of 15%. For the valley-bottom stratum, the cover of nurse plants was closer to the reference value of 10%; the percent cover of nurse plants in this stratum may warrant discussion by SODN and park managers. Overall, we judge this measure to be in good condition. Data are not available to report trends at this time, but as SODN continues monitoring such information will be available in the future.
	Occurrence of Buffelgrass in Saguaro Habitat		Based on park monitoring, buffelgrass is known to occur in approximately 12% of the saguaro habitat in the RMD and 2% in the TMD. Buffelgrass is difficult to control and poses a substantial threat to saguaros and their habitat. Because not all of the park has been surveyed for buffelgrass to date, these estimates are probably underestimates. The overall condition (i.e., both districts combined) is of moderate to significant concern. Despite the lack of systematic, complete surveys of this plant on an annual basis, the park has been effective in eliminating buffelgrass in some areas of saguaro habitat and controlling the infestation in other places. However, untreated areas remain. Therefore, the trend is variable across space.

Table 5.1-12. Summary of overall desert and riparian vegetation and soils condition, indicators and measures, and rationale for assigning condition assessment at Saguaro National Park.

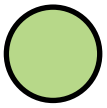
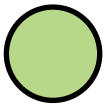
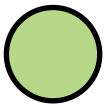
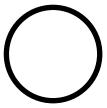
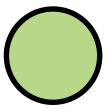
Desert and Riparian Vegetation & Soils				
Indicator	Strata	Measures	Condition Status/Trend	Rationale
Plant Community Resilience	Foothills	Tree and Shrub Cover (subcanopy)		Tree and shrub cover, combined and individually, indicate good condition since these measures were well below the 30% threshold. Confidence is high. No data on trend are available.
	Foothills	Perennial Grass Cover (field)		The value is slightly below the criteria for good condition; however, the standard error of the mean overlaps the management assessment point. Confidence is high. No data on trend are available.
Erosion Hazard	Valley bottom/ Bajada/ Foothills	Bare Ground Cover (with no overhead vegetation)		In valley bottom and the foothills of both districts and in the TMD bajada the threshold for good condition was met; however, in RMD's bajada region the standard error of the mean overlaps the management assessment point for rocky sites and approaches the management assessment point in non-rocky sites. Confidence is high. No data on trend are available.
	Bajada & Foothills	Soil Stability Class Index (no canopy)		At least one plot in all strata in both districts exhibited an average soil stability class less than two, which warrants moderate to significant concern.
Fire Hazard	Valley Bottom/ Bajada/Foothills	Ratio of Annual Plant Cover to Total Plant Cover (field)		This measure was within the range for good condition for all strata in both districts. Confidence is high. No data on trend are available.
		Extent of Red Brome		No condition thresholds have been developed for this measure. Confidence is high. No data on trend are available.
	Bajada	Grass and Forb Combined Cover (field)		Grass and forb cover in the bajada was within the range considered good for each district. Confidence is high. No data on trend are available.
Non-native and Invasive Plants	Valley Bottom/ Bajada/Foothills	Total Cover of All Non-native Plants (field)		Non-native plant cover was low and well below the 5% threshold identified as the trigger point between good and moderate to significant concern. Confidence is high. No data on trend are available.
	Park-wide	New Species Detected (2004-2014)		Of new non-native species listed in 2014 that were not listed in 2004, 24 are known to occur in low elevation areas of the park. Nine of these species are considered invasive. Condition is deteriorating. Confidence is high.

Table 5.1.12. Summary of overall desert and riparian vegetation and soils condition, indicators and measures, and rationale for assigning condition assessment at Saguaro National Park continued.

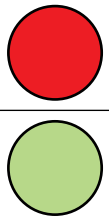
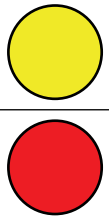
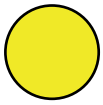
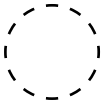
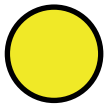
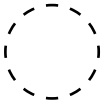
Desert and Riparian Vegetation & Soils				
Indicator	Strata	Measures	Condition Status/Trend	Rationale
Non-native and Invasive Plants	Valley Bottom/ Bajada/Foothills	Occurrence of Buffelgrass		In all strata buffelgrass exceeded 1% of the total area, which warrants significant concern, except in the foothills of the TMD, where no buffelgrass was mapped. Confidence is medium. Trend data were not available.
		Occurrence of Non-native Plants		The proportion of non-native plants in the TMD was relatively low for each of the three strata (0.05-0.9%). In the RMD's bajada stratum, non-native plants were mapped in 4.7% of the area and 0.8% of the foothills stratum. Confidence is medium. Trend data were not available.
	Park-wide	Buffelgrass Control Effort		Overall, buffelgrass control efforts in Saguaro NP have been successful, but require constant effort to limit the spread of existing patches and to prevent new patches from forming. Therefore, we consider this measure to warrant moderate concern.
		Non-native Plant Control Effort (excluding Buffelgrass)		The area of all other non-native plants mapped has remained relatively constant as has the area of non-native plants that were treated (excluding buffelgrass), but data on the effectiveness of these treatments is lacking. Therefore, the condition for this measure is unknown.
Conservation Potential of Rincon Creek	Rincon Creek	Land Use Type (%)		Since 25% of Rincon Creek is protected and an additional 15% is planned for protection, we consider the condition for this measure to warrant moderate concern. Confidence in is high. No trend data were available.
Prevalence of Native Vegetation Along Rincon Creek		Age Class Distribution		We did not assign a condition for this measure because of the conflicting results and because data were limited. Confidence is low since these data are 13 years old. No trend data were available.
		Species Diversity		At least 19 species of tree, shrub, and forb were documented along Rincon Creek. Confidence in this condition rating is low since these data are 13 years old and do not necessarily represent current condition. No trend data were available.
		Species Wetland Status		Twelve of the 19 species were considered facultative or facultative wetland, which indicates good condition. Confidence in this condition rating is low since these data are 13 years old. No trend data were available.

Table 5.1.12. Summary of overall desert and riparian vegetation and soils condition, indicators and measures, and rationale for assigning condition assessment at Saguaro National Park continued.

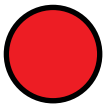
Desert and Riparian Vegetation & Soils				
Indicator	Strata	Measures	Condition Status/Trend	Rationale
Prevalence of Native Vegetation Along Rincon Creeek *continued*	Rincon Creek	Percent Cover		Total vegetation cover of key species averaged 70% across terrace and floodplain plots, but was lower in floodplain plots than in terrace plots. Confidence in this condition rating is low since these data are 13 years old. No trend data were available.
Prevalence of Non-native Vegetation Along Rincon Creeek		New Non-native Species Detected (2004-2014)		Three new non-native plants, all of which are invasive, were documented in 2014 that were not documented in 2004. Condition is deteriorating. Confidence is high.
		Occurrence of Non-native Plants		Since buffelgrass was mapped in <1% of riparian habitat we consider the condition to warrant moderate concern, but the combination of all other native plants exceeds 1% of riparian habitat, which warrants significant concern. Confidence is medium. No trend data were available.

Table 5.1-13. Summary of overall grasslands, woodlands, and forest vegetation and soils condition, indicators and measures, and rationale for assigning condition assessment at Saguaro National Park.

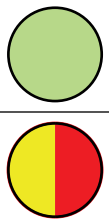
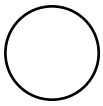
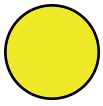
Grasslands, Woodlands, and Forest Vegetation & Soils				
Indicator	Strata	Measures	Condition Status/Trend	Rationale
Plant Community Resilience	High Mountain and Mountaintop	Total Tree Cover (canopy)		Canopy cover for high mountain plots fell within the range for good condition (23.2%), while mountaintop plots (53.7%) exceeded 30%. Confidence is medium. No data on trend are available.
	Mid-mountain	Tree and Shrub Cover (subcanopy)		Tree and shrub cover, combined and individually, indicate good condition since these measures were well below the 30% threshold. Confidence is medium. No data on trend are available.
		Perennial Grass Cover (field)		The value meets the criteria for good condition; however, the standard error of the mean overlaps the management assessment point. Confidence is medium. No data on trend are available.
		Ratio of Annual Plant Cover to Total Plant Cover (field)		This measure was within the range for good condition (23)%; however, is approaching the threshold of 25%. Confidence is medium. No data on trend are available.
Erosion Hazard	Mid-mountain, High Mountain, Mountaintop	Bare Ground Cover (with no overhead vegetation)		This measure averaged <5% for each stratum, which indicates low potential for erosion. Confidence is medium. No data on trend are available.
		Soil Stability Class Index (no canopy)	No Data	Average soil stability across mid-mountain and high mountain plots was <3, which indicates good condition; however, the condition rating is based on any one plot exceeding class 3. This occurred in 7 mid-mountain and 5 high mountain plots. Confidence is medium. No trend data are available.
Departure From Fire Return Interval	Mid-mountain, High Mountain, Mountaintop	Proportion of Area Outside Fire Return Interval		For mid-mountain and high mountain strata, 77% and 75% of the total area, respectively, was within three or more fire return intervals. Only a small proportion of high mountain and mountaintop strata were within one fire return interval, and none of the mid-mountain strata was within one fire return interval. Confidence is medium. No trend data are available.
Forest Health	Mid-mountain, High Mountain, Mountaintop	Bark Beetle Infestation (hectares)		An average of 54 ha (133 ac) has been impacted by bark beetles in each of the last three years (2013-2015). In 2015, tree mortality decreased over the previous two years but still remains elevated compared to mortality observed during 2003-2012. Overall, the condition is of moderate concern. Confidence is medium.

Table 5.1.13. Summary of overall grasslands, woodlands, and forest and riparian vegetation and soils condition, indicators and measures, and rationale for assigning condition assessment at Saguaro National Park continued.

Grasslands, Woodlands, and Forest Vegetation & Soils				
Indicator	Strata	Measures	Condition Status/Trend	Rationale
Non-native and Invasive Plants	Mid-mountain, High Mountain, Mountaintop	Total Cover of All Non-native Plants (field)		Overall, non-native plant cover was low and well below the 5% threshold identified as good condition. Confidence is medium. Trend data are not available.
		Ratio of Non-native Plant Cover to Total Plant Cover (field)		The proportion of total plant cover comprised of non-native plants was highest (3.17%) in the mid-mountain stratum and lowest (0.09%) in the high mountain stratum. Since less than 5% (1:20) of non-native plants comprised the total plant cover, this measure is in good condition for all three strata. Confidence in medium. No data on trend are available.
	Rincon Mountain District	New Non-native Species Detected (2004-2014)		Since seven known new non-native species have invaded upper elevation areas in the RMD, this measure warrants moderate to significant concern. The condition is deteriorating. Confidence is medium.
	Mid-mountain, High Mountain, Mountaintop	Occurrence of Buffelgrass		Since buffelgrass occurs in less than 1% of the mid-mountain strata and 0% of the high mountain or mountaintop strata, the condition for this measure is good. Trend data are not available. Confidence is medium.
		Occurrence of Non-native Plants		Non-native plants (excluding buffelgrass) represent 0.05% of the mid-mountain stratum, <0.01% of the high mountain stratum, and 0.01% of the mountaintop stratum. This is below the 1% threshold. Trend data are not available. Confidence is medium.

NPS / CHERYL MCINTYRE

Biological soil crust in Saguaro National Park.

Table 5.1-14. Summary of overall biological soil crusts condition, indicators and measures, and rationale for assigning condition assessment at Saguaro National Park.

Biological Soil Crusts			
Indicators of Condition	Specific Measures	Condition Status/Trend	Rationale
Biological Soil Crusts	Soil Crust Cover		Soil crusts were in good condition in all strata assessed in the Rincon Mountain District. In the Tucson Mountain District, biological soil crusts were only in good condition in the bajada stratification. Percent cover for crusts was in moderate condition in valley bottom, and of significant concern in the foothills stratum in the Tucson Mountain District.

Table 5.1-15. Summary of overall mammals condition, indicators and measures, and rationale for assigning condition assessment at Saguaro National Park.

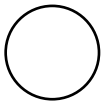
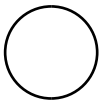
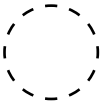
Mammals			
Indicators of Condition	Specific Measures	Condition Status/Trend	Rationale
Species Occurrence	Presence / Absence of Medium and Large Mammals (Including Squirrels)		For the RMD, we considered condition to be good based on the comparison of medium and large mammal species observed during the 1999-2005 survey and 2011-2012 survey. All species observed during the earlier survey were observed during the later survey (when including non-random camera results). For the TMD, condition is considered to be of moderate concern, because four native species that were observed in the earlier survey were not observed in the later survey. Two of the four species were observed by park partners in 2015. There is insufficient data to determine trends at this time..
	Presence / Absenceo of Small Mammals and Bats (Excluding Squirrels)		Approximately 37 species of small mammals and bats have been recorded in the RMD, and 16 species have been recorded in the TMD. The Swann and Powell (2006 and 2007) surveys in 2001-2002 are the most comprehensive surveys of these species as a group to date. The results of the surveys provide a baseline for future monitoring and assessment. However, because there are no current, comparable surveys by which to judge condition, species occurrence of small mammals and bats in the park is unknown at this time.
Population Status / Abundace of Selected Species	Status of Lesser Long-Nosed Bats		Based on available information from lesser long-nosed bat roost surveys in the RMD, current condition of this species in the park appears stable, and therefore in good condition. Roost count data from 2005-2014 varies from 30,000 to a few hundred, but this variation is expected, as the bats are believed to utilize several different local roosts when in the area.
	Status of Mule and White-tailed Deer		The condition of mule deer within the park is of significant concern, primarily due to their observed decline in the RMD. The condition of mule deer in the TMD does not appear to be a concern at this time, but data are sparse. The condition of white-tailed deer at the park (RMD) appears to be good, as their numbers have increased in recent years, at least in the lower elevations of the RMD. White-tailed deer have never been confirmed in the TMD. While mule deer have declined and white-tailed deer have increased in the RMD, it is unclear whether the species are continuing to decrease/increase.
Habitat Corridors / Connectivity	Connectivity Within Surrounding Landscape		Connectivity with the surrounding landscape is good to moderate for the RMD. Based on Perkl et al. (2015) a number of modeled corridors exist, connecting the district with the surrounding landscape, and high naturalness exists to the east and south (except for near I-10). Condition for the TMD is of significant concern. More development surrounds the district, and this is projected to increase in the future. In addition to its location adjacent to Tucson Mountain Park, the district currently has only two modeled corridors. As taken into account with the projected scenario modeling, negative trends are expected to continue.

Table 5.1-16. Summary of overall birds condition, indicators and measures, and rationale for assigning condition assessment at Saguaro National Park.

Birds			
Indicators of Condition	Specific Measures	Condition Status/Trend	Rationale
Occupancy of Species Common in the SODN	Change in Occupancy Over Time		Occupancy was estimated for 11 species that occur at the park that are common in the SODN. Occupancy was estimated at 0.90 or higher for seven of the species in at least some of the habitats/districts in the areas sampled. Estimated occupancy of at least two of the other species was 0.66 or higher. No information on trends is available from this analysis at this time. Under our reference conditions, which are defined using trends in occupancy, condition is unknown.
Species Richness in SODN Annual Survey Areas	Change in Species Richness Over Time		Species richness in the areas sampled by SODN was estimated separately for upland habitat and riparian habitat in the RMD, and upland habitat in the TMD (2009-2015). Overall, there were no significant trends over time. Using our reference conditions, species richness in the areas sampled is unchanging, and therefore good.
Species Richness & Abundance Category using 2016 Comprehensive Park Bird List	Number of Native Species Recorded Per District According To 2016 List	NA	A total of 218 native bird species have been recorded in the park. A total of 216 native species have been recorded in the RMD, and 153 native species have been recorded in the TMD. We did not use this measure to judge condition, but, rather, to provide a broader view of species richness in the park than that provided under the "Species Richness in SODN Annual Survey Areas" indicator.
	Change in Abundance Category, Comparing 2016 List To Previous List (1985) for TMD		Our comparison of abundance category for species in the TMD revealed that 18 species dropped in abundance category from 1985 to 2016 lists (with one of the species being a non-native), and the drop was supported by Christmas Bird Count data. An additional six species in the TMD dropped in abundance category from 1985 to 2016, but CBC data could not be used to support the category drop. Although our confidence level in this analysis is low due to its subjective nature, we consider condition moderate under the measure, with a declining trend.
Status of Threatened and Endangered Species	Status of the Southwestern Willow Flycatcher Status of the Yellow-billed Cuckoo		There is not enough information to assign a condition.
	Status of the Mexican Spotted Owl		There are five breeding territories in the RMD and all appear to be occupied in most years. SNP (2013) reported that the Mexican Spotted Owl population in the park appears to be stable. However, there is some concern for the species on Mica Mountain due to wildfire effects (Helens 2 fire).
Extirpated Bird Species	# of Species		Since there are no confirmed extirpated bird species in Saguaro NP, the condition for this measure is considered good.
Non-native Bird Species	# and Significance of Species		Although four species of non-native birds occur in both districts, their distribution is limited and their effects on native birds appears to be minor. The trend appears unchanging.

NIC PERKINS / NPS

Gila monster (*Heloderma suspectum*) is found in Saguaro National Park.

Table 5.1-17. Summary of overall herpetofauna condition, indicators and measures, and rationale for assigning condition assessment at Saguaro National Park.

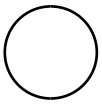
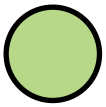
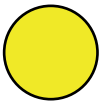
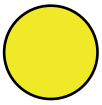
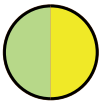
Herpetofauna			
Indicators of Condition	Specific Measures	Condition Status/Trend	Rationale
Species Occurrence	Presence or Absence of Herpetofauna Species		Condition in both districts is unknown because no group-wide, comprehensive surveys have been conducted in the park since 2001-2002. Of 61 species of amphibians and reptiles recorded during the surveys (or during past studies), 46 species were documented in the RMD and 34 were documented in the TMD. Out of the 61 species, 9 are amphibians and 52 are reptiles. Three of the 61 species are non-native; 15 of the species are considered SGCN with the State.
Population Status / Abundace of Selected Species	Sonoran Desert Tortoise		Estimates of density for the tortoise are available from three different studies (from 1996-1997, 2005-2006, and 2010-2011). The methods differ, but there do not appear to be any obvious concerns with density (i.e., substantial changes) over these years. Zylstra et al. (2010) estimated density and occupancy and found their density estimates to be similar to others for southern Arizona using similar methods. For the entire park (in the areas surveyed), there were an estimated 0.30 adults/ha. The estimated average density from 2010-2011 was 0.35 tortoises/ha across all the plots.
	Lowland Leopard Frog in RMD		Based on 16 years of monitoring in the RMD, as well as observations on occupancy and abundance from the last few years (2011-2015), condition is considered to be of moderate concern. Although occupancy and abundance of lowland leopard frogs in the study varied substantially over space and time (in response to environmental conditions), estimated trends were not significant. It is unclear, however, whether occupancy rates since 2011 (in drainages) are part of normal fluctuations or part of a more systematic decline. Also, the species is uncommon and vulnerable in the park.

Table 5.1.17. Summary of overall herpetofauna condition, indicators and measures, and rationale for assigning condition assessment at Saguaro National Park continued.

Herpetofauna			
Indicators of Condition	Specific Measures	Condition Status/Trend	Rationale
Occurrence of Herpetofauna Diseases	Upper Respiratory Tract Disease in Desert Tortoise		Desert tortoises in the park were sampled for evidence of antibodies to *M. agassizii* and for clinical signs of URTD. A total of 48 tortoises were sampled in three sites in the park in 2002-2005 (Jones 2008). At one site in RMD, 52% of tortoises had antibodies to *M. agassizii*, and at two sites (combined) in TMD, 47.8% of tortoises had antibodies. For the three sites combined, 37.5% of animals showed clinical signs of URTD. Although these data are more than 10 years old, we chose to assign condition (moderate concern) because once a tortoise has been infected it can remain a carrier for life. We have only moderate confidence in the assessment.
	Amphibian Chytrid Fungus (*Bd*) (in RMD)		Sampling in 2008-2010 in the Rincon Mountains revealed that both amphibian species tested showed infection with *Bd* in all three canyons sampled (Ratzlaff 2012). Levels of prevalence and infection intensity varied. When averaged across all sites, prevalence and infection intensity was higher for the lowland leopard frog than for the canyon tree frog. For leopard frogs, Chimenea and Tanque Verde canyons had substantially higher prevalence and infection intensity than Wildhorse. Sixteen years of leopard frog monitoring in the park (1996-2011) has not pointed to population decreases due to the disease. We consider condition to be of moderate concern, but have only moderate confidence due to the lack of current data.
Presence of Non-native Species	Effects on Herpetofauna		Three non-native herpetofauna species were discussed, plus the domestic/feral dog. The main species of concern at this time is the domestic/feral dog and its impact on the desert tortoise. Based on 2005-2007 sampling, desert tortoises were more affected by free-ranging dogs in the TMD than in the RMD.Two areas of the TMD (area south of Panther Peak and south of the visitor center) had relatively higher proprtions of tortoises with injuries. Injuries were higher in 2006-2007 compared to an earlier period.
Habitat Connectivity and Corridors	Habitat Connectivity Within the Landscape		Connectivity with the surrounding landscape is good to moderate for the RMD. A number of modeled corridors exist and high naturalness exists to the east and south (except for near I-10). Condition for the TMD is of significant concern. More development surrounds the district, and this is projected to increase in the future. In addition to its location adjacent to Tucson Mountain Park, the district currently has only two modeled corridors (one of which connects it to RMD). Negative trends are expected to continue.

5.2. Management Considerations and Opportunities For Park Planning

The current and projected primary drivers threatening Saguaro NP's resources and associated values include land use practices that are outside the park's jurisdiction and the uncertain ramifications of climate change. The ultimate and long-term viability of the majority of park resources are interdependent upon the status of these landscape-scale stressors and upon the conditions of natural resources regionally-surrounding the park.

Large-scale landscape fragmentation is currently and will increasingly have an impact on species richness and diversity, particularly in the TMD. The health and integrity of the Sonoran Desert vegetation community is also threatened by the continued spread of invasive non-native plants, such as buffelgrass. Buffelgrass not only directly outcompetes native species but also introduces a non-natural fire regime that can lead to the conversion of the Sonoran Desert to a non-native grassland. Additionally, climate change, which may be associated with extended periods of drought, and drawdown of localized water tables are having a negative influence on the resilience of native vegetation and other biological communities. Understanding projected future outcomes and having the ability and resources to adapt management actions to curtail predictable negative consequences to the park's resources is an urgent reality for ensuring the health of these resources into the future.

The park shares common boundaries with the US Forest Service, the city of Tucson, the Town of Marana, Pima County, and Arizona State Trust Lands. Each of these jurisdictions presents different challenges and opportunities regarding designated and changing land use practices and land development policies. For example, Pima County implemented a progressive and protective Buffer Overlay Zone extending 0.6 km (1 mi) around the perimeter of the park's boundary designed to incorporate development guidelines that help enhance protection of park resources, or at least minimize impacts to these resources. However, these county lands may be, and are aggressively annexed by adjacent municipalities that are not required to keep these protective measures in place. Accordingly, the trend has been for some other jurisdictions, particularly the Town of Marana, to rezone annexed parcels to promote suburban development, which leads to accelerated and irreversible habitat loss and fragmentation. Based on recent trends, we expect these actions, which have led to extensive development of previously functional natural habitat, to continue and lead to further degradation of lands surrounding the park. These actions will quite likely geographically isolate TMD unless current external land management practices are changed.

In addition, existing major linear infrastructure, such as Interstate 10 and the Central Arizona Project canal, continues to be built. A new major highway bypass is being proposed for construction very close to the west side of TMD. Currently, RMD has large areas surrounding some of its boundary that should remain mostly undisturbed due to U.S. Forest Service ownership, unless the development of the San Pedro River corridor east of RMD occurs.

Considering these circumstances, it is important that park staff continue efforts to encourage compatible nearby land management policies that reflect conservation needs and increases the knowledge of park resources and their susceptibility to change. In addition, it is important that park staff take a larger role in communicating to the public the significant impacts that new linear infrastructure, particularly major highways, will have on the natural resource and wilderness values of the park.

Specific needs and continued efforts should include:

- Determine status and trends of wildlife populations, especially species dependent upon an interconnected landscape that transcends park boundaries.

- Establish water rights for resource benefit in the Rincon Creek watershed.
- Implement an Early Detection and Rapid Response strategy for invasive species.
- Slow the spread of buffelgrass by expanding management efforts.
- Continue to implement an active fire management program that includes prescribed fire (natural and managed).
- Identify data gaps and research needs and pursue partnerships with universities and other researchers to address these unknowns. Seek out ways to encourage and facilitate research in the park that helps to meet this objective. Give preference to research that will provide information to improve management of park resources in a manner that ensures their integrity now and into the future.
- Collect meteorological data at multiple elevations within the Rincon Mountains to monitor conditions expected to be affected by climate change.
- Strive to encourage broad landscape-scale management and collaboration similar to the current Resilient Landscapes Collaborative.

To further these objectives, developing a Natural Resource Stewardship Strategy will be important, not only for evaluating future management needs, but also for identifying the most urgent current and near-term demands. Managing towards ecosystem integrity and resilience are broad overarching goals and inherently challenging. Identifying stressors and opportunities to improve resource conditions are important components of an adaptive management approach. Addressing these issues at a landscape-scale will require new and unique methods and collaborations to document physical and biological changes occurring across the landscape and to encourage development of realistic management strategies. As we move into the next century of park stewardship, it will be imperative that park managers work across bureaucratic boundaries to overcome the limitations and uncertain challenges that lay ahead in our mission to protect Saguaro National Park's natural resources for current and future generations.

DON SWANN / NPS

Student sampling dragonflies for mercury at Saguaro NP.

5.3. Sources of Expertise

Scott Stonum, Division Chief, Saguaro National Park Division of Science and Resource Management authored the management considerations and opportunities for park planning section.

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Appendix A: Team Members and Subject Matter Experts/Reviewers

Table A.1. Saguaro National Park NRCA Project Team Members

NRCA Project Team
Jeff Albright, NPS Water Resources Division's Coordinator of Natural Resource Condition Assessment and State of the Park Report Series
Dana Backer, NPS Saguaro National Park Restoration Ecologist
Lisa Baril, Utah State University, Writer/Editor
Nina Chambers, Northern Rockies Conservation Cooperative, Writer/Editor
Colleen Filippone, NPS Intermountain Region Hydrologist
Perry Grissom, NPS Saguaro National Park Fire Ecologist
Evan Gwilliam, NPS Sonoran Desert Inventory and Monitoring Network Ecologist
Andy Hubbard, NPS Sonoran Desert Inventory and Monitoring Network Program Manager
Natasha Kline, NPS Saguaro National Park Biologist
Becky MacEwen, NPS Saguaro National Park GIS Specialist
Allyson Mathis, Northern Rockies Conservation Cooperative and Utah State University, Writer/Editor
Cheryl McIntyre, NPS Sonoran Desert Inventory and Monitoring Network Physical Scientist
Donna Shorrock, NPS Intermountain Region Natural Resource Condition Assessment Regional Coordinator, Former
Darla Sidles, NPS Saguaro National Park Superintendent
Scott Stonum, NPS Saguaro National Park Chief Science and Resource Management
Kim Struthers, Utah State University, Writer/Editor and NRCA Team Coordinator
Sarah Studd, NPS Sonoran Desert Inventory and Monitoring Network Vegetation Ecologist
Don Swann, NPS Saguaro National Park Biologist
John Thornburg, NPS Saguaro National Park Fire Management Officer
Patty Valentine-Darby, University of West Florida, Biologist and Writer/Editor

Table A.2. Saguaro National Park NRCA Subject Matter Experts and/or Assessment Reviewers

Subject Matter Expert/Assessment Reviewer	Topic(s)	Project Deliverable(s)
Scott Stonum, National Park Service Saguaro National Park, Chief Science and Resource Management	Phase I Tables, Viewshed, Soundscape, Biodiversity, Sonoran Desert, Grasslands, Woodlands, and Forests, Chapter 5	Park expert review and guidance for viewshed, biodiversity, vegetation, soundscape, and Chapter 5 management considerations
Don Swann, National Park Service Saguaro National Park, Biologist	Full report	Park expert review and author of science legacy
Dana Backer, National Park Service Saguaro National Park, Ecologist	Phase I Tables, Science Legacy, Biodiversity, Saguaro Cactus, Sonoran Desert, Grasslands, Woodlands, and Forests	Park expert review
Perry Grissom, National Park Service Saguaro National Park, Fire Ecologist	Phase I Tables, Science Legacy, Biodiversity, Sonoran Desert, Grasslands, Woodlands, and Forests	Park expert review
Natasha Kline, National Park Service Saguaro National Park, Biologist (former)	Phase I Tables, Science Legacy, Surface Water Quantity, Biodiversity, Saguaro Cactus, Mammals, Birds	Park expert review

Table A.2. Saguaro National Park NRCA Subject Matter Experts and/or Assessment Reviewers continued.

Subject Matter Expert/Assessment Reviewers	Topic(s)	Project Deliverable(s)
Adam Springer, National Park Service Saguaro National Park, Resource Management Specialist	Full Report	Park expert review
Andy Hubbard, National Park Service Sonoran Desert Inventory and Monitoring Network Program Manager	Phase I Tables, Science Legacy, Grasslands, Woodlands, and Forests	I&M expert review
Colleen Filippone, National Park Service Intermountain Region Hydrologist	Phase I Tables, Science Legacy, Tinajas, Springs, and Seeps	IMRO/SODN expert review and author of groundwater assessments
Donna Shorrock, National Park Service Intermountain Region Natural Resource Condition Assessment Regional Coordinator	Groundwater, Biodiversity	Provided review of TMD groundwater and assisted with sections for biodiversity assessment
Christopher J. Eastoe, University of Arizona Department of Geosciences	Groundwater	Reviewed groundwater assessments
Steve Rice, PG, National Park Service Water Resources Division Aquatic Systems Branch Hydrogeologist	Groundwater	Reviewed groundwater assessments
Jennifer Back, National Park Service Water Resources Division	Groundwater	Reviewed groundwater assessments
Chuck Perger, National Park Service Saguaro National Park Volunteer Scientist	Groundwater	Reviewed groundwater assessments
Robin Pinto, University of Arizona Environmental Historian	Science Legacy	Reviewed science legacy section
Joshua Conver, National Park Service Saguaro National Park	Saguaro Cactus	Reviewed saguaro cactus assessment
Jeremy White, National Park Service Natural Sounds and Night Skies Division Physical Scientist	Night Sky	Reviewed night sky assessment including Bortle Key Appendix C
Emma Brown National Park Service Natural Sounds and Night Skies Division Acoustical Resource Specialist	Soundscape	Reviewed soundscape section including Appendix D and provided NRCA template
Ksienya Pugacheva, National Park Service Air Resources Division, Natural Resource Specialist	Air Quality	Reviewed air quality assessment and provided NRCA template
Greg Eckert, National Park Service Restoration Ecologist	Biological Soil Crusts	Reviewed biological soil crusts assessment
Cheryl McIntyre, National Park Service, Sonoran Desert Inventory and Monitoring Network, Physical Scientist	Biological Soil Crusts	Provided expert review of biological soil crusts assessment and also provided answers to Greg Eckert's review comments
Mike Martin, National Park Service Water Resources Division, Hydrologist	Surface Water Quantity	Reviewed water quality assessment
Mike Wrigley, National Park Service, Intermountain Regional Office, Wildlife Biologist	Mammals	Reviewed mammals assessment
Erin Zylstra, University of Arizona	Herpetofauna	Reviewed herpetofauna assessment
Moez Ali, Lead Biologist for National Park Service, Sonoran Desert, Chihuahuan Desert and Southern Plains Inventory and Monitoring Networks Bird Monitoring Program	Birds	Provided input to information used to develop the assessment.
Larry Norris, Adjunct professor and a research associate at the University of Arizona	Birds	Provided input to information used to develop the assessment.
Robert Bennetts, National Park Service Southern Plains Inventory and Monitoring Network Program Manager	Birds	Provided input to information used to develop the assessment.

Appendix B: Viewshed Analysis Steps

The steps followed to complete Saguaro National Park's viewshed analyses is listed below.

A 10 meter (32.8 ft) National Elevation Dataset (NED) Digital Elevation Model (DEM) (USGS 2015), clipped to eastern Pima County was provided by Pima County's GIS Department (Pima County 2016) and used to create the viewshed Area of Analysis (AOA) as seen from each of the seven key observation points.

Observation point layers were created for viewshed analyses by importing GPS'd points for all key observation point locations (7 total) selected for viewshed analysis. Data were exported to a shapefile. Added field named "OFFSETA" (type = double) to shapefile and set value to an observer height of 1.68 m (~5'6") for all points except for Spud Rock, Cactus Forest Scenic Drive, and North Scenic Drive Trail, which were increased to approximate the panoramic views.

Ran Viewshed Analysis using the Viewshed Tool in ESRI's ArcGIS 10.2.2, Spatial Analyst Toolbox, ran viewsheds using the following inputs.

- Input raster = Pima County's 10m NED DEM
- Input point observer feature = obs_point.shp.

The rasters were reclassified into visible areas only to create the viewshed maps. The Observer Point Tool in Spatial Analyst was used, creating a composite viewshed, which showed all combined visible areas.

A 97 km (60 mi) buffer was created surrounding both park districts, reprojected into the Albers Equal Area Conic USGS projection, then used to clip NPS NPScape's housing and road density rasters using NPScape tools (NPS 2011a). A text attribute field was added to the dataset for the area of analysis identifier (NPS 2011b).

Housing (CONUS, Density, SERGoM, 1970 - 2100, Metric Data (ESRI 9.3 File Geodatabase) (Theobald 2005), road (United States and Canada, Density - All Roads, ESRI, 2005, Metric Data (ESRI 9.3 File Geodatabase) (ESRI 2010), and conservation status (NPS 2014 c, USGS 2016) GIS datasets were downloaded from NPScape's website at http://science.nature.nps.gov/im/monitor/npscape/gis_data.cfm?tab=1.

Standard Operating Procedures for both density tools (NPS 2014a,b) were followed based on NPScape instructions: https://irma.nps.gov/DataStore/Reference/Profile/2193329 and https://irma.nps.gov/DataStore/Reference/Profile/2193334. Features in the conservation status dataset were extracted by the composite viewshed mask.

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Appendix C: Bortle Dark-Sky Scale

Key for the Summer Sky— Latitudes 30° to 50° N

The Milky Way is not visible and sky glow extends above 35 degrees. Little to no dark adaptation is possible. Ground texture is easily seen, and artificial light dominates the landscape. Visible constellations are limited to the very brightest if any. The sky has a uniform washed out appearance.[1]

If this describes your nighttime environment, continue below

If the nighttime environment appears darker than this description, jump to the next section

Sky appears nearly completely washed out, and is luminous. Dark adaptation is not possible, ground is brightly illuminated and fewer than 200 stars are visible. Only the most major constellations are identifiable. For instance, the entire keystone of Hercules or the five stars of Delphinus are not completely visible.

this is accurate **Bortle Class 9** if darker—proceed below

Constellations are visible but may be missing key stars, sky background has a uniform washed out glow with light domes reaching 60 degrees above the horizon. Stars such as the tip of Sagitta or epsilon Lyrae are not visible. If clouds are present they are brilliantly lit.

this is accurate **Bortle Class 8** if darker—proceed below

Brighter constellations are easily seen in full, yet sky background has greyish or yellow background. Milky Way may be just barely seen near the zenith. The Scutum and Cygnus star clouds are not visible.If clouds are present they are brilliantly lit. Ground texture is still visible.

this is accurate **Bortle Class 7**

The Milky Way is visible but discontinuous, and lost to light domes near the horizon. Fine details and structure are not easily visible, if at all. Ground texture is still visible, and shadows are cast from light pollution. Light domes are clearly visible along the horizon and appear brighter than any portion of the visible Milky Way.[2]

If this describes your nighttime environment, continue below

If the nighttime environment appears darker than this description, jump to the next section

The Milky Way is just visible overhead, but is not continuous and is diminished to obvious skyglow. Cygnus ,Scutum, and Sagittarius star fields just visible. If clouds present they are illuminated and reflecting light. Ground texture is seen with difficulty.

this is accurate **Bortle Class 6** if darker—proceed below

Milky Way is faintly present, but may have occasional gaps and is lost to skyglow near the horizon. Great rift in Cygnus is just visible. Any clouds present are brighter than the background sky and reflect light back. Zodiacal light may be glimpsed, but is difficult to see amidst the light pollution. Ground texture is not visible but forms are easily seen.

this is accurate **Bortle Class 5** if darker—proceed below

Milky Way is evident from horizon to horizon, but fine details are lost. Clouds are just brighter than background sky, but appear dark at zenith. Light domes are much brighter than brightest part of Milky Way and extend to up to 15 degrees above the horizon. Zodiacal light is evident in west after sunset or in east before dawn. Deep sky objects such as the M13 globular cluster and Northern Coal Sac are visible.

this is accurate **Bortle Class 4**

The Milky Way has a defined outline with visible structure and detail. Very few light domes are visible just along the horizon and do not cast shadows. You may see color in the Zodical light when compared to bluish-white color of the Milky Way. Scattered clouds appear dark against the night sky except those clouds just above light domes.[3]

If this describes your nighttime environment, continue below

Milky Way appears complex with visible outline, however some light pollution is still evident along the horizon. Light domes only slightly brighter than brightest part of the Milky Way. Zodiacal light easily seen, but band and gegenschein difficult or absent. Many summer globular clusters and emission nebulae are visible with the naked eye despite distracting light domes along the horizon. Venus casts an obvious shadow.

this is accurate **Bortle Class 3** if darker—proceed below

Very few light domes are visible; with none extending above 5 degrees and fainter than the Milky Way. Airglow is often visible, and character in its brightness may be seen. Ground is mostly dark. The Zodiacal band (away from the Milky Way and at least 45 degrees above the horizon) and gegenschein are visible. The rift in the Cygnus star cloud is visible. The Prancing Horse in Sagittarius and Fingers of Ophiuchus dark nebulae are visible, extending to Antares. Jupiter and Milky Way cast barely visible shadows.

this is accurate **Bortle Class 2** if darker—proceed below

The Milky Way is intricate, marbled, and veined with Sagittarius region of the Milky Way casting obvious shadows. Milky Way appears 40 degrees wide in some parts with a convoluted outline. The horizon completely free of light domes, though some distant light domes may be visible from mountain tops. Transparency and seeing are excellent (among the best of the year) with very low airglow. Many objects such as M81 or the Helix nebula are visible with the naked eye. Zodical light is striking as a complete band. Any clouds are very difficult to see.

this is accurate **Bortle Class 1**

The Bortle Dark-Sky Scale is a qualitative scale developed by John Bortle and published in Sky & Telescope Magaine in 2001. It provides a useful complement to quantitative measures. The National Park Service is testing this dichotomous key for use by professional and citizen scientists. Some knowledge of the night sky and visual observational techniques are required to properly implement this assessment.

note 1) At least 5 minutes of dark adaptation is required to properly differentiate Class 7,8 & 9 skies.

note 2) At least 10 minutes of dark adaptation is required to properly differentiate Class 4, 5 & 6 skies.

note 3) 20 to 120 minutes of dark adaptation is required to properly differentiate Class 1, 2 & 3 skies.

Developed by Jeremy White, Dan Duriscoe, and Chad Moore of the NPS Natural Sounds & Night Skies Division, www.nature.nps.gov/night

August 2, 2012

Appendix D: Soundscape Models

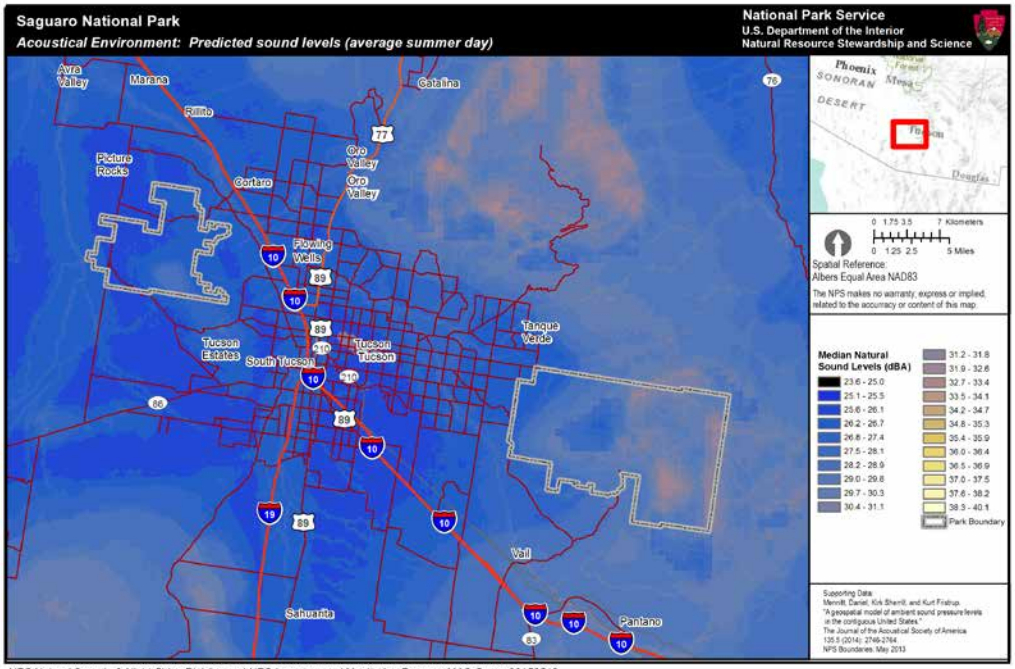

Figure D-1. Natural CONUS soundscape model zoomed to Saguaro NP.

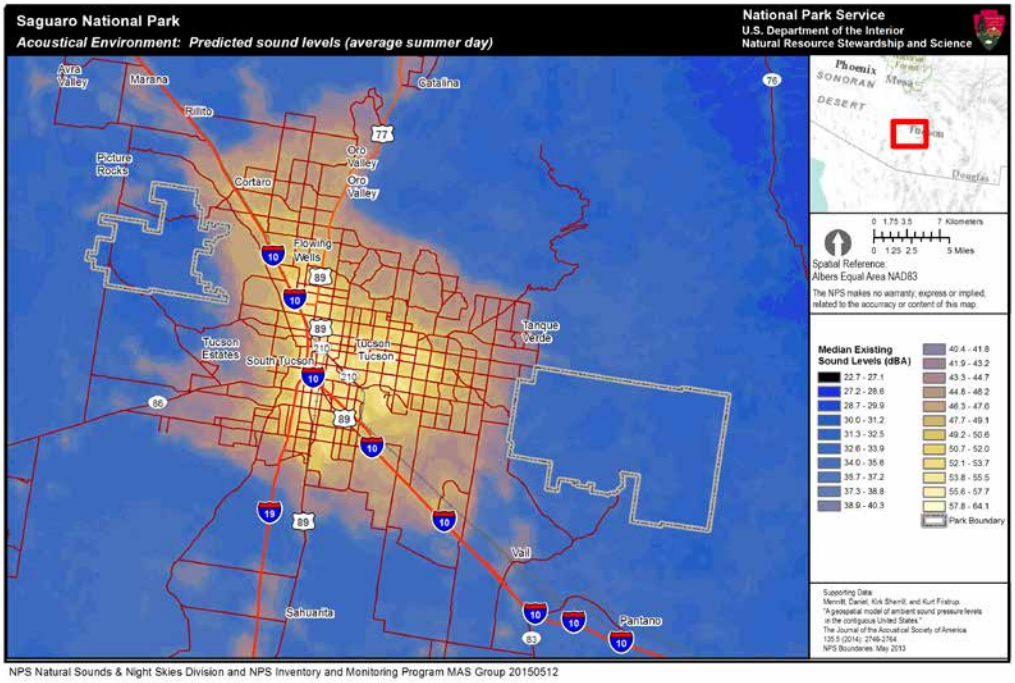

Figure D-2. Existing CONUS soundscape model zoomed to Saguaro NP.

Mennitt et al. (2013) developed a geospatial sound model by mapping sound pressure levels on a continental U.S. scale. The model included biological, climatic, geophysical, and anthropogenic factors to assess expected sound pressure levels for natural and existing conditions. The model suggested that the area within and surrounding Saguaro NP had a natural L_{50} dBA median of 29.0 (Figure D-1) and an existing L_{50} dBA median of 32.6 (Figure D-2) (Emma Brown, Acoustical Resource Specialist, NPS Natural Sounds and Night Skies Division, provided Excel spreadsheet with values). The L_{50} represents the sound level reported that is exceeded 50 percent of the stated time period.

The impact of anthropogenic sound sources to the national park's soundscape, which is the existing L_{50} dBA minus natural L_{50} dBA, was estimated to be a 4.1 dBA (map is included in the assessment). For further details refer to the soundscape assessment in section 4.3.

As NSNSD's predictive soundscape model continues to be developed and refined, it is intended to help park staff anticipate impacts by projecting future developments that have the potential to degrade soundscape condition.

Literature Cited

Mennitt, D., K. Fristrup, K. Sherrill, and L. Nelson. 2013. Mapping sound pressure levels on continental scales using a geospatial sound model. Proceedings from Internoise Conference, Innsbruck, Austria, September 15-18, 2013. 11pp.

Appendix E: Saguaro NP Comprehensive Bird List

Listed below are the bird species that have been recorded at Saguaro NP. This is a comprehensive listing provided by Natasha Kline, Biologist, Saguaro NP, in March 2016. A full description of the list can be found in the bird condition assessment in Chapter 4.

Common Name	Rincon MD	Tucson MD
Abert's Towhee	X	X
Acorn Woodpecker	X	
American Kestrel	X	X
American Robin	X	X
Anna's Hummingbird	X	X
Arizona Woodpecker	X	
Ash-throated Flycatcher	X	X
Band-tailed Pigeon	X	
Barn Owl	X	X
Barn Swallow	X	X
Bell's Vireo	X	X
Belted Kingfisher	X	
Bendire's Thrasher	X	X
Bewick's Wren	X	X
Black Phoebe	X	X
Black Vulture	X	X
Black-chinned Hummingbird	X	X
Black-chinned Sparrow	X	X
Black-crowned Night-Heron		X
Black-headed Grosbeak	X	X
Black-tailed Gnatcatcher	X	X
Black-throated Gray Warbler	X	X
Black-throated Sparrow	X	X
Blue Grosbeak	X	X
Blue-gray Gnatcatcher	X	X
Brewer's Blackbird	X	X
Brewer's Sparrow	X	X
Bridled Titmouse	X	X
Broad-billed Hummingbird	X	X
Broad-tailed Hummingbird	X	X
Bronzed Cowbird	X	X
Brown Creeper	X	
Brown-crested Flycatcher	X	X
Brown-headed Cowbird	X	X
Buff-breasted Flycatcher	X	
Bullock's Oriole	X	X
Burrowing Owl	X	X

Common Name	Rincon MD	Tucson MD
Bushtit	X	
Cactus Ferruginous Pygmy-Owl	X	X
Cactus Wren	X	X
Calliope Hummingbid		X
Canyon Towhee	X	X
Canyon Wren	X	X
Cassin's Finch	X	
Cassin's Kingbird	X	
Cassin's Sparrow	X	X
Cassin's Vireo	X	X
Cedar Waxwing	X	X
Chipping Sparrow	X	X
Clark's Nutcracker	X	
Cliff Swallow	X	X
Common Black-Hawk	X	X
Common Gound-Dove	X	X
Common Nighthawk	X	X
Common Poorwill	X	X
Common Raven	X	X
Common Yellowthroat	X	
Cooper's Hawk	X	X
Cordilleran Flycatcher	X	
Costa's Hummingbird	X	X
Crested Caracara	X	X
Crissal Thrasher	X	X
Curve-billed Thrasher	X	X
Dark-eyed Junco	X	X
Dusky Flycatcher	X	X
Dusky-capped Flycatcher	X	
Eastern Bluebird	X	
Eastern Meadowlark	X	
Elegant Trogon	X	
Elf Owl	X	X
Eurasian Collared-Dove	X	X
European Starling	X	X
Evening Grosbeak	X	
Ferruginous Hawk	X	
Flammulated Owl	X	
Fox Sparrow	X	X
Gambel's Quail	X	X
Gila Woodpecker	X	X
Gilded Flicker	X	X
Golden Eagle	X	X
Golden-crowned Sparrow	X	
Grace's Warbler	X	
Gray Flycatcher	X	X
Gray Hawk	X	

Common Name	Rincon MD	Tucson MD
Gray Vireo	X	X
Great Blue Heron	X	
Great Horned Owl	X	X
Greater Pewee	X	
Greater Roadrunner	X	X
Great-tailed Grackle	X	X
Green-tailed Towhee	X	X
Hairy Woodpecker	X	
Hammond's Flycatcher	X	X
Harris's Hawk	X	X
Hepatic Tanager	X	
Hermit Thrush	X	X
Hermit Warbler	X	X
Hooded Oriole	X	X
Horned Lark	X	
House Finch	X	X
House Sparrow	X	X
House Wren	X	X
Hutton's Vireo	X	
Inca Dove	X	X
Indigo Bunting	X	
Juniper Titmouse	X	
Killdeer	X	X
Ladder-backed Woodpecker	X	X
Lark Bunting	X	X
Lark Sparrow	X	X
Lawrence's Goldfinch	X	X
Lazuli Bunting	X	X
Lesser Goldfinch	X	X
Lesser Nighthawk	X	X
Lincoln's Sparrow	X	X
Loggerhead Shrike	X	X
Long-eared Owl	X	X
Lucy's Warbler	X	X
MacGillivray's Warbler	X	X
Magnificent Hummingbird	X	
Mallard	X	X
Marsh Wren	X	
Merlin	X	X
Mexican Jay	X	
Mexican Spotted Owl	X	
Mexican Whip-poor-will	X	
Montezuma Quail	X	
Mountain Bluebird	X	X
Mountain Chickadee	X	
Mourning Dove	X	X
Nashville Warbler	X	X

Common Name	Rincon MD	Tucson MD
Northern Beardless-Tyrannulet	X	
Northern Cardinal	X	X
Northern Flicker	X	X
Northern Goshawk	X	
Northern Harrier	X	X
Northern Mockingbird	X	X
Northern Parula	X	
Northern Pygmy-Owl	X	
Northern Rough-winged Swallow	X	X
Northern Saw-whet Owl	X	
Olive Warbler	X	
Olive-sided Flycatcher	X	X
Orange-crowned Warbler	X	X
Osprey	X	X
Pacific-slope Flycatcher	X	X
Painted Redstart	X	
Peregrine Falcon	X	X
Phainopepla	X	X
Pine Siskin	X	X
Pinyon Jay	X	
Plumbeous Vireo	X	X
Prairie Falcon	X	X
Purple Martin	X	X
Pygmy Nuthatch	X	
Pyrrhuloxia	X	X
Red Crossbill	X	
Red-breasted Nuthatch	X	
Red-faced Warbler	X	
Red-naped Sapsucker	X	X
Red-tailed Hawk	X	X
Red-winged Blackbird	X	X
Rock Pigeon	X	X
Rock Wren	X	X
Rose-breasted Grosbeak	X	X
Ruby-crowned Kinglet	X	X
Rufous Hummingbird	X	X
Rufous-crowned Sparrow	X	X
Rufous-winged Sparrow	X	X
Sage Sparrow	X	X
Sage Thrasher	X	X
Sandhill Crane	X	X
Savannah Sparrow	X	
Say's Phoebe	X	X
Scaled Quail	X	
Scott's Oriole	X	X
Sharp-shinned Hawk	X	X
Song Sparrow	X	

Common Name	Rincon MD	Tucson MD
Spotted Sandpiper	X	
Spotted Towhee	X	X
Steller's Jay	X	X
Sulphur-bellied Flycatcher	X	
Summer Tanager	X	X
Swainson's Hawk	X	X
Townsend's Solitaire	X	X
Townsend's Warbler	X	X
Tree Swallow	X	X
Tropical Kingbird	X	
Turkey Vulture	X	X
Varied Bunting	X	X
Vaux's Swift	X	X
Verdin	X	X
Vermilion Flycatcher	X	X
Vesper Sparrow	X	X
Violet-green Swallow	X	X
Virginia's Warbler	X	X
Warbling Vireo	X	X
Western Bluebird	X	X
Western Kingbird	X	X
Western Meadowlark	X	
Western Screech-Owl	X	X
Western Scrub-Jay	X	
Western Tanager	X	X
Western Wood-Pewee	X	X
Whiskered Screech-Owl	X	
White-breasted Nuthatch	X	
White-crowned Sparrow	X	X
White-throated Sparrow	X	X
White-throated Swift	X	X
White-winged Dove	X	X
Wild Turkey	X	
Williamson's Sapsucker	X	
Willow Flycatcher	X	X
Wilson's Warbler	X	X
Yellow Warbler	X	
Yellow-billed Cuckoo	X	X
Yellow-breasted Chat	X	
Yellow-eyed Junco	X	
Yellow-green Vireo	X	
Yellow-headed Blackbird	X	X
Yellow-rumped Warbler [1]	X	X
Zone-tailed Hawk	X	X
Total number of bird species		
222	220	157

[1] Yellow-rumped Warbler (*Setophaga coronata*) listing includes Audubon's Warbler (*Setophaga coronata auduboni*), which has been recorded in the Rincon MD.

The Department of the Interior protects and manages the nation's natural resources and cultural heritage; provides scientific and other information about those resources; and honors its special responsibilities to American Indians, Alaska Natives, and affiliated Island Communities.

NPS 151/135629, January 2017

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U.S. Department of the Interior

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